Verified Rust Monitors for Lola Specifications

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An Age-Old Question

QUIS CUSTODIET IPSOS CUSTODES?

~ Juvenal (100-200ad)

Quis Custodiet Ipsos Custodes?

Cannot be trusted!

observes

Monitor

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Why trust the monitor?

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Our Goal:
Verify the Monitor!

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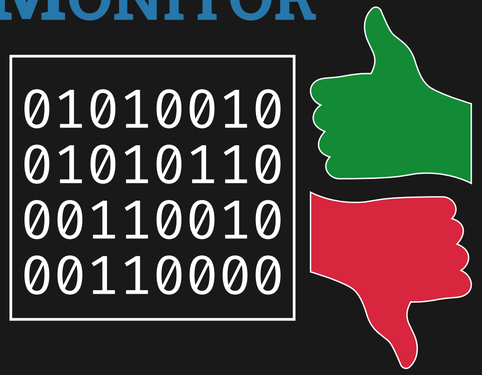
Lola Specification

Monitor



Quis Custodiet Ipsos Custodes?

observes

Our Goal:
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Lola Specification

Compilation

```
Impl Monitor {

 while let Some(i)
        = get_input() {
  …
 }}
```

Rust Code

Monitor

```
01010010
01010110
00110010
00110000
```

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Our Goal:
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Lola Specification

Compilation

+ Annotation Generation

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Stream-Based Monitoring with Lola

sensors

$i_{1,1}$	$i_{1,2}$	$i_{1,3}$	$i_{1,4}$	$i_{1,5}$	$i_{1,6}$	$i_{1,7}$	$i_{1,8}$
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$o_{1,1}$	$o_{1,2}$	$o_{1,3}$	$o_{1,4}$	$o_{1,5}$	$o_{1,6}$	$o_{1,7}$	$o_{1,8}$
$o_{2,1}$	$o_{2,2}$	$o_{2,3}$	$o_{2,4}$	$o_{2,5}$	$o_{2,6}$	$o_{2,7}$	$o_{2,8}$
$t_{1,1}$	$t_{1,2}$	$t_{1,3}$	$t_{1,4}$	$t_{1,5}$	$t_{1,6}$	$t_{1,7}$	$t_{1,8}$

```
input i1

input i2

input i3

output o1 := i3 + 3

output o2 := i1 + i2 + o1

trigger o2 > 7
```

Stream-Based Monitoring with Lola

sensors

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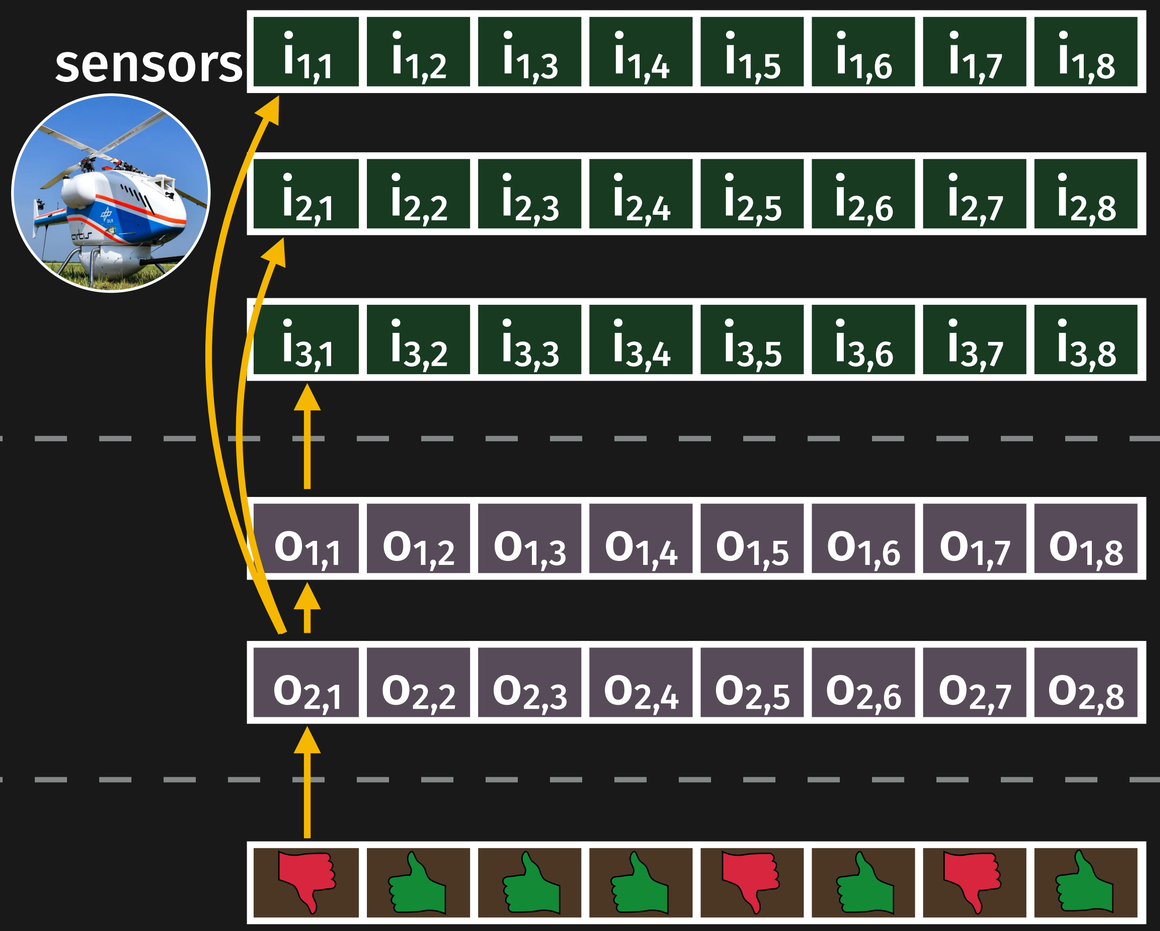


