CISPA
HELMHOLTZ CENTER FOR INFORMATION SECURITY

Active Monitoring with RTLola

A Specification-Guided Scheduling Approach

Jan Baumeister, Bernd Finkbeiner, ***Frederik Scheerer***

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Motivation

Photo: DLR (CC BY-NC-ND 3.0)

Motivation

GPS Sensor

Altitude Sensor

Camera

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Monitor

Motivation

Photo: DLR (CC BY-NC-ND 3.0)

Monitoring Drone Sensors: Low Frequency

Video

Motivation

Photo: DLR (CC BY-NC-ND 3.0)

Limited Bandwidth

because restrictions concerning energy consumption, size or weight.

Motivation

Photo: DLR (CC BY-NC-ND 3.0)

Motivation

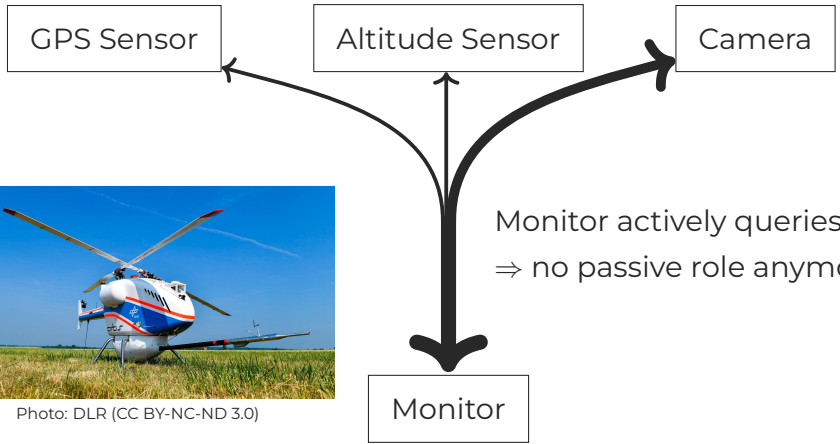


Photo: DLR (CC BY-NC-ND 3.0)

Monitoring Drone Sensors: Scheduled

Video

Monitor Semantics

Evaluation Model $\mathbb{W}$ is valid, if:

- Values are calculated according to specification
- Timestamps are monotonically increasing

Scheduled Monitor Semantics

Evaluation Model $\mathbb{W}$ is valid, if:

- Values are calculated according to specification
- Timestamps are monotonically increasing, and
- Inputs arrive according to **scheduling constraint**.

Dynamic Scheduling Constraints

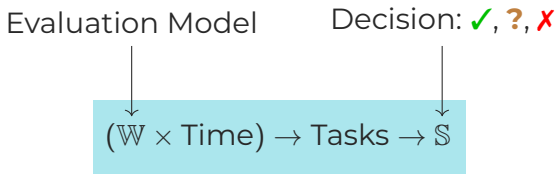
$$(\mathbb{W} \times \text{Time}) \to \text{Tasks} \to \mathbb{S}$$

Dynamic Scheduling Constraints

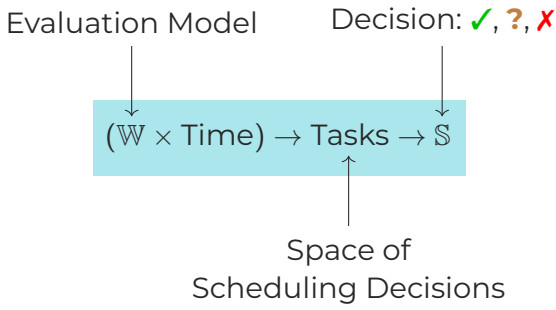
Evaluation Model

$$(\mathbb{W} \times \text{Time}) \to \text{Tasks} \to \mathbb{S}$$

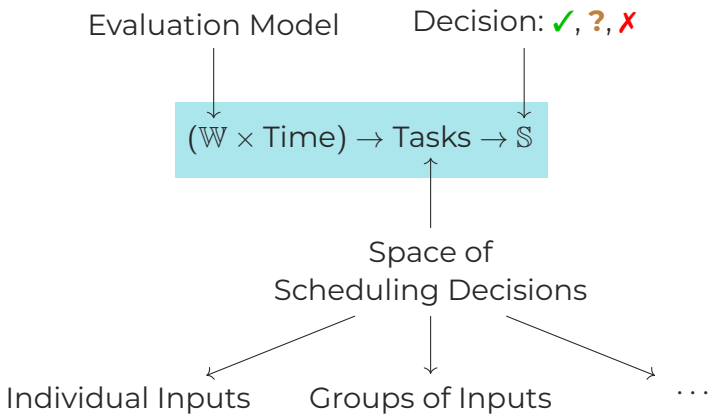
Dynamic Scheduling Constraints



Dynamic Scheduling Constraints



Dynamic Scheduling Constraints



Scheduling Constraints

Dynamic Constraint

$$(\mathbb{W} \times \text{Time}) \rightarrow \text{Tasks} \rightarrow \mathbb{S}$$

