A ROS 2 Response-Time Analysis Exploiting Starvation Freedom and Execution-Time Variance

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MAX PLANCK INSTITUTE FOR SOFTWARE SYSTEMS

BOSCH Invented for life

This Paper in a Nutshell

ROS 2 is one of the most popular robotics frameworks, with peculiar timing properties.

We **improve** upon existing response-time analyses with three techniques.

1. Address large **execution-time variance** over time
2. Exploit **starvation-freedom** in the callback scheduler
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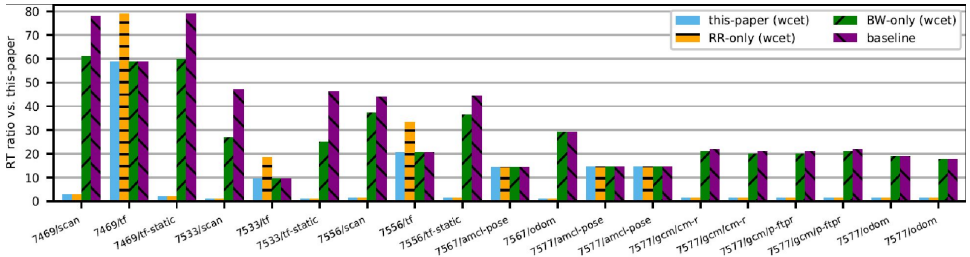
Experiments show significant improvements (10-80x) in **real-world ROS packages**.



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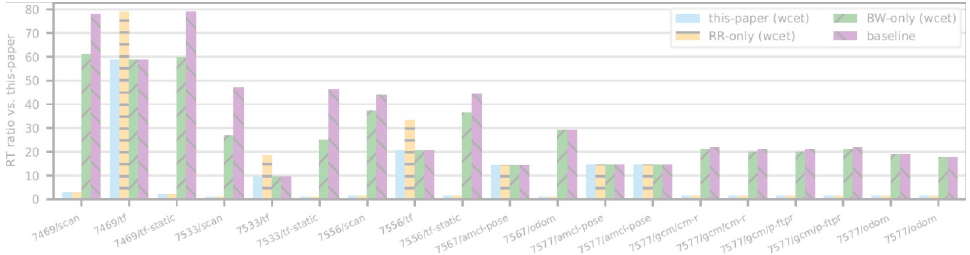

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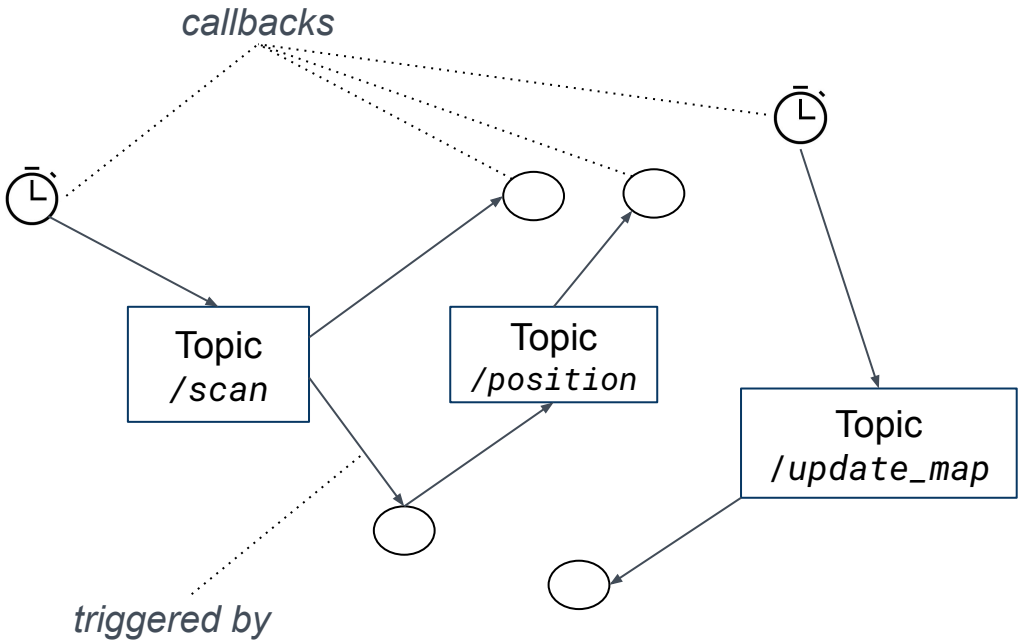
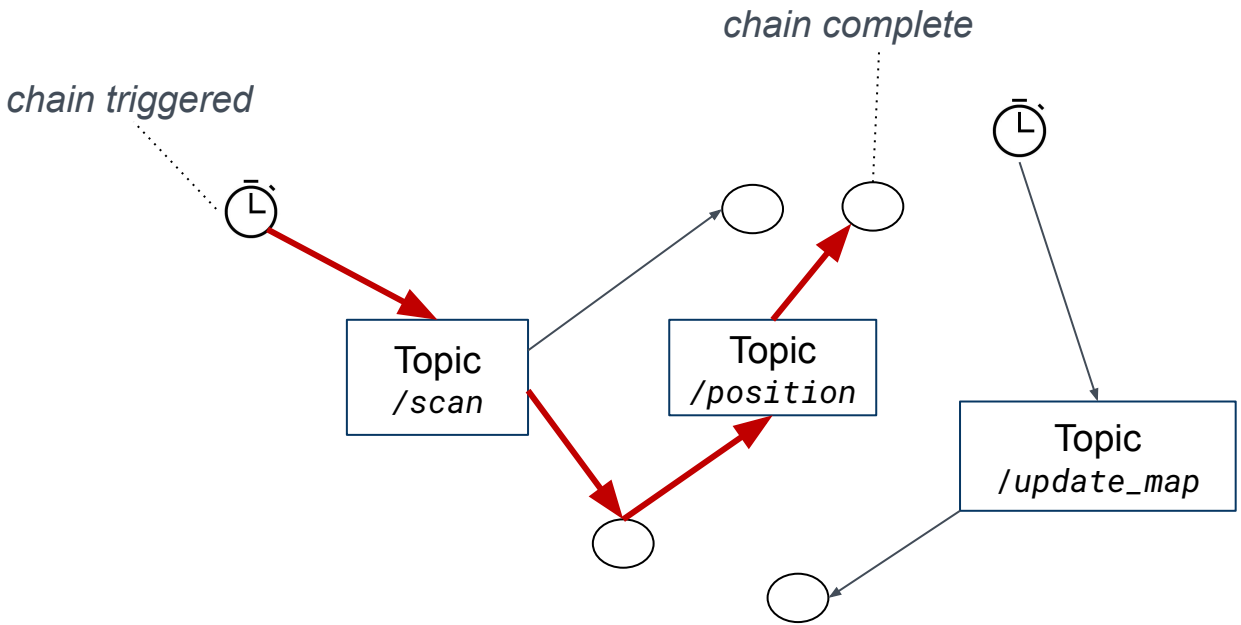
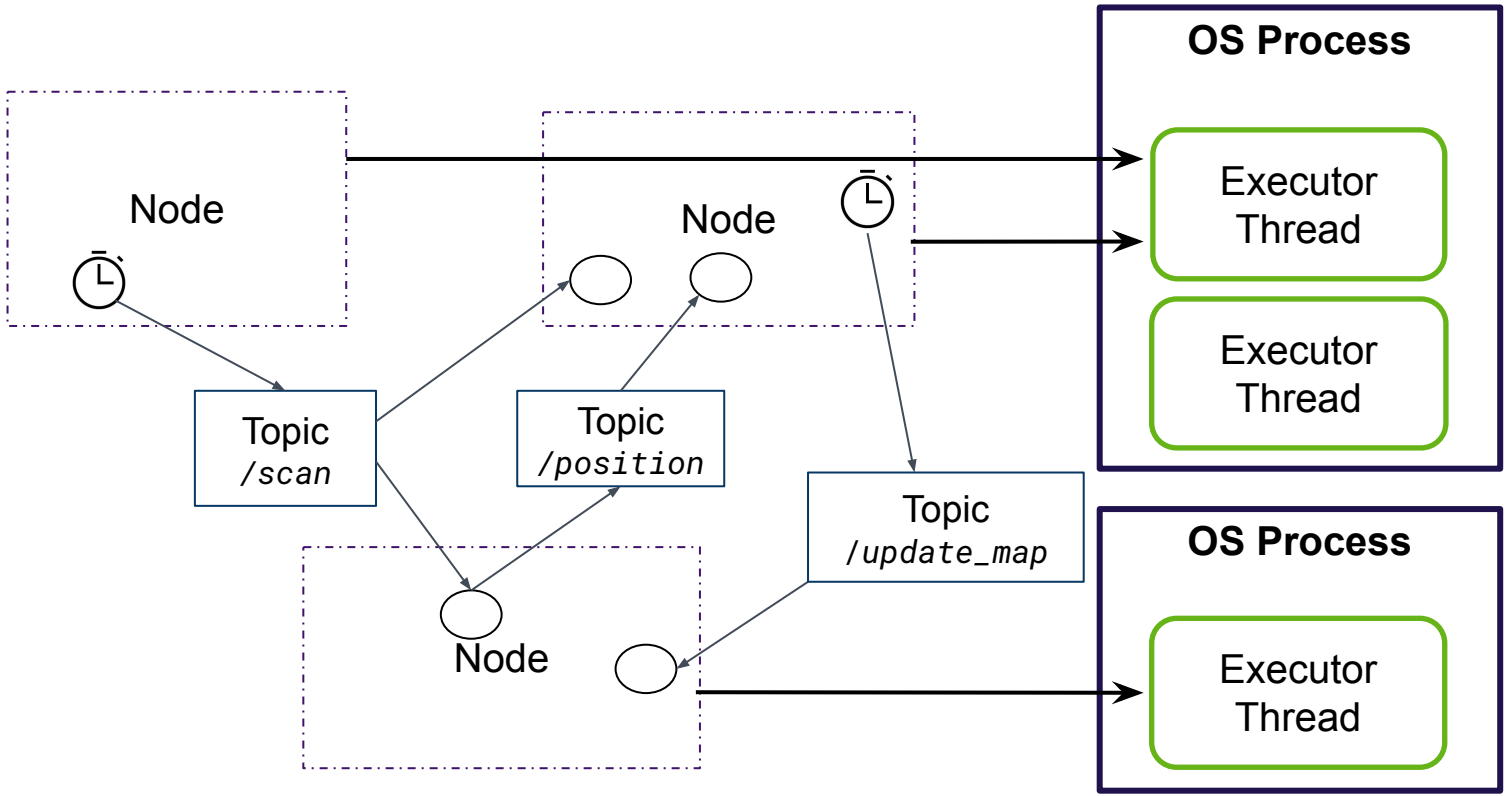
Background: ROS Callback Graph



