Runtime Instrumentation for Reactive Components

ECOOP 2024 · L. Aceto · **D. P. Attard** · A. Francalanza · A. Ingólfsdóttir

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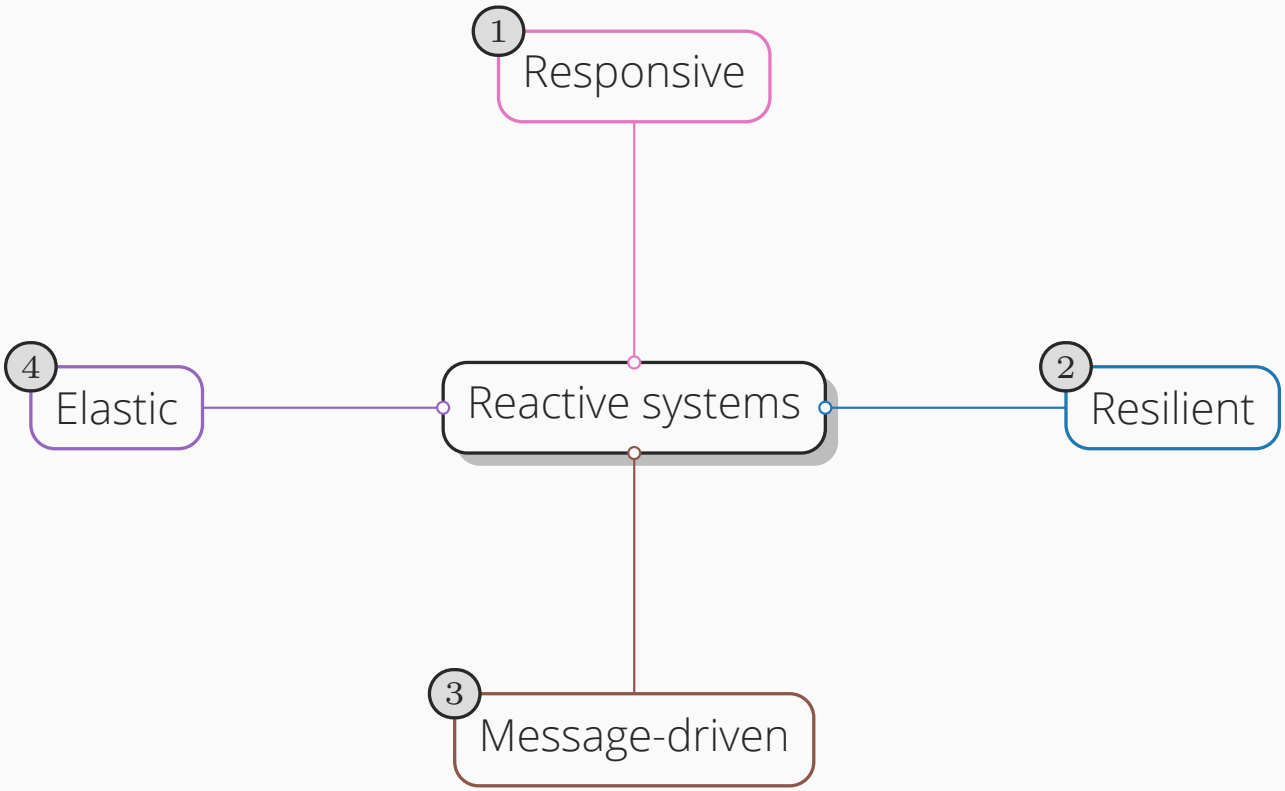
GRAN SASSO SCIENCE INSTITUTE

Reactive systems



Runtime monitoring... Why?

> *Understanding system behaviour requires the system to run*

profiling · resource usage analysis · security audit trails

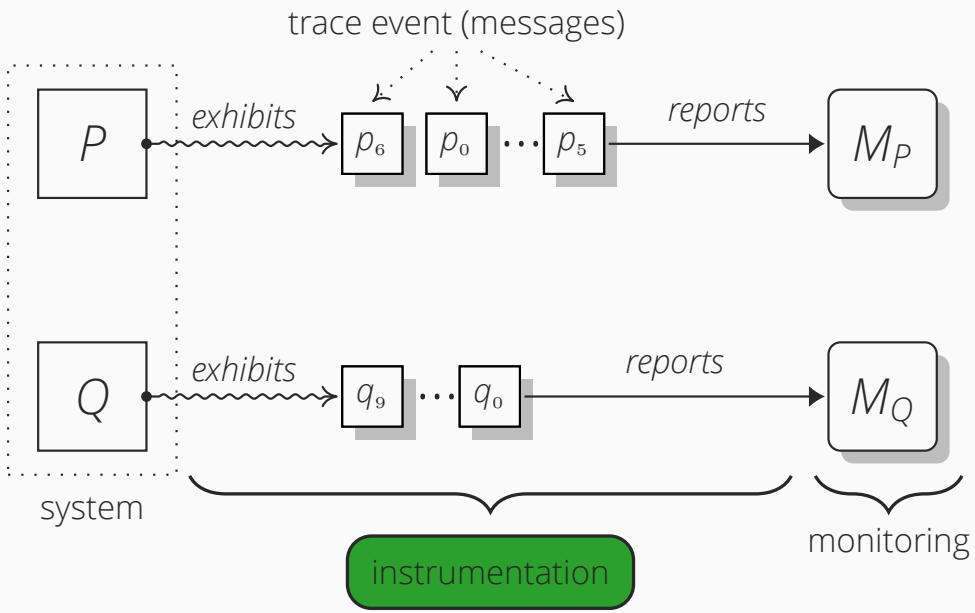
OR

> *Correctness of system is hard to analyse statically*

debugging · information flow · runtime verification

Runtime monitoring... How?

> *Extract runtime information and report it to monitors*



Runtime monitoring requirements

> *Instrumentation **must** preserve the reactiveness of the system*

Runtime monitoring requirements

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Low overhead preserves the Responsive attribute

Independent failure preserves the Resilient attribute

Non-blocking preserves the Message-driven attribute

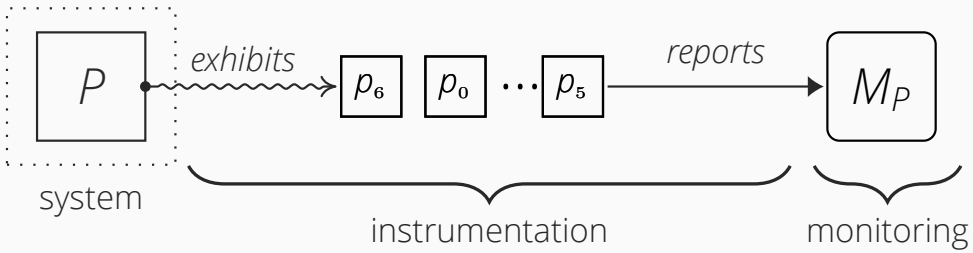
Grows and shrinks preserves the Elastic attribute