Requires access to the whole evaluation model

Scheduling Constraints

Dynamic Constraint

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Requires access to the whole evaluation model

Static Constraint

$$\text{Tasks} \to \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Can be evaluated during runtime

Scheduling Constraints

Dynamic Constraint

$$(\mathbb{W} \times \text{Time}) \to \text{Tasks} \to \mathbb{S}$$

Requires access to the whole evaluation model

Static Constraint

$$\text{Tasks} \to \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Can be evaluated during runtime

Translated by the scheduling algorithm

Static Constraints

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Static Constraints

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Deadline

$\mathbb{V}$ are time durations:
e.g. 100ms, 1s, 5s

maximum duration
between evaluations

Static Constraints

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Deadline	**Priority**
$\mathbb{V}$ are time durations: e.g. 100ms, 1s, 5s	$\mathbb{V}$ are priorities: high, medium, low
maximum duration between evaluations	highest priority tasks are evaluated first

Static Constraints

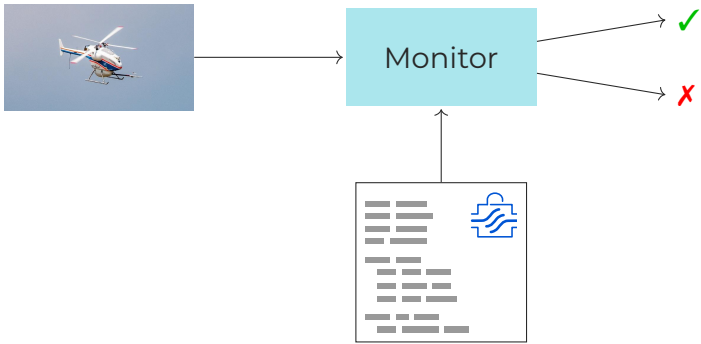
$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Deadline	**Priority**	**Priority + Deadline**
$\mathbb{V}$ are time durations: e.g. 100ms, 1s, 5s	$\mathbb{V}$ are priorities: high, medium, low	$\mathbb{V}$ are priorities: high, medium, low
maximum duration between evaluations	highest priority tasks are evaluated first	tasks become overdue after deadline