Background: Processing Chains



Background: Executing a Callback Graph



Background: Compositional Performance Analysis

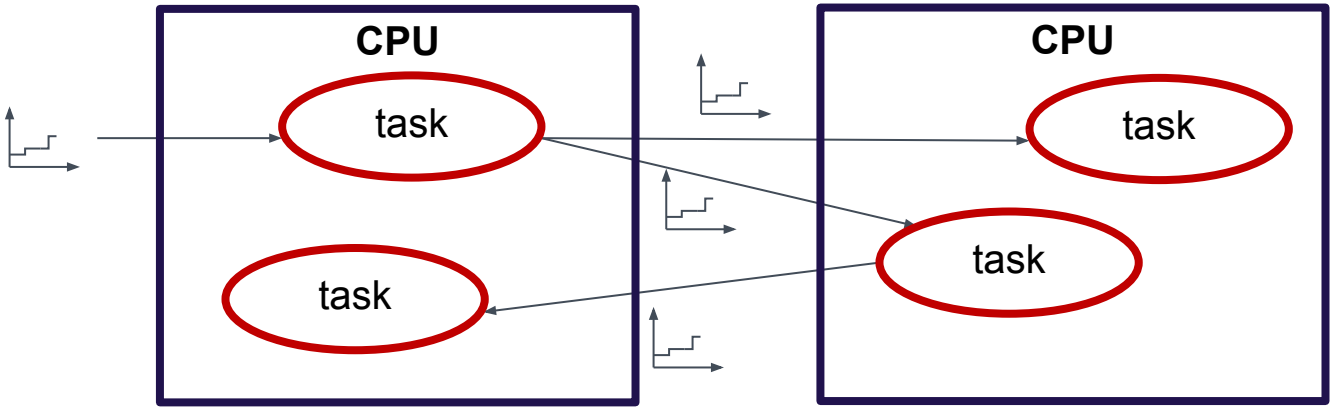
Per-CPU Analysis

Computes task response times given event arrival curves

Fixed-point search

Arrival-Curve Propagation

Computes event arrival curves given task response times