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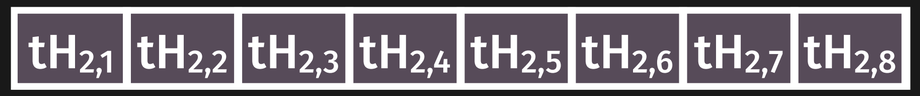


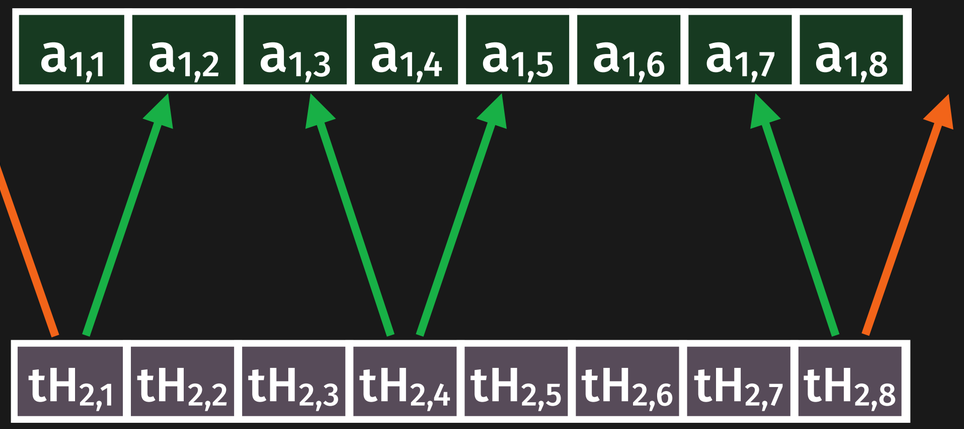
```
input alt

output tooHigh :=
  alt.offset(by: -1, dft: 0) > 500
  ∧ alt > 500
  ∧ alt.offset(by: +1, dft: 0) > 500

trigger tooHigh
```

Stream-Based Monitoring with Lola

sensors



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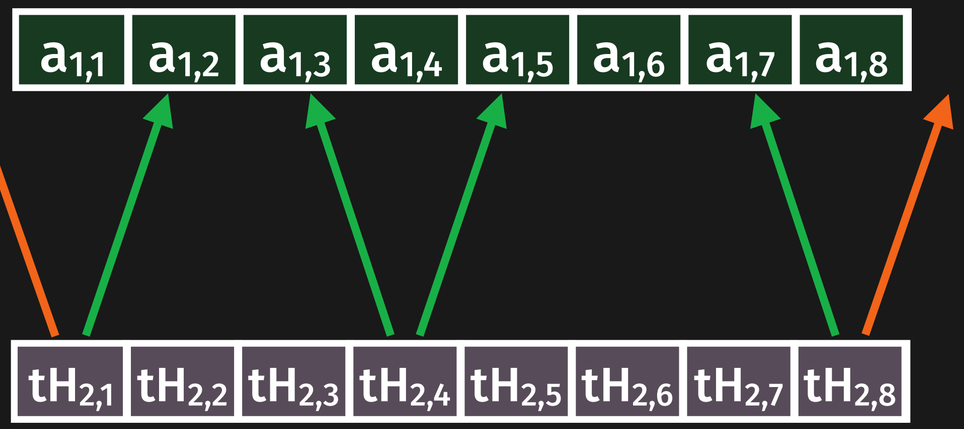
Stream-Based Monitoring with Lola

sensors



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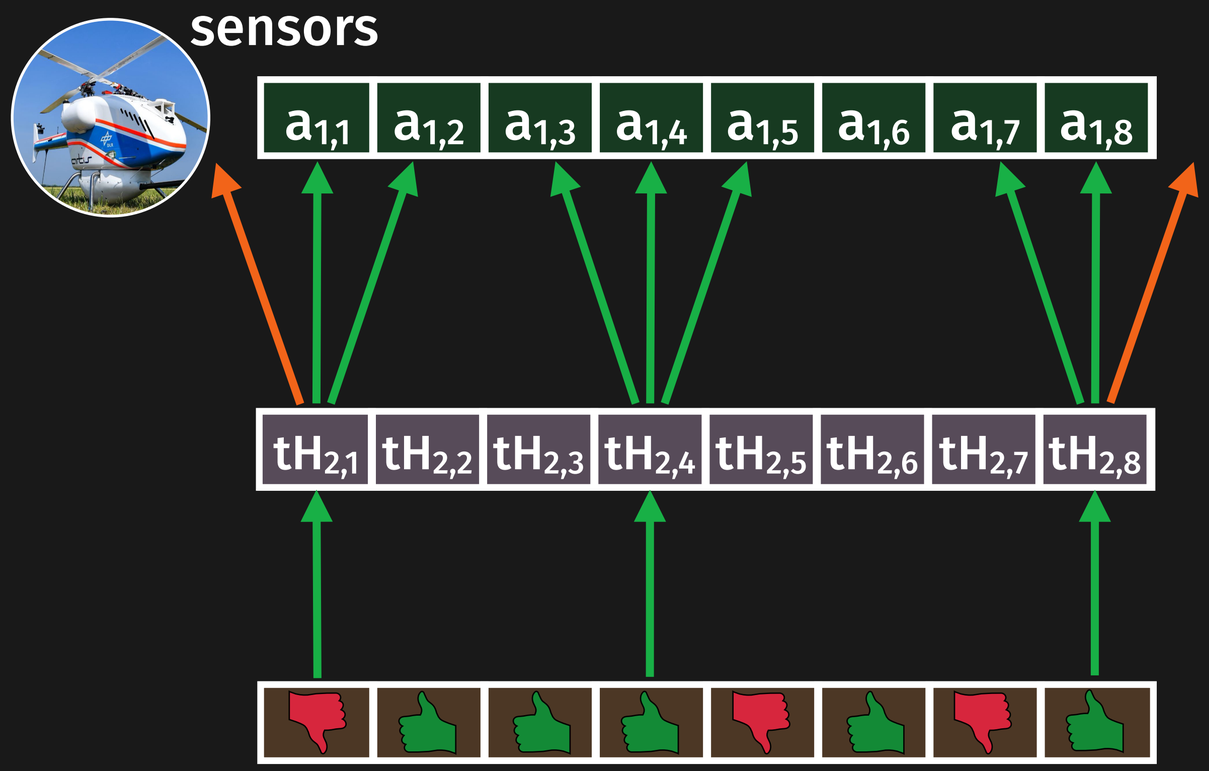
trigger tooHigh
```

fails @ t=1

fails @ t=|σ|

Stream-Based Monitoring with Lola




