Adaptive Online First-Order Monitoring

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Srđan Krstić Dmitriy Traytel

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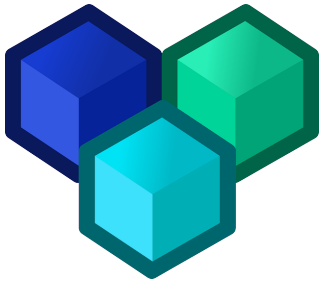
ETH zürich

Verification



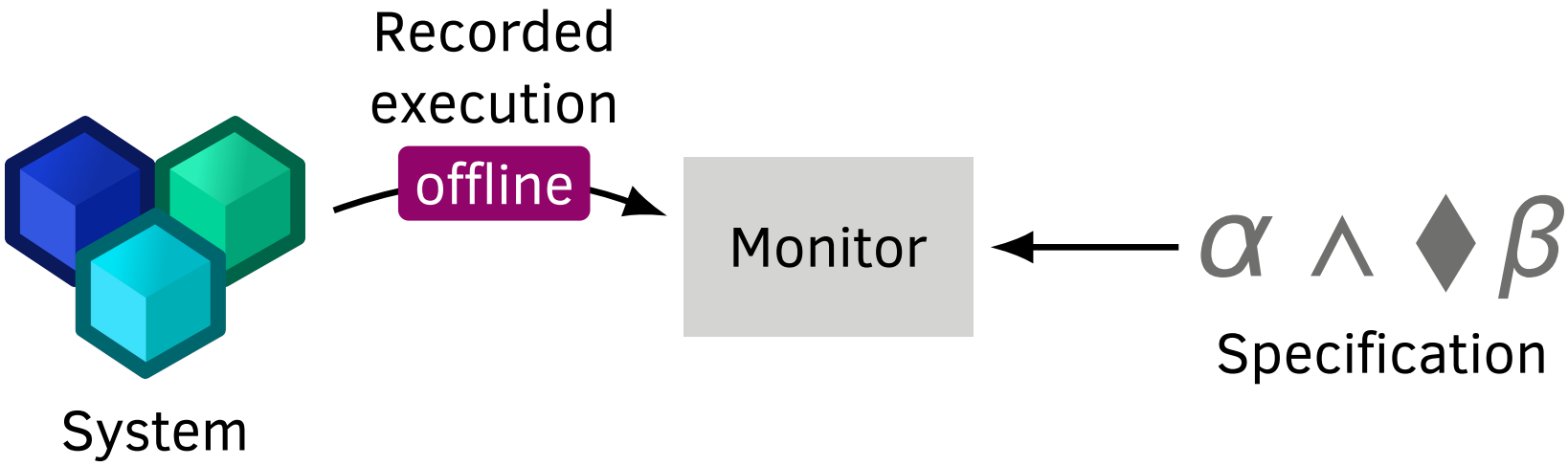
System

?

$\alpha \wedge \blacklozenge \beta$

Specification

Runtime Verification



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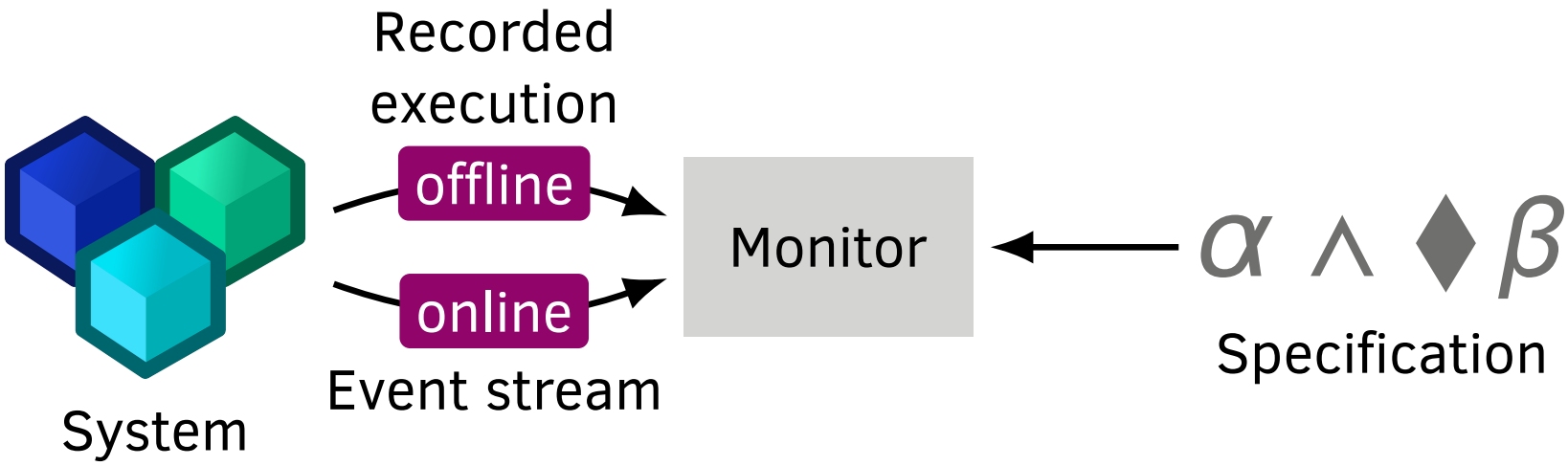

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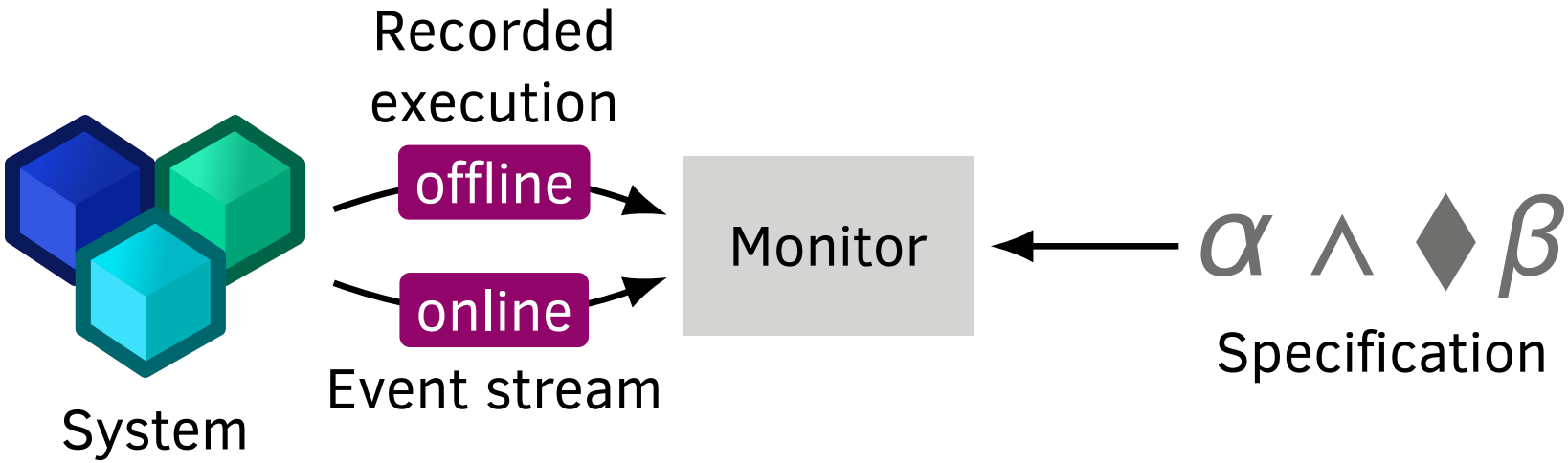

Example: a document management system

"A cached document must be updated to the latest version of its embedded resources (e.g., images) before being sent to a user."

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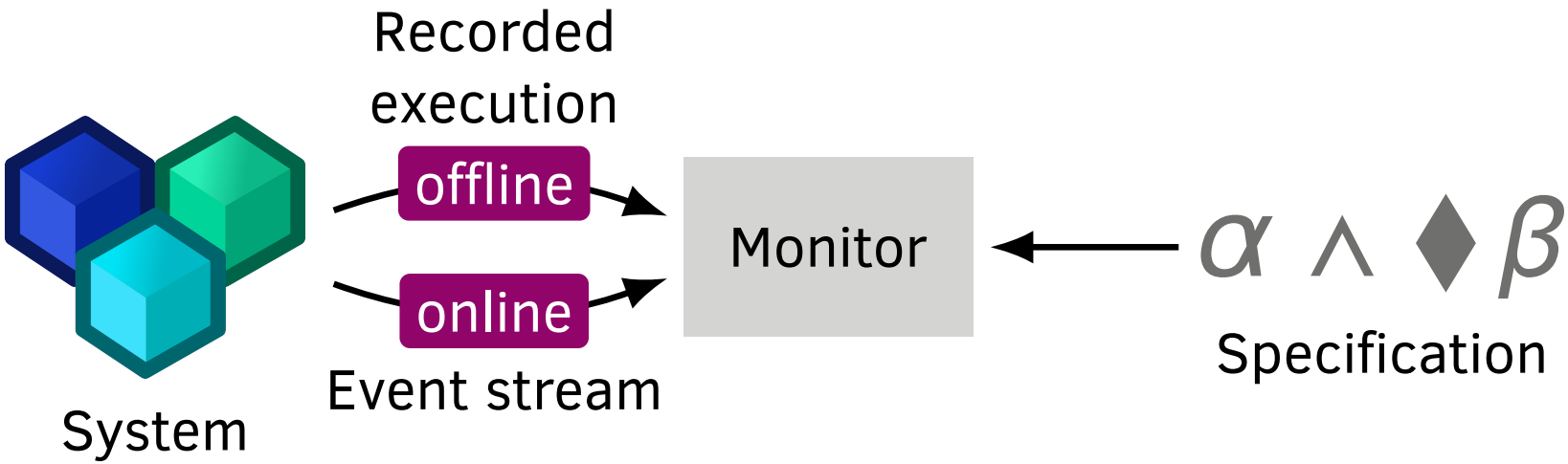

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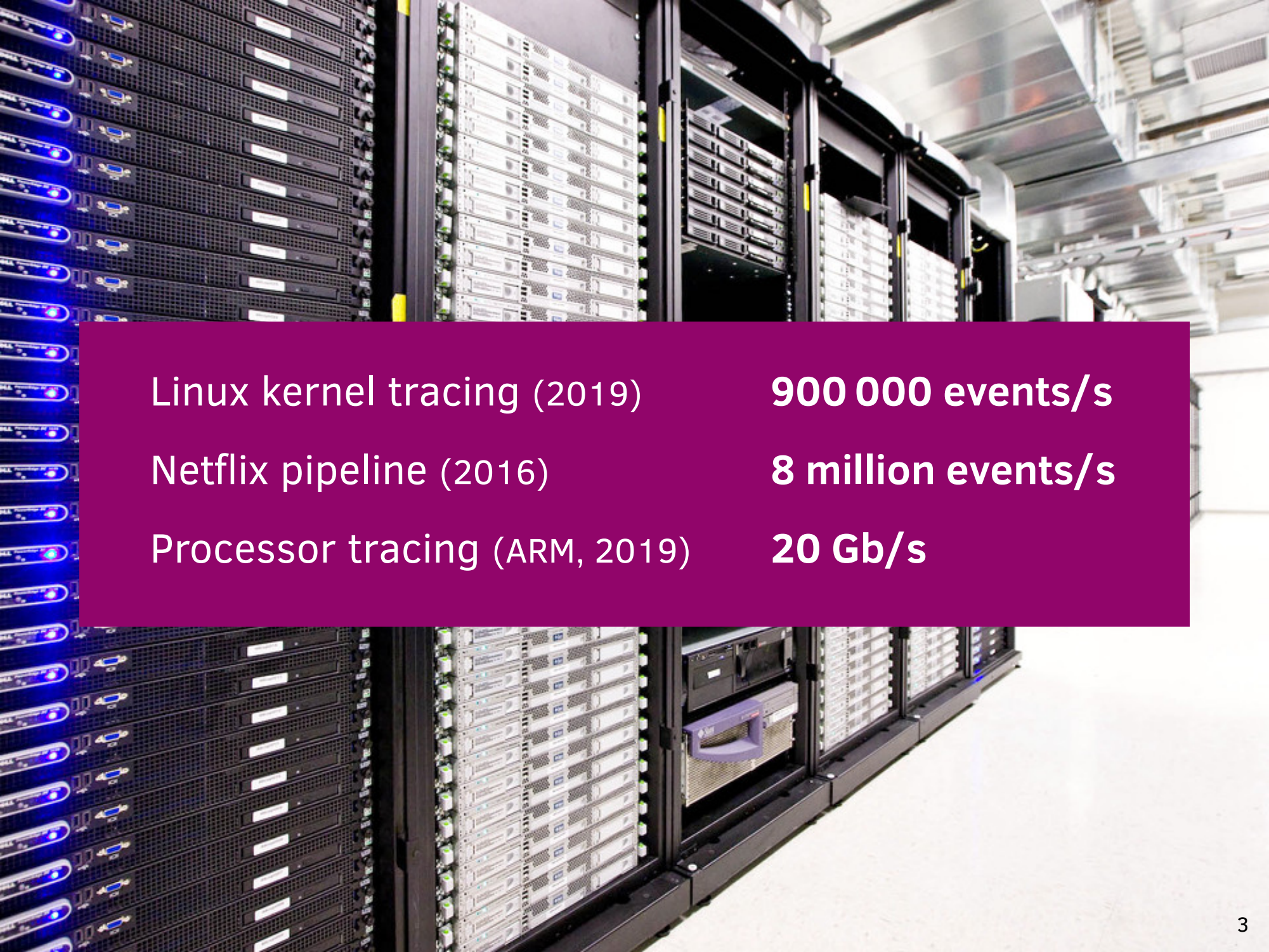
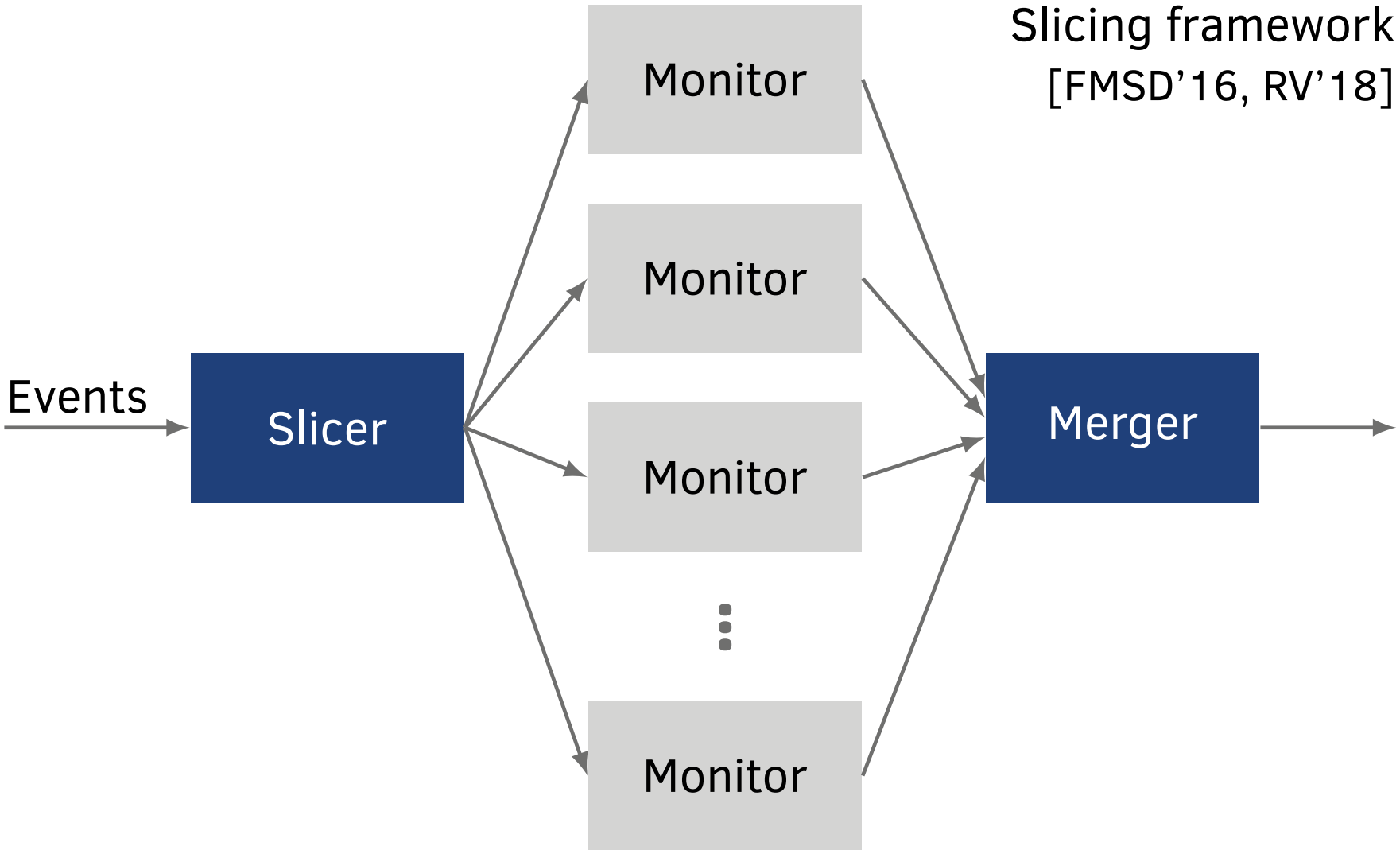
Events: update(*d*), mod(*r*), addResource(*d, r*), send(*d*)



Linux kernel tracing (2019)	**900 000 events/s**
Netflix pipeline (2016)	**8 million events/s**
Processor tracing (ARM, 2019)	**20 Gb/s**