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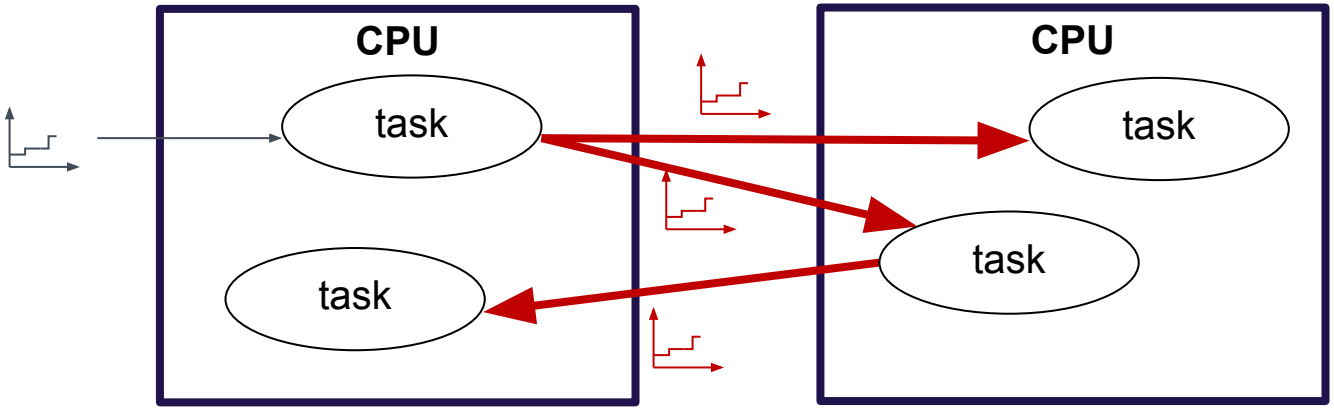

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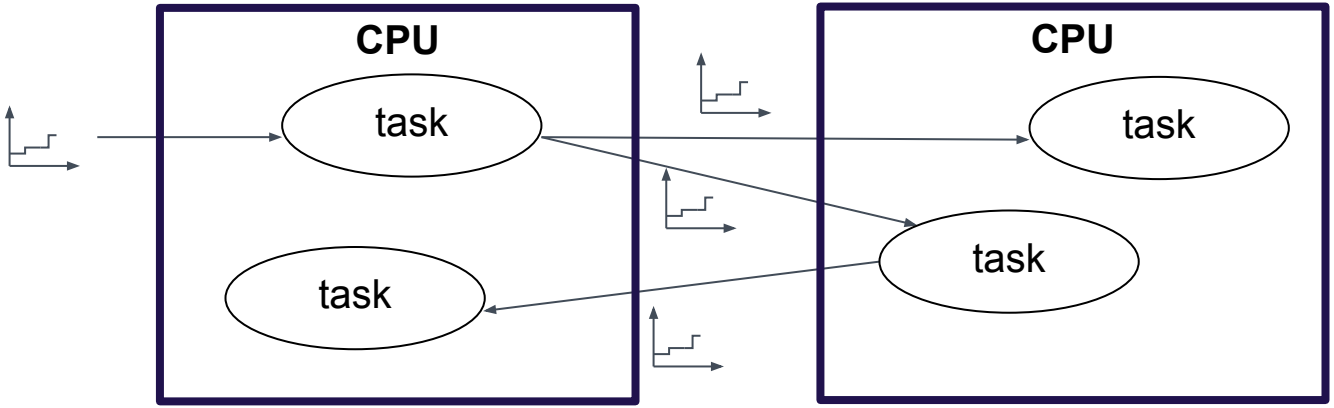

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Per-Executor Analysis

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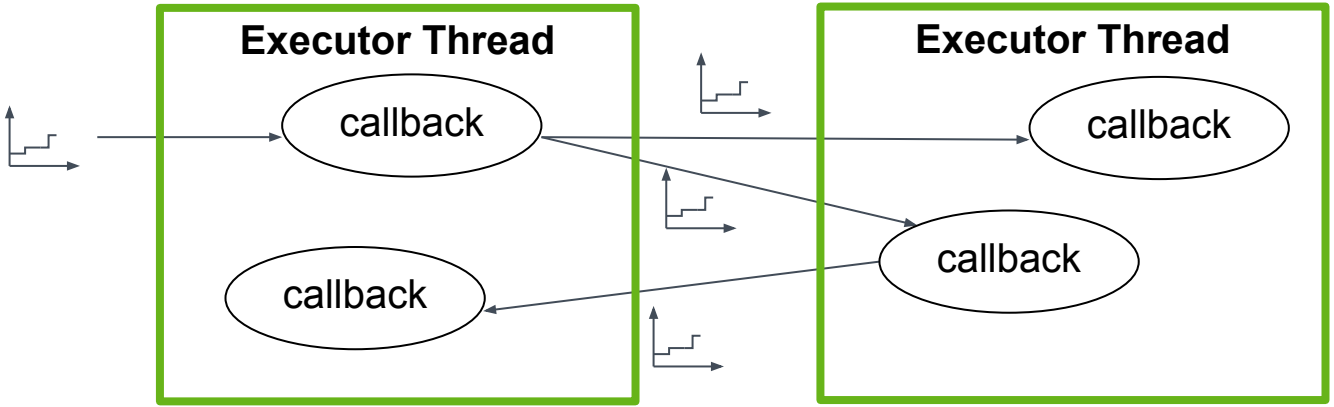
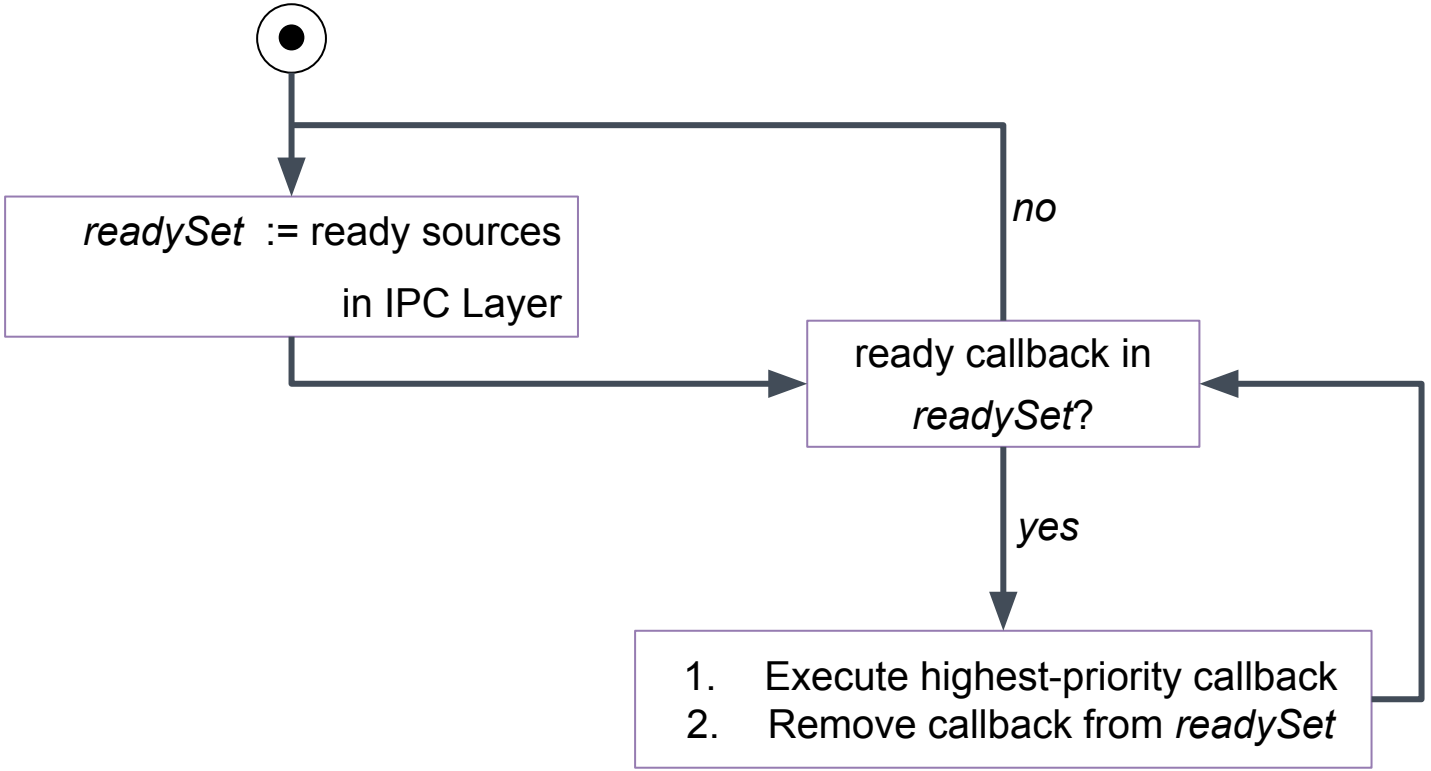