```
input alt

output tooHigh :=
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  ∧ alt > 500
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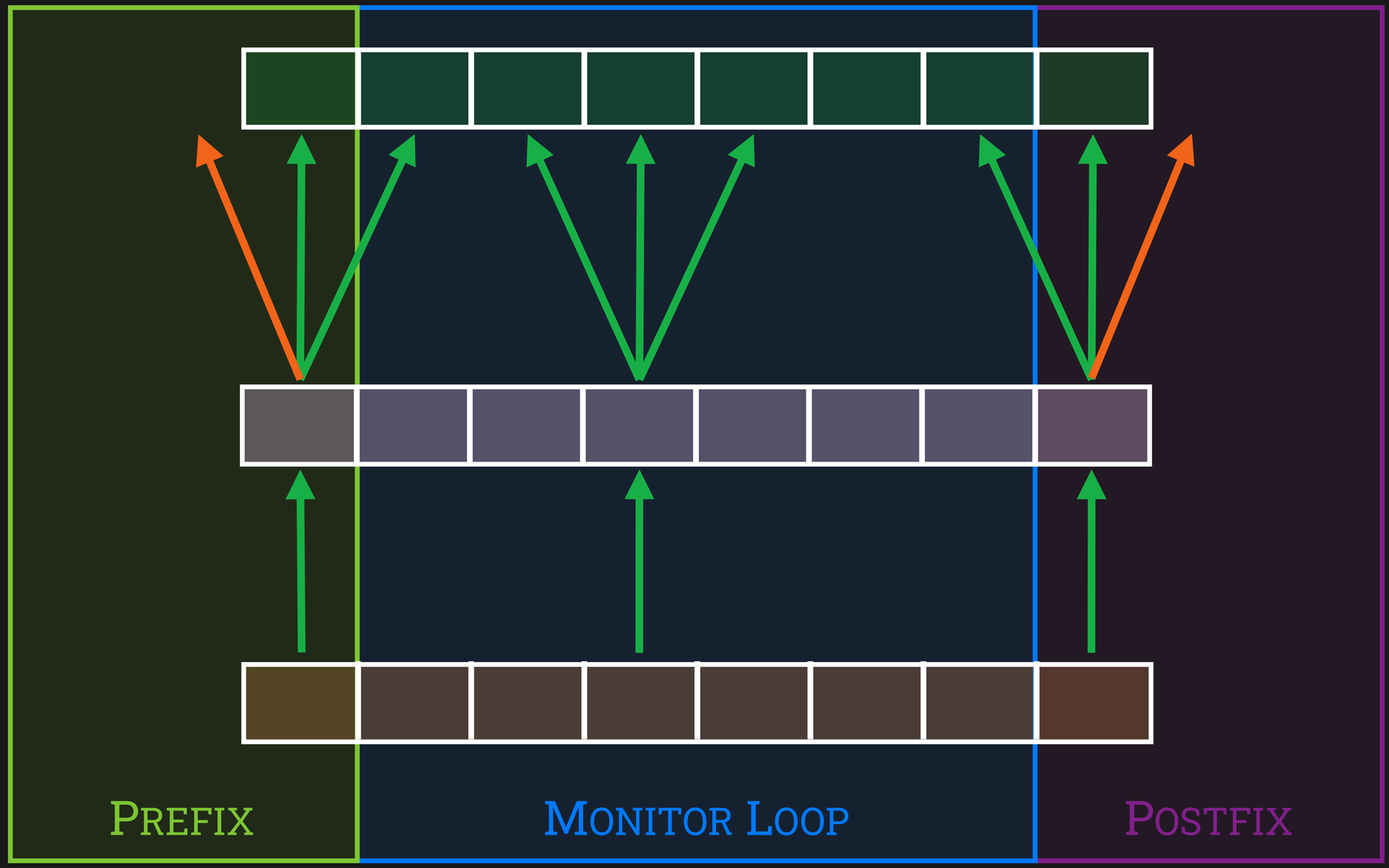
trigger tooHigh
```

fails @ t=1

never fails

fails @ t=|σ|

Three Phases



Three Code Fragments

```
fn prefix() {
 a-1 > 500
  ∧ a0 > 500
  ∧ a+1 > 500
}
```

Prefix

```
while let Some(…)
            = get_input() {
   a-1 > 500
     ∧ a0 > 500
     ∧ a+1 > 500
}
```

Monitor Loop

```
fn postfix() {
 a-1 > 500
  ∧ a0 > 500
  ∧ a+1 > 500
}
```

Postfix

Three Code Fragments