Parallel Online Monitoring



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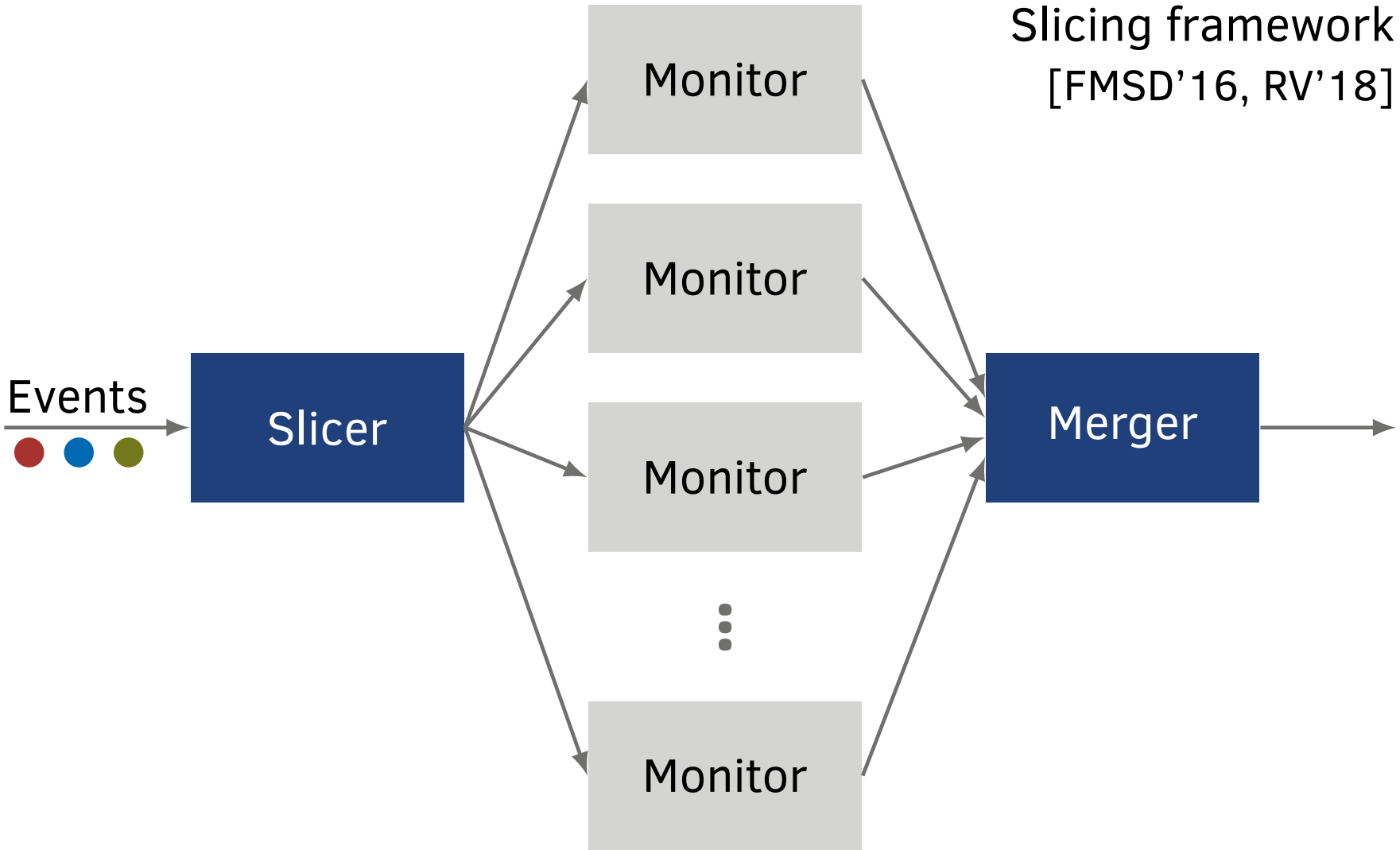

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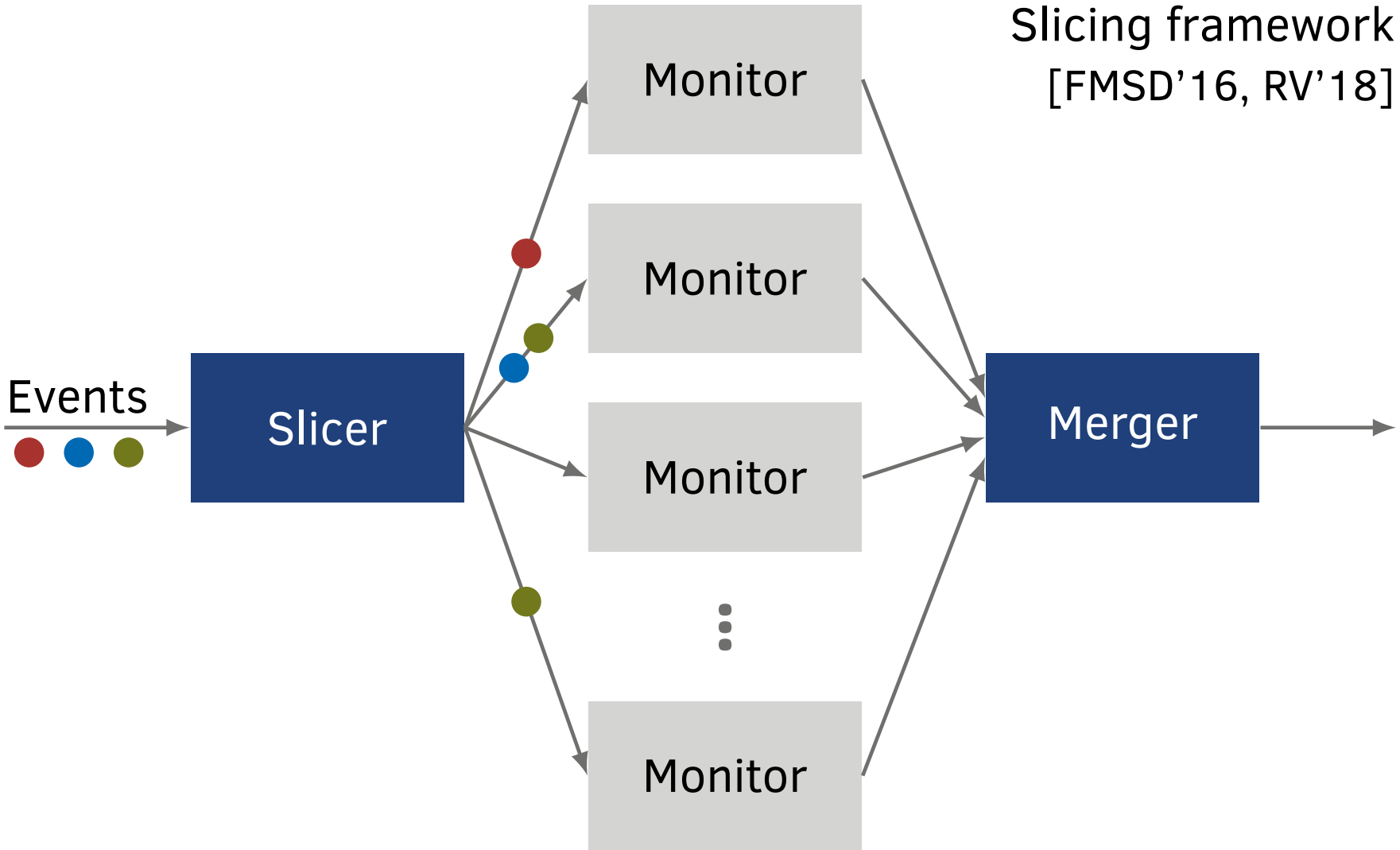

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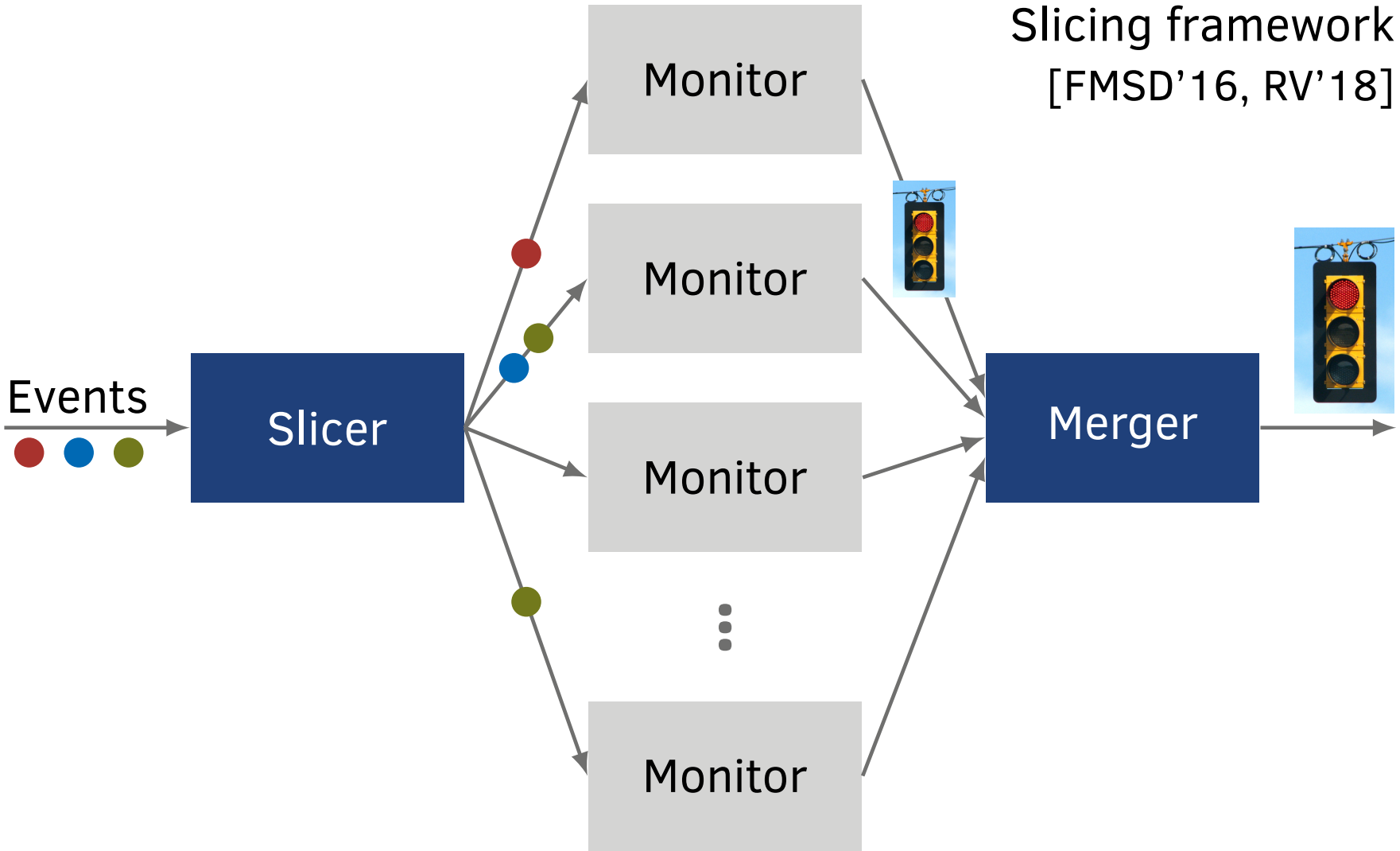

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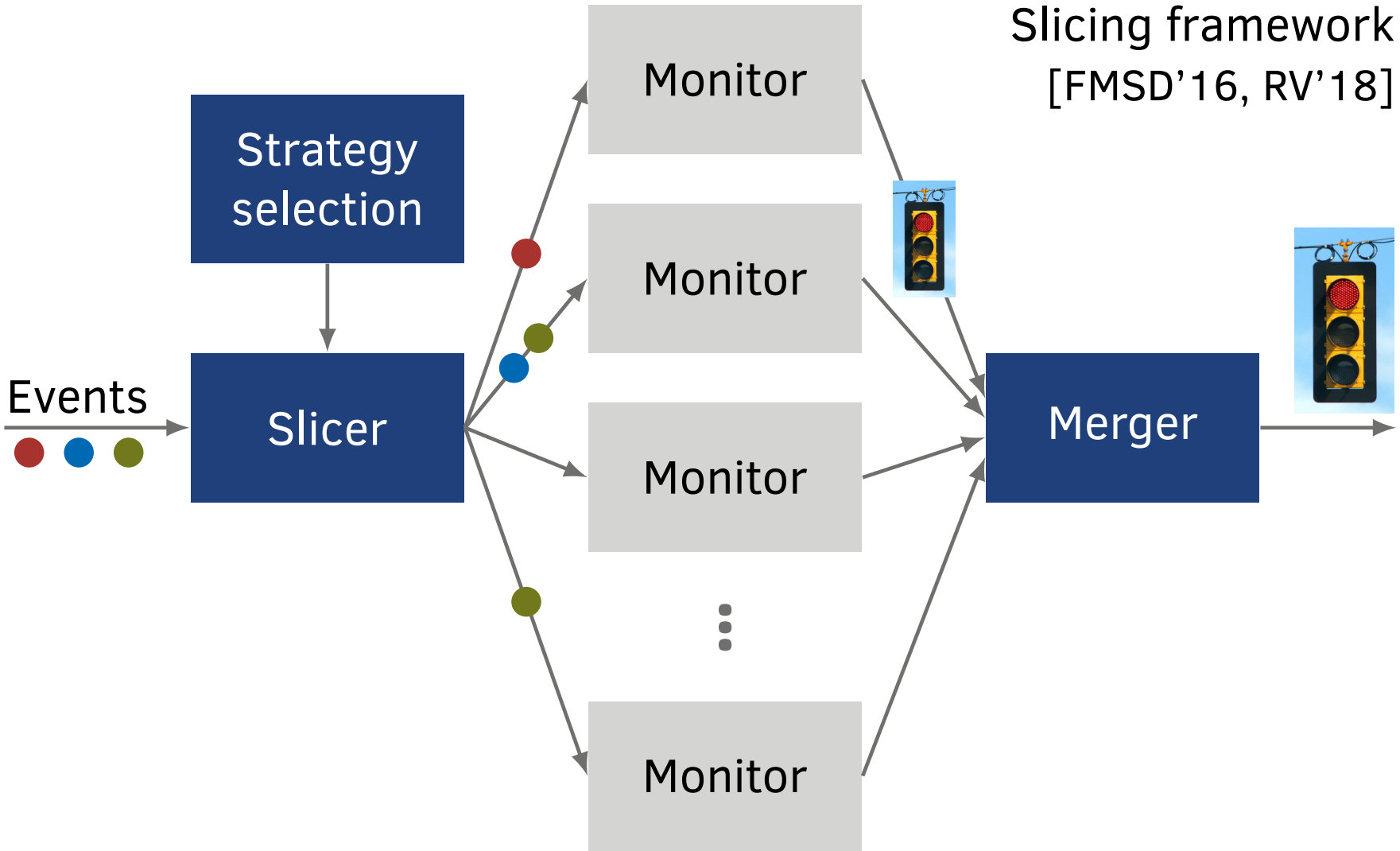

Slicing Strategies

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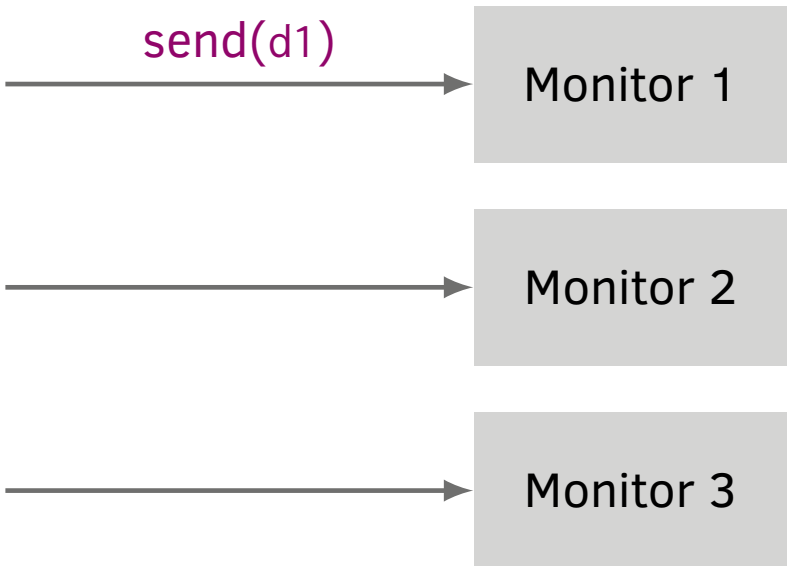

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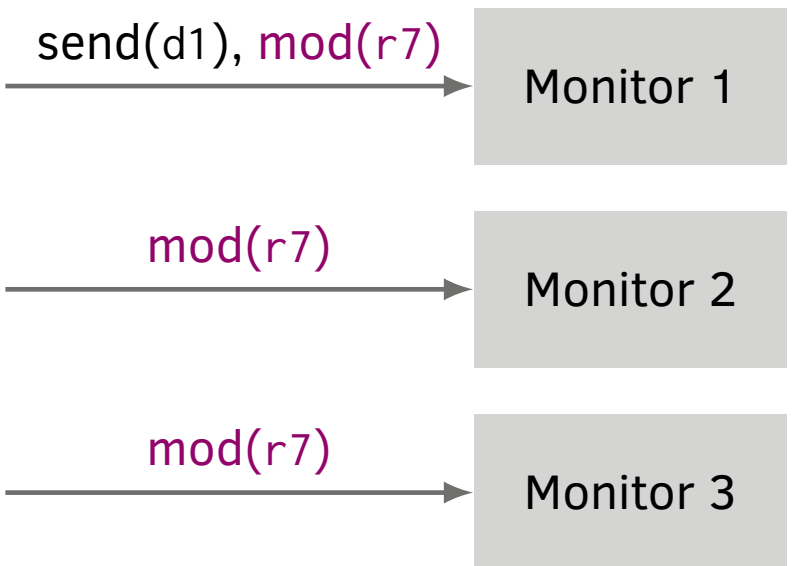

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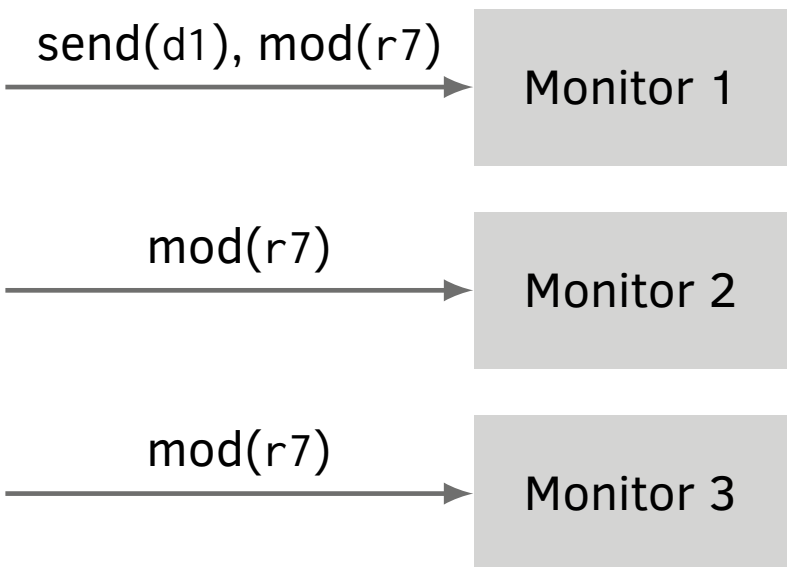

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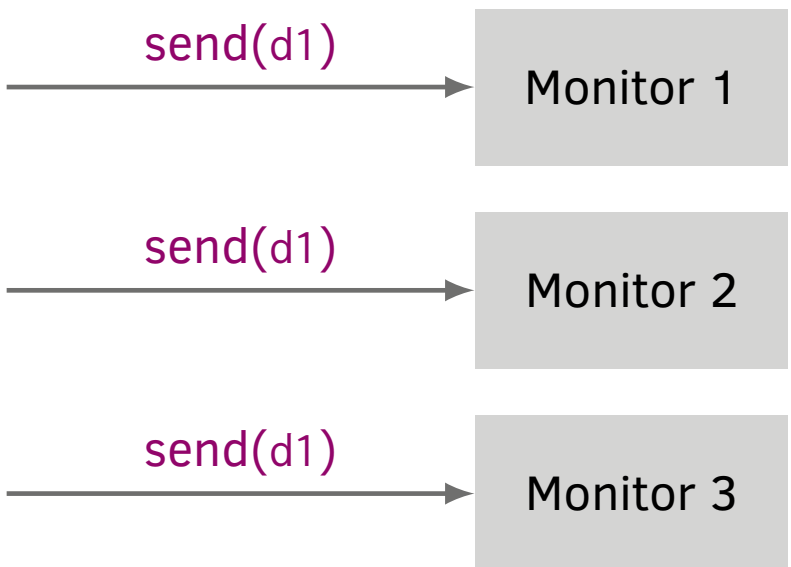