Background: The ROS 2 Executor (simplified)



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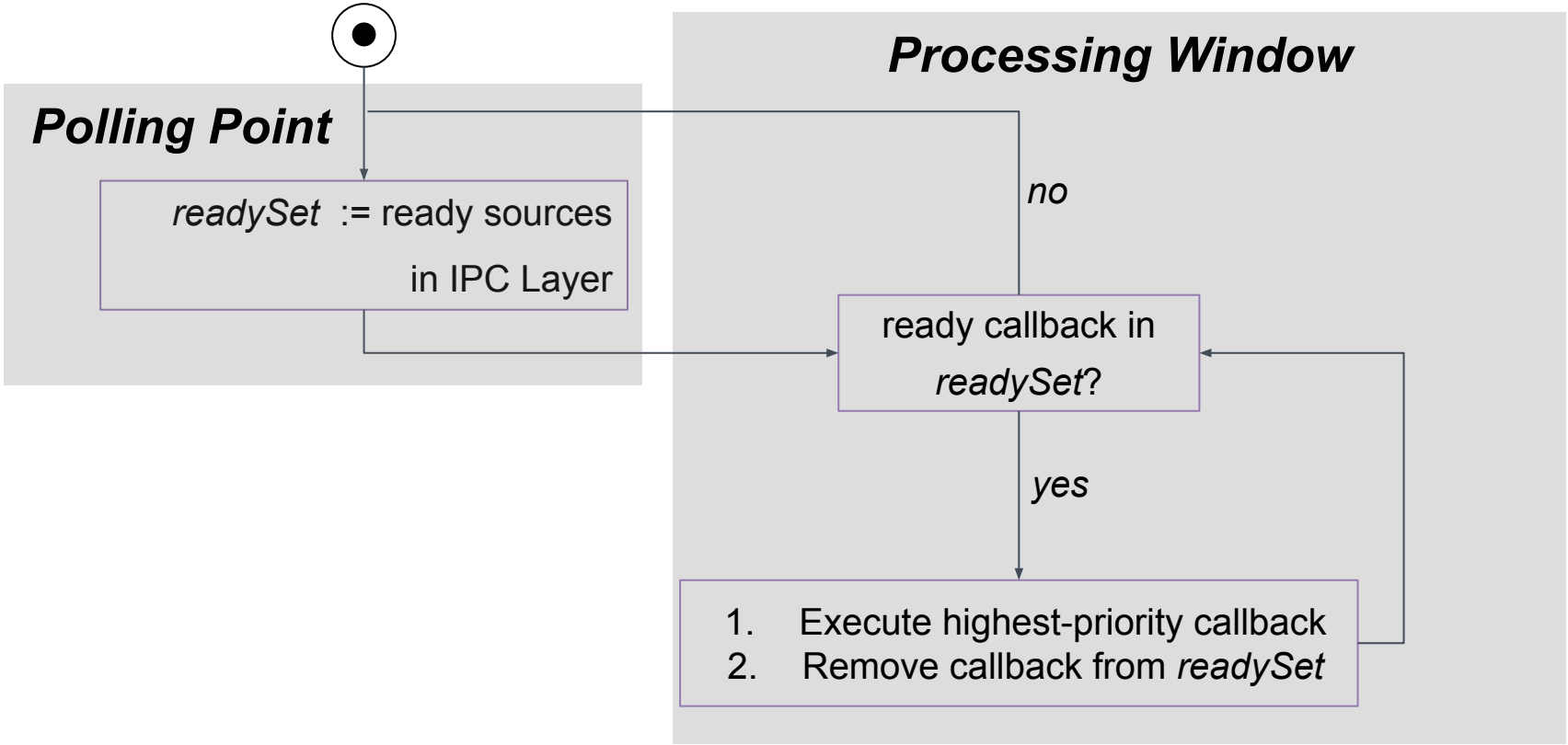
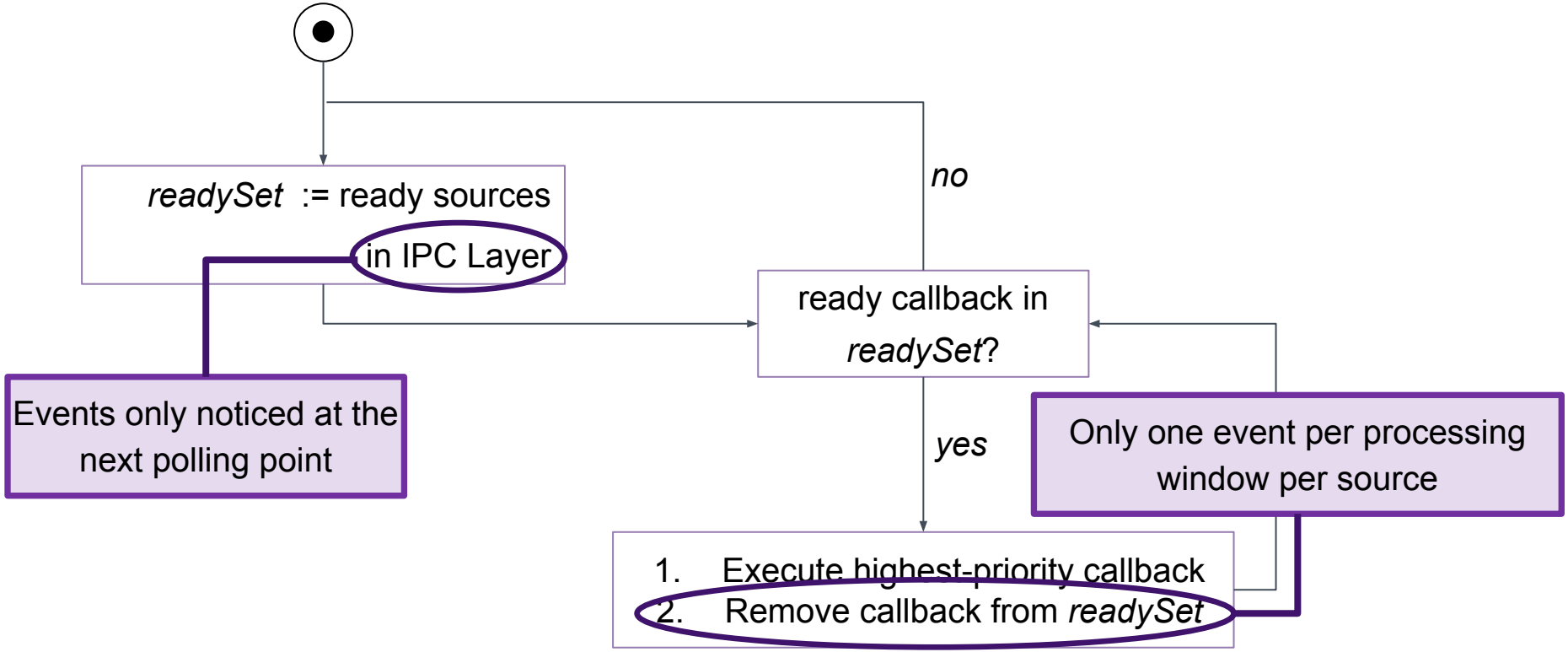