Runtime monitoring requirements

> *Instrumentation **must** preserve the reactiveness of the system*

= the instrumented system **remains** Reactive

Runtime verification requirements



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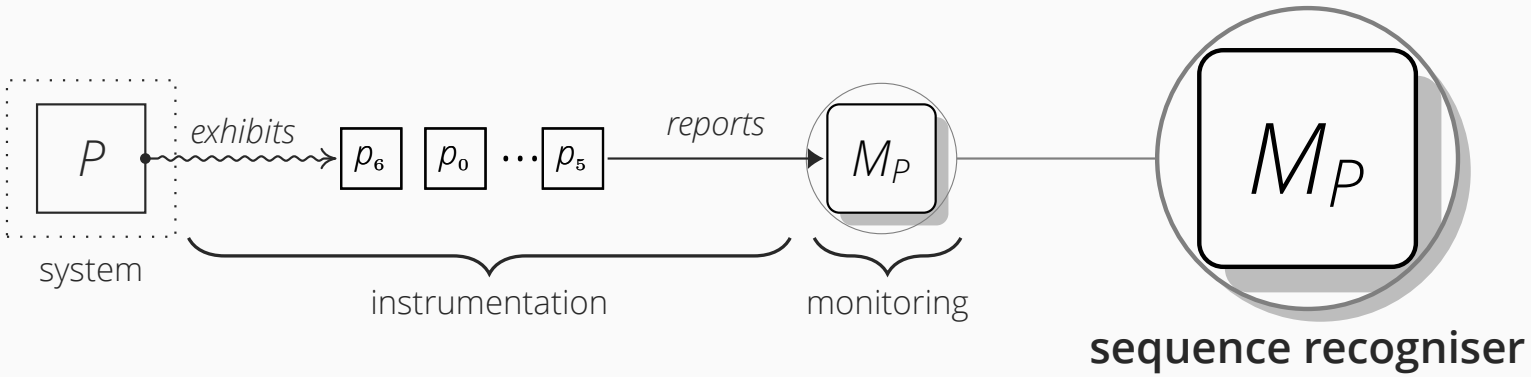

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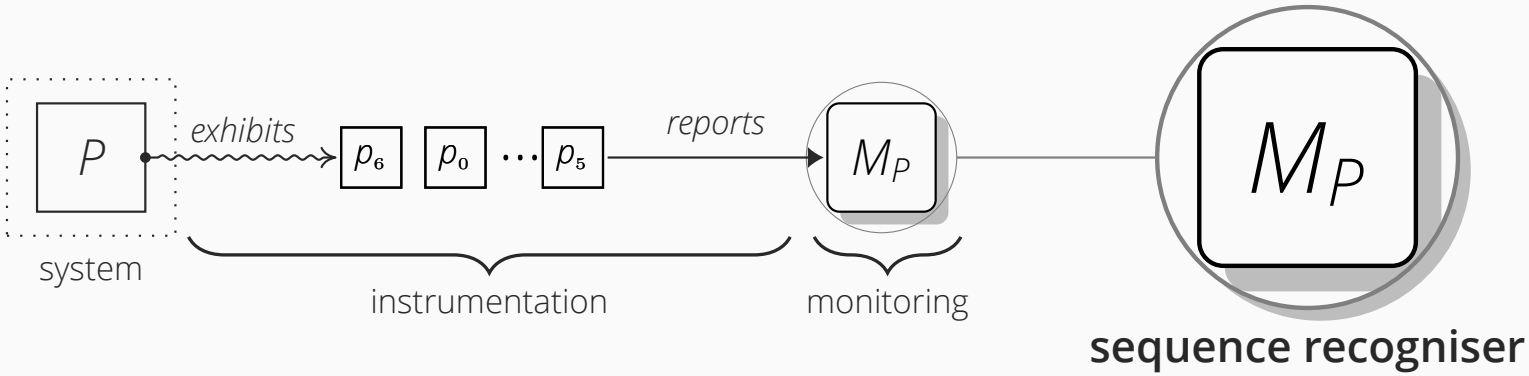
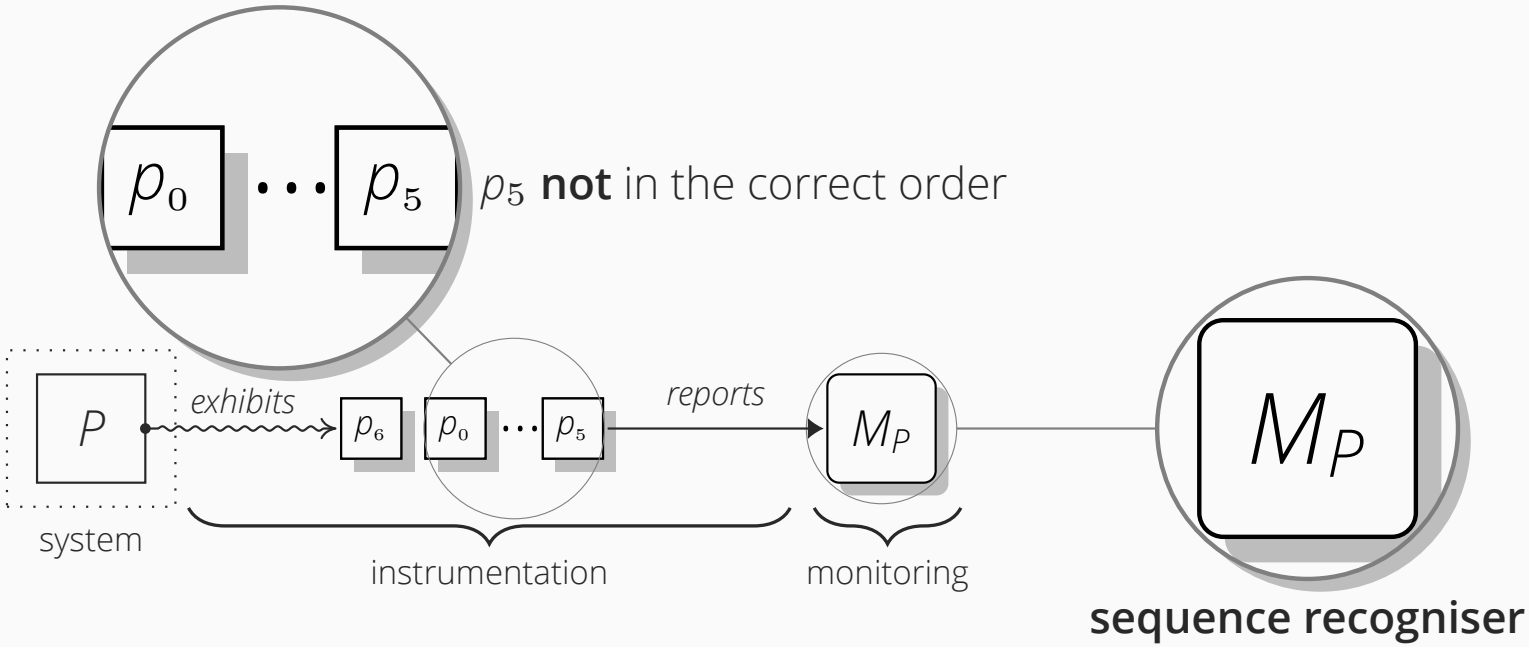


Trace soundness

- **Complete:** trace contains **all** the events exhibited by *P* so far
- **Consistent:** events reflect the **same order** *P* exhibits them