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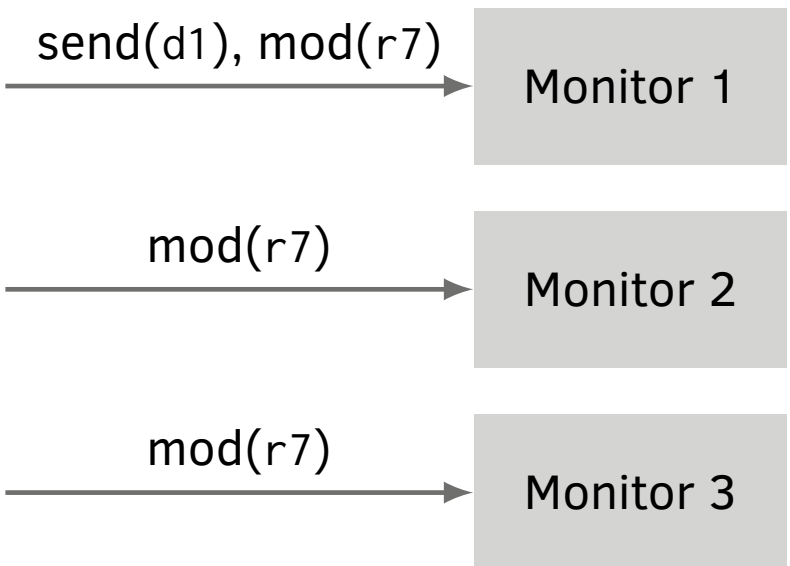

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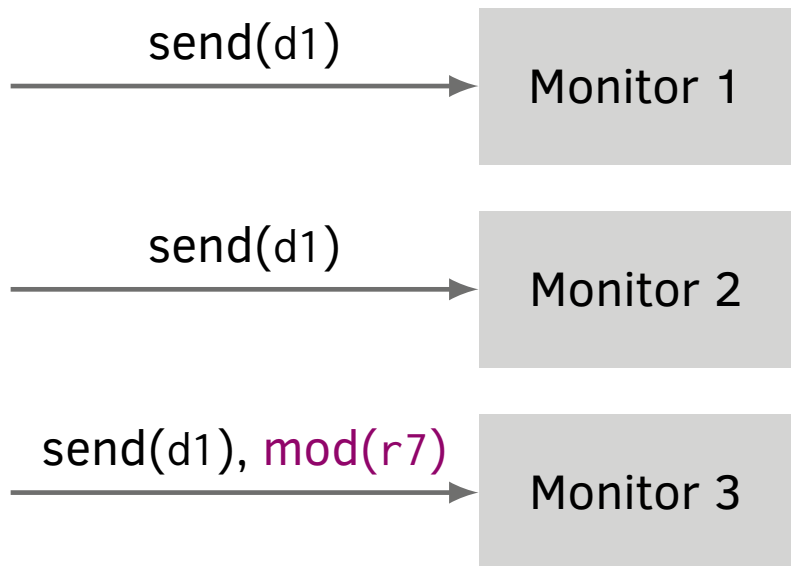
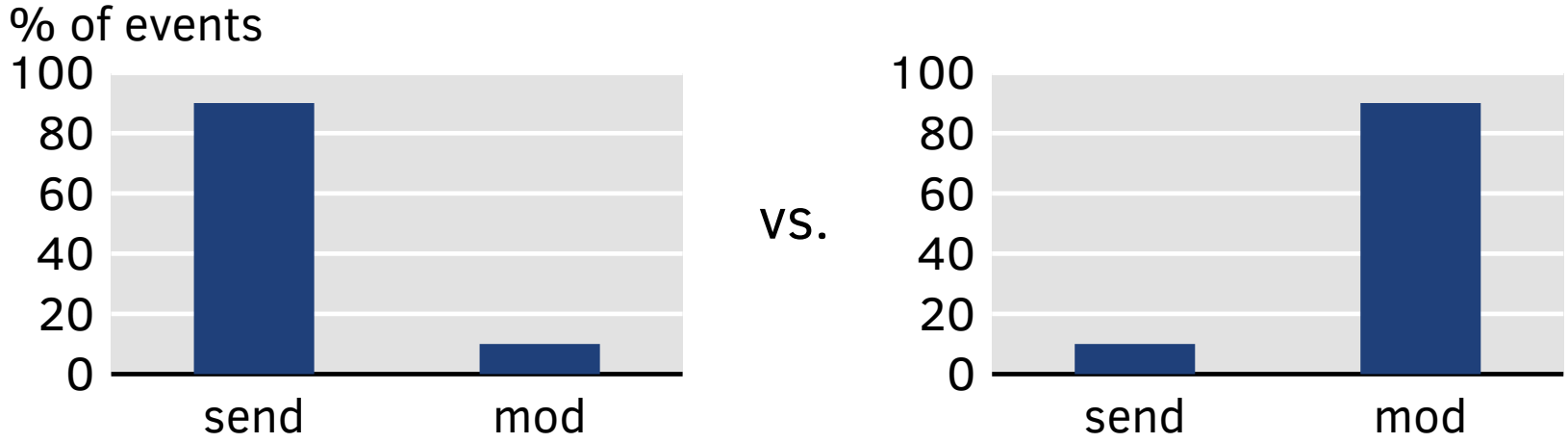


Stream Statistics

1. **Relative frequency** of the different types of events:



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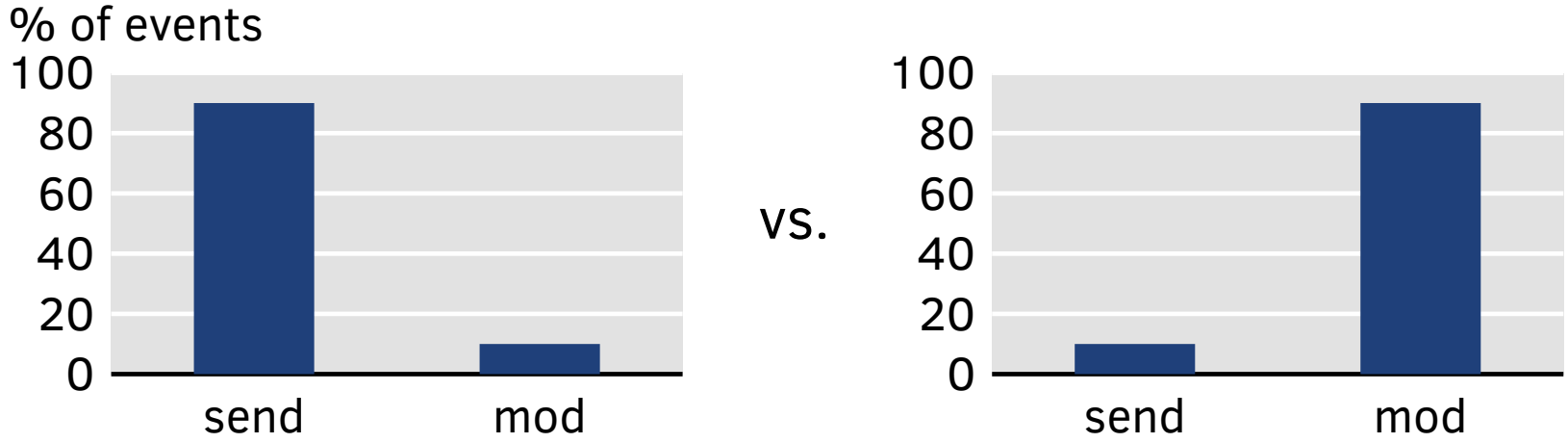
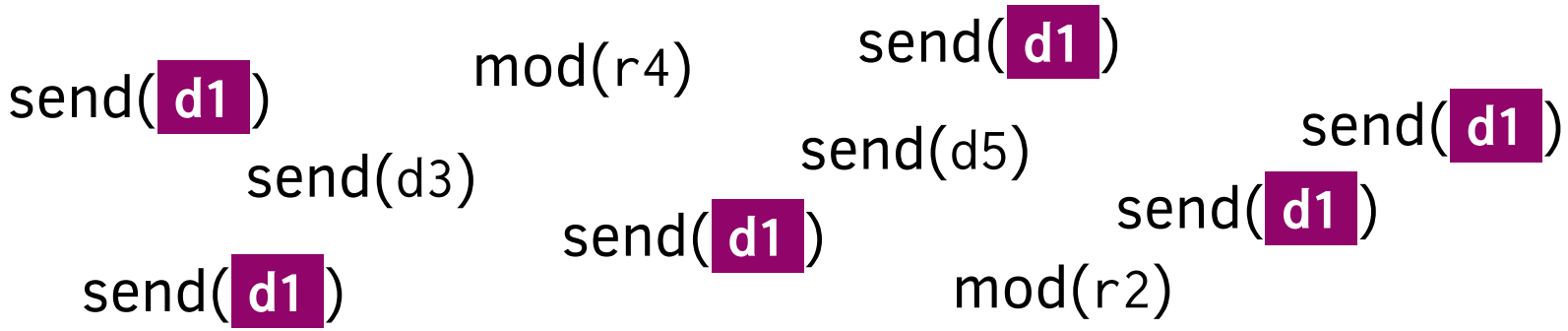


2. **Heavy hitters** (very frequent parameter values):



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The first **parallel online monitor** for first-order specifications capable of **adapting to changing stream statistics**.

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1. Adaptive monitoring algorithm
2. State migration operations for a metric first-order temporal logic (MFOTL) monitor
3. Correctness proved using Isabelle/HOL
4. State migration implemented in MonPoly
5. Evaluation: up to **tenfold run-time improvement**

Monitors

Monitor function $\mathcal{M}_\varphi$ for specification φ:

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Requirements:

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A (online) monitor computes $\mathcal{M}_\varphi$ (incrementally).

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We focus on Metric First-Order Temporal Logic.

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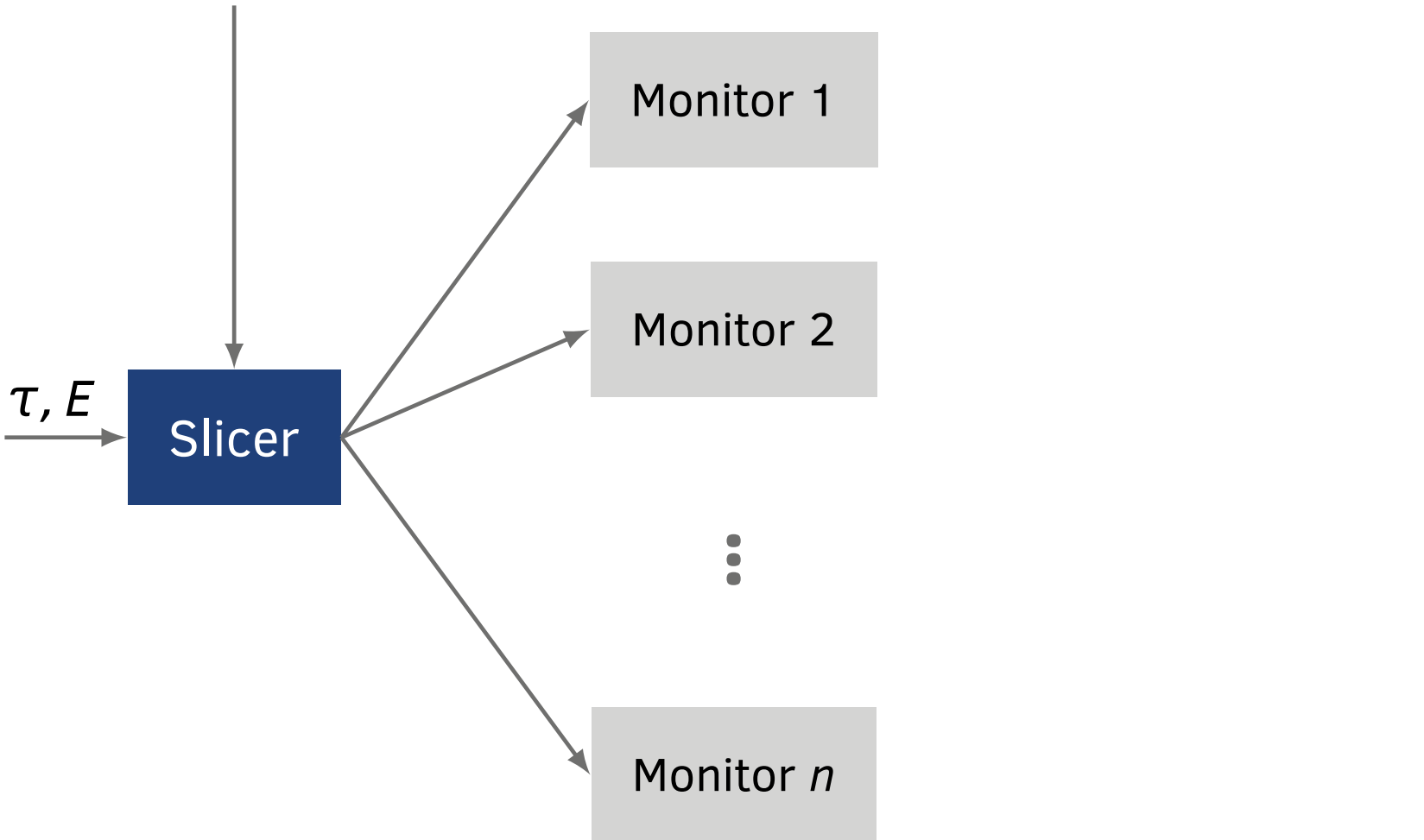
Monitor implemented in the MonPoly tool [JACM'15, RV-CuBES'17]

(Simplified) Data Slicer [RV'18]

Strategy $r : \{1, \ldots, n\} \to \mathcal{P}(\text{Values})$ with $\bigcup_k r(k) = \text{Values}$



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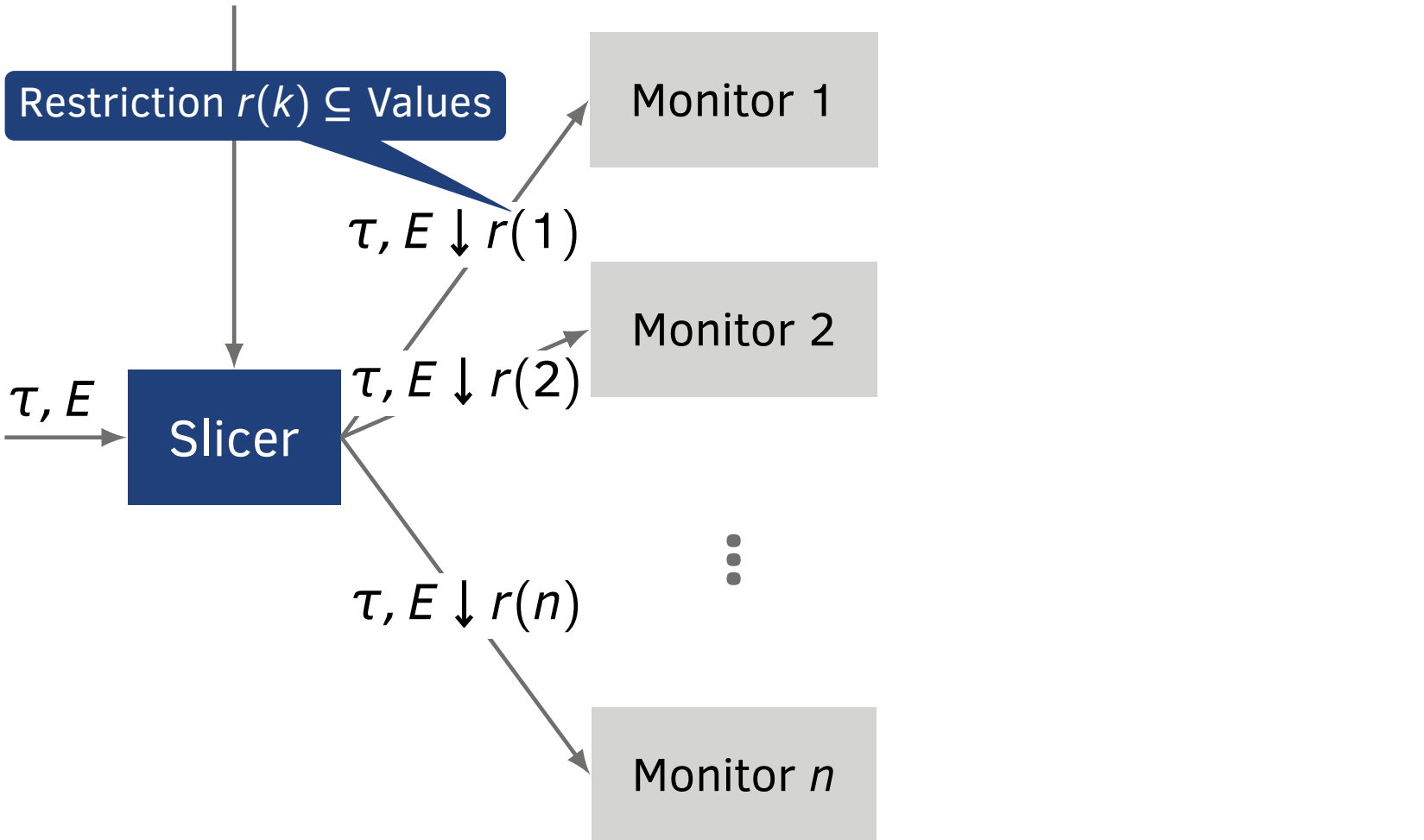

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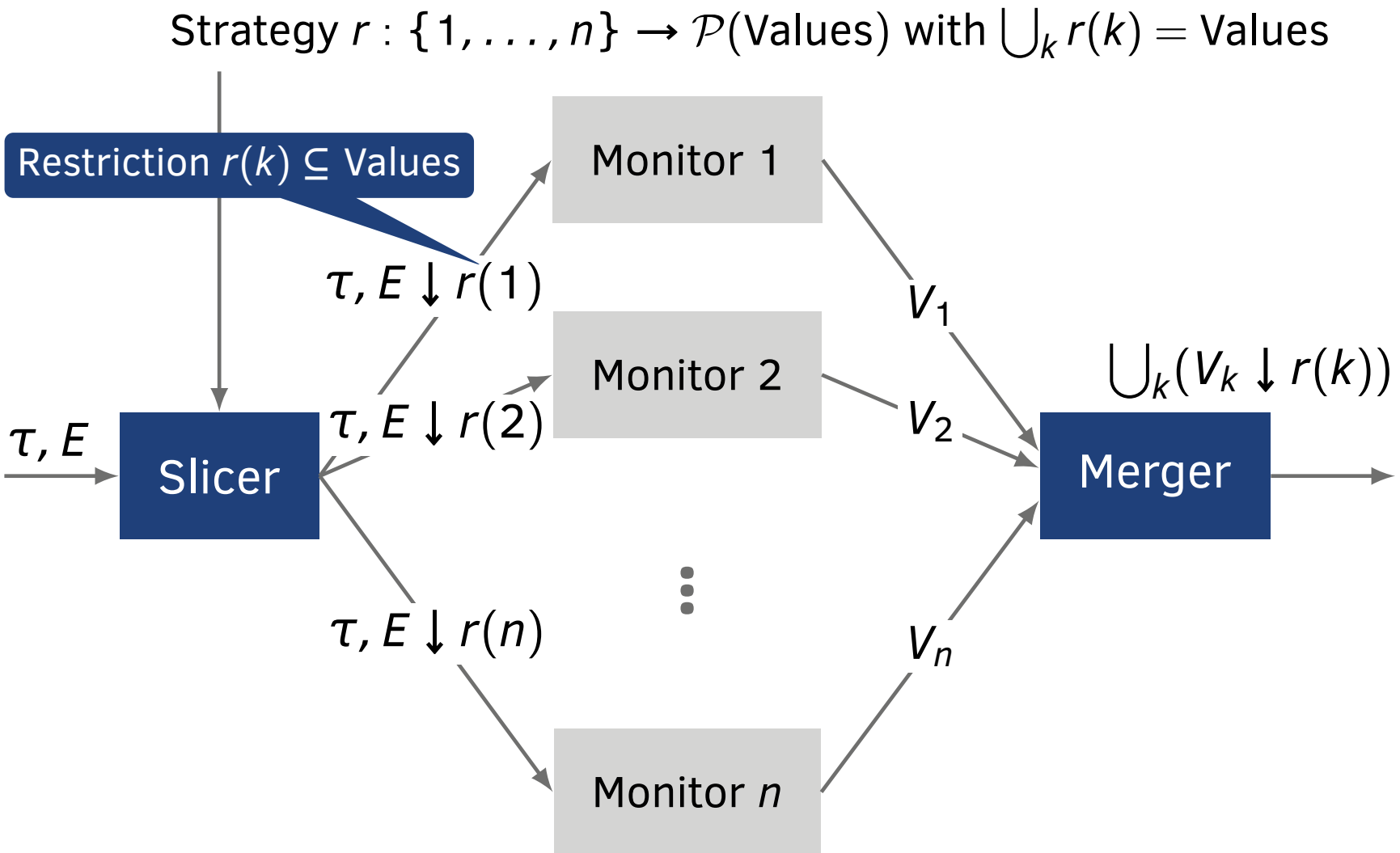

Problem: State Consistency

A submonitor's state stores a partial history of its input.