Background: Peculiar Properties of the Executor



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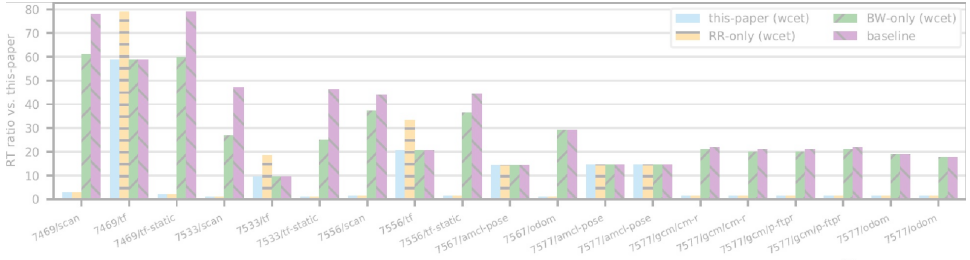

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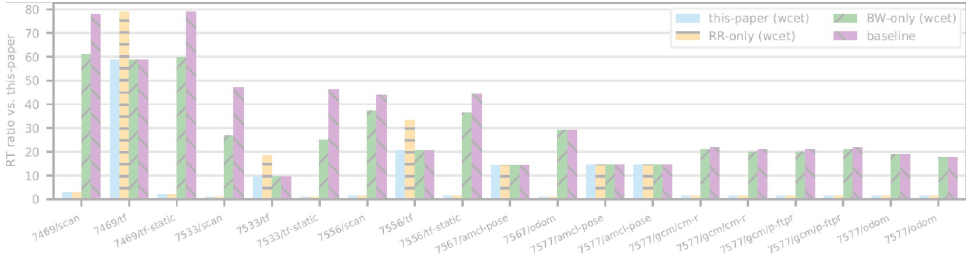

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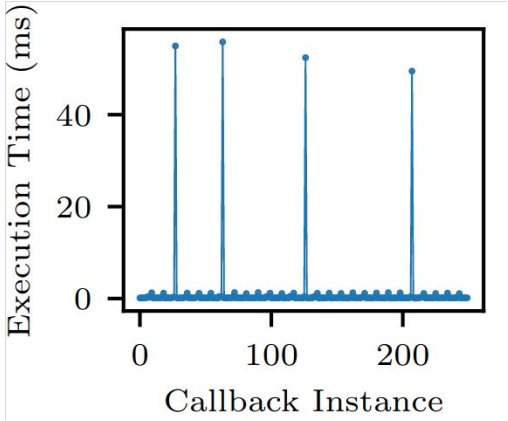
Address Large Execution-Time Variance

Problem: scalar WCET is too pessimistic



AMCL /tf callback in the navigation 2 package

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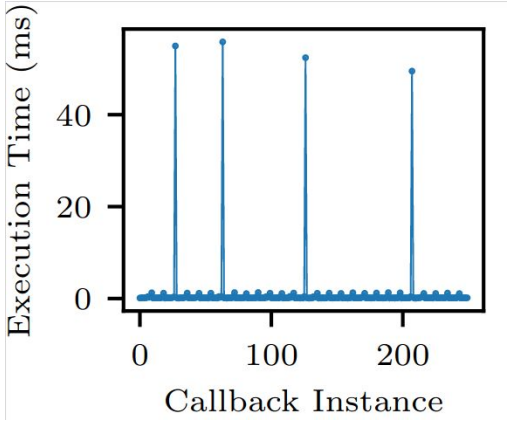

AMCL /tf callback in the navigation 2 package

Solution: Execution-Time Curves
(Quinton et al., 2012)

Bound execution time of multi-instance **sequences**

\+ More precise execution-time model

\- More complex analysis

Details in the paper

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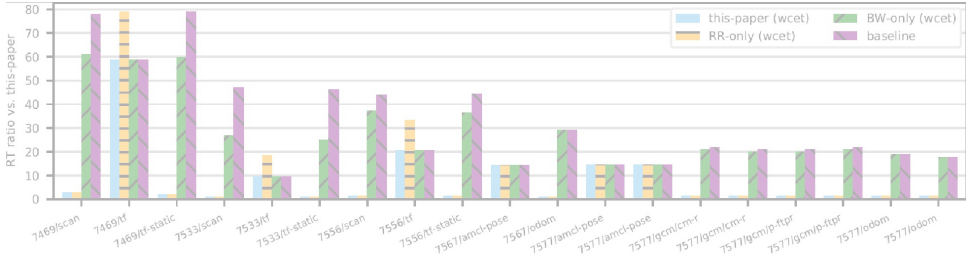