Runtime verification requirements



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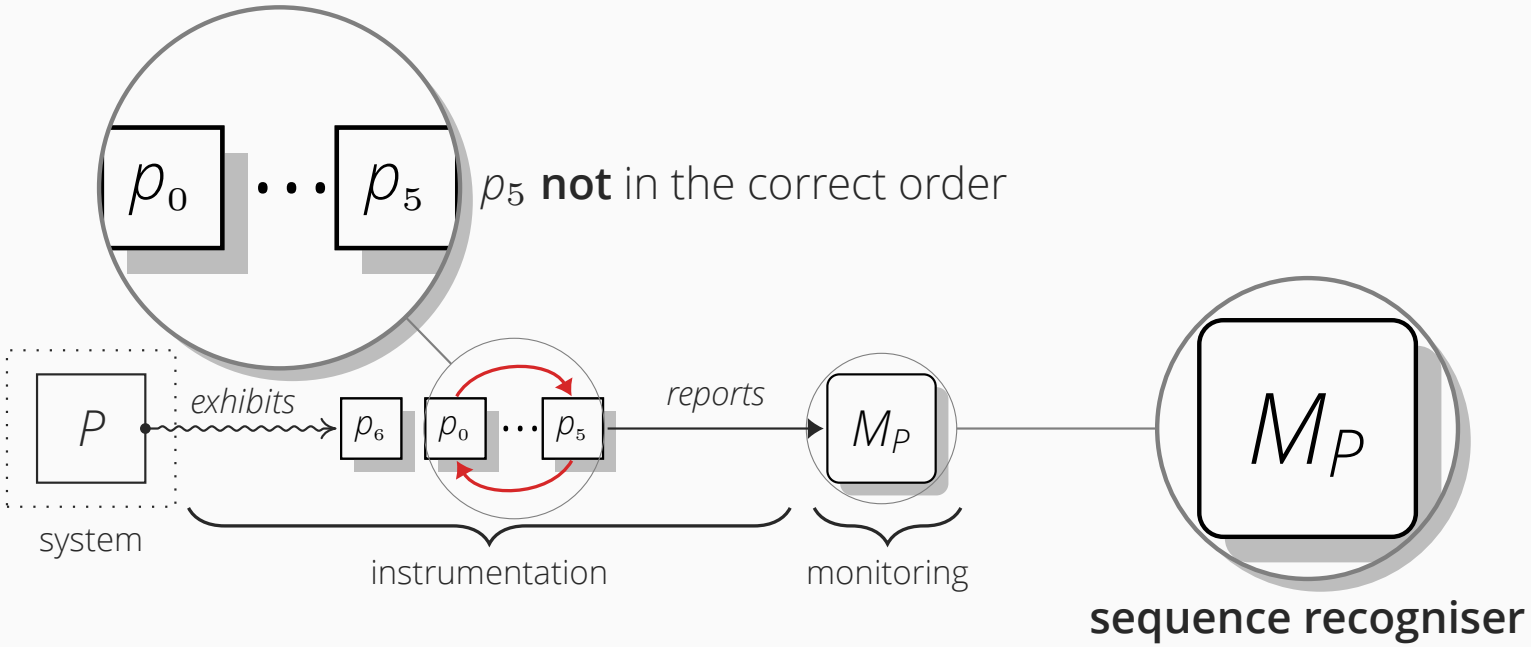

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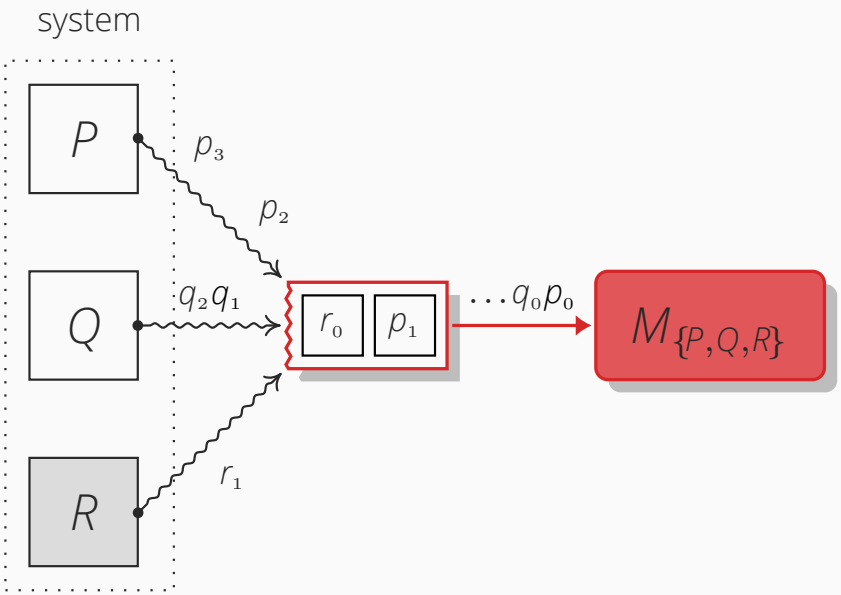
Centralised outline instrumentation



High overhead ✗ Responsive

Suffers from SPOF ✗ Resilient

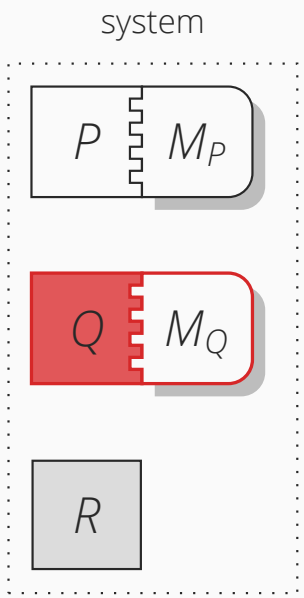
Asynchronous ✓ Message-driven

Does not shrink ✗ Elastic

Not scalable due to contention and singleton monitor

Requires **demultiplexing** for analysing events

Inline instrumentation



Typically low overhead ✓ Responsive

Embeds monitors ✗ Resilient

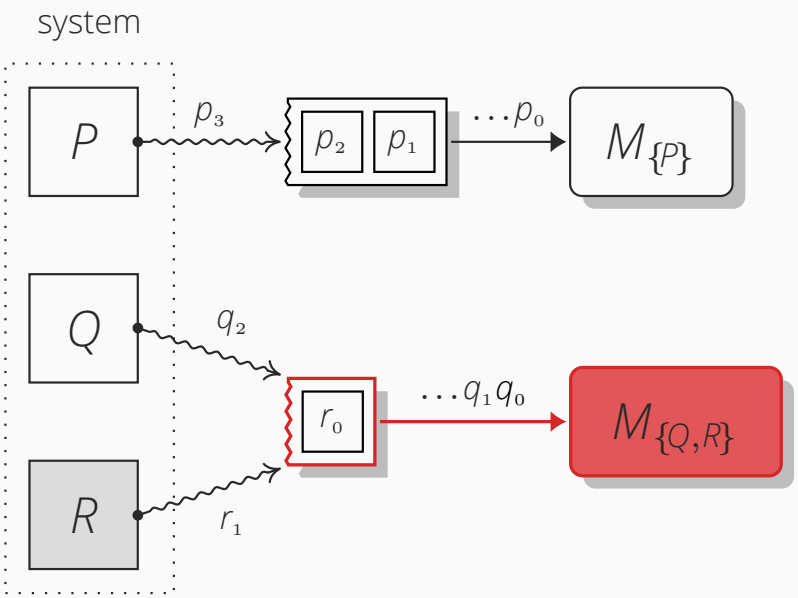
Synchronous ✗ Message-driven

Grows and shrinks ✓ Elastic

Inapplicable when code modification is not possible

Slow monitors may **impact latency**

Decentralised outline instrumentation



Feasible overhead ✓ Responsive

Isolates monitors ✓ Resilient

Asynchronous ✓ Message-driven

Grows and shrinks ✓ Elastic

Tracing uses an asynchronous **tracing infrastructure**

Dynamic outline instrumentation = **challenging** engineering

Criticism against decentralised outline monitoring

> *Decentralised outline monitoring induces **high** overhead*

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What **is** runtime overhead?

Many take the **execution duration** as an overhead metric

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What **is** runtime overhead?

~~Many take the **execution duration** as an overhead metric~~ ✗

Latency

Memory consumption + Scheduler usage ✓

RIARC

*“ A **reactive** decentralised outline instrumentation algorithm ”*

L. Aceto · **D. P. Attard** · A. Francalanza · A. Ingólfsdóttir · RU · GSSI · UM · U*of*G

Core idea of RIARC (details in paper)

> *Buffers react to **key trace events** to reorganise monitors*

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- spawn ($-\diamond$), exit ($*$)
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Control messages

- route packet (rtd)
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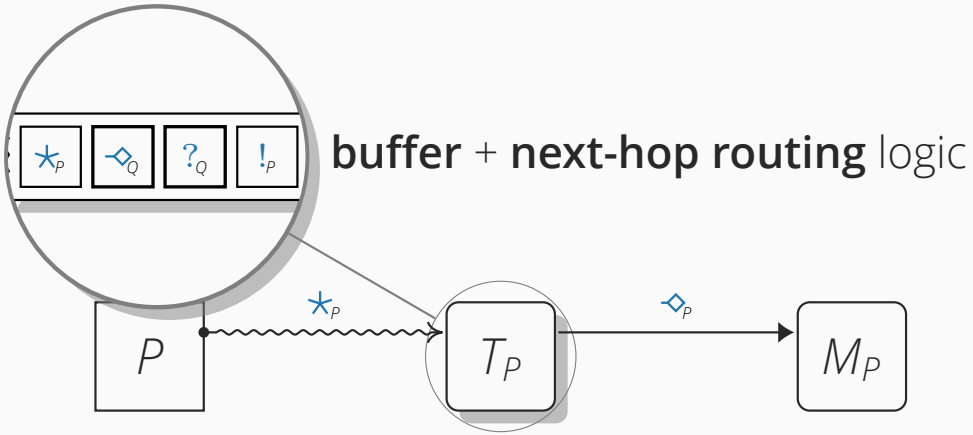