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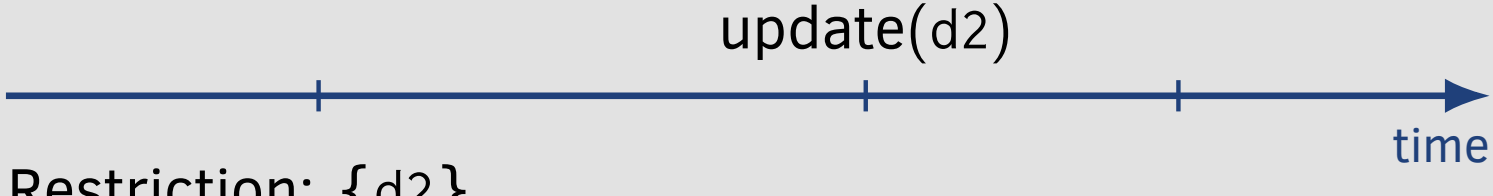
Restriction: {d1, d3}

2



Restriction: {d2}

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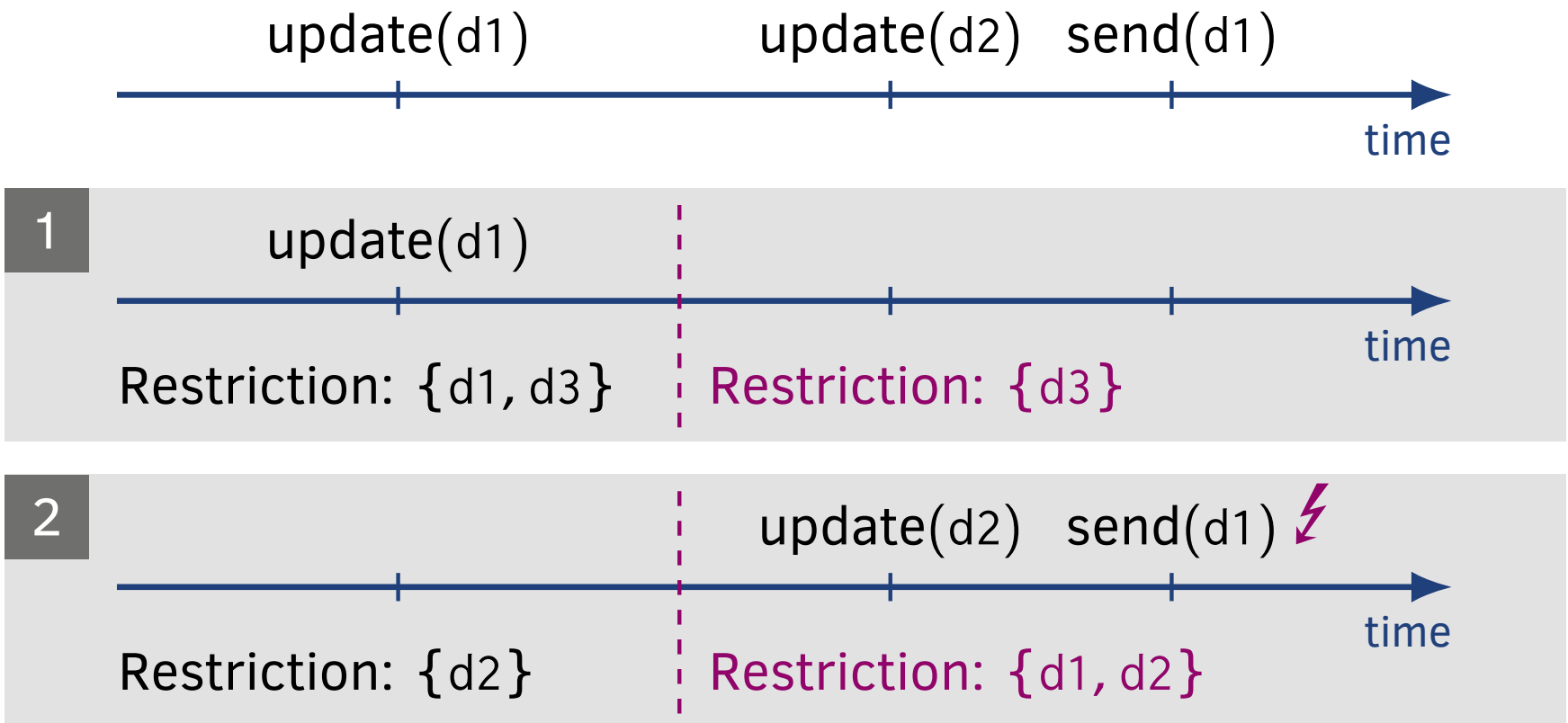

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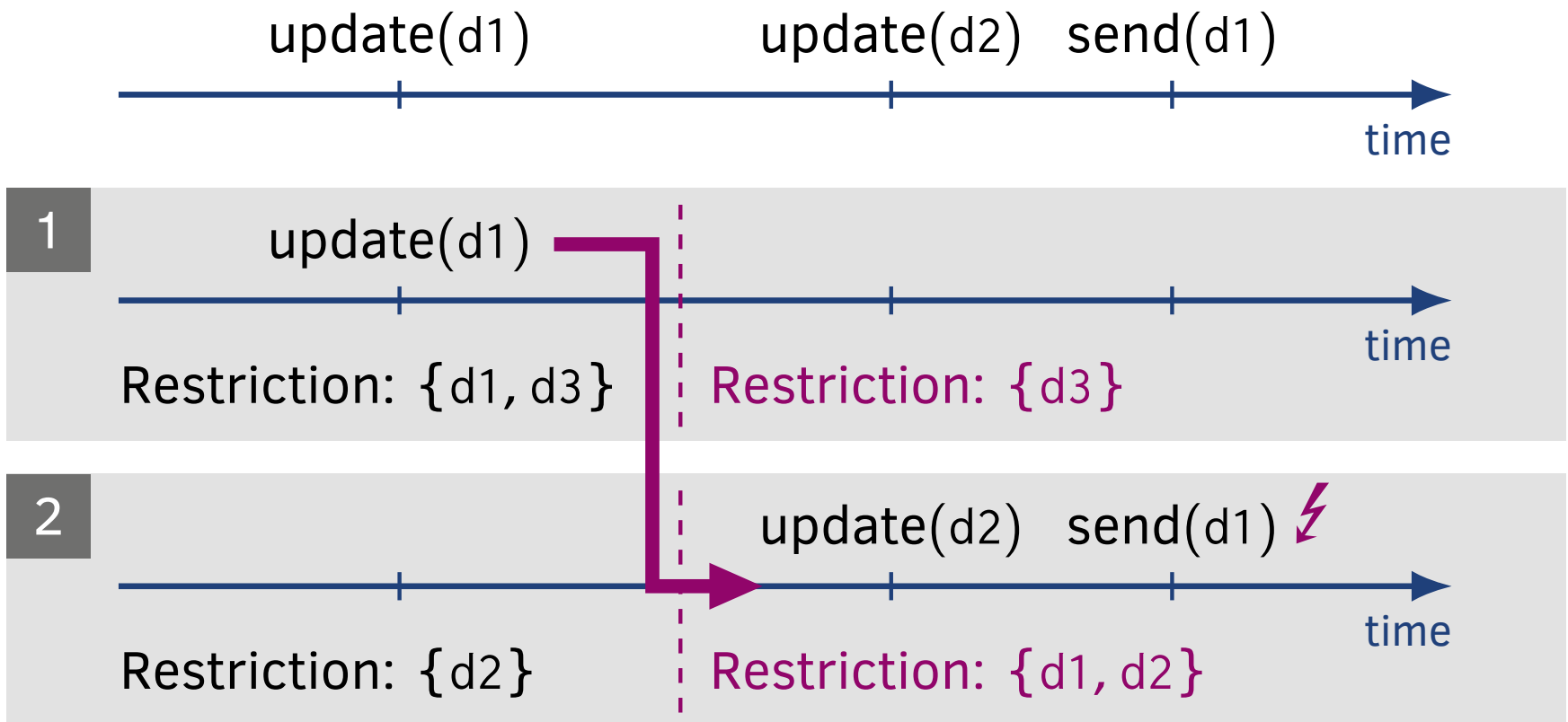

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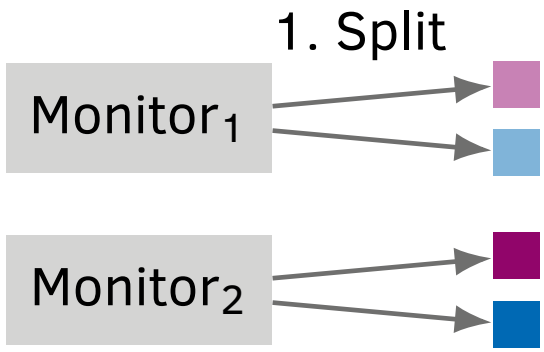

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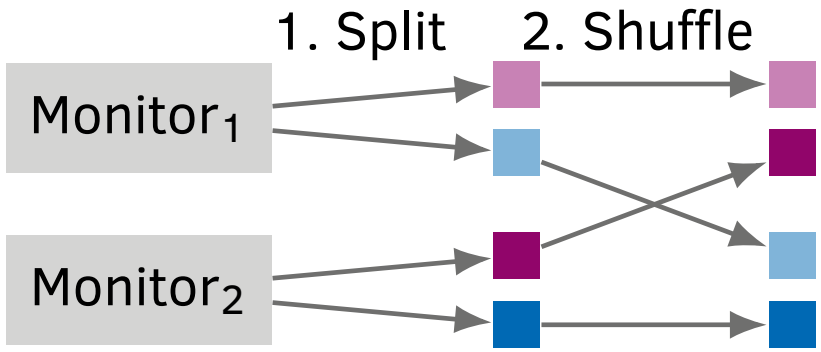

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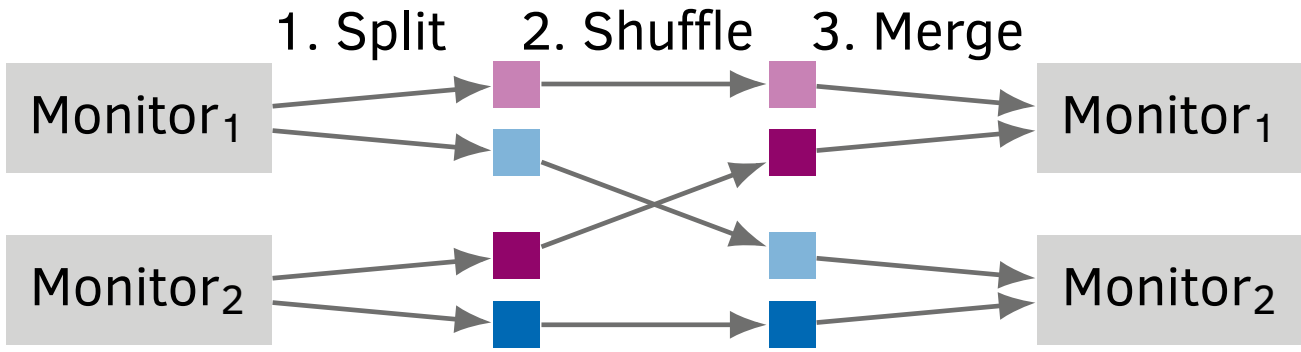

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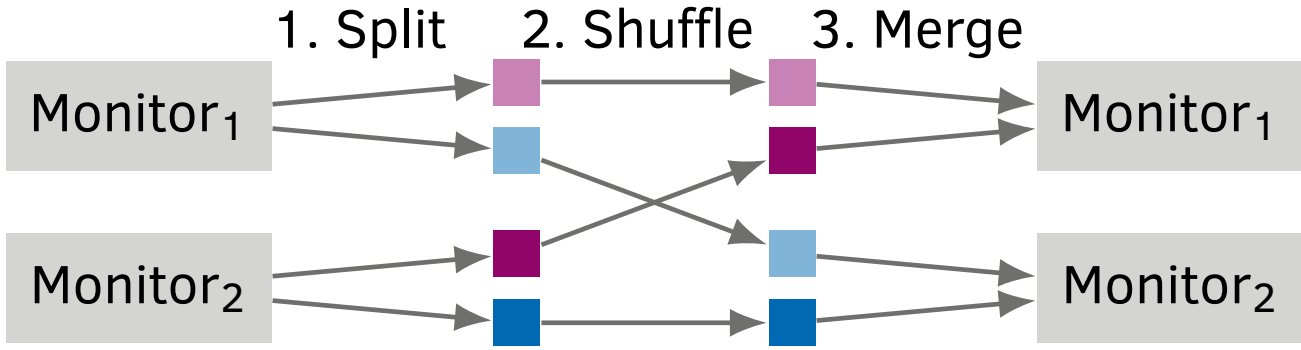

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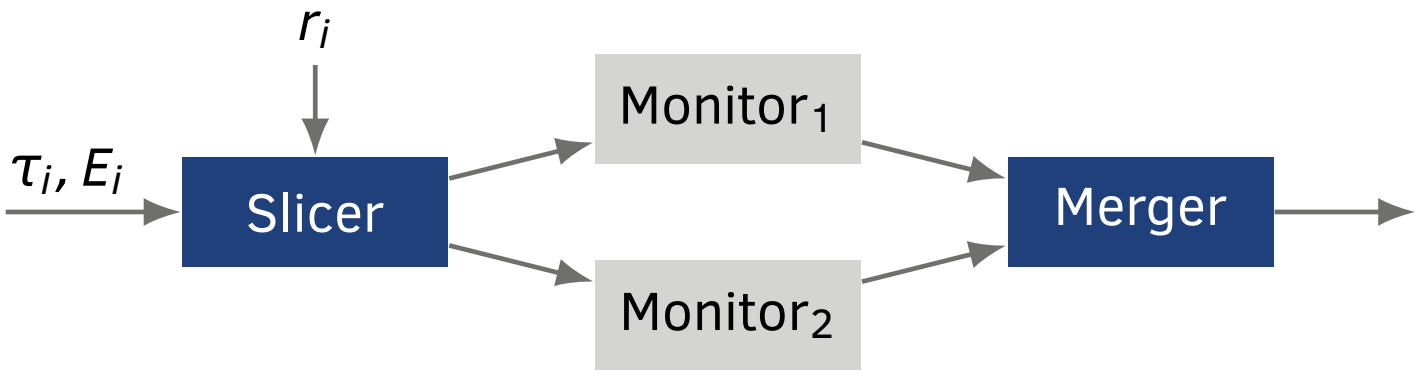

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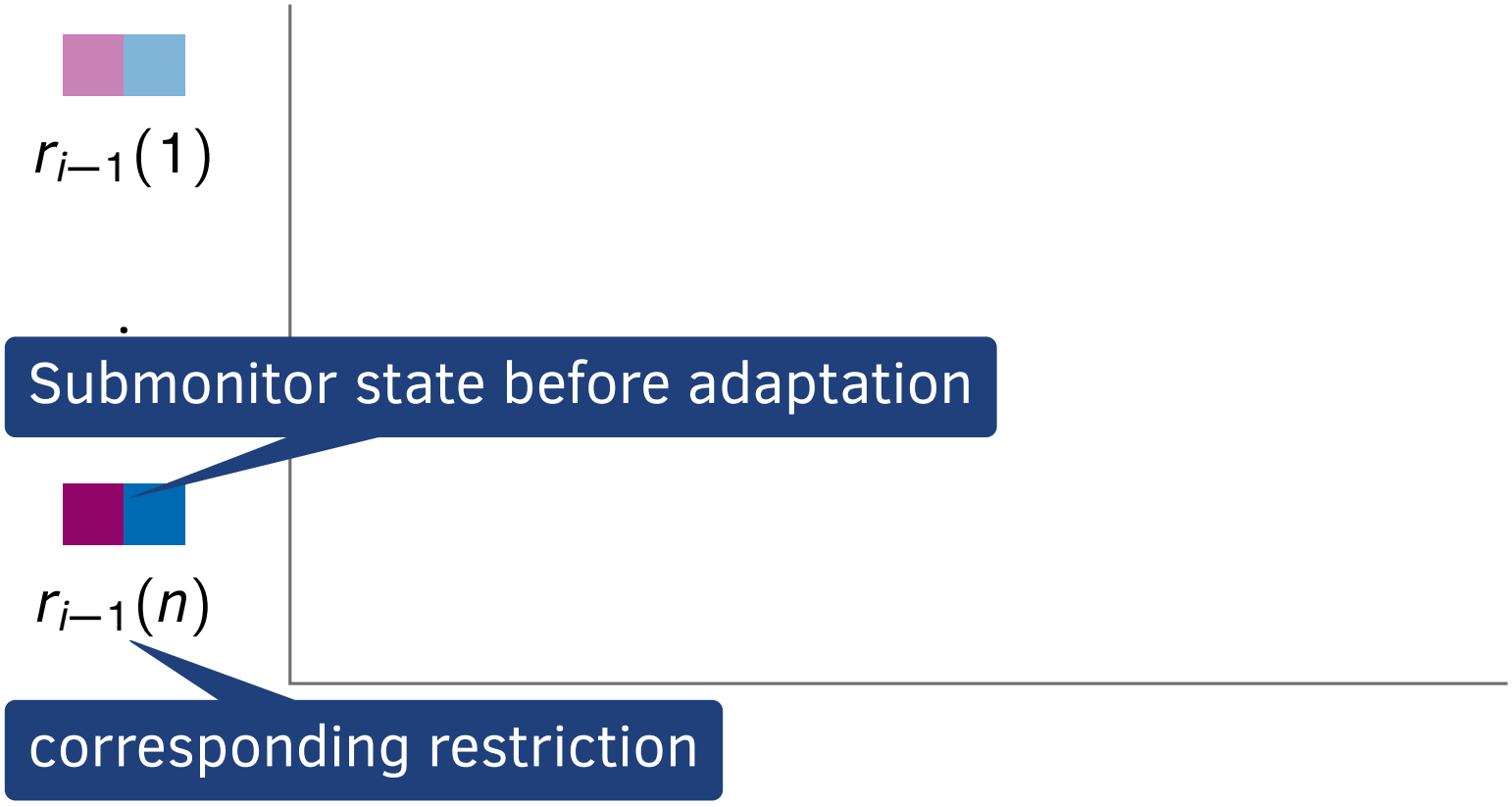
Split & Merge Interface