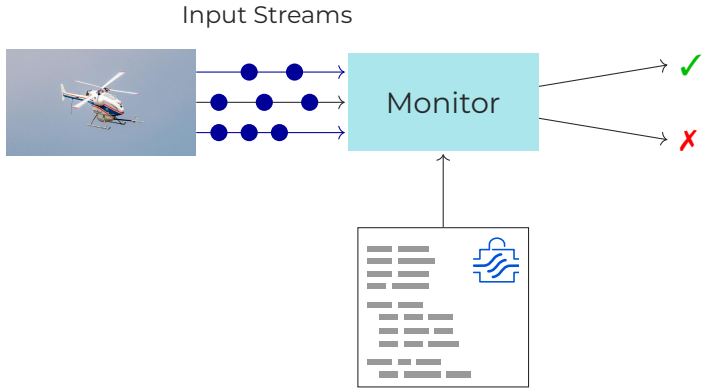
Monitor

✓

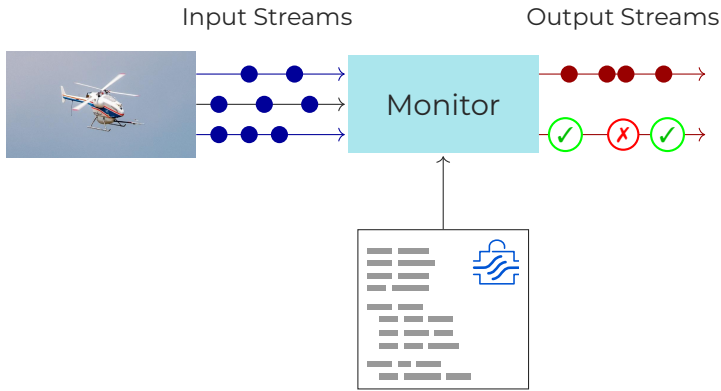
✗

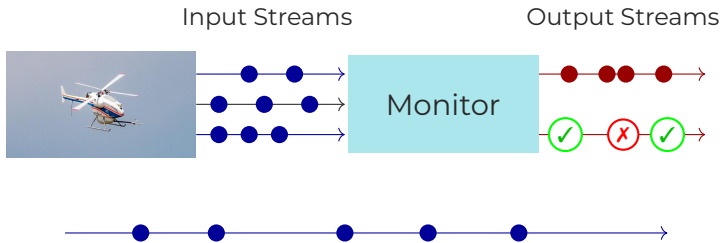

Monitor
✓
✗

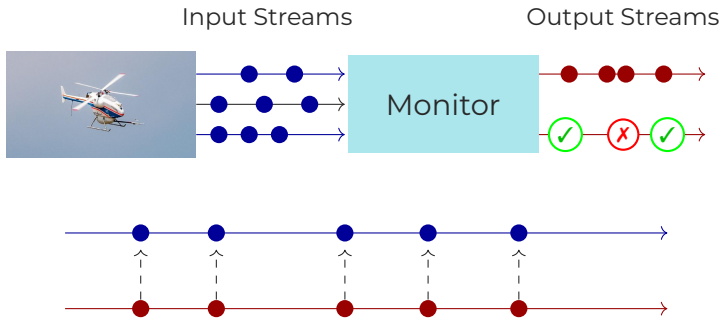
RTLola

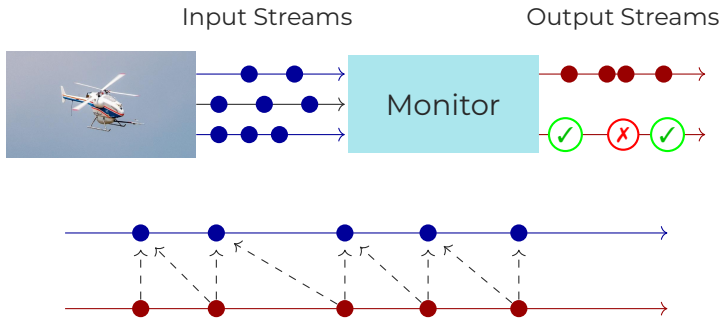


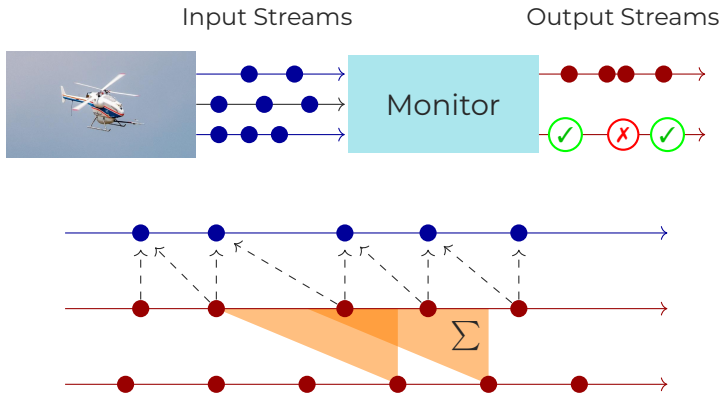
RTLola




Input Streams
Output Streams
Monitor

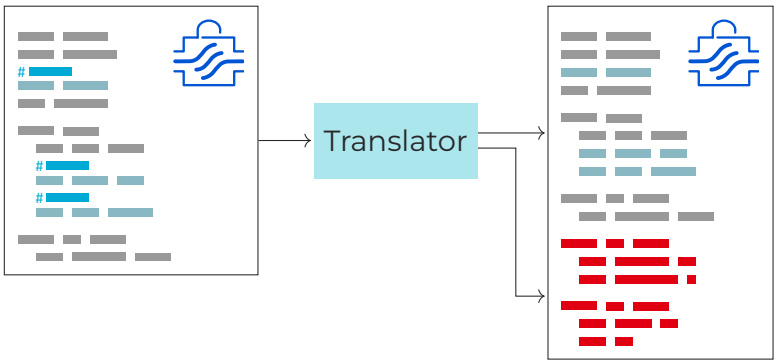

Input Streams
Output Streams
Monitor


Input Streams
Output Streams
Monitor

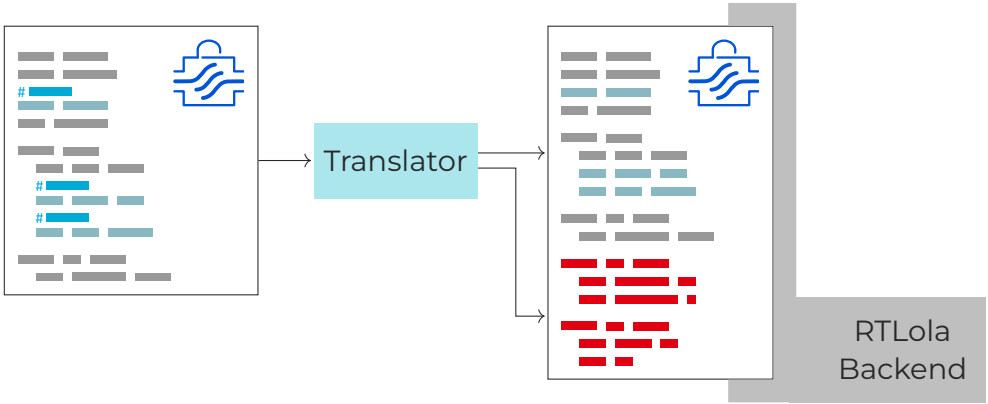

Input Streams
Output Streams
Monitor
✓
✗
✓
Σ

Overview

Overview



Overview



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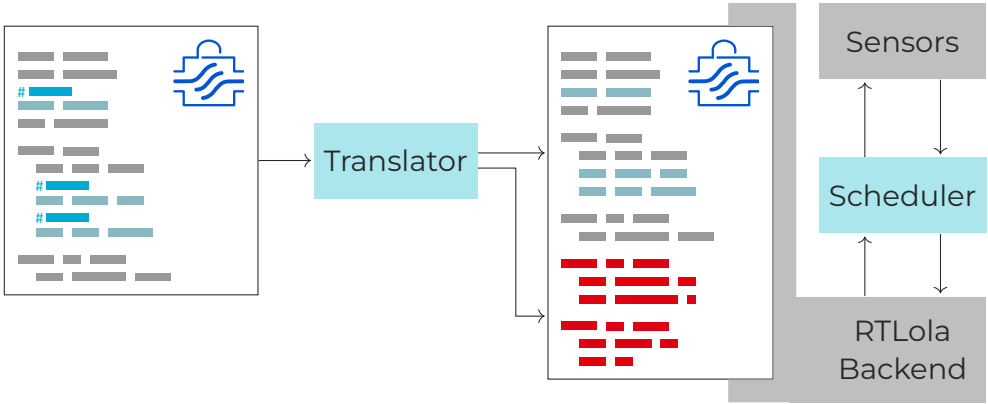

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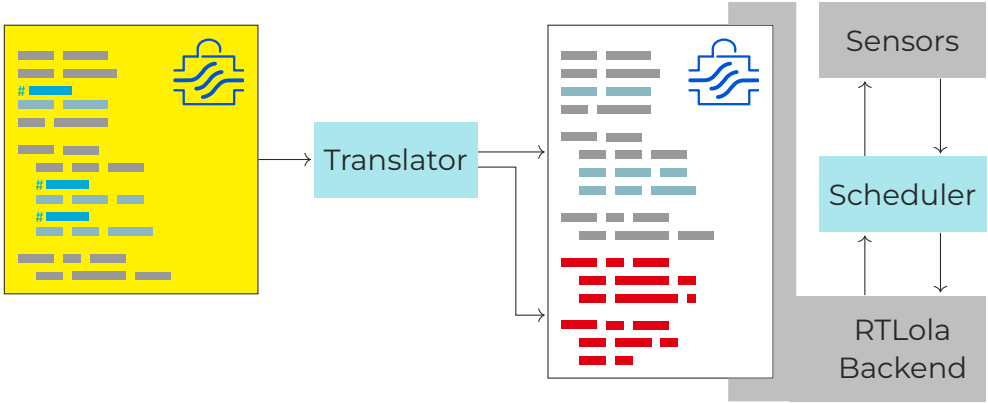

Scheduling Annotations

```
output dist @lat∧lon := ...
output dist_violation
  #[priority=low]
  eval @lat∧lon when dist < 20.0
                with false
  #[priority=medium]
  eval @lat∧lon when dist < 50.0
                with false
  #[priority=high]
  eval @lat∧lon when true
                with dist > 70.0
```

Scheduling Annotations

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output dist @lat∧lon := ...
output dist_violation
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$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

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$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

@lat∧lon	
dist < 20	low

Scheduling Annotations

```
output dist @lat∧lon := ...
output dist_violation
  #[priority=low]
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  eval @lat∧lon when true
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```

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

@lat∧lon	
dist < 20	low
20 ≤ dist < 50	medium

Scheduling Annotations