```
fn prefix() {
   0 > 500
   ∧ a₀ > 500
   ∧ a₊₁ > 500
}
```

Prefix

```
while let Some(…)
             = get_input() {
   a₋₁ > 500
      ∧ a₀ > 500
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}
```

Monitor Loop

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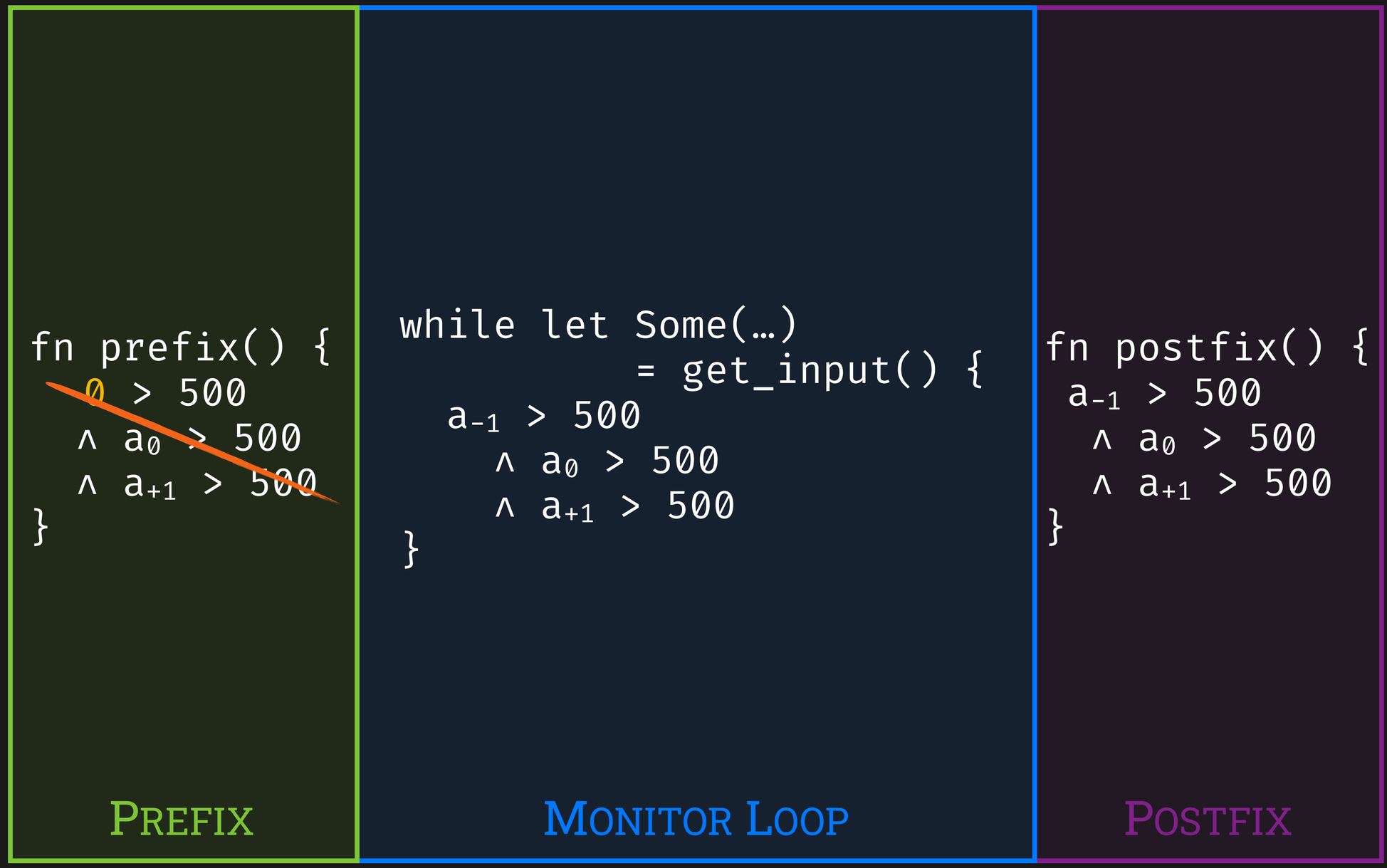
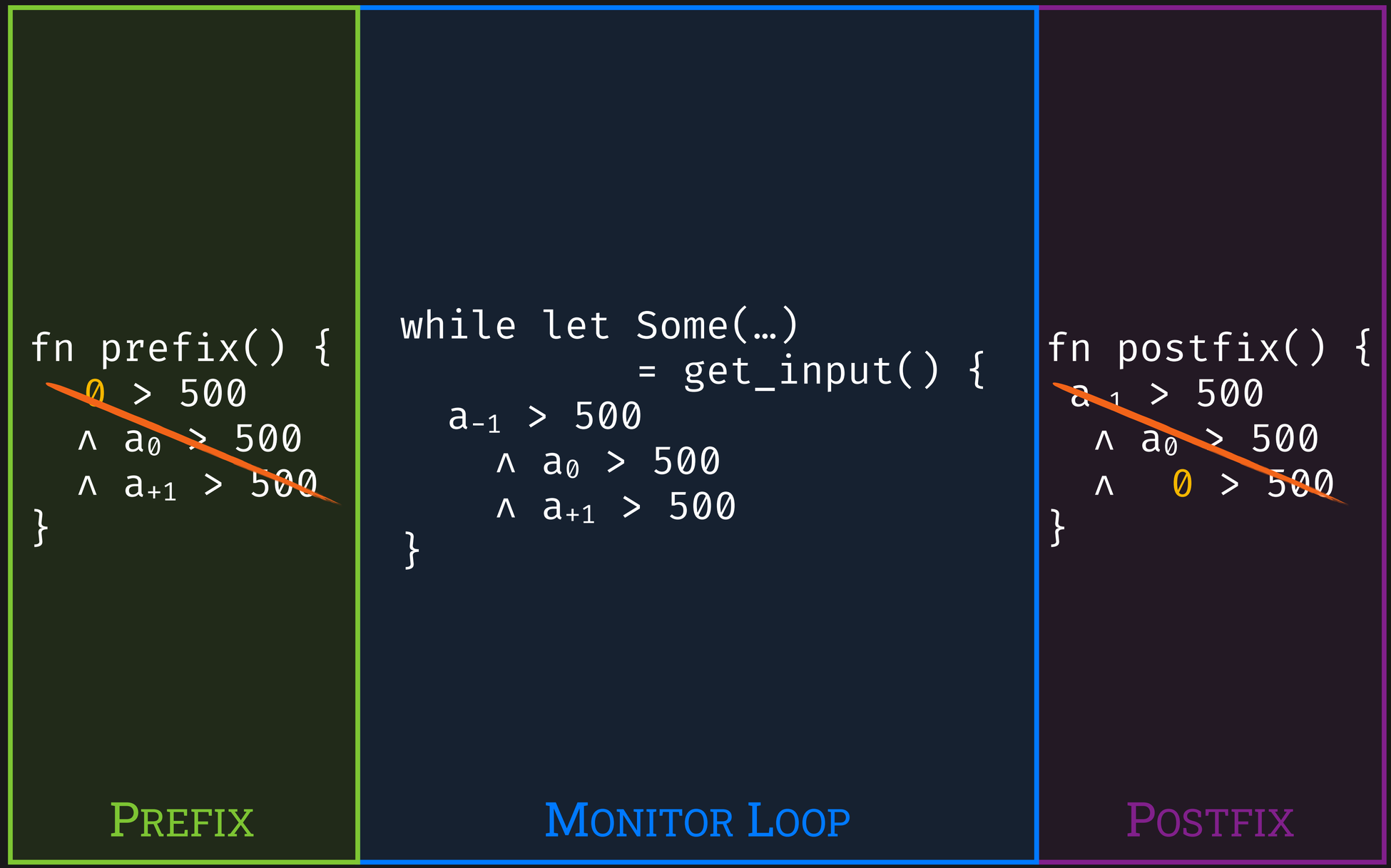
Three Code Fragments



Three Code Fragments



Three Code Fragments

I. Eradicate Most Conditionals
II. Memory Accesses Become Constants