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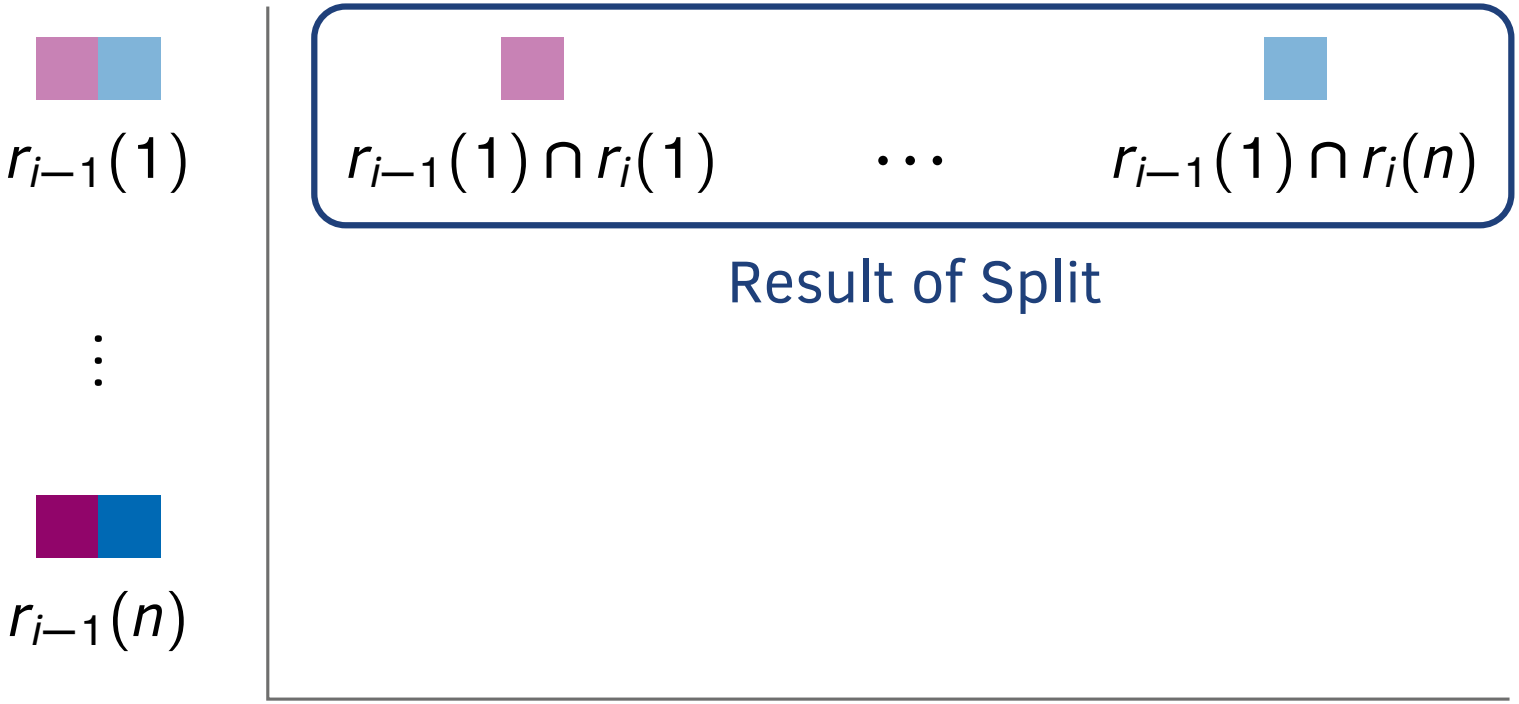

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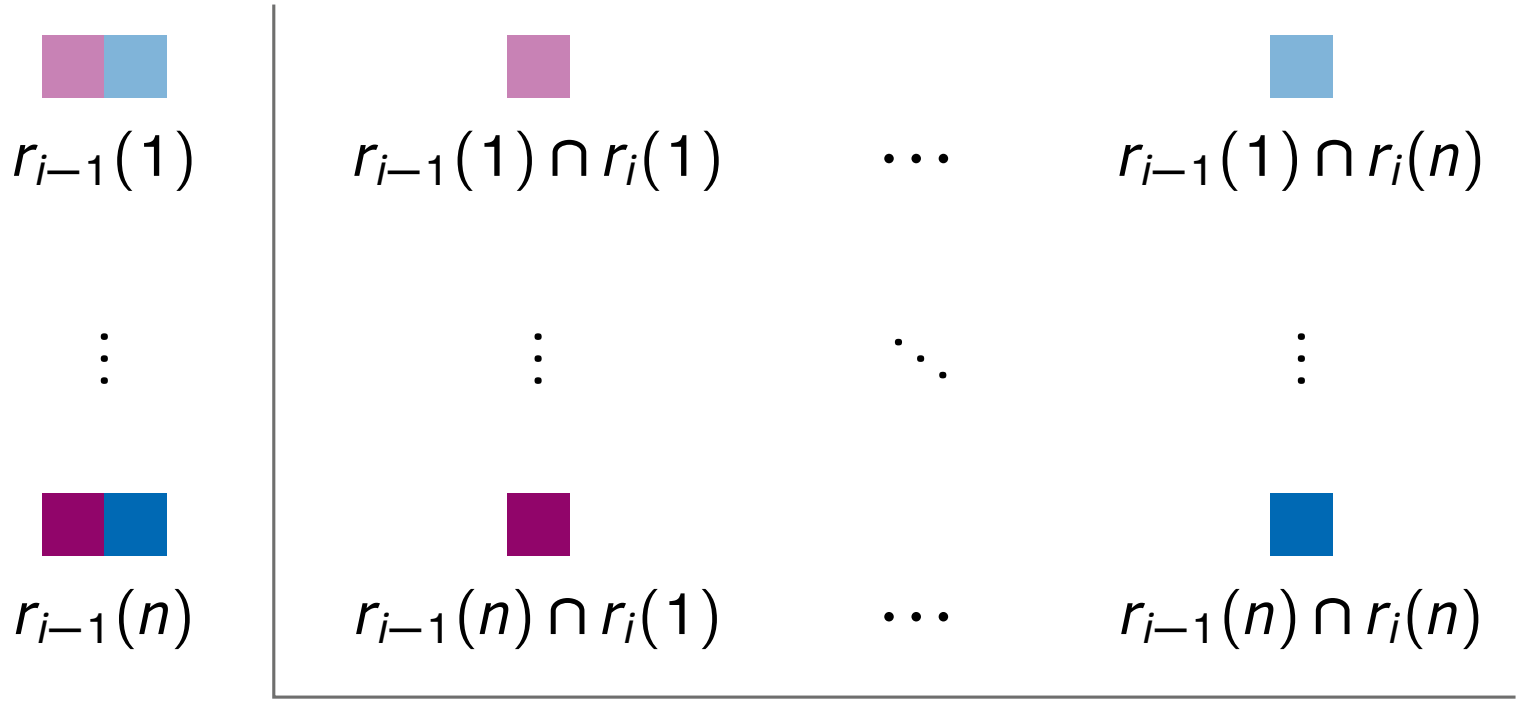

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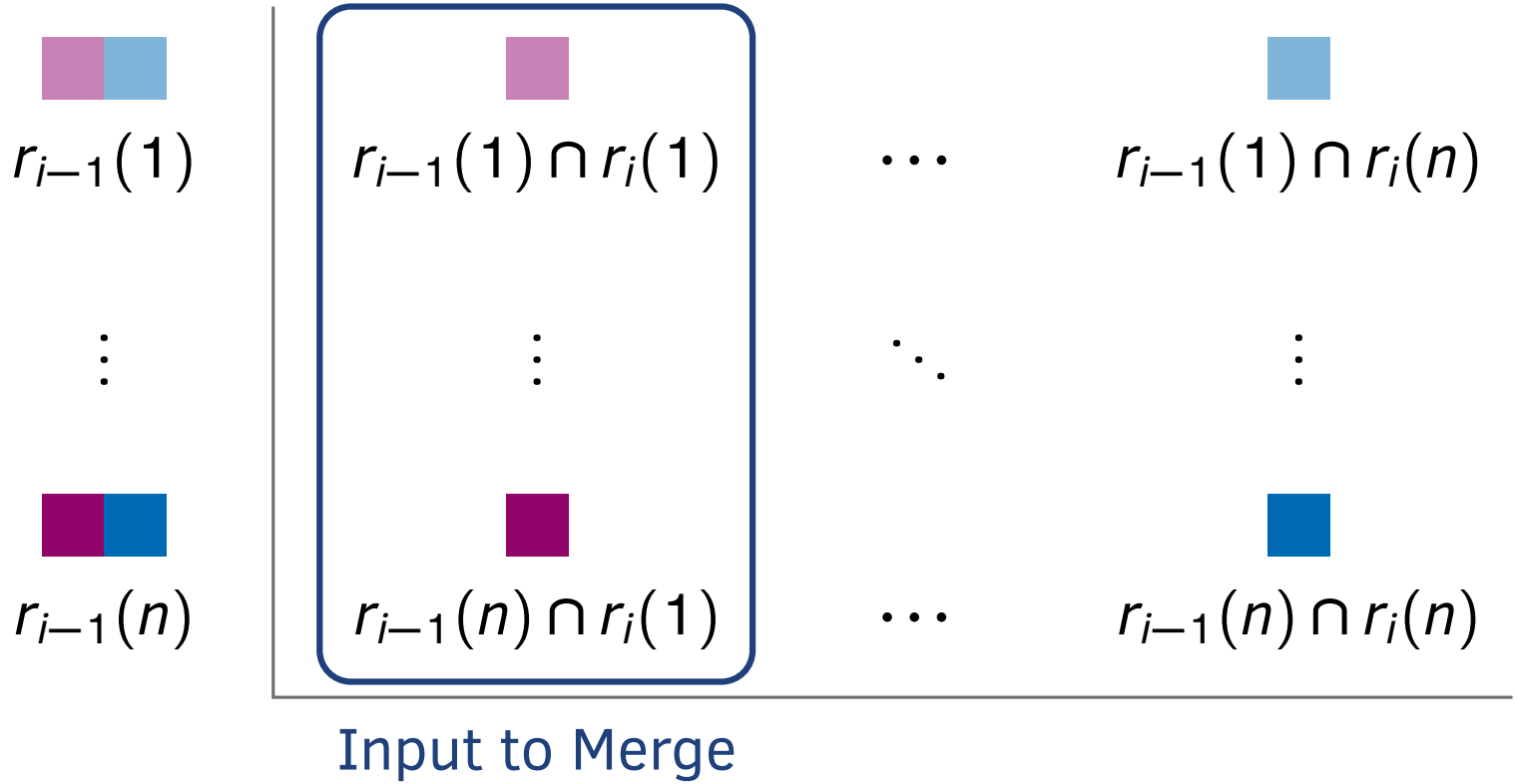

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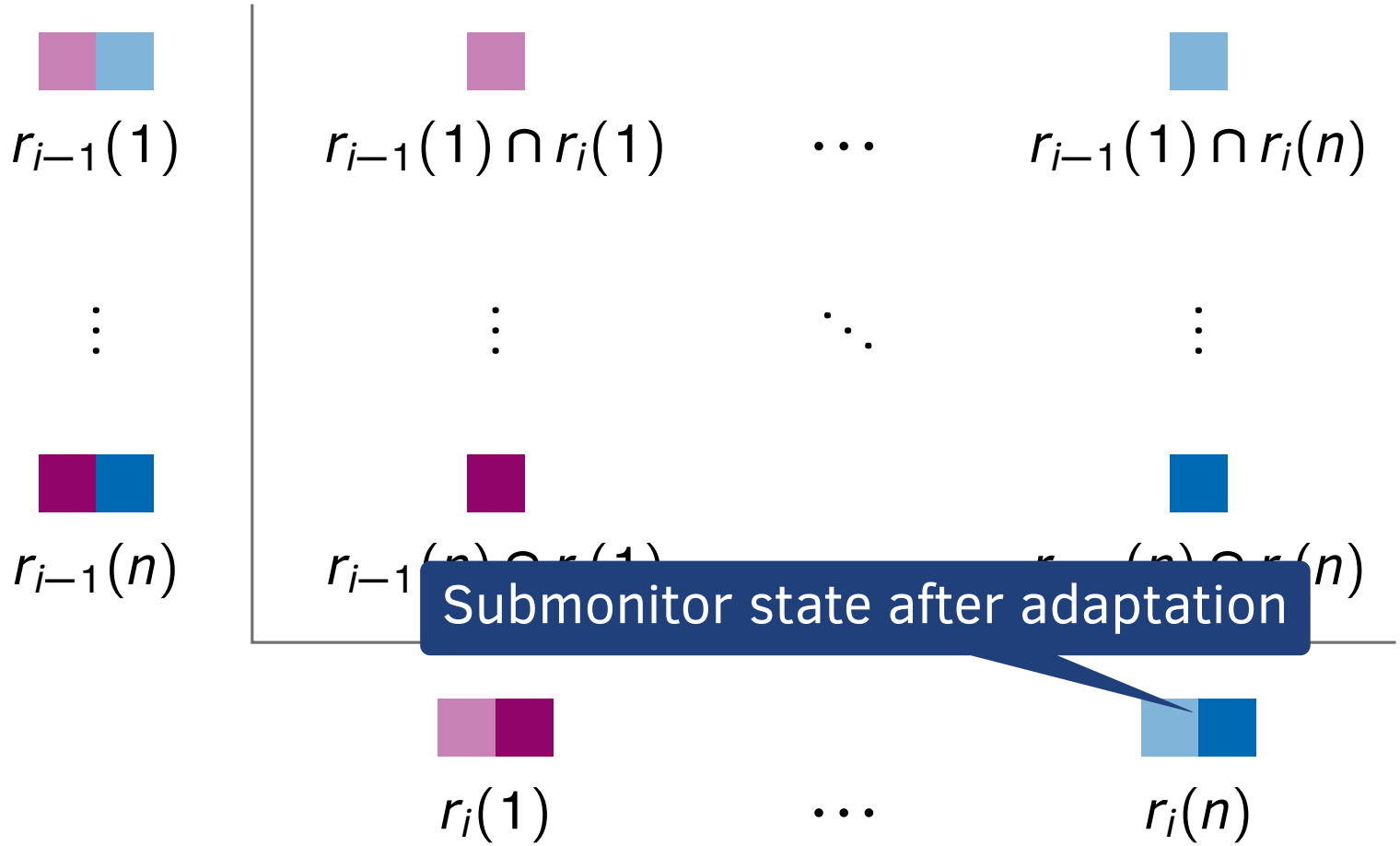
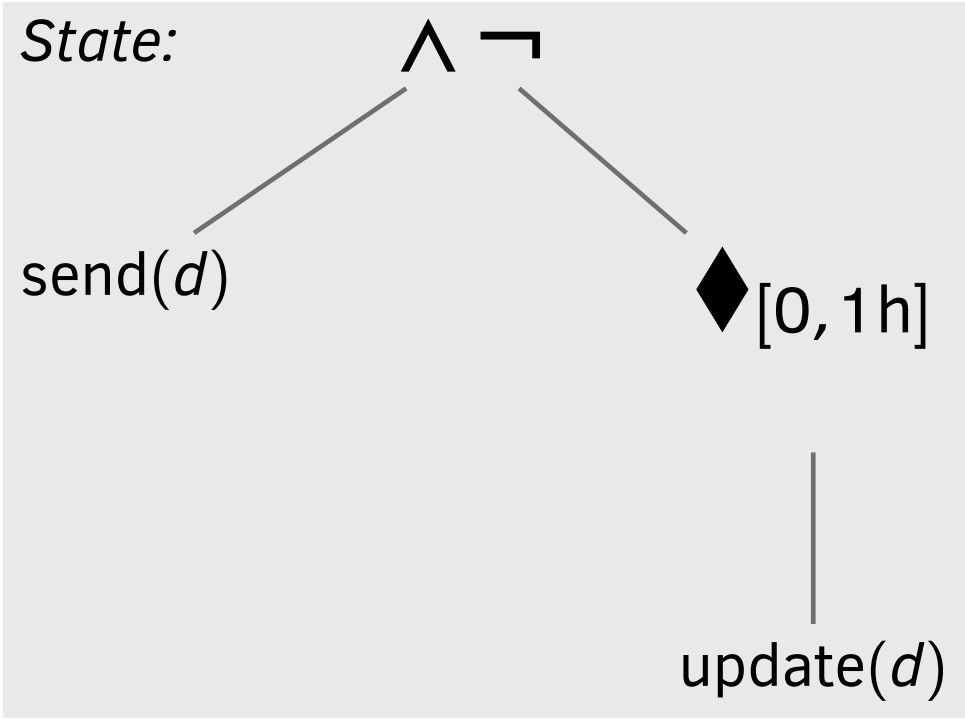


MonPoly's Monitor State

Evaluating $\text{send}(d) \wedge \neg \blacklozenge_{[0,1h]} \text{update}(d)$ to find violations:



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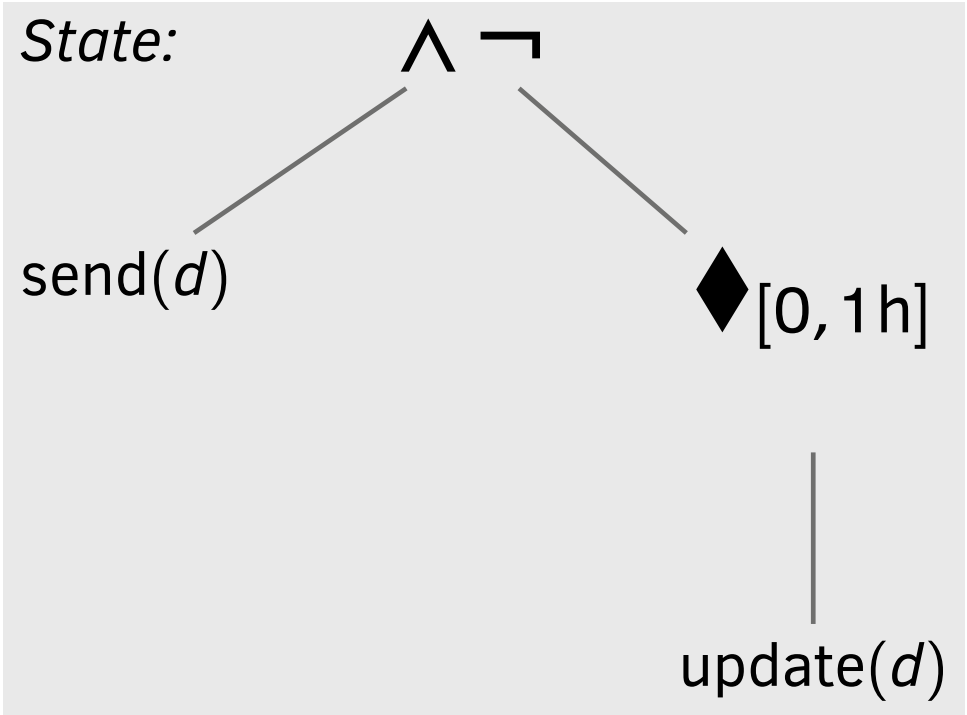
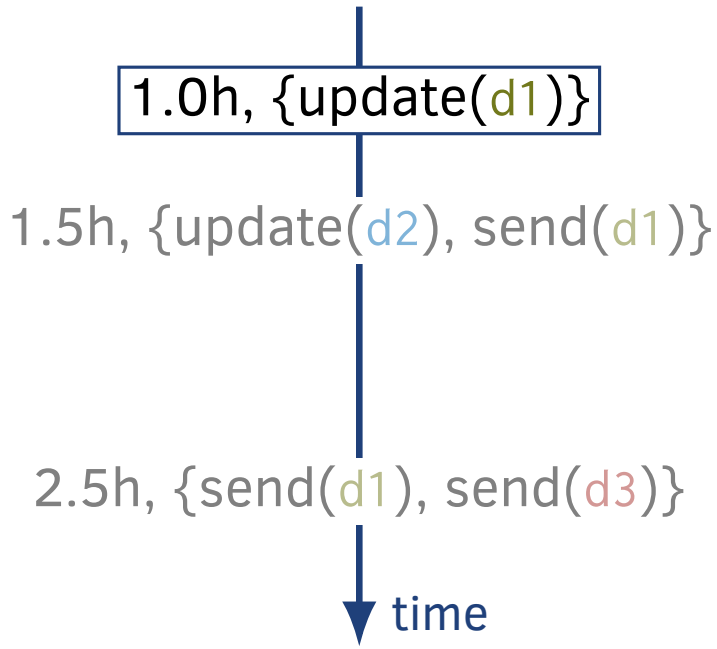