```
output dist @lat∧lon := ...
output dist_violation
  #[priority=low]
  eval @lat∧lon when dist < 20.0
                with false
  #[priority=medium]
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  eval @lat∧lon when true
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```

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

@lat∧lon	
dist < 20	low
20 ≤ dist < 50	medium
dist ≥ 50	high

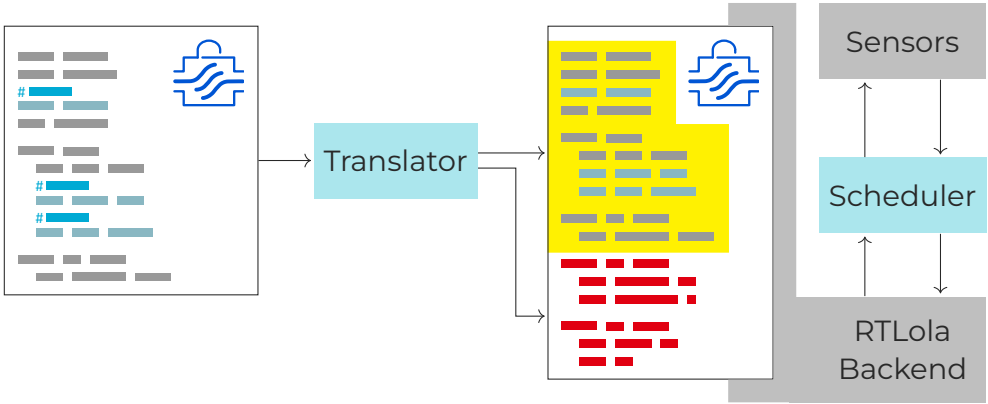
Scheduling Annotations

```
output dist @lat∧lon := ...
output dist_violation

  eval @lat∧lon when dist < 20.0
               with false

  eval @lat∧lon when dist < 50.0
               with false

  eval @lat∧lon when true
               with dist > 70.0
```

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

@lat∧lon	
dist < 20	low
20 ≤ dist < 50	medium
dist ≥ 50	high

Overview



Additional Streams

@lat∧lon	
dist < 20	low
20 ≤ dist < 50	medium
dist ≥ 50	high

Additional Streams

separate stream
for each task

@lat∧lon	
dist < 20	low
20 ≤ dist < 50	medium
dist ≥ 50	high

```
output schedule_lat∧lon
  eval @lat∧lon when dist ≥ 50 with high
  eval @lat∧lon when 20 ≤ dist < 50 with medium
  eval @lat∧lon when dist < 20 with low
```