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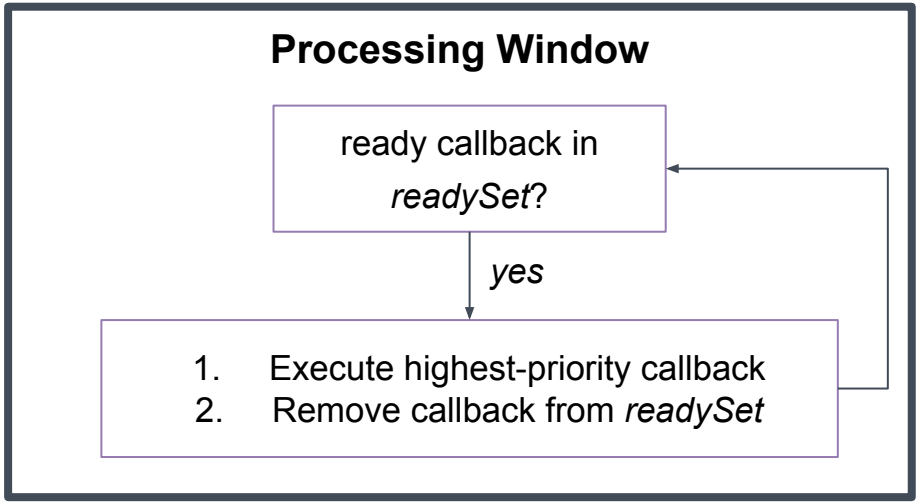
Problem: Bursty Callbacks

Scenario:

- Callback c_1 is triggered periodically
- Callback c_2 triggers bursts of 20 instances
- Assume c_1's response time < c_1's period

Prior Work:

20 instances of c_2 in c_1's busy window.



Pessimistic! Only one instance of c_2 runs in each processing window.

Solution: Round-Robin Analysis

Idea: count polling points

one polling point in this interval
(per self-interfering instance of c_1)

Scenario:

- Callback c_1 is triggered periodically
- Callback c_2 triggers bursts of 20 instances
- Assume c_1's response time < period

\+ Independent of c_2's activation frequency

\- Incompatible with busy-window principle

Combined Analysis

Round-Robin Analysis

- \+ Effective in executors with bursty callbacks
- \- Lacks busy-window principle

Busy-Window Analysis

- \+ Benefits of busy-window principle
- \- Pessimistic in executors with bursty callbacks

Just try both!

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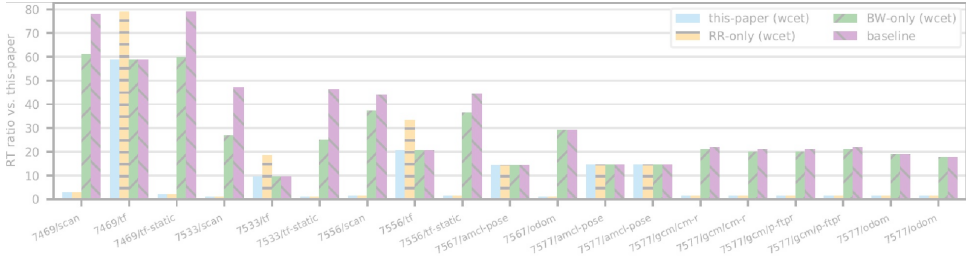

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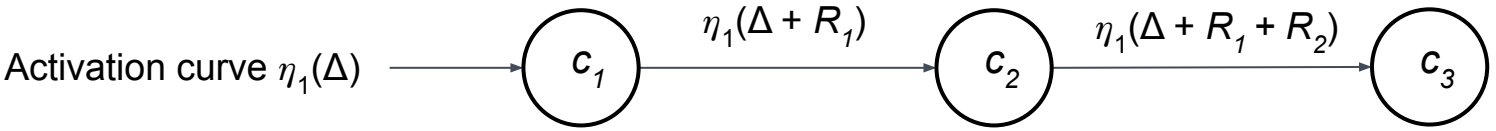
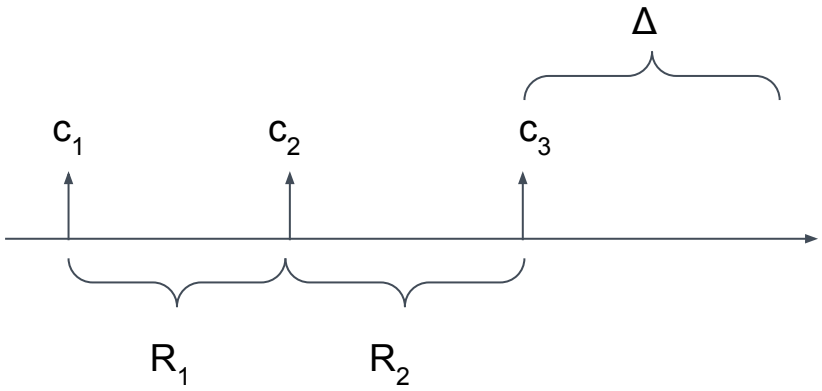
Activation Curve Propagation within Executors

Activation curves are propagated with response-time jitter (Henia et. al., 2005)

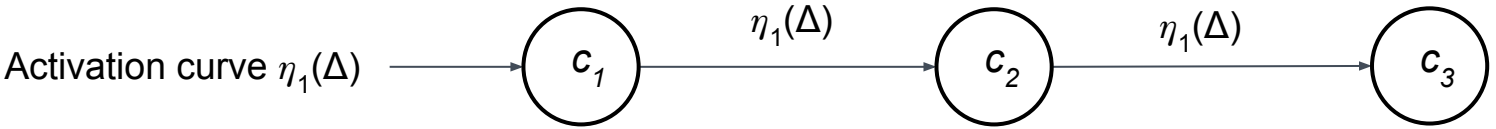


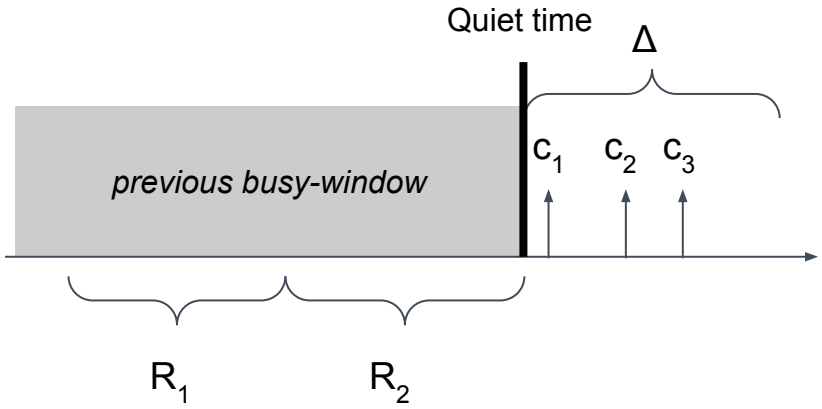


Rationale:
Activations of c_3 ultimately result from activations of c_1 outside the window

Activation Curve Propagation within Executors

If c_1, c_2, c_3 belong to the **same executor** and the Δ-interval starts at a **quiet time**:





Rationale:
Activations of c_1,c_2 cannot cross the quiet time.