Trace:



Current event: 1.0h, {update(d1)}

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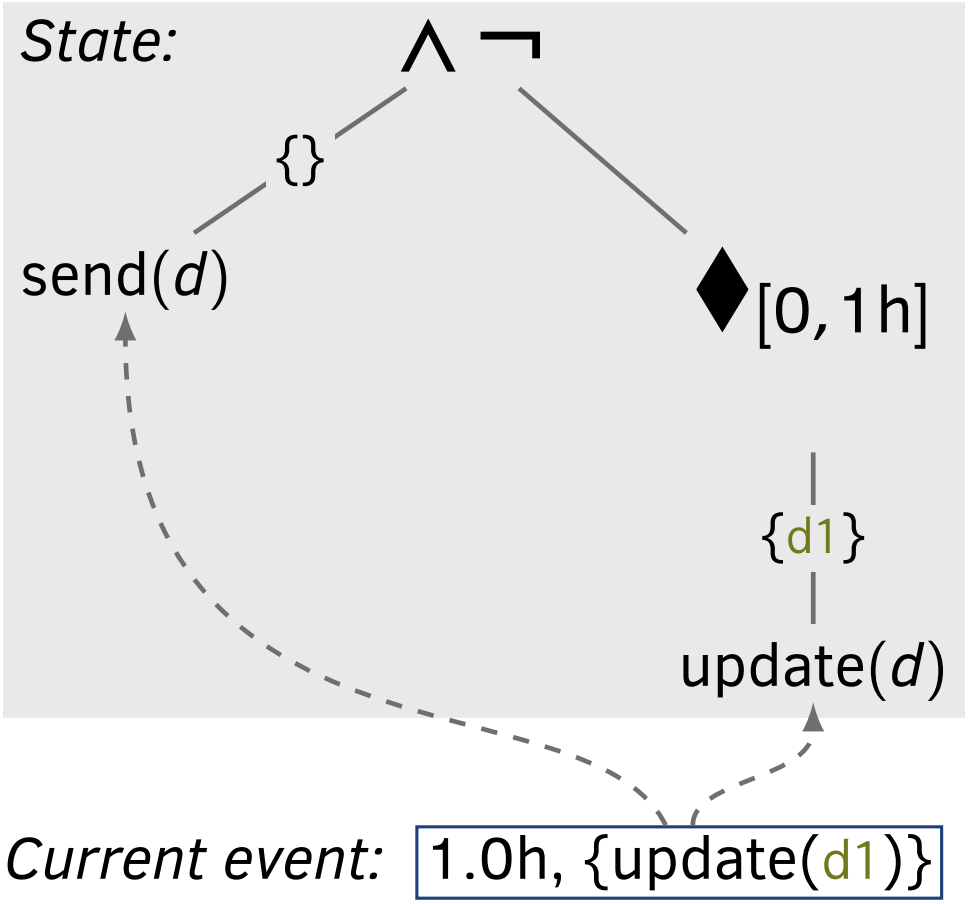

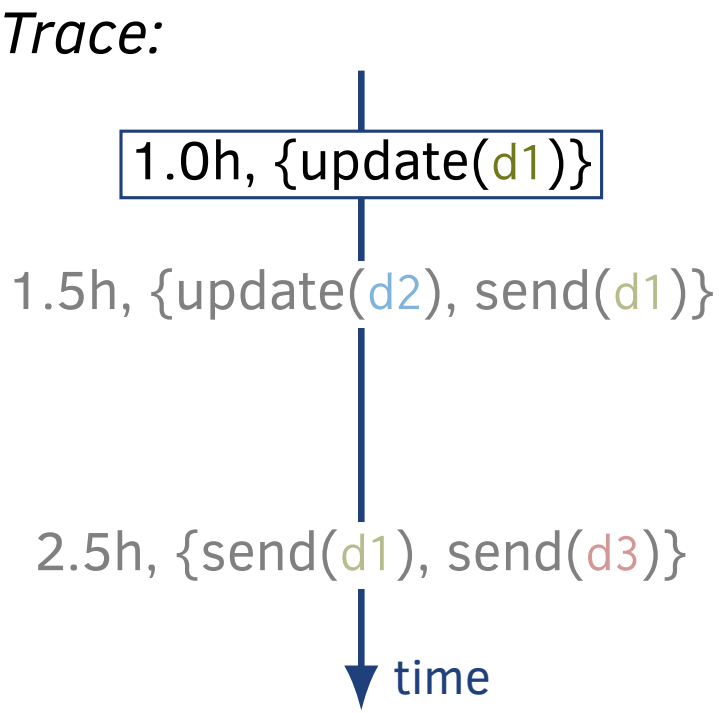

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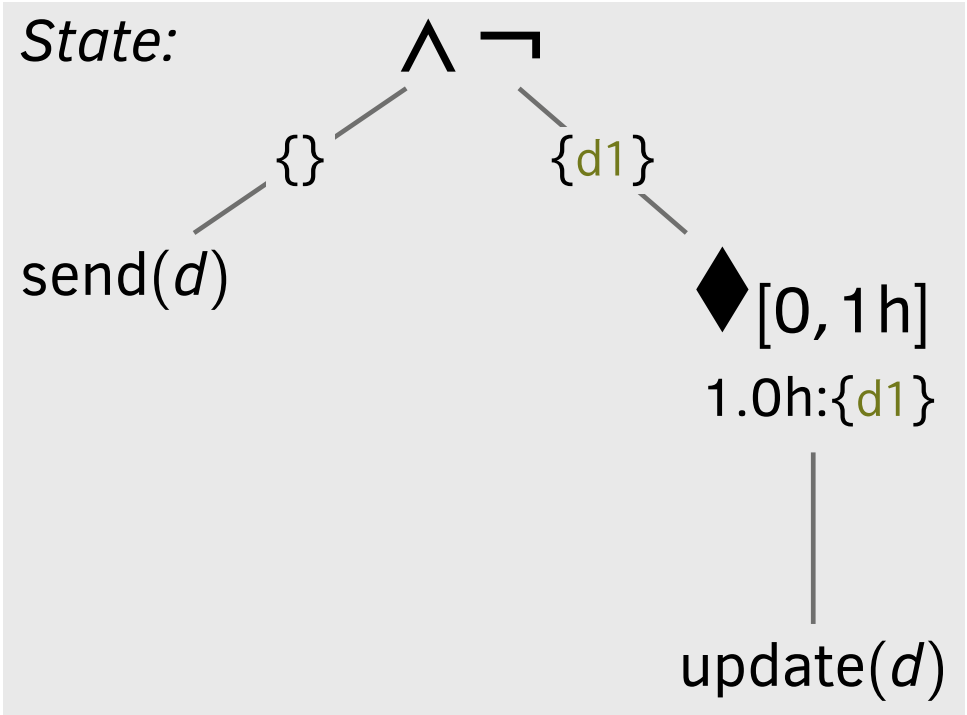

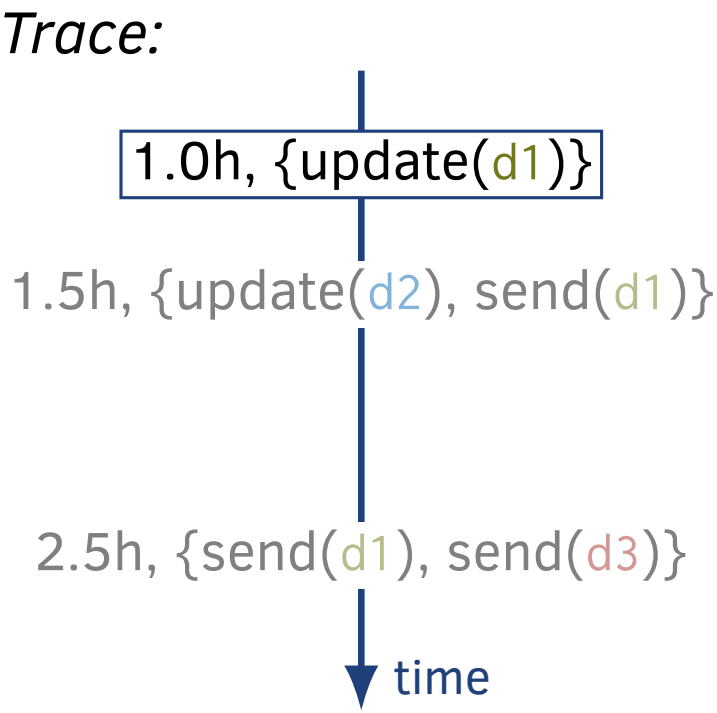

Current event: 1.0h, {update(d1)}

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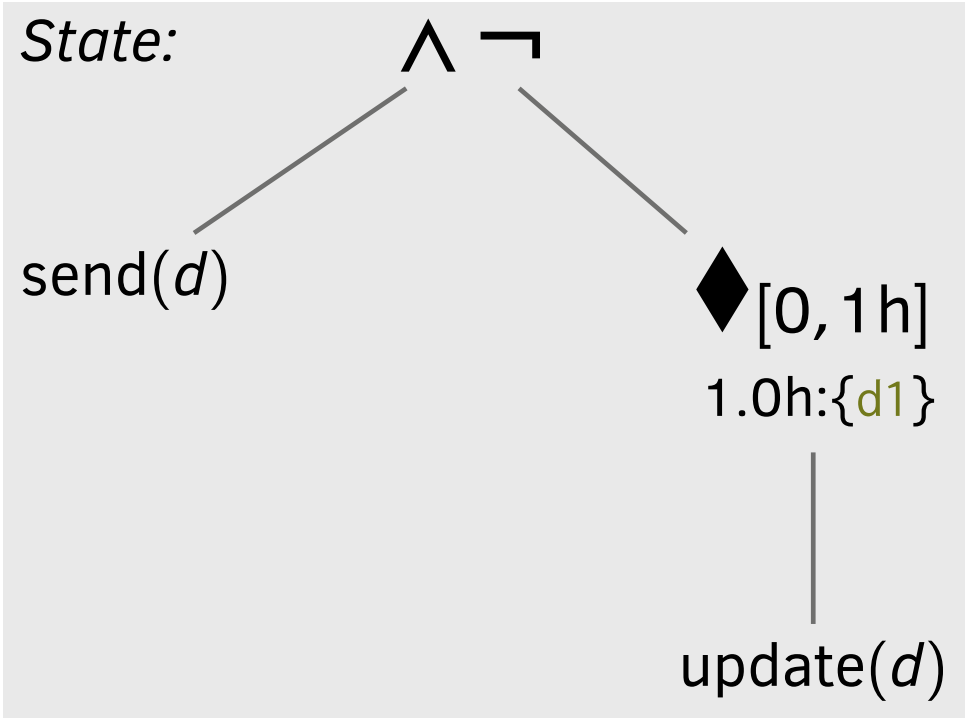

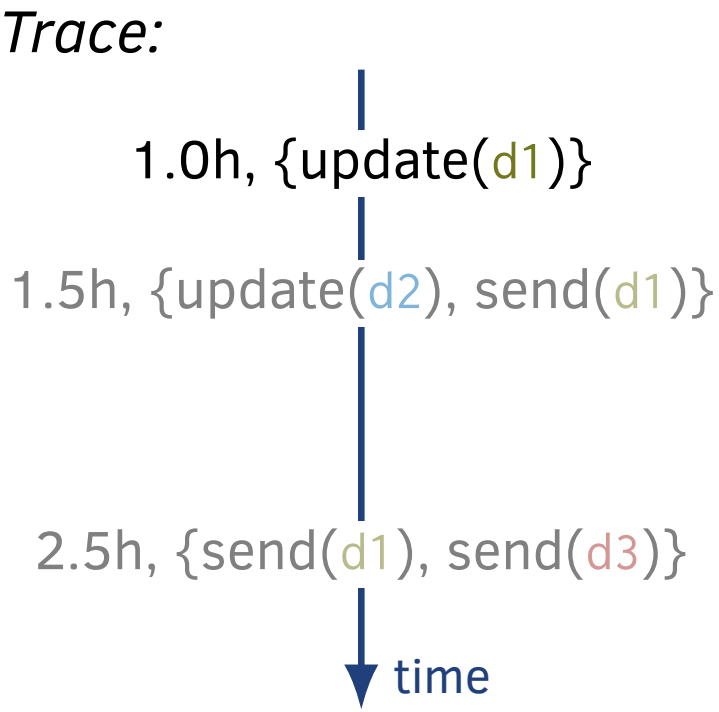

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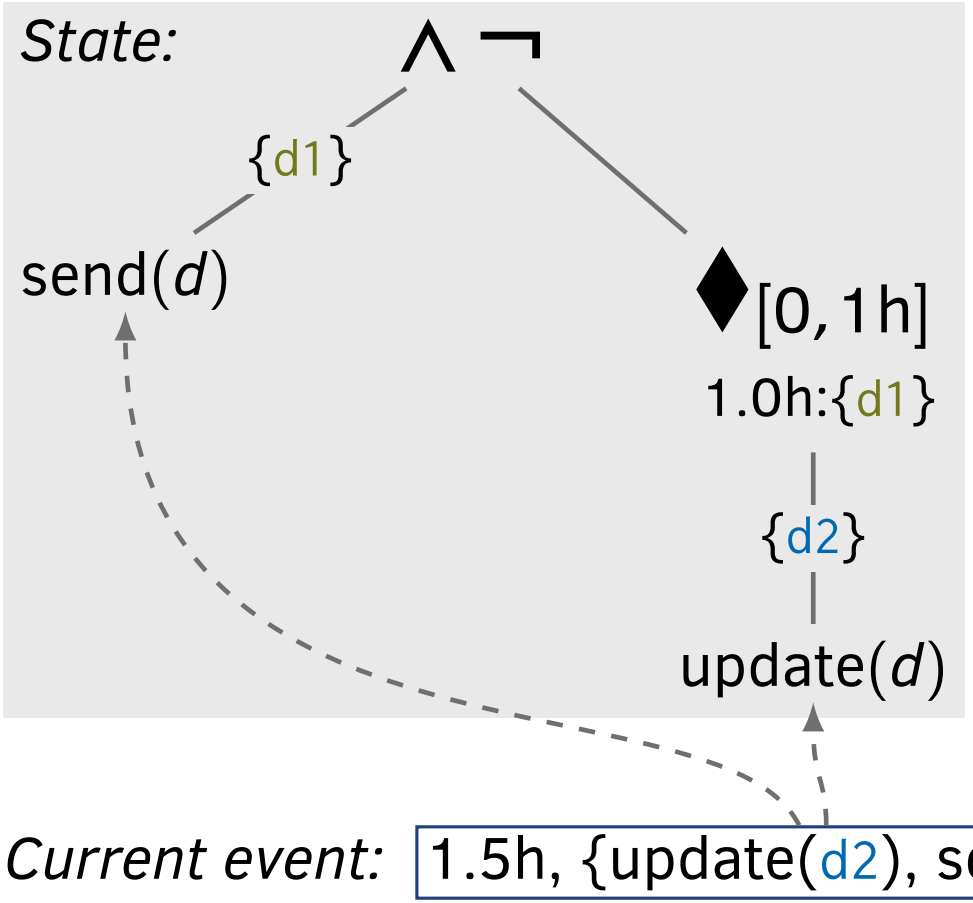

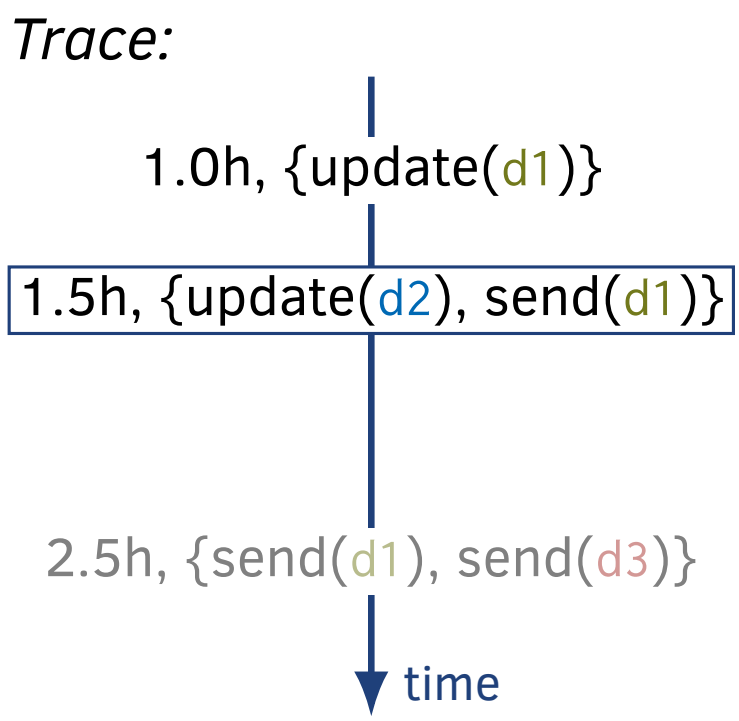

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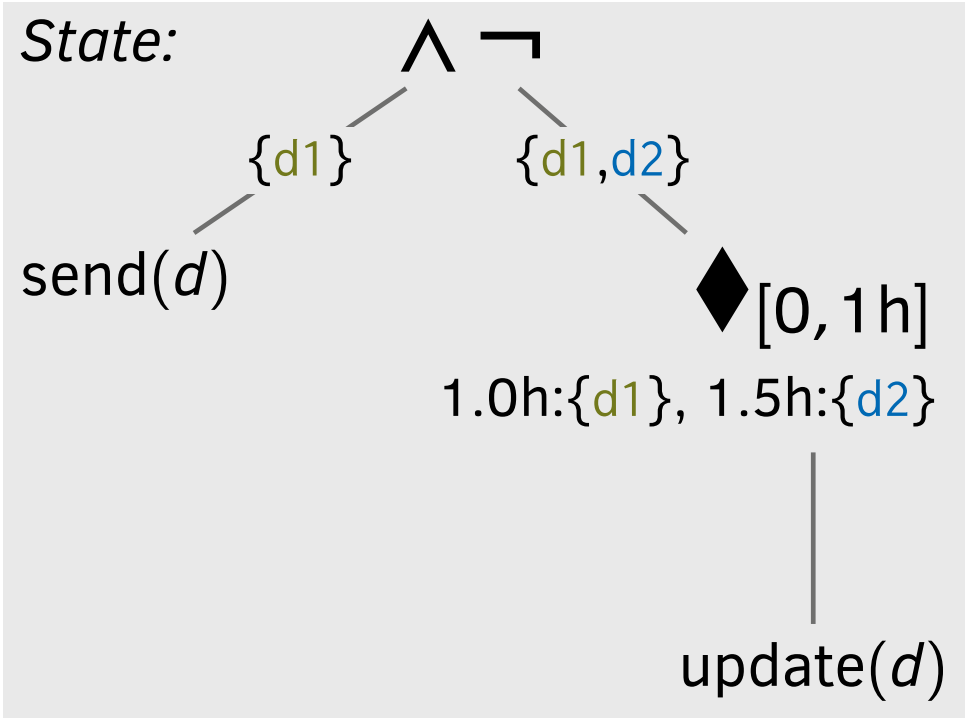