Additional Streams

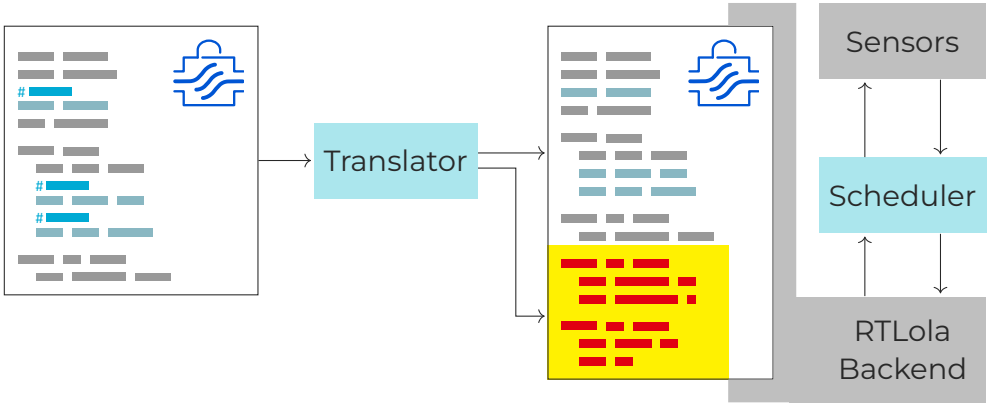
separate stream
for each task

@lat∧lon	
dist < 20	low
20 ≤ dist < 50	medium
dist ≥ 50	high

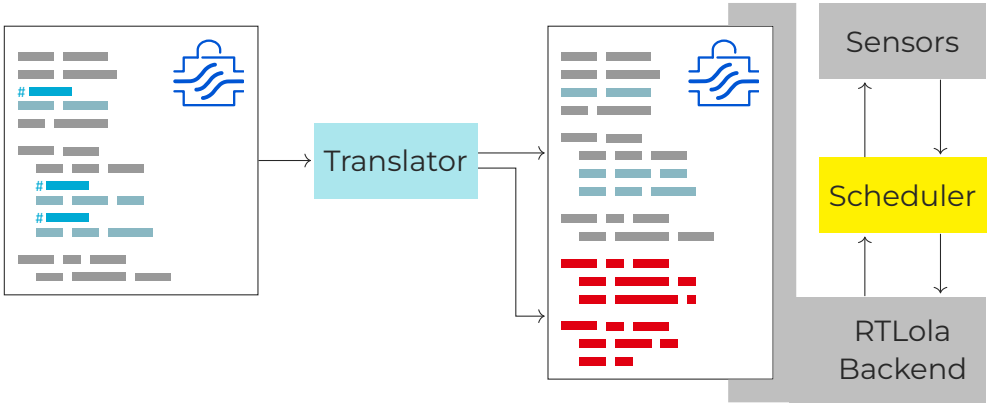
```
output schedule_lat∧lon
  eval @lat∧lon when dist ≥ 50 with high
  eval @lat∧lon when 20 ≤ dist < 50 with medium
  eval @lat∧lon when dist < 20 with low
```

sorted descendingly

Overview



Overview



Scheduling Algorithms

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Deadline **Priority** **Priority + Deadline**

Scheduling Algorithms

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Deadline

Fill available bandwidth with tasks that are due the soonest (Earliest Deadline First)

Priority

Priority + Deadline

Scheduling Algorithms

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Deadline	Priority	Priority + Deadline
Fill available bandwidth with tasks that are due the soonest (Earliest Deadline First)	Fill available bandwidth with highest priority tasks	

Scheduling Algorithms

$$\text{Tasks} \rightarrow \mathcal{P}(\text{Cond} \times \mathbb{V})$$

Deadline

Fill available bandwidth with tasks that are due the soonest (Earliest Deadline First)

Priority

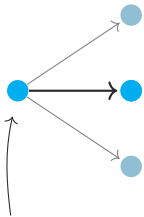
Fill available bandwidth with highest priority tasks

Priority + Deadline

Overdue tasks are assigned new, highest priority

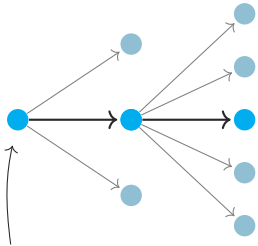
Getting stuck

Getting stuck



Scheduling options based
on current monitor state

Getting stuck



Scheduling options based
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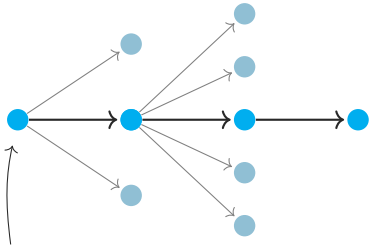
Getting stuck



Scheduling options based
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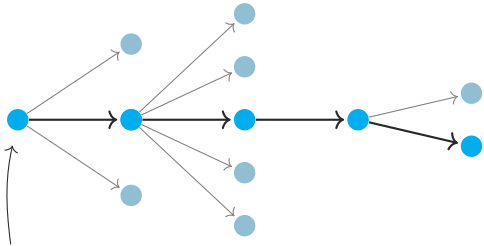
Getting stuck



Scheduling options based
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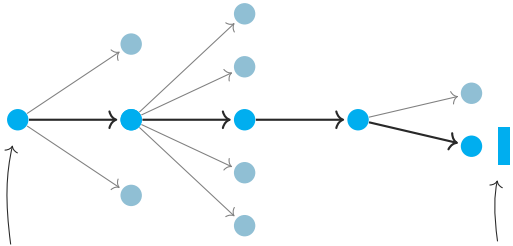
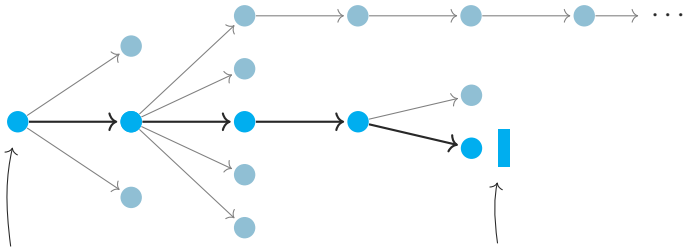
Getting stuck



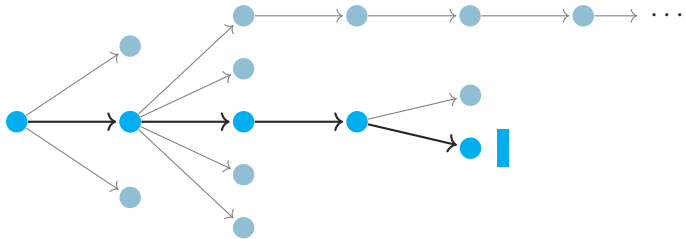
Scheduling options based on current monitor state

No option satisfies the schedule

Getting stuck



Getting stuck



A scheduling algorithm should always be able to continue, independent of the future inputs!