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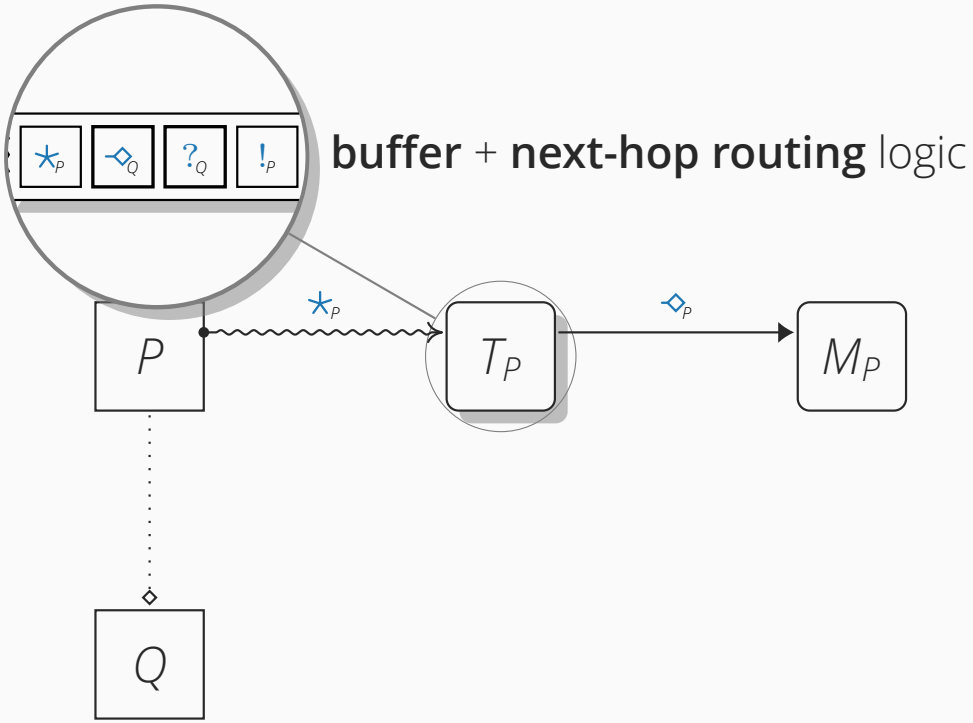

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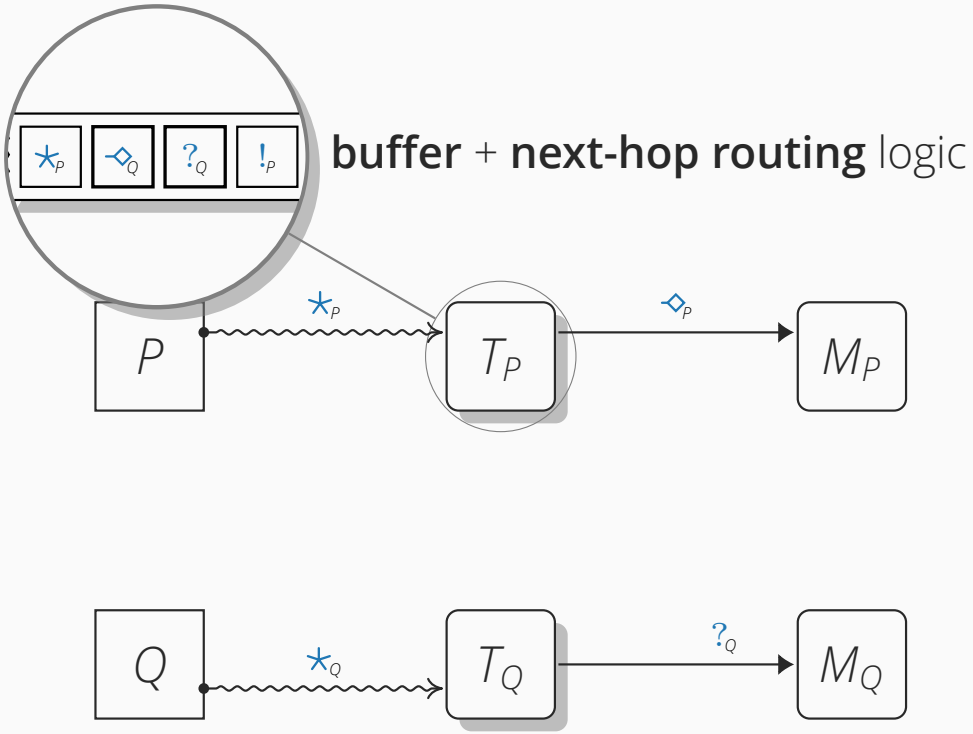

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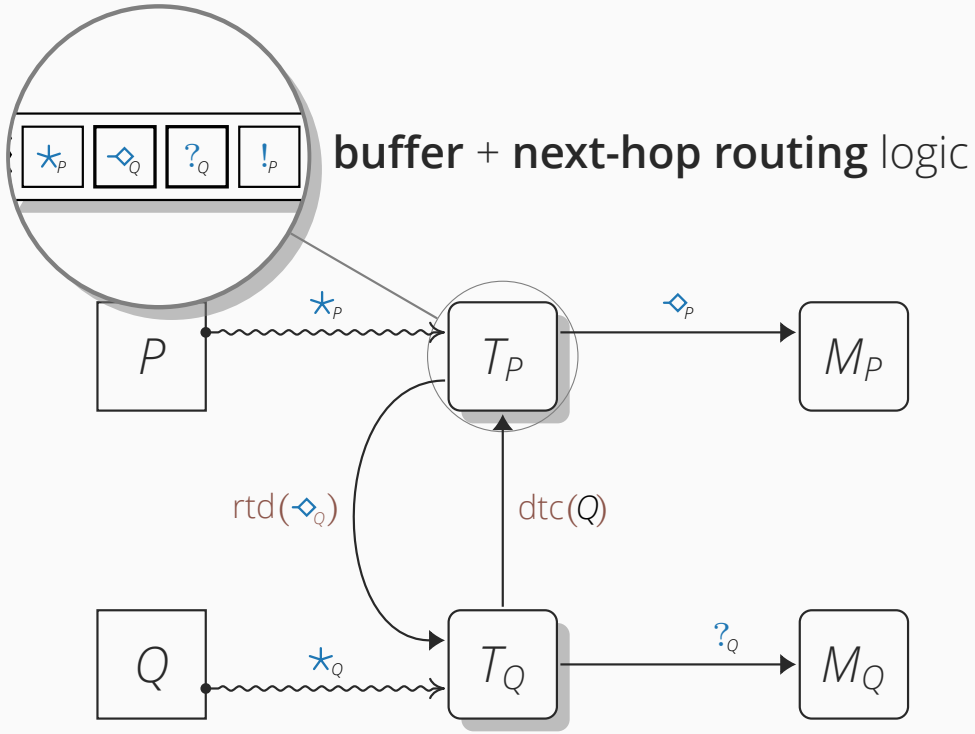