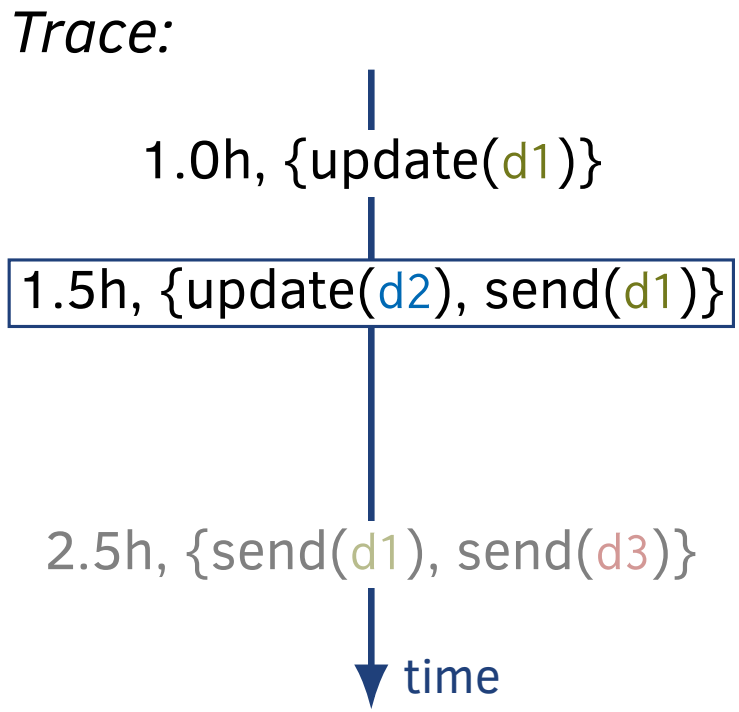

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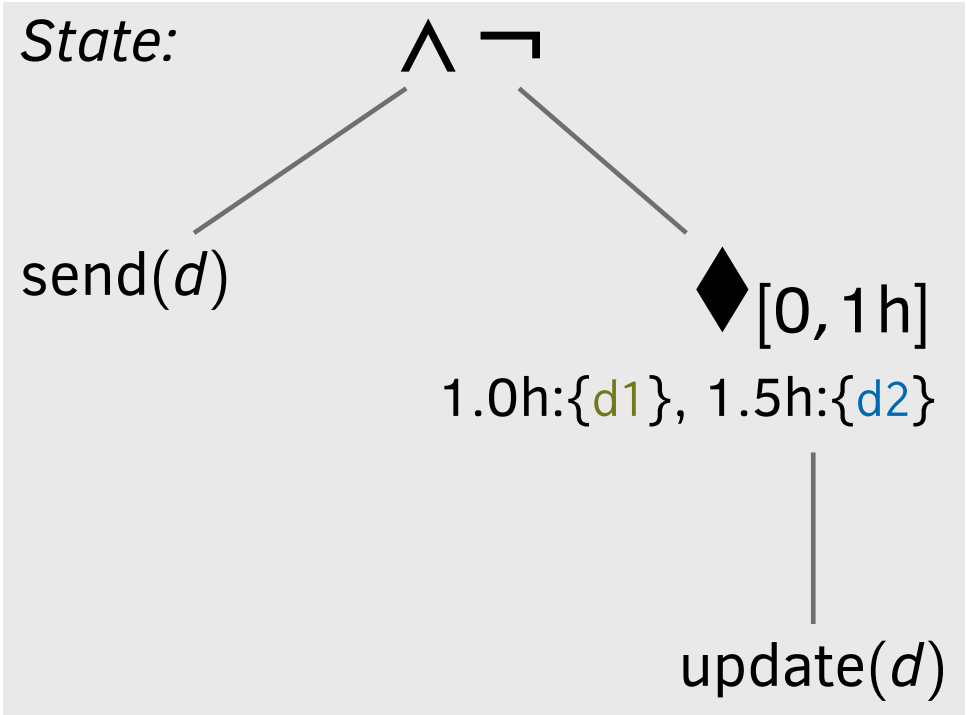

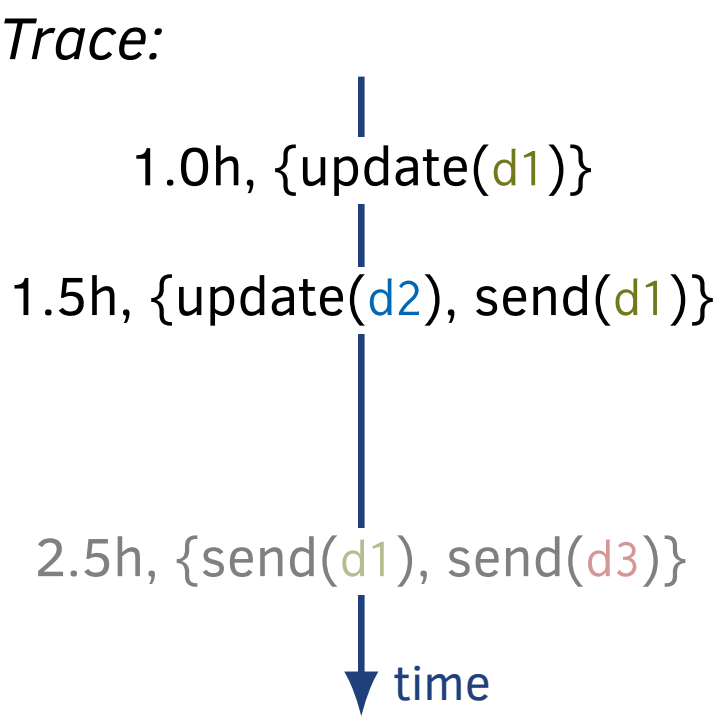

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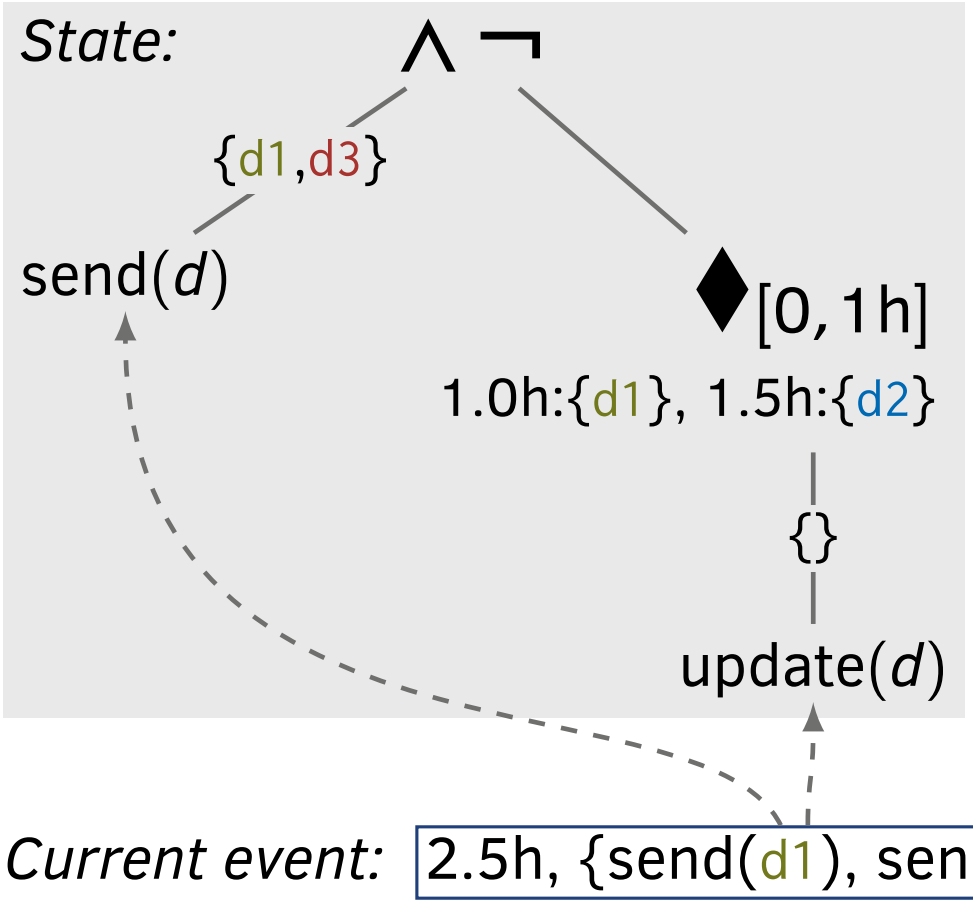

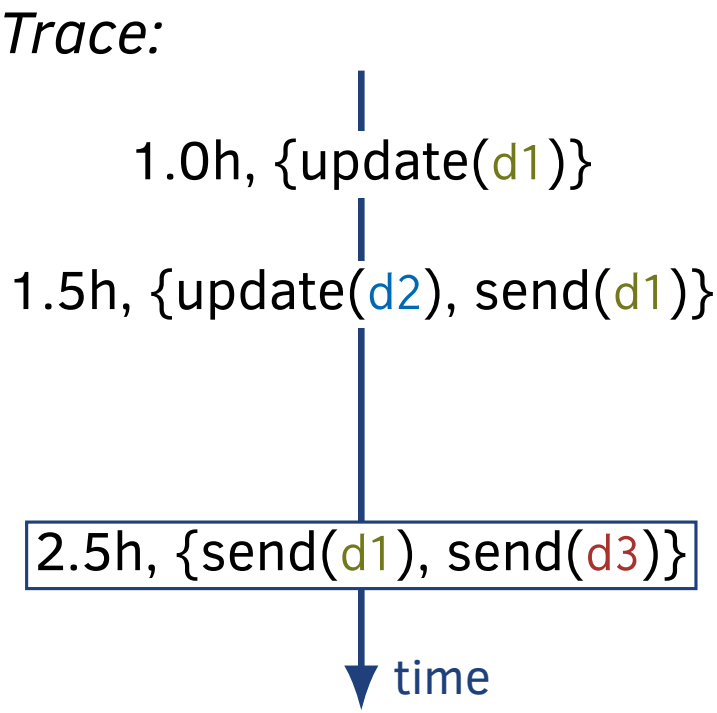

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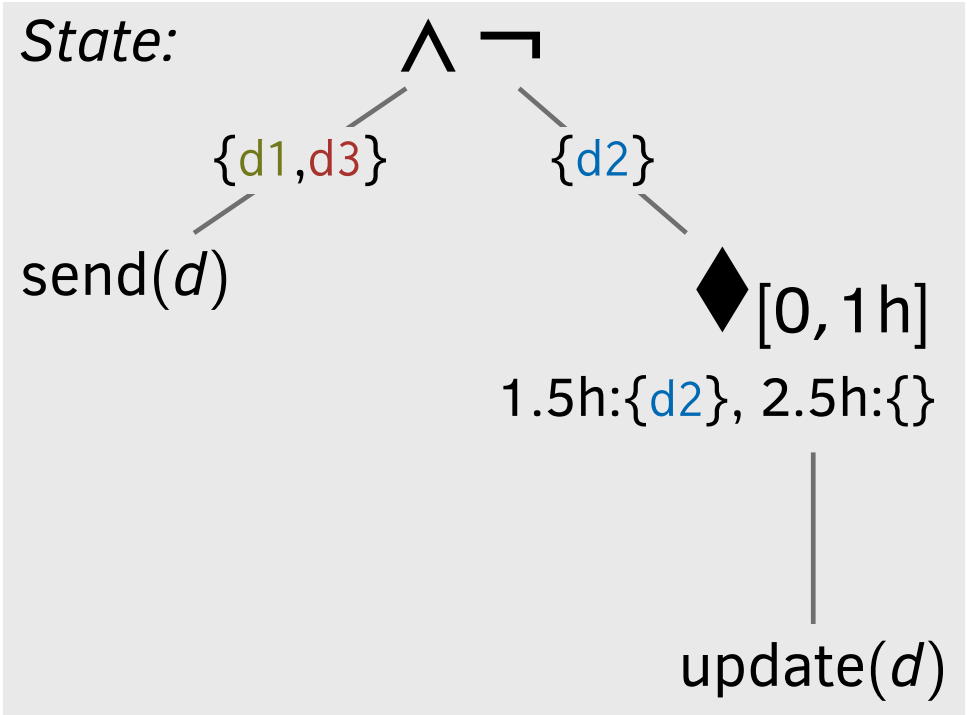

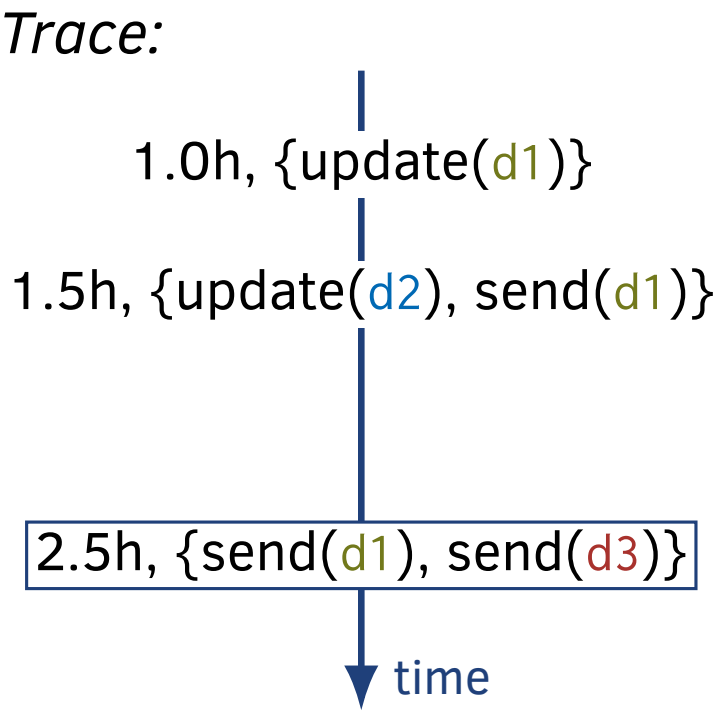

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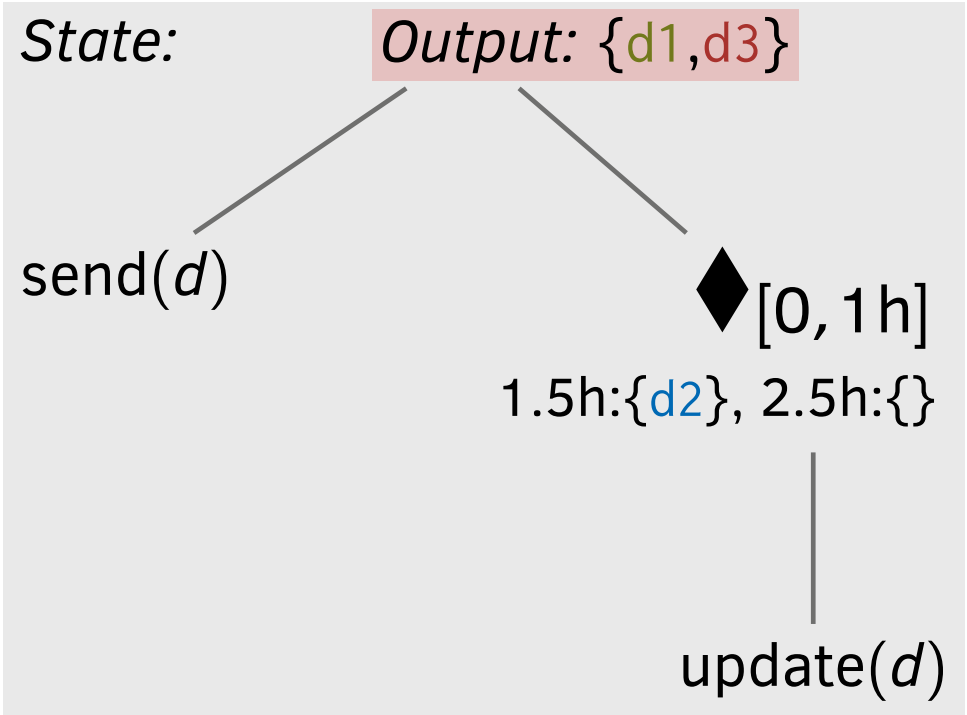

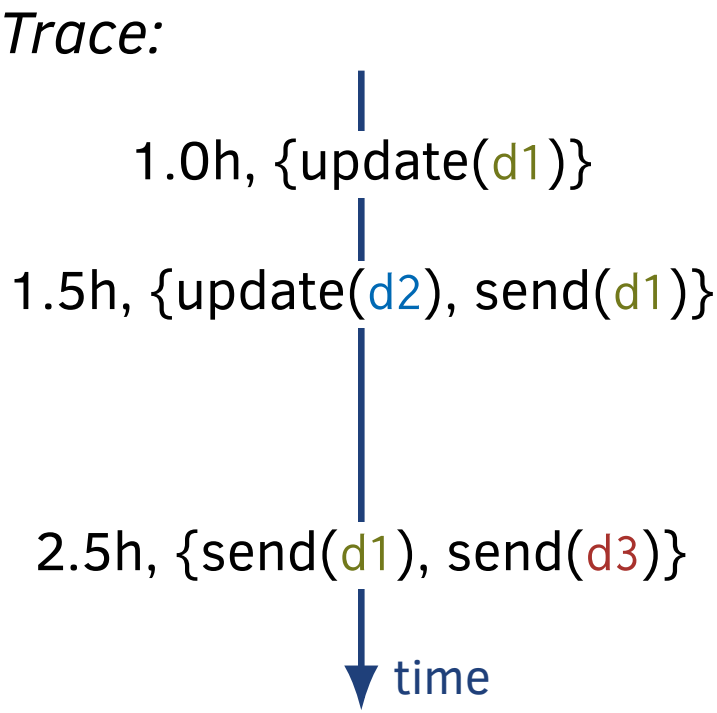

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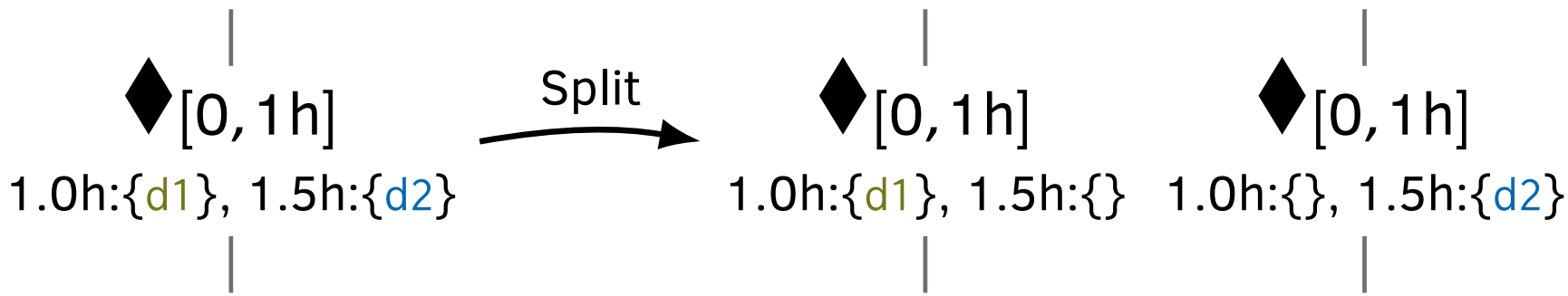