- **Checked by static analysis on the constraint**

Evaluation

- Can we detect triggers earlier while using the same bandwidth?

Evaluation

- Can we detect triggers earlier while using the same bandwidth?
- Can we reduce bandwidth without compromising monitoring quality?

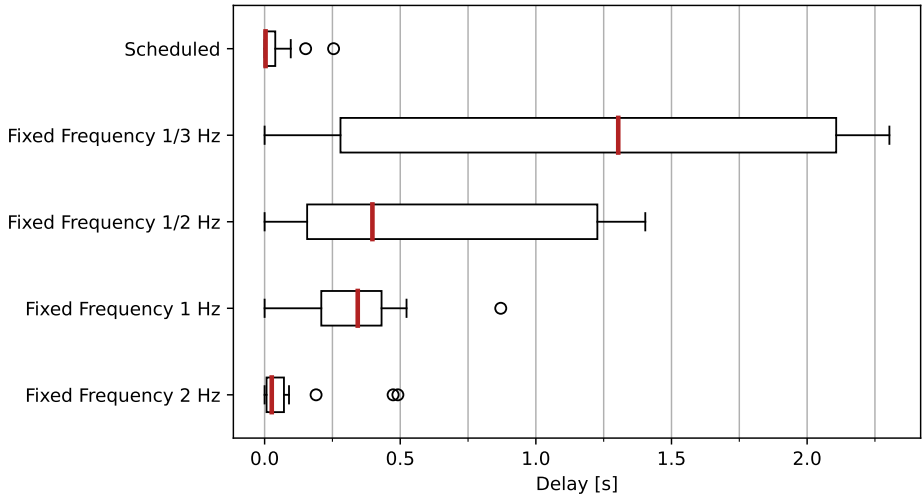
Evaluation

- Can we detect triggers earlier while using the same bandwidth?
- Can we reduce bandwidth without compromising monitoring quality?

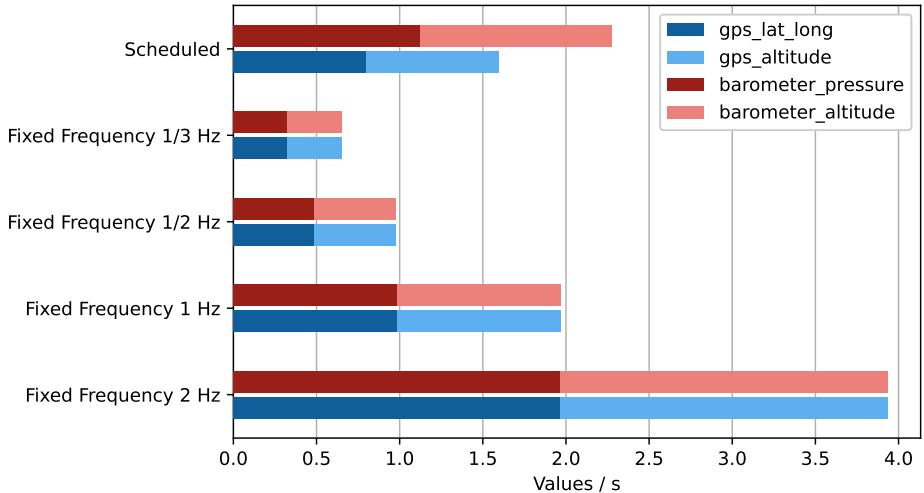
Evaluation with Microsoft AirSim [Sha+18]