```
fn prefix() {
  0 > 500
    ∧ a0 > 500
    ∧ a+1 > 500
}
```

Prefix

```
while let Some(…)
            = get_input() {
    a-1 > 500
      ∧ a0 > 500
      ∧ a+1 > 500
}
```

Monitor Loop

```
fn postfix() {
  a-1 > 500
    ∧ a0 > 500
    ∧  0 > 500
}
```

Postfix

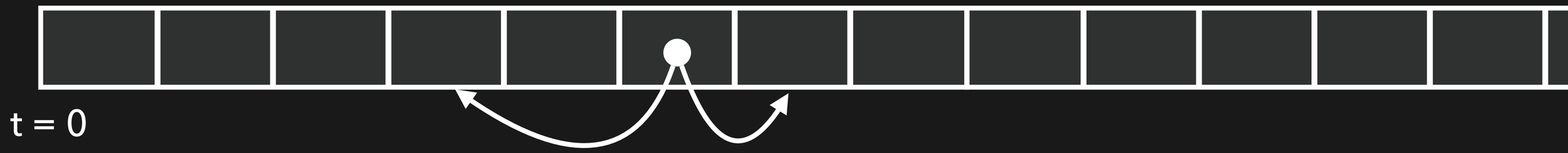
Performance Benefits

Interpretation [CAV'19]	438ns	1.535µs
Compilation	6ns (1.4%)	63ns (4%)

Verification

stream ≜ infinite sequence of values

Lola



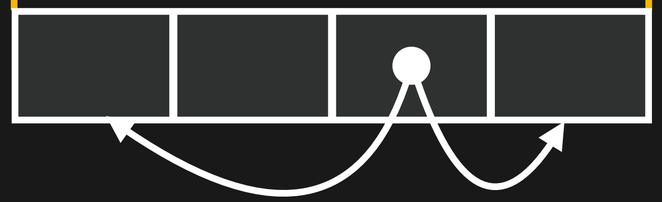
Rust

Verification

stream ≙ infinite sequence of values

Lola

Rust



memory ≙ finite excerpt of stream

Verification

stream ≜ infinite sequence of values

Lola

t = 0

Viper

t = 0

Ghost Memory

Rust

memory ≜ finite excerpt of stream

Ghost Memory in Action

```
#[invariant="forall i: usize ::
    (0 ⩽ i && i < μ(a))
        ⟹ mem.get_a(i) == gm.get_a(iter - i)
"]

#[invariant="new_tooHigh == gm.get_a(iter - 2) > 500 ∧ …"]

while let Some(input) = get_input() {

    mem.add_input(&input);