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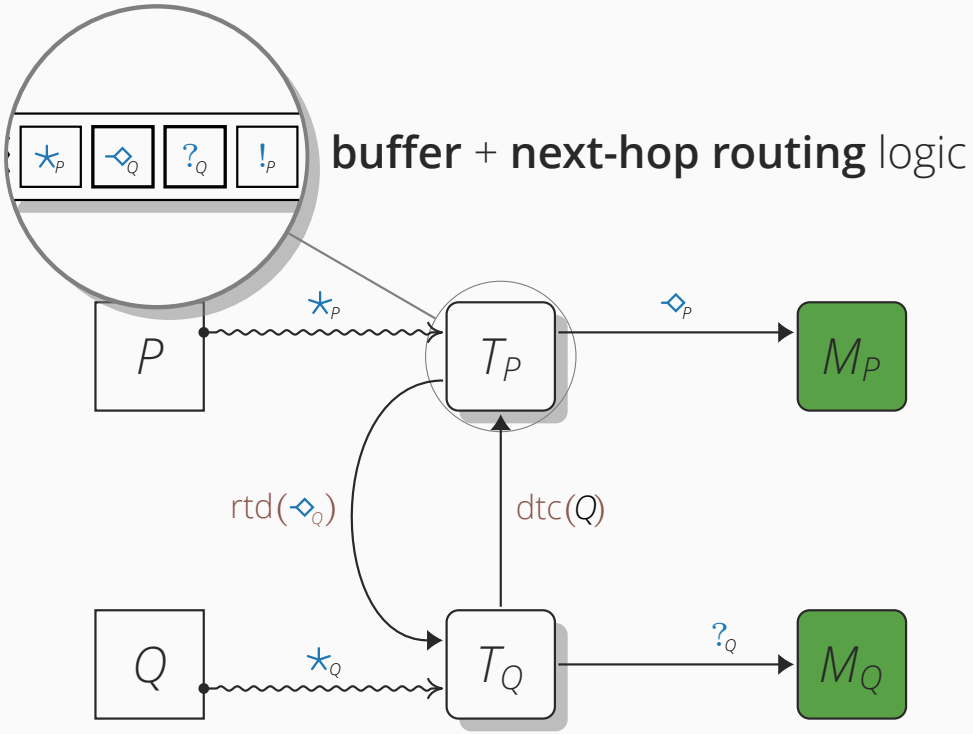

Evlauating RIARC

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Evlauating RIARC

Implementability

To confirm that RIARC can be used in **practice**

Evaluating RIARC

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Correctness

To confirm that all traces RIARC reports are **sound**

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Correctness

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Performance

To confirm that RIARC preserves the system **reactiveness**

Summary of empirical experiments (details in paper)

Limited hardware - **40 M** events

High concurrency experiments

(short-lived, computationally-light tasks)

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Inline is the **most efficient**

Latency RIARC ≈ latency Inline

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RIARC **scales** and uses schedulers

Latency RIARC **=** latency Inline

Inline prone to **slow analysis**

Instrumentation yields **most** overhead %

Take away

Centralised instrumentation

Applicable ✗

Inline instrumentation

Low overhead ✓

May impact system ✗

Not always applicable ✗

RIARC

- Leaves the system **reactive** ✓
- Guarantees **trace soundness** ✓
- **Low overhead** feasible for soft real-time applications ✓

Further details

Paper (extended version)

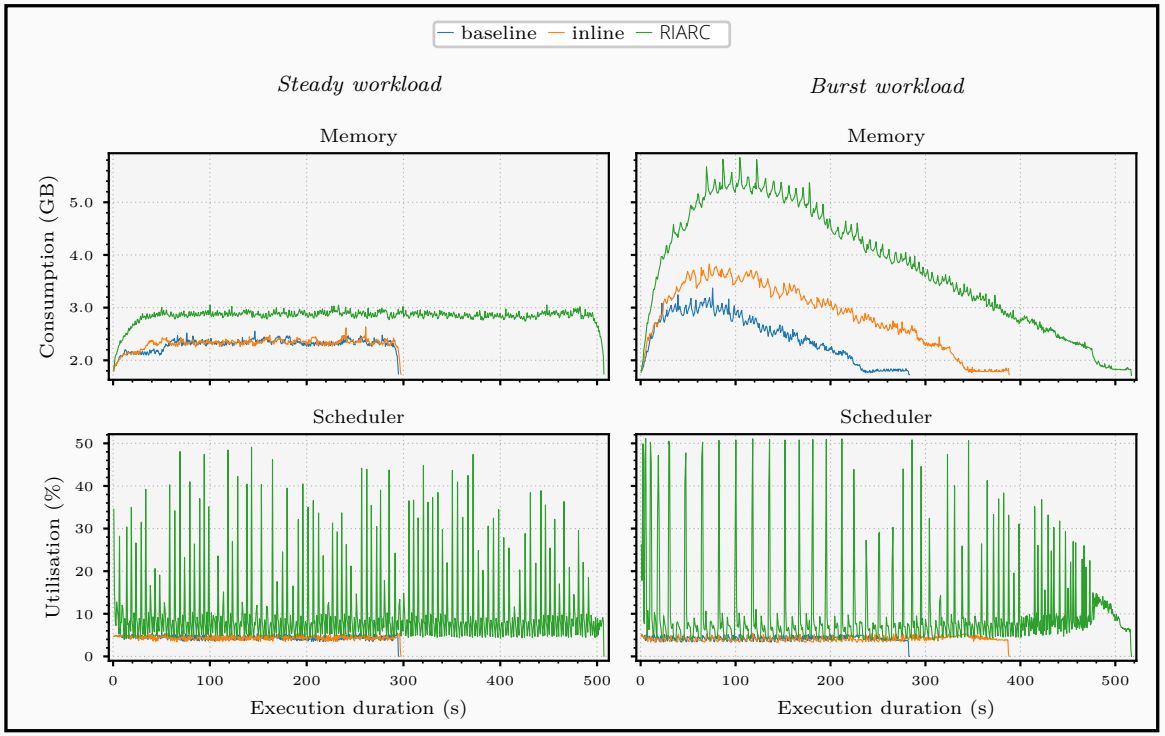
RIARC use in detectEr

Backup slides

Aim: study scalability and elasticity of monitoring

Resource usage

(complete system runs)



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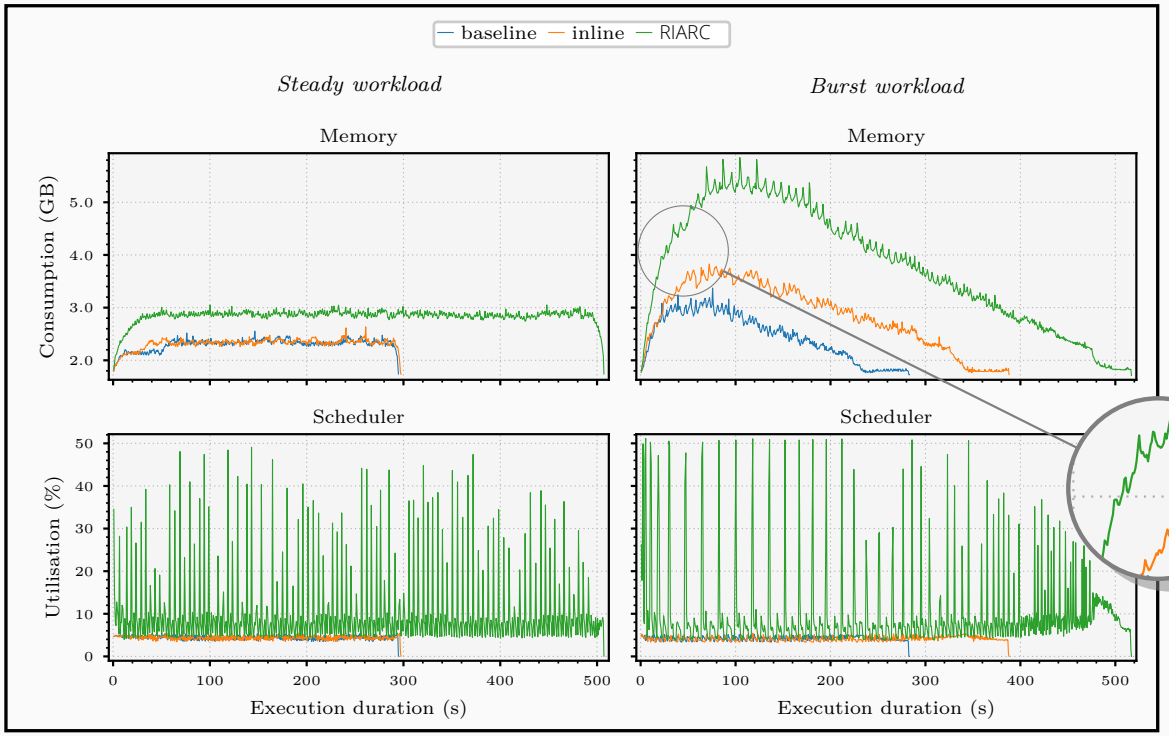