- Compare scheduled monitor to multiple fixed-frequency monitors

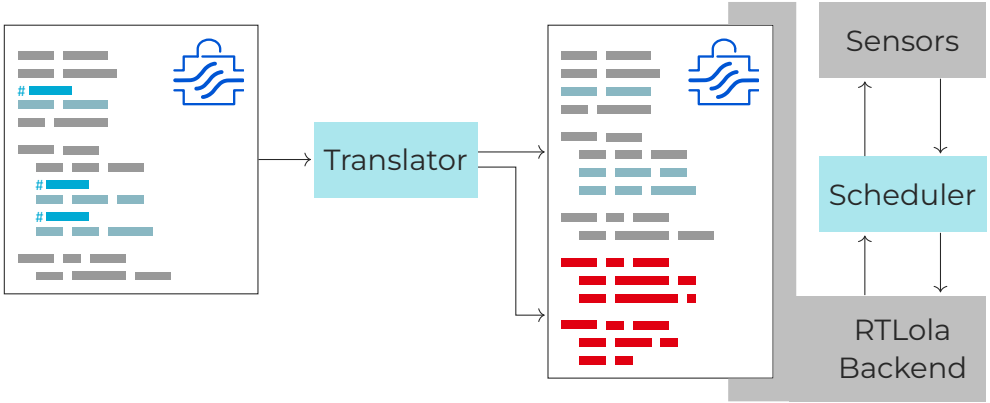
Trigger Delay Comparison



Average Bandwidth Comparison



Conclusion & Outlook



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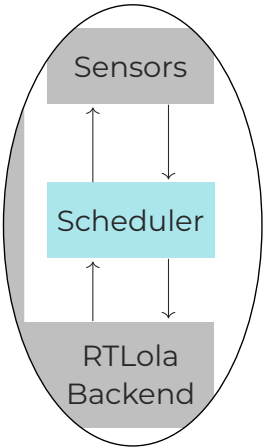

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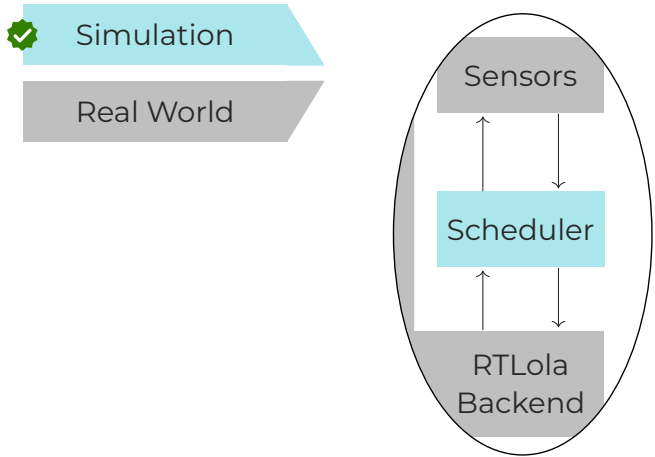

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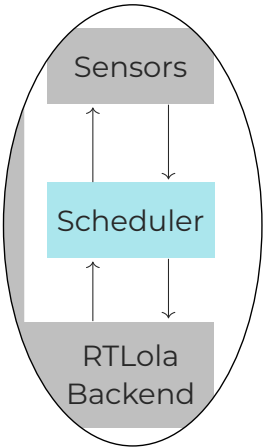

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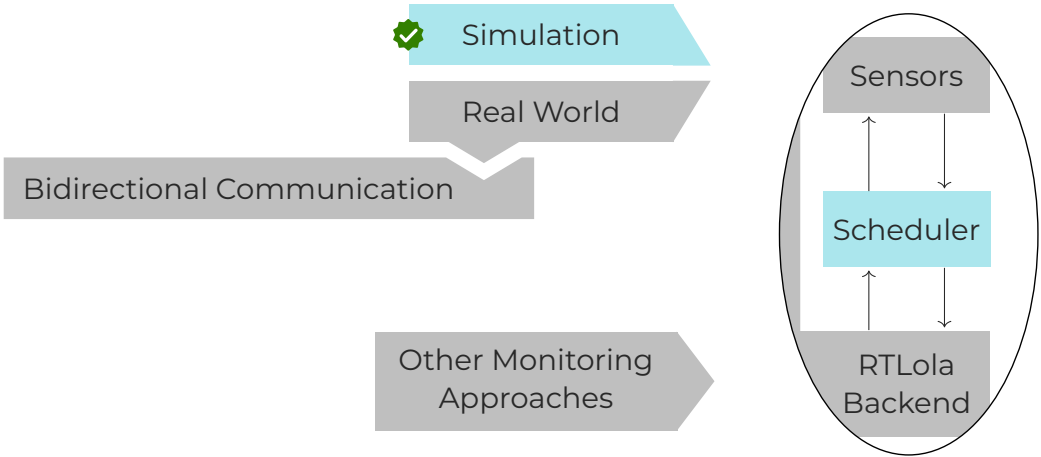

References

[Sha+18] S. Shah, D. Dey, C. Lovett, and A. Kapoor. AirSim: High-Fidelity Visual and Physical Simulation for Autonomous Vehicles. In: Field and Service Robotics. Ed. by M. Hutter and R. Siegwart. Cham: Springer International Publishing, 2018, pp. 621–635. ISBN: 978-3-319-67361-5.