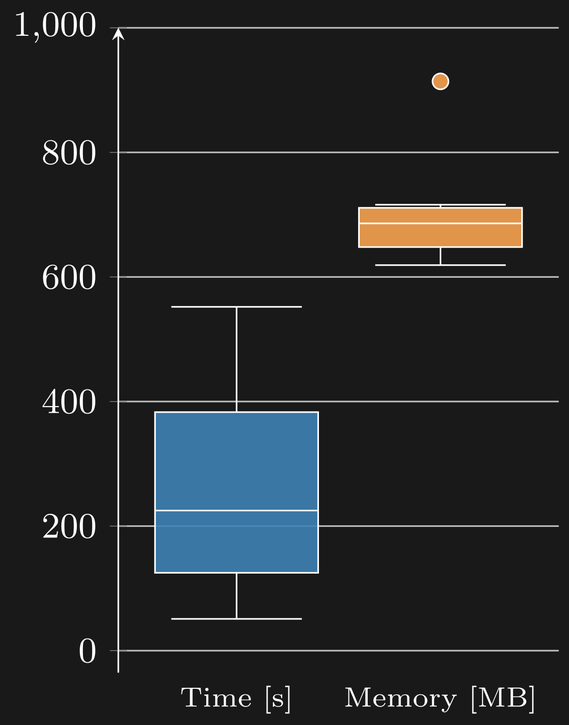
    [[ EVALUATION LOGIC ]]

    mem.store(new_tooHigh);
    gm.store(new_tooHigh);