Inline RIARC

Elastic and follow shape of baseline workload

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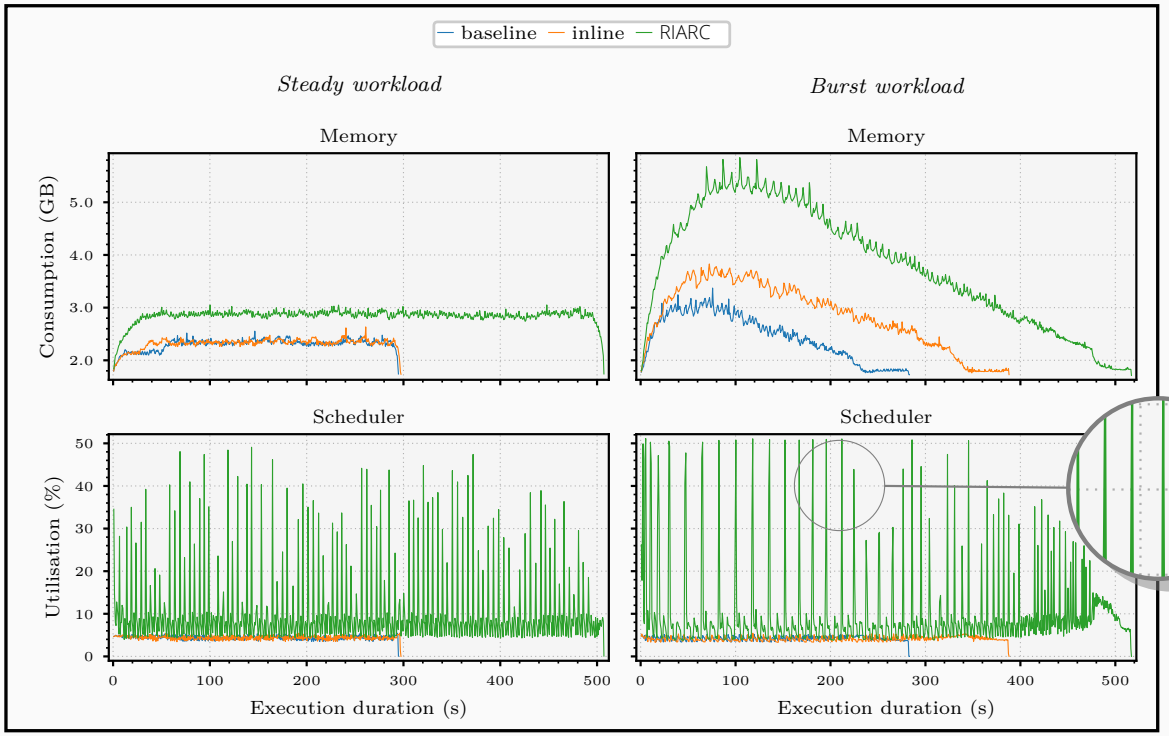

RIARC

Tracer **reconfiguration** evident in scheduler oscillations

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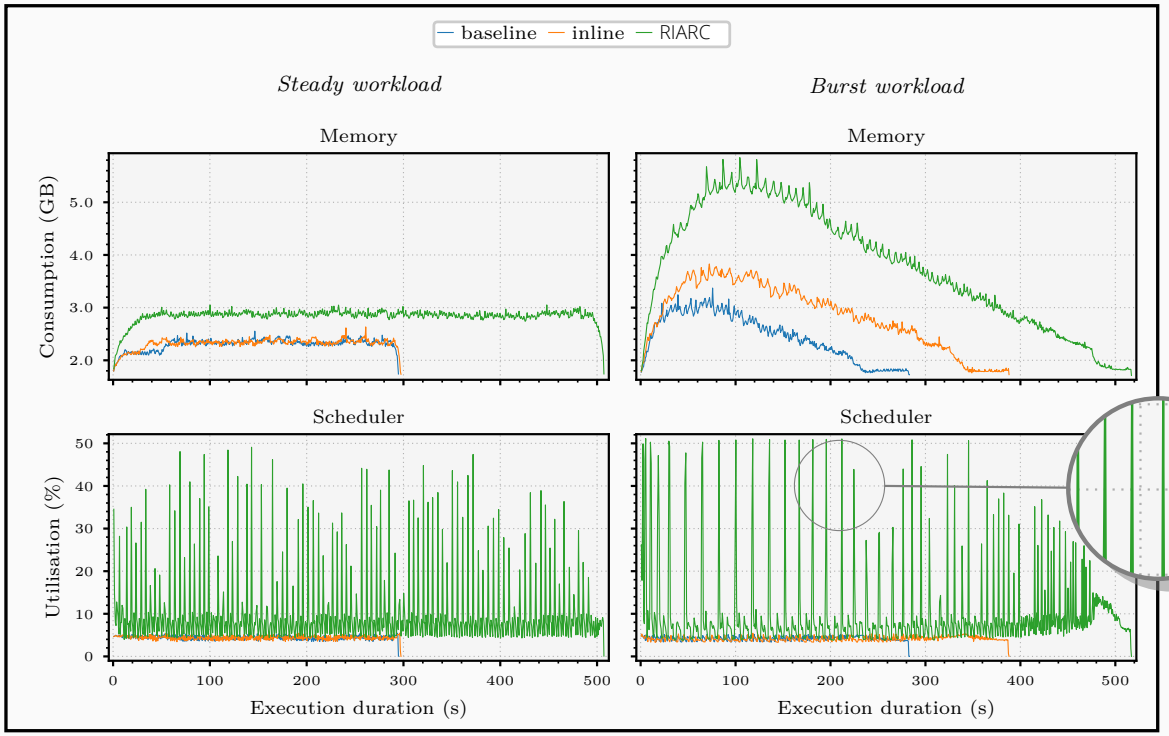