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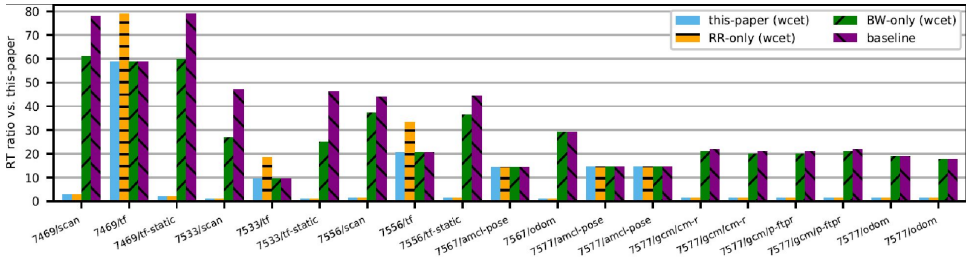

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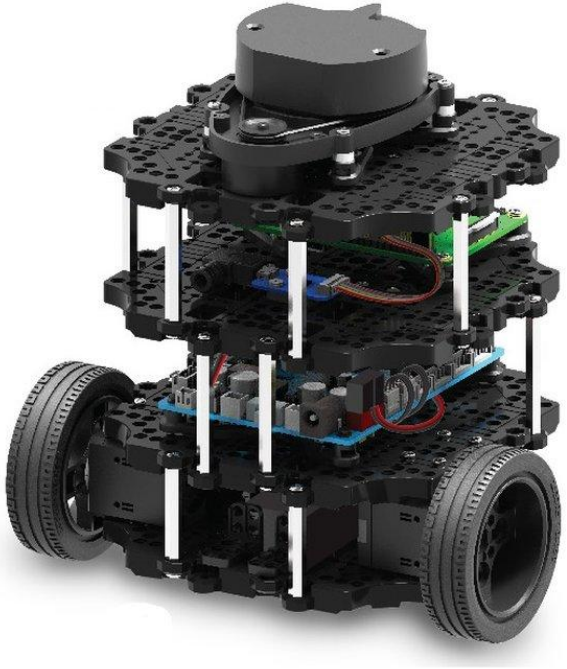
Evaluation

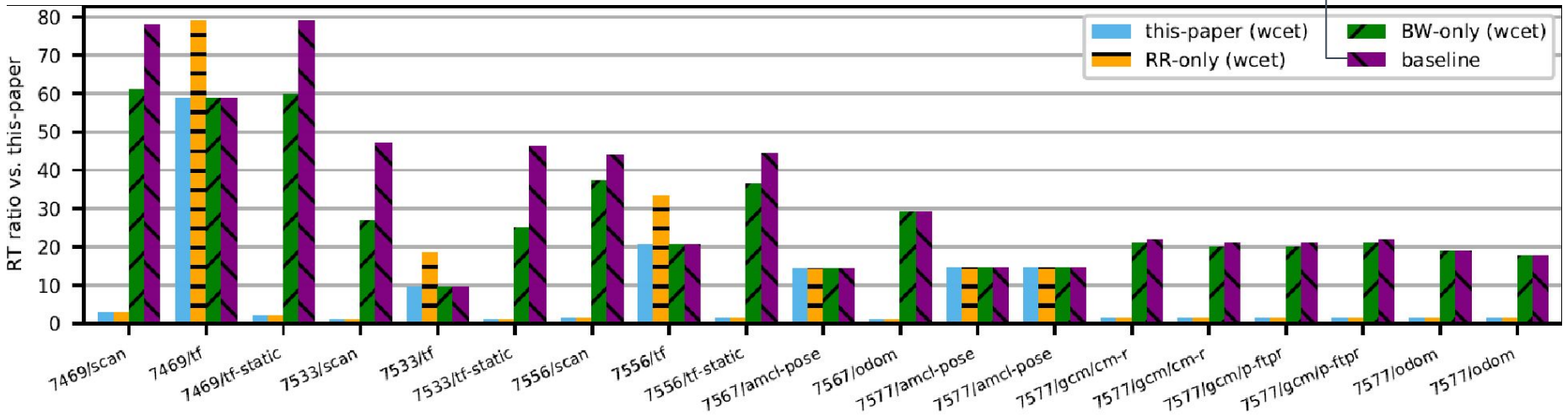
- **Turtlebot 3** “Burger” controlled by a **Raspberry Pi 4B**
- Running various **ROS packages**
  - Navigation 2 packages
  - Turtlebot 3 drivers
- Callback graph extracted from measurements

  See Blass et al., “Automatic Latency Management for ROS 2: Benefits, Challenges, and Open Problems”, RTAS *2021*



Evaluation

Casini et. al., “*Response-Time Analysis of ROS 2 Processing Chains under Reservation-Based Scheduling*”, ECRTS 2019