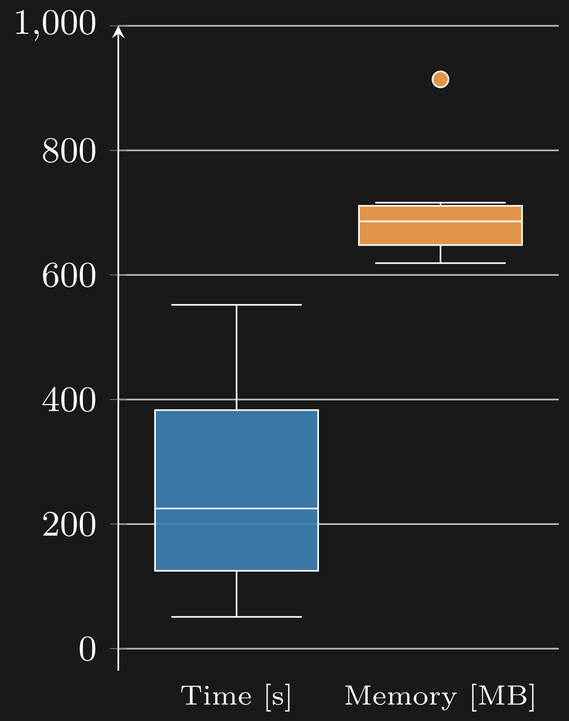
    if trigger_1 { emit( trigger_1_msg) }
}
```

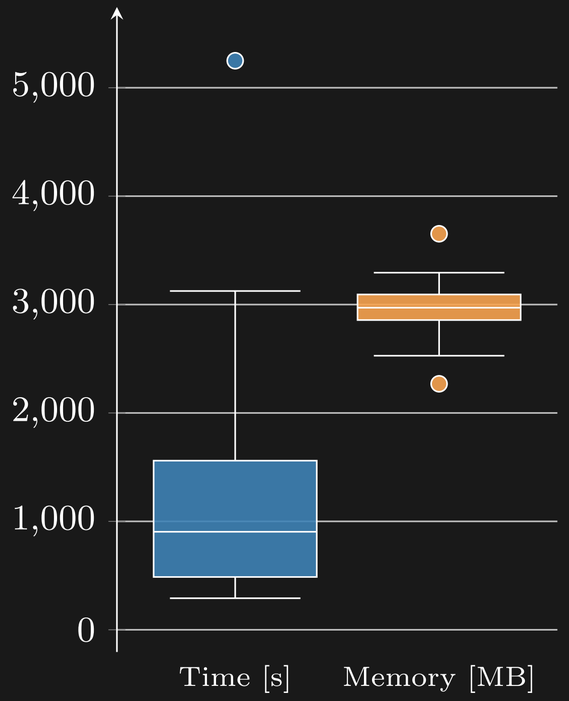
Experiments

Experiments



Experiments

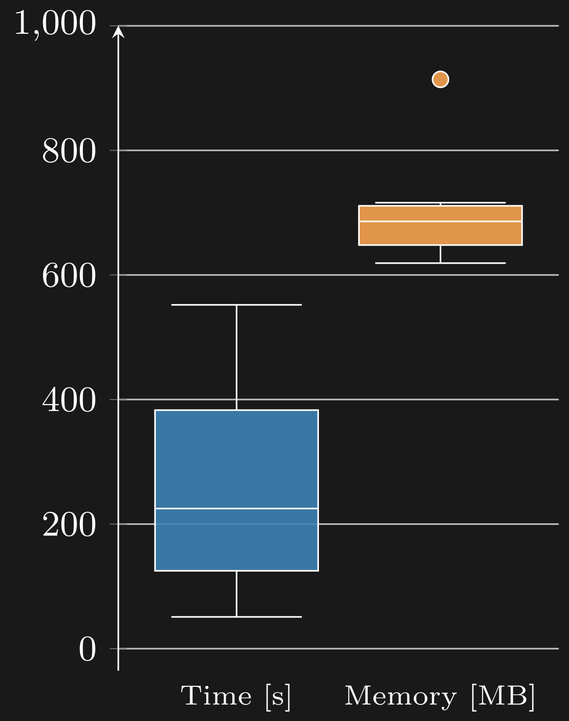


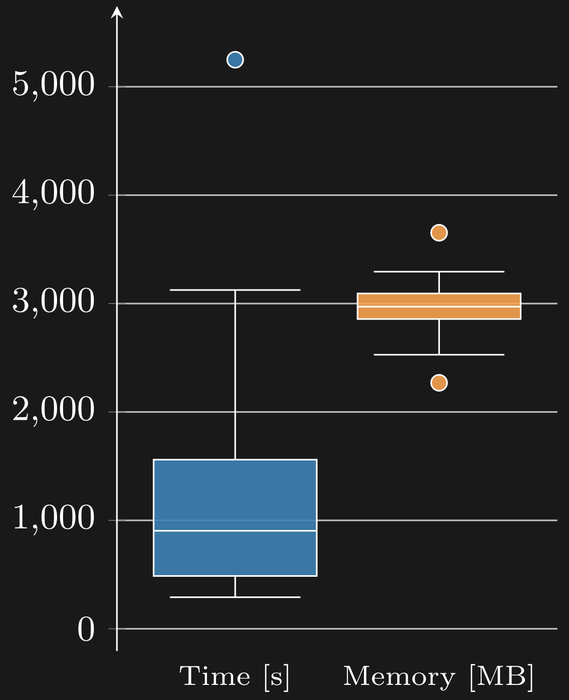


Experiments

altitude

flight phase





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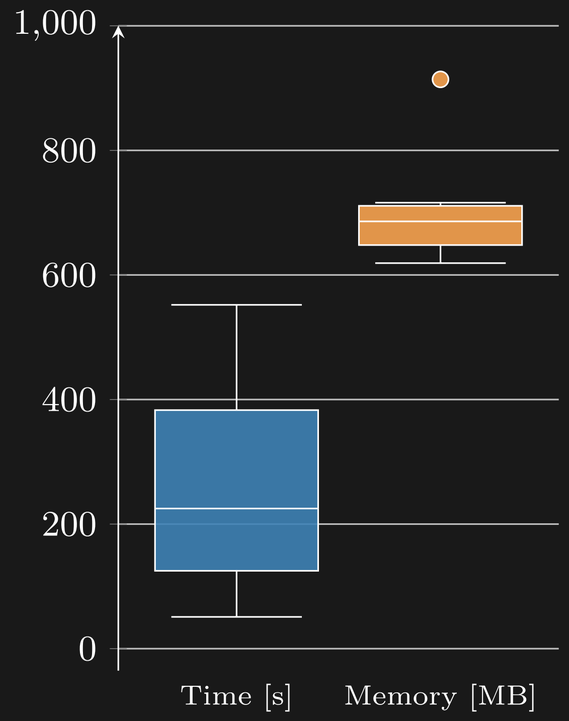

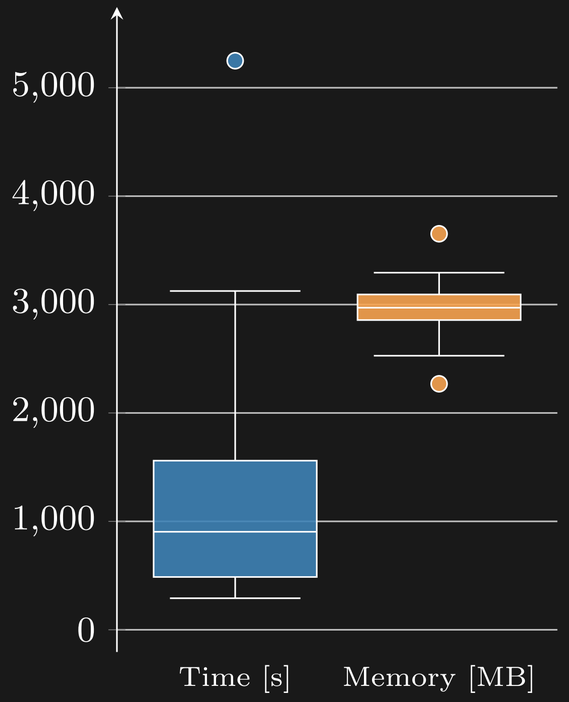

Detected implicit assumption on input stream!

Experiments

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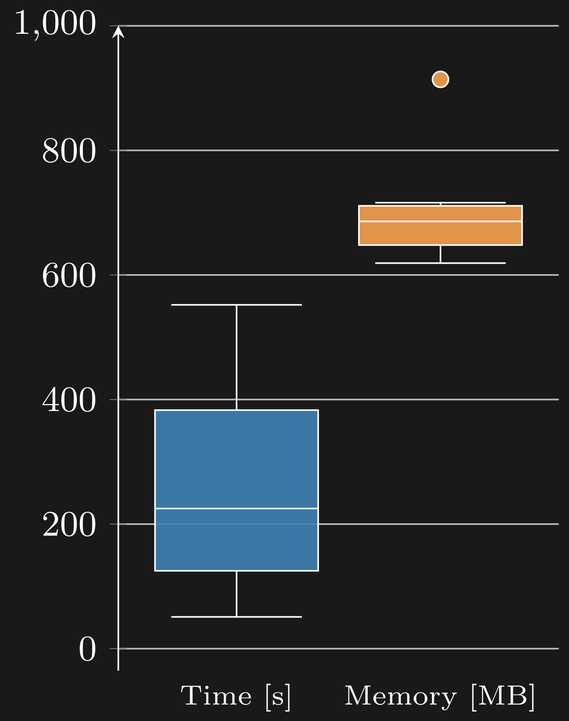

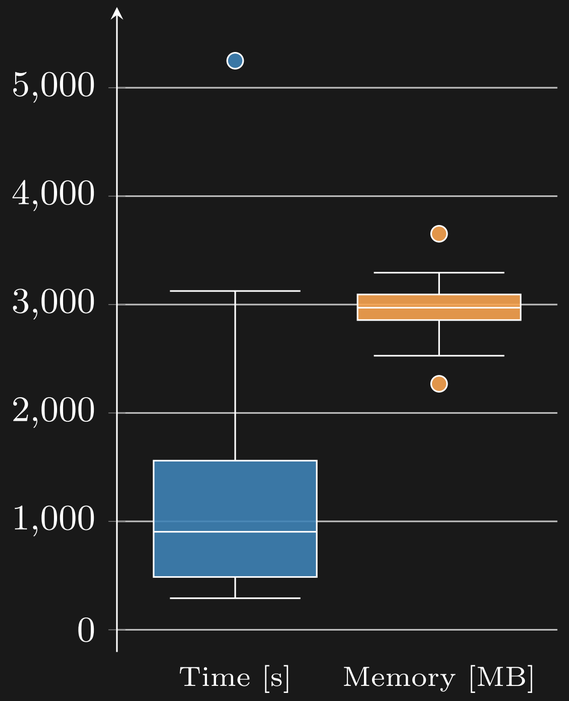