RIARC

Tracer **activation** is shown as peaks

Aim: study scalability and elasticity of monitoring

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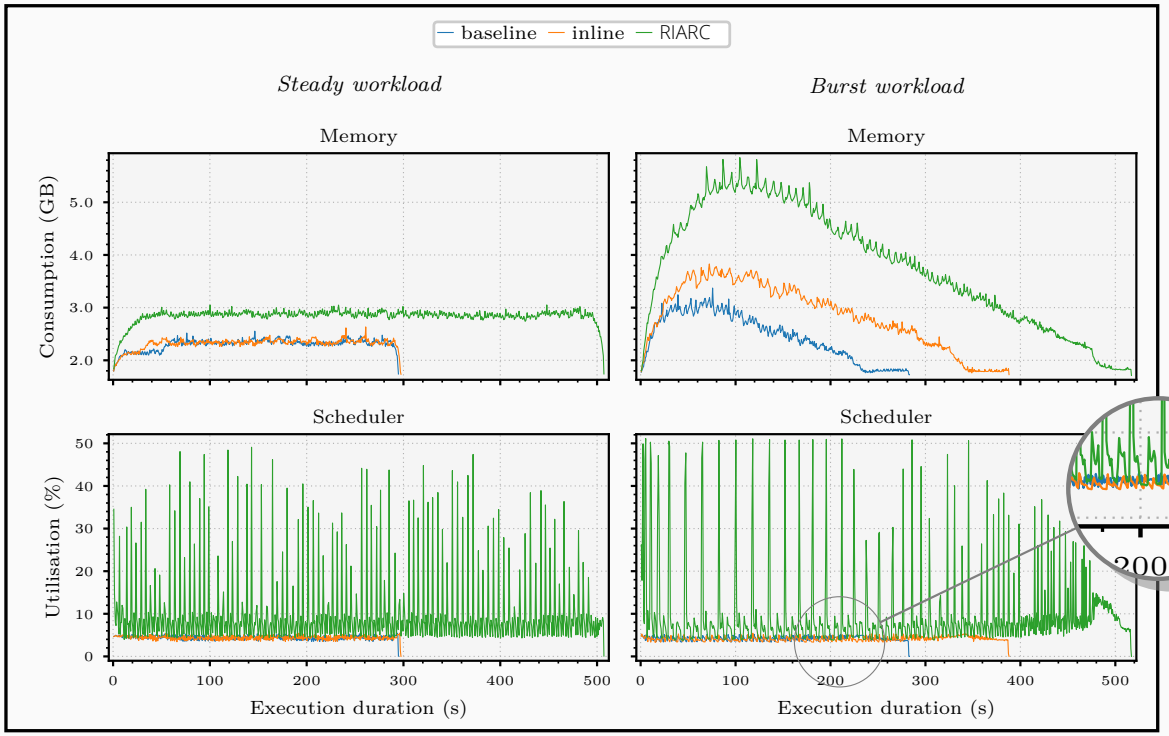

RIARC

Tracer **idle** period is shown as troughs = **message driven**

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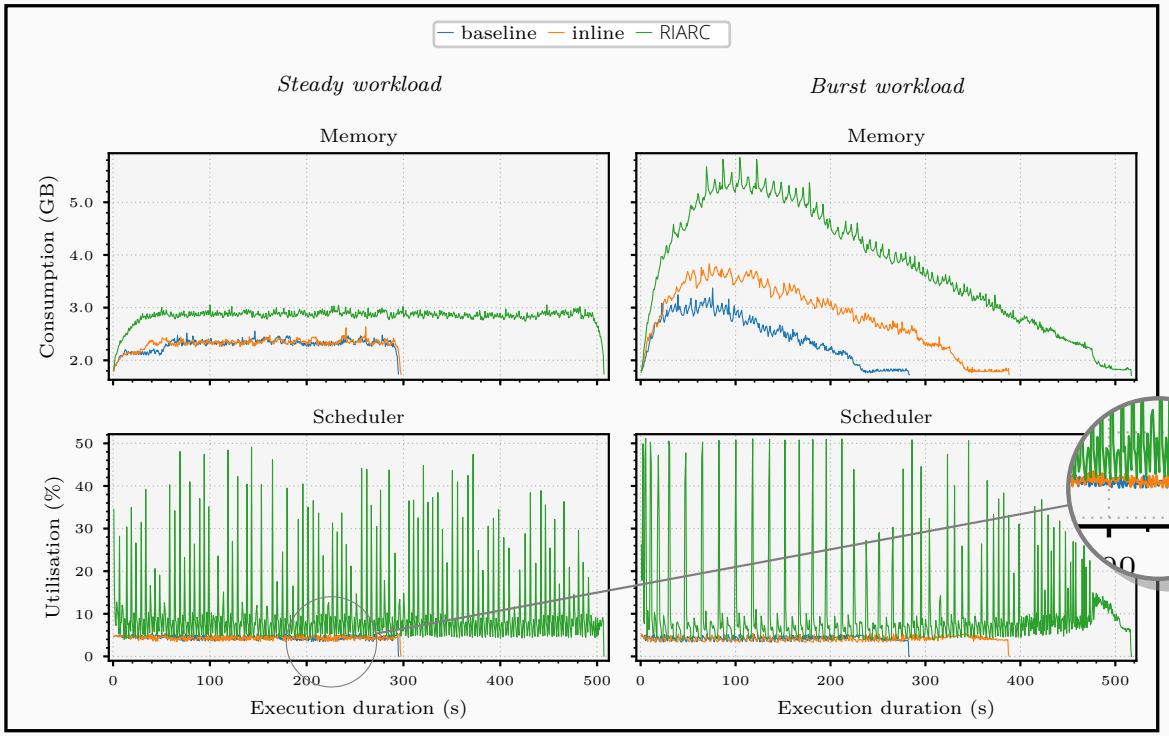

Inline

Minimal oscillations due to **lock-step** execution with system

Aim: inline and RIARC vs. centralised monitoring

Resource usage

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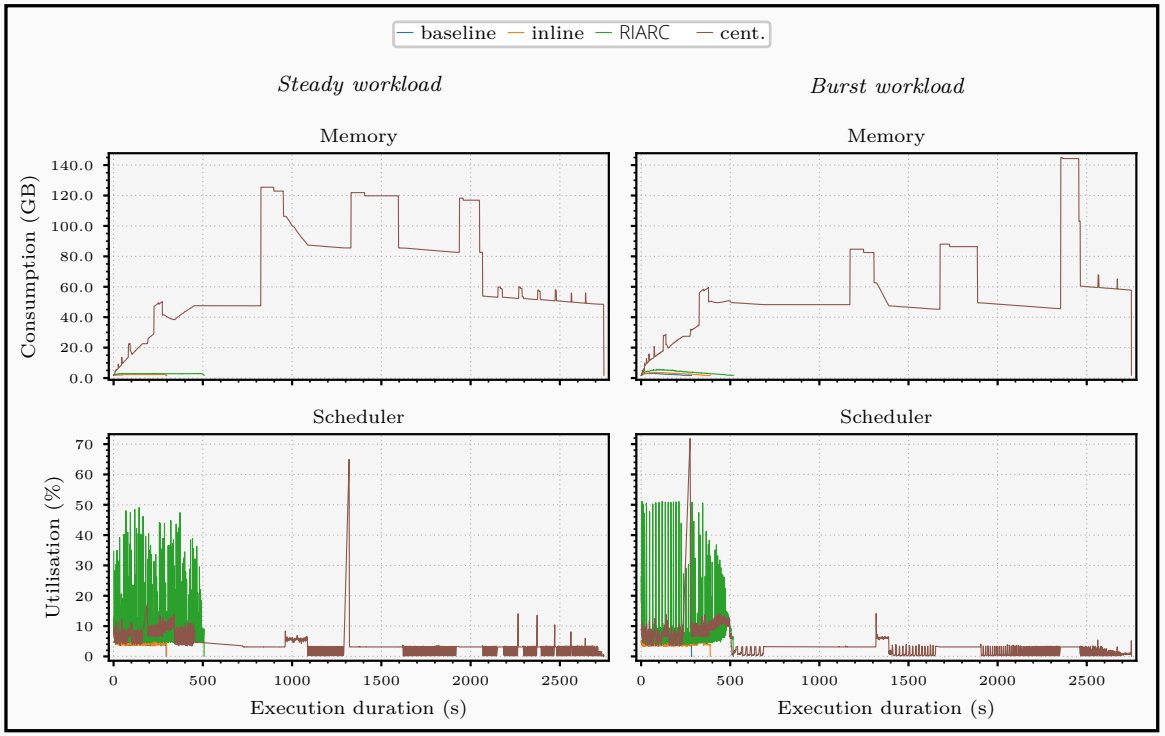