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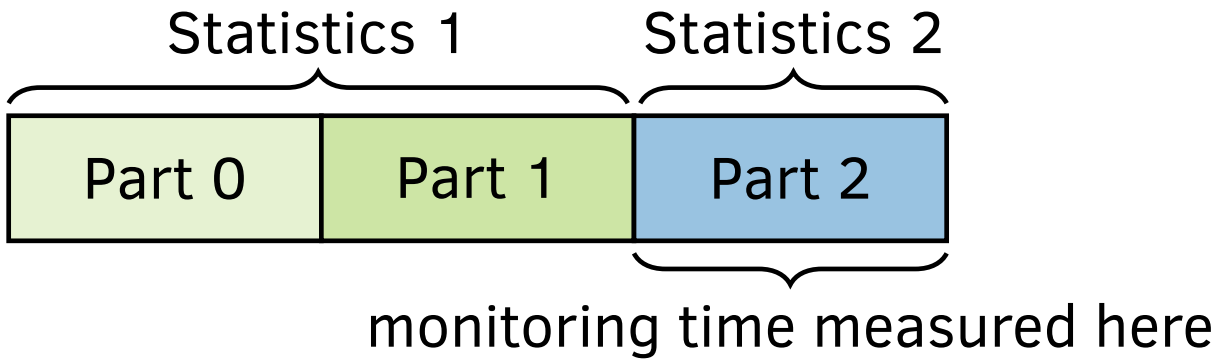
Synthesized stream fragments according to given statistics:



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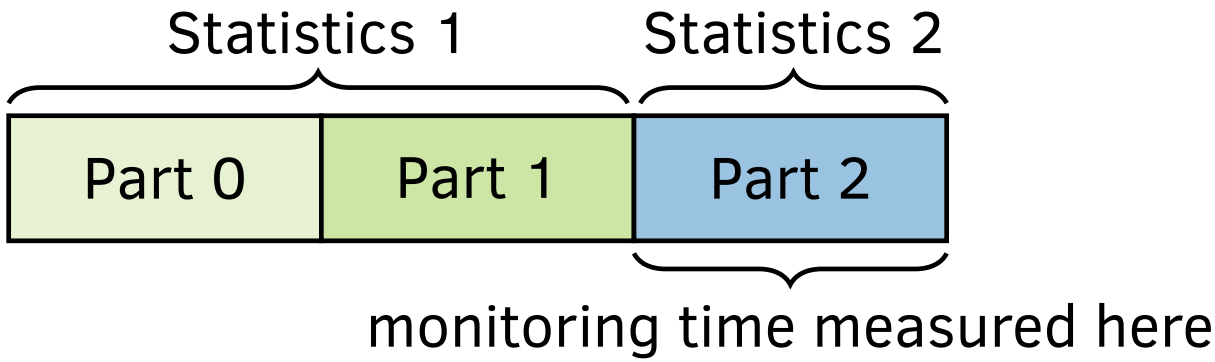

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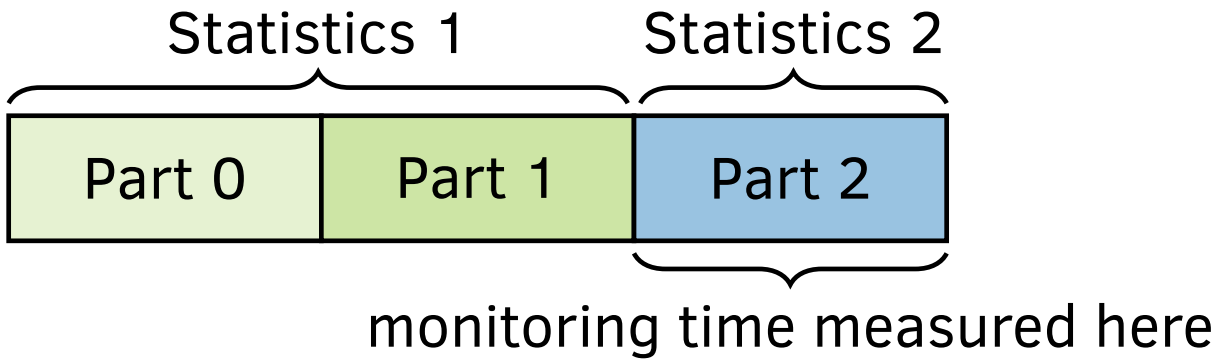

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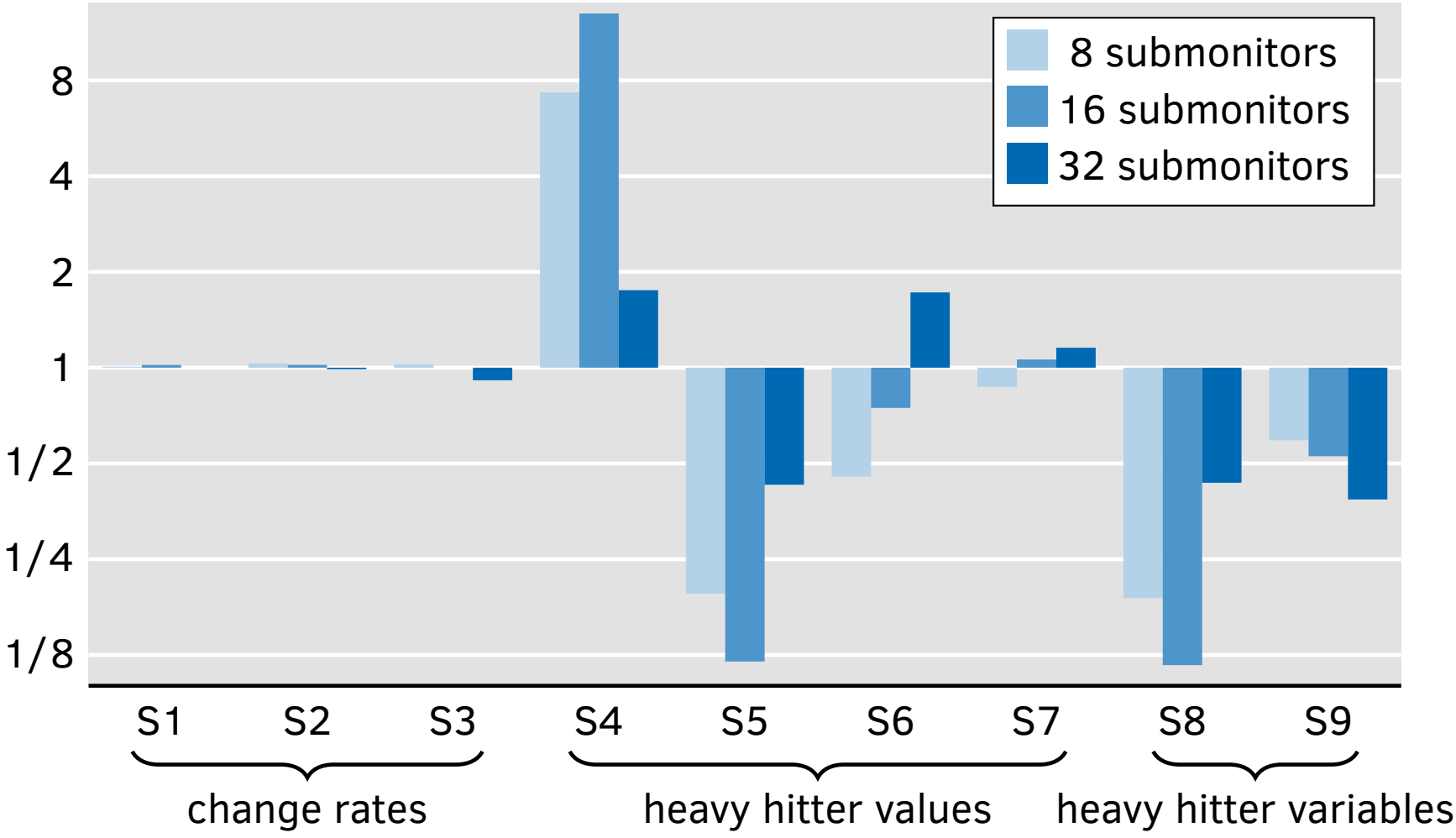
Parameters:

- 3 formulas with different variable patterns
- 9 pairs of statistics (change rates, add/remove heavy hitters)
- 8, 16, and 32 submonitors

Results (1)

Star formula: $\left(\left(\blacklozenge_{[0,10\,\mathrm{s})}\, P(\boldsymbol{a}, b)\right) \wedge Q(\boldsymbol{a}, c)\right) \wedge \Diamond_{[0,10\,\mathrm{s})}\, R(\boldsymbol{a}, d)$

Speedup (log.) – higher is better



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Triangle formula: $\big((\blacklozenge_{[0,10\,\mathrm{s})}\, P(a, b)) \wedge Q(b, c)\big) \wedge \lozenge_{[0,10\,\mathrm{s})}\, R(c, a)$

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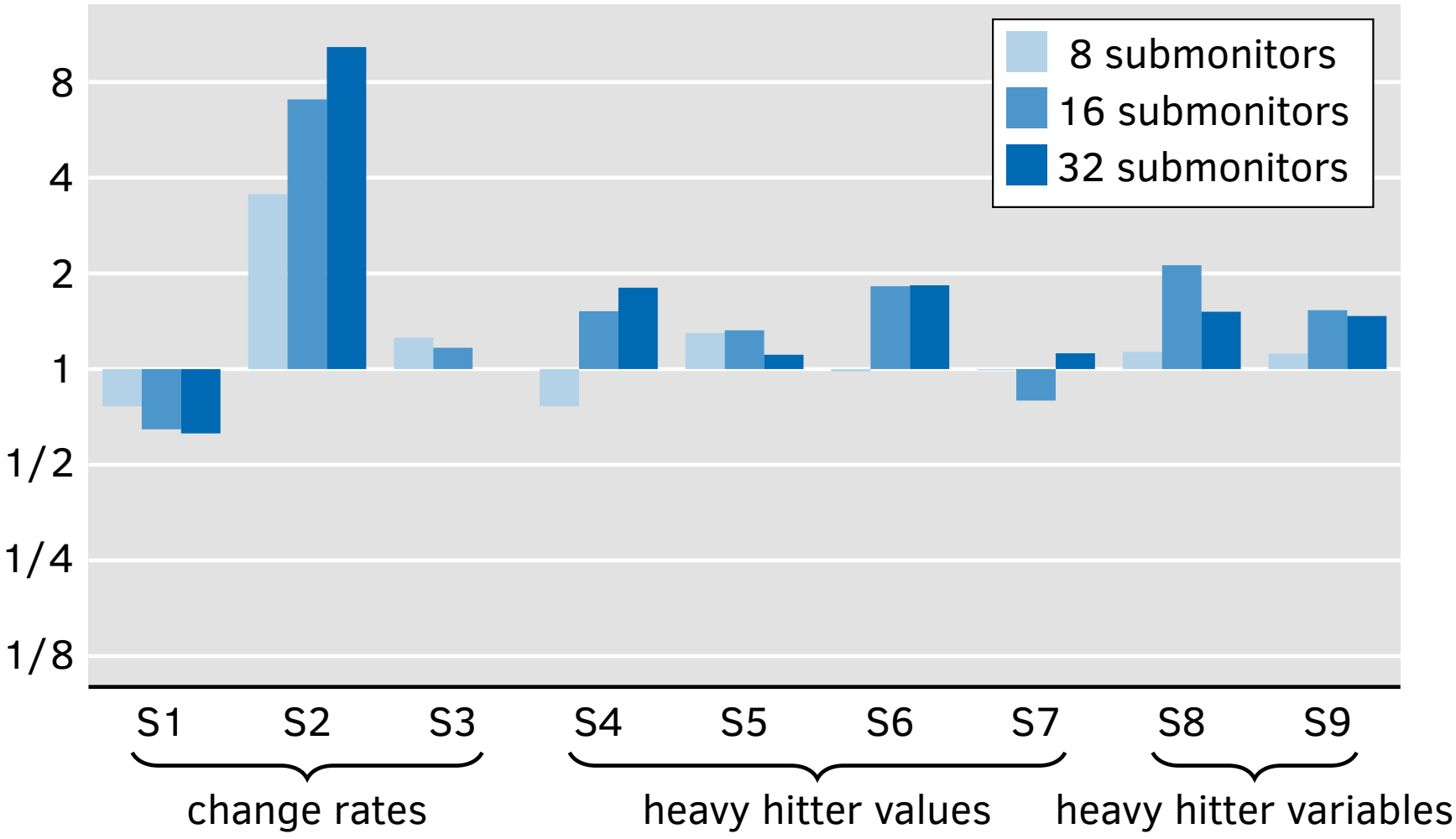

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Steps towards **when** to adapt & **what** strategy to use
[thanks to Christian Fania]:

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Future work:

- Taking state imbalance into account
- Prediction of future statistics
- Concurrent adaptation

Adaptive Online First-Order Monitoring

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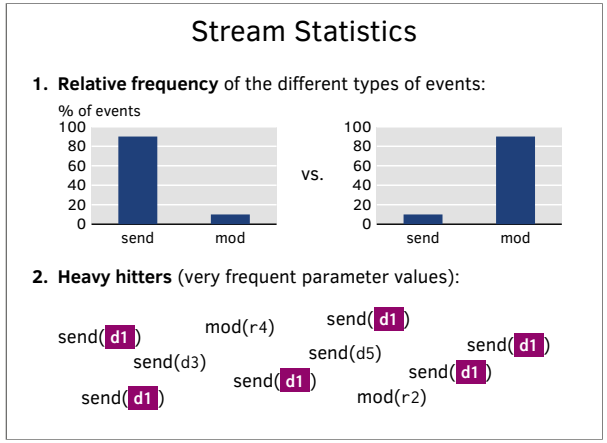

Adaptive Online First-Order Monitoring

Stream Statistics

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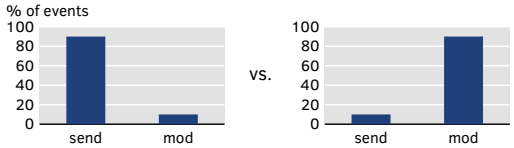

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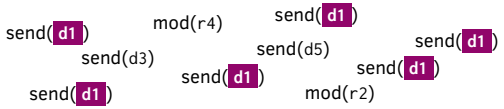

Solution: Adaptive Algorithm

Parameter: sequence $(r_i)_{i \geq 0}$ of slicing strategies

for the i-th input $\langle \tau_i, E_i \rangle$, $i \geq 1$, **do**

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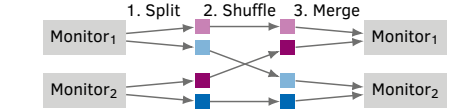
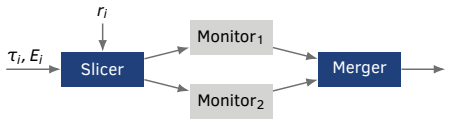


end



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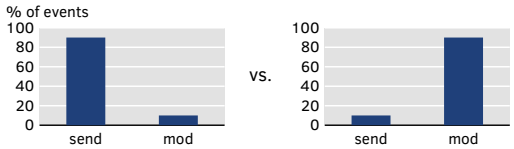

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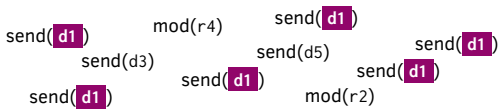

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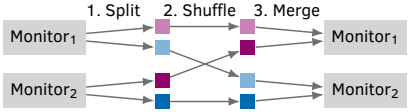

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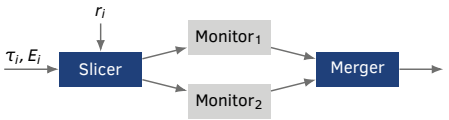

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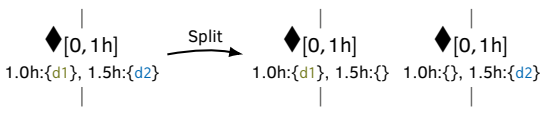

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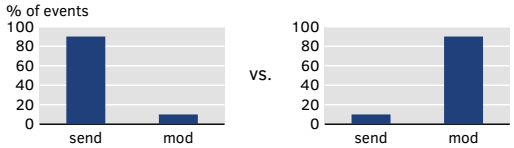

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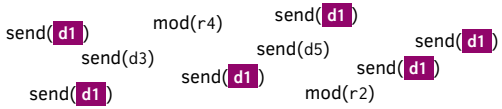

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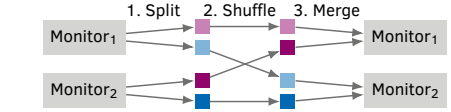

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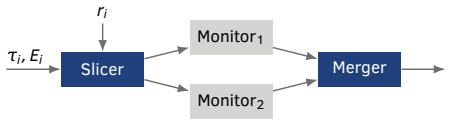

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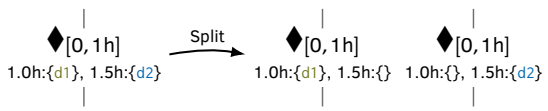

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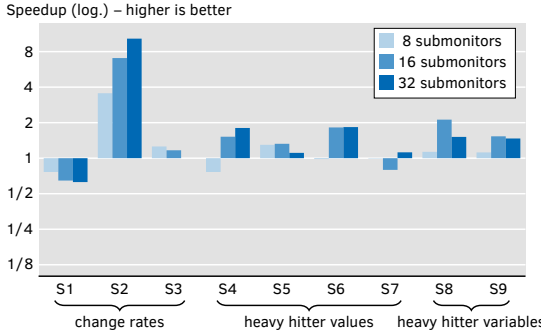

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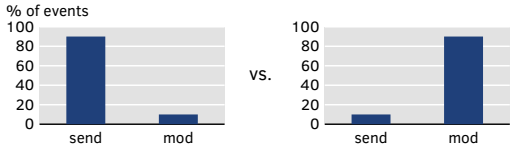

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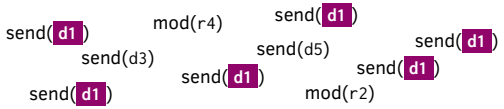

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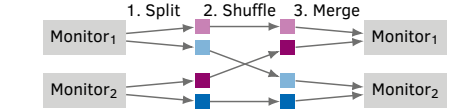

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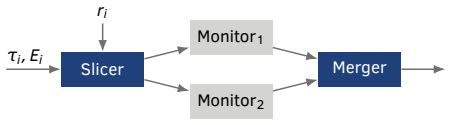

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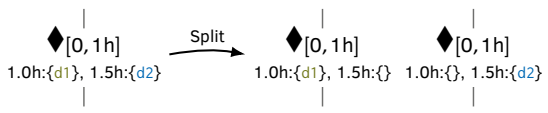

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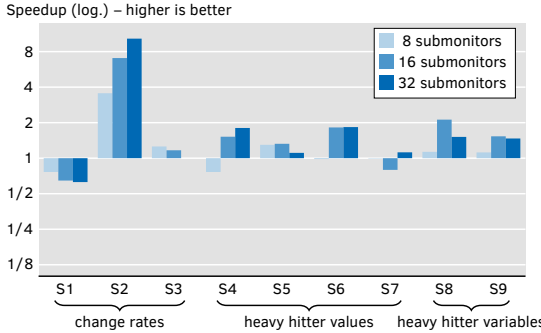
Triangle formula: $((\blacklozenge_{[0,10\,s)}\, P(a, b)) \wedge Q(b, c)) \wedge \lozenge_{[0,10\,s)}\, R(c, a)$

Speedup (log.) – higher is better



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