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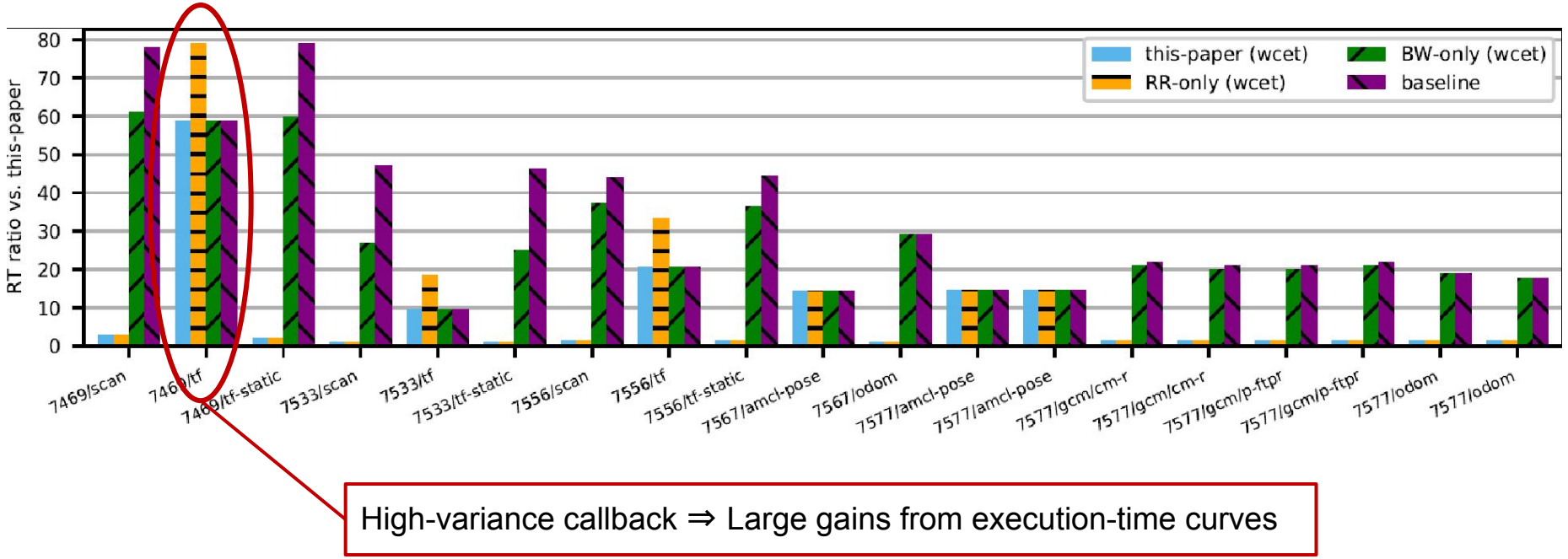
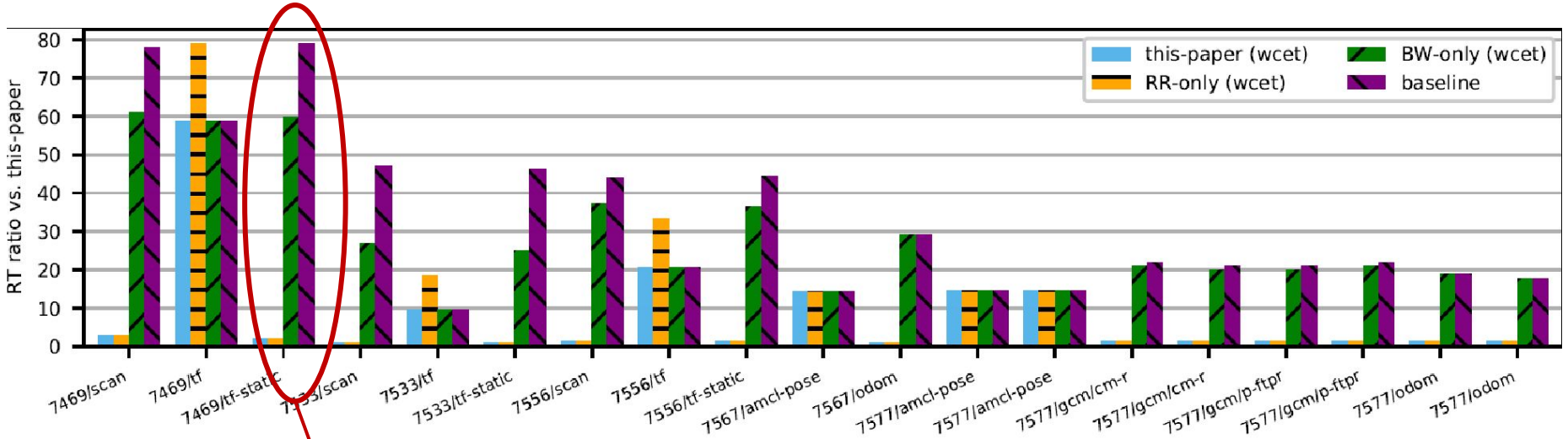


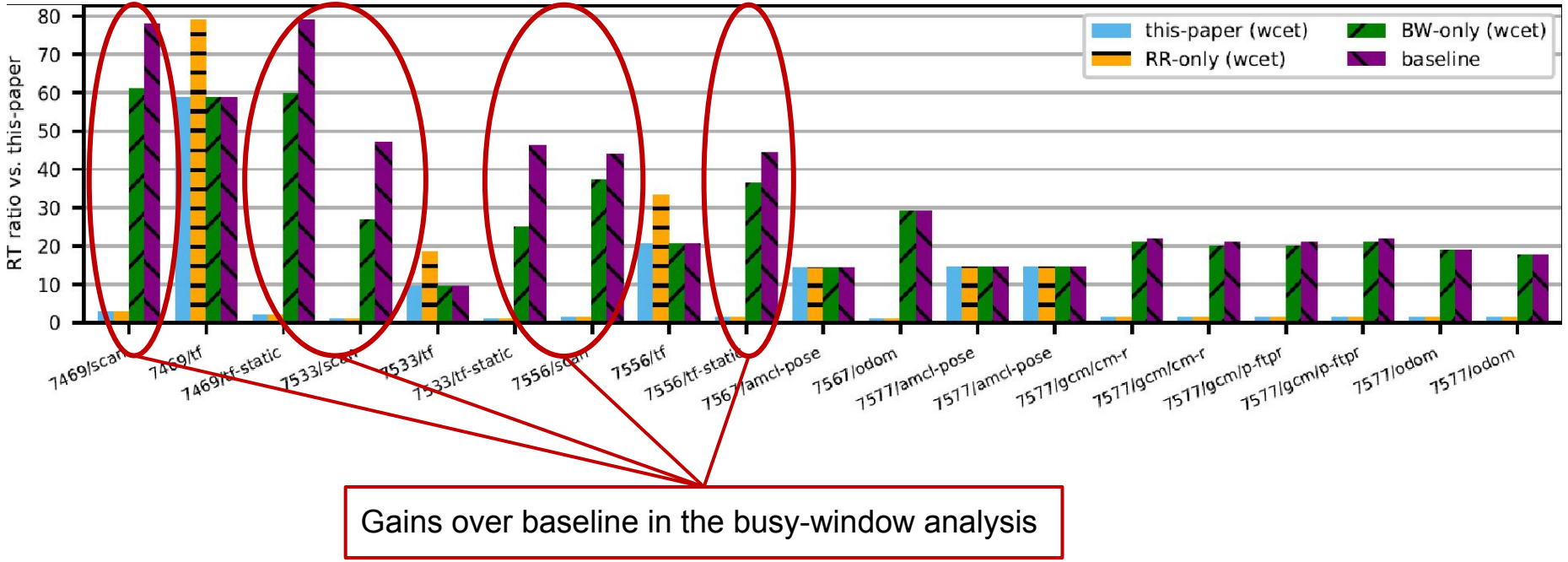
High-variance callback ⇒ Large gains from execution-time curves

Evaluation



Shares executor with bursty callback
⇒ Large gains from round-robin analysis

Evaluation



Gains over baseline in the busy-window analysis

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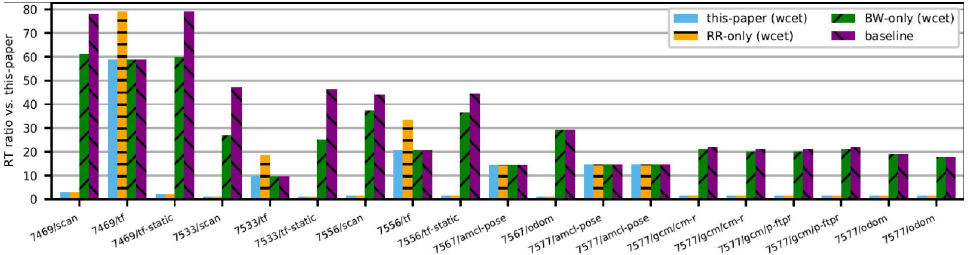

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