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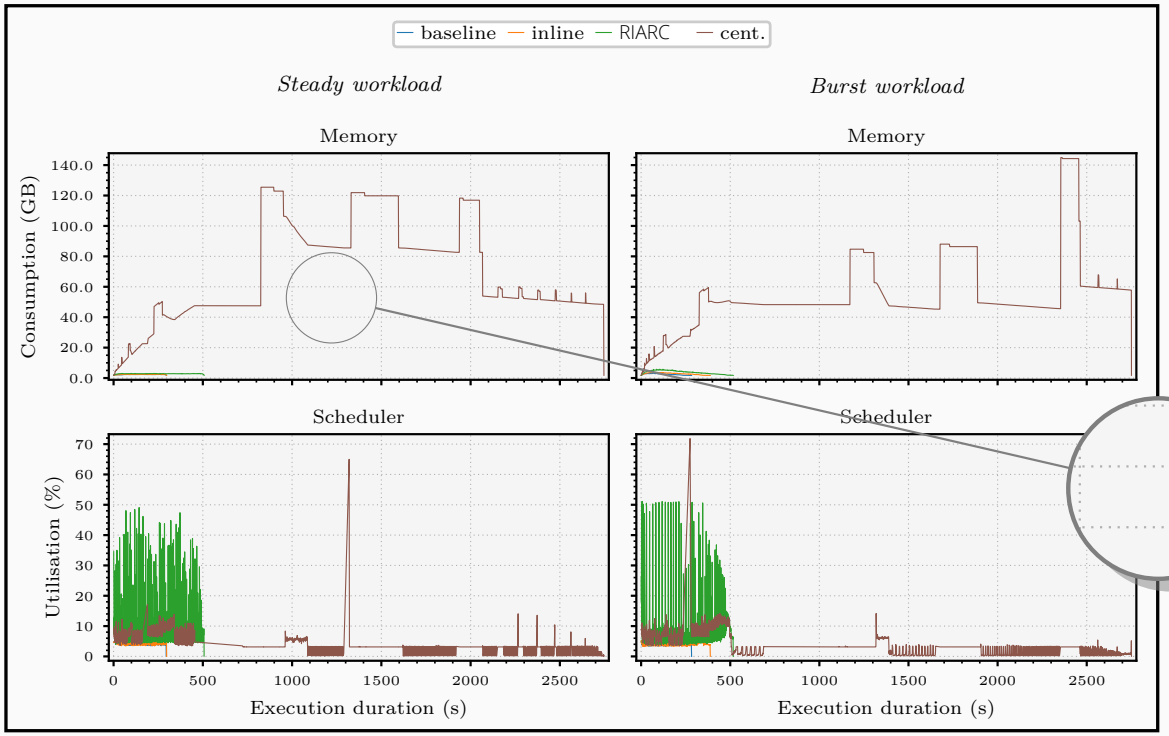

Centralised

Insensitive to workload shape

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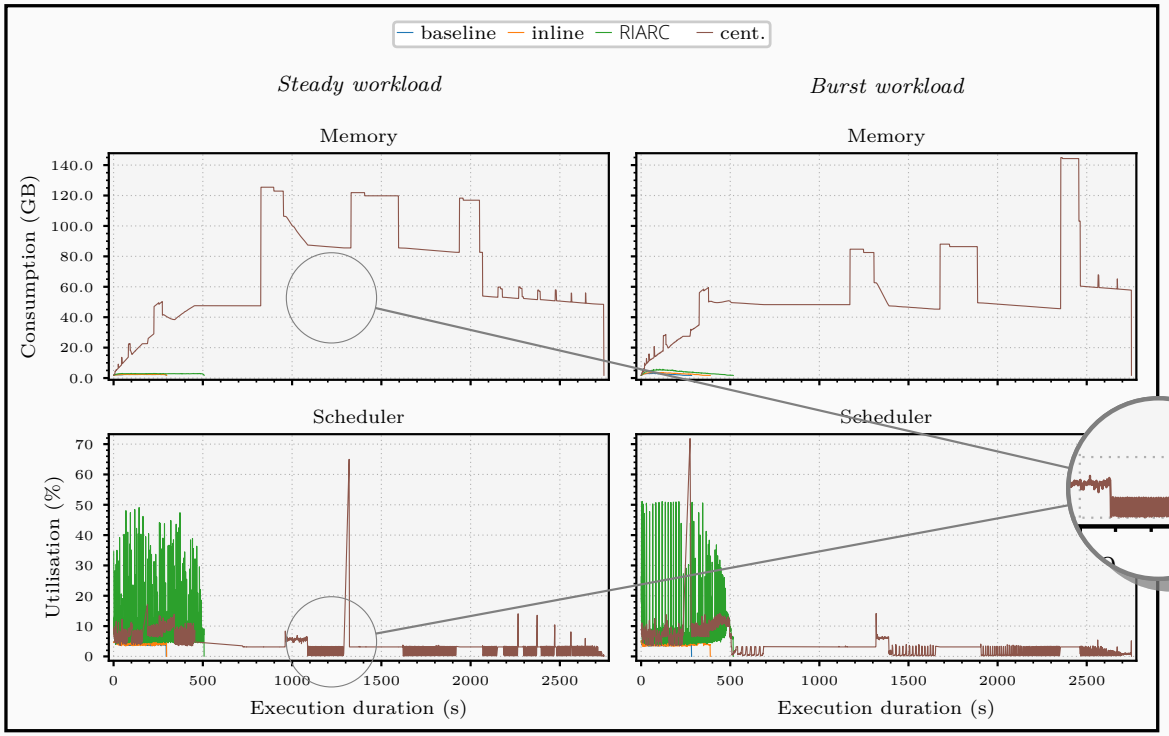

Centralised

Does **not scale**

(*cf.* RIARC)

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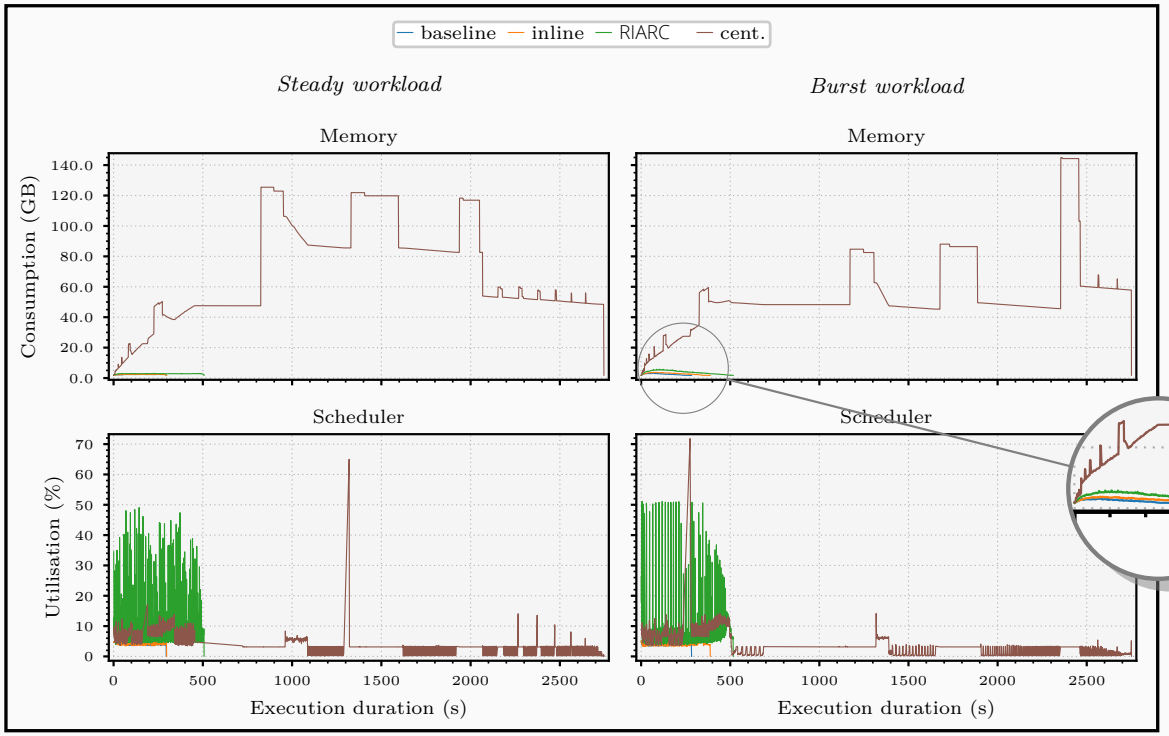

Inline RIARC

Dwarfed by memory requirements of centralised