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On corrected spec:

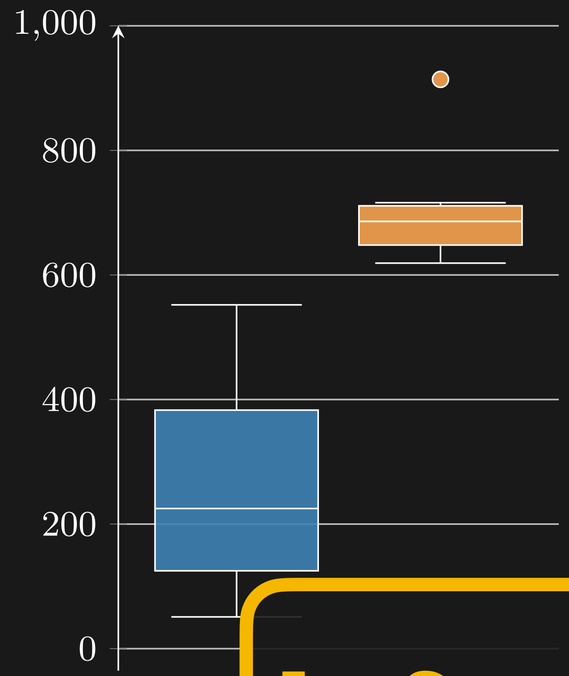
6 – 16min
1.38 – 1.66GB

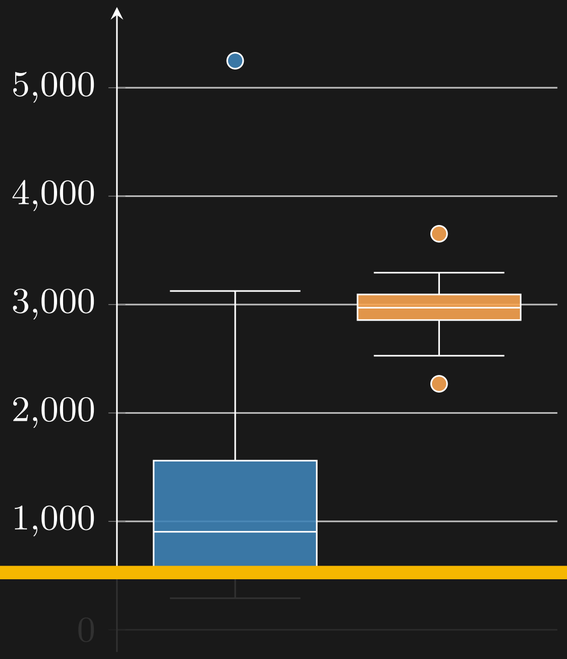
2 T/O (10%)
4 fails (20%)

Experiments

altitude

flight phase





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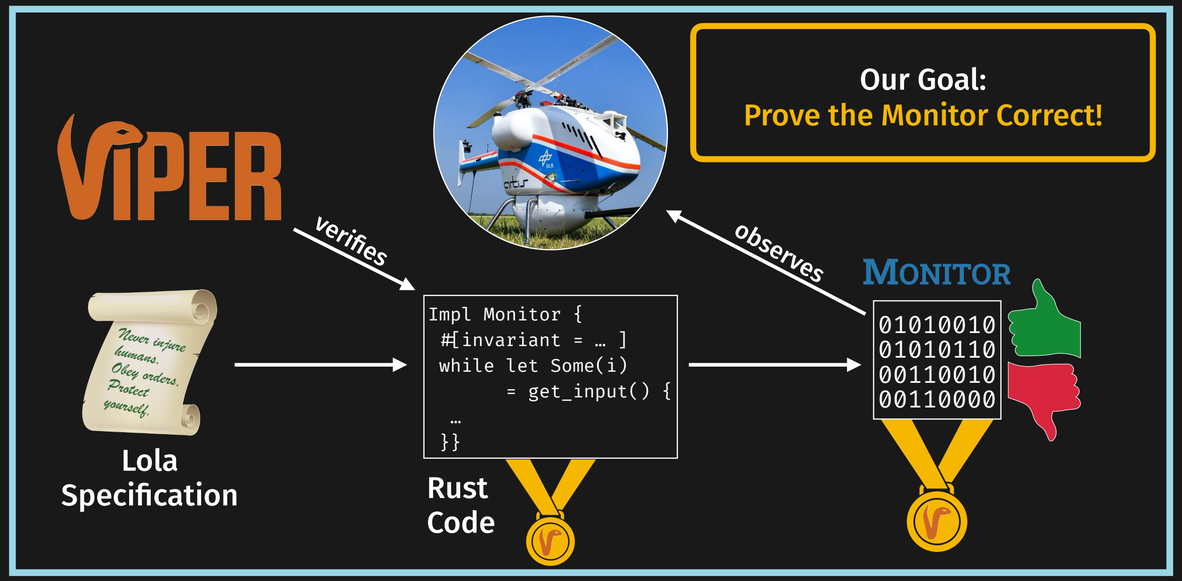
I. Successfully detected specification error
II. Verified monitors for complex specifications

Conclusion



More information:

Compiled Code:

- Github → Lola2RustArtifact

In Paper:

- Specification Analysis
- Concurrent Implementation

Bottom Line:

- Quis Custodiet Ipsos Custodes? Viper does!
- Successful verification
- Highly performant Code