

A Monitoring Tool for Linear-Time μ -HML

L. Aceto *et al.* · Monday, September 12th 2022
CS, Reykjavík University and CS, University of Malta

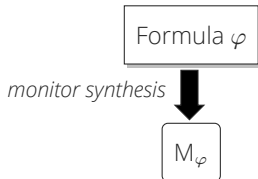
Overview: Runtime verification (RV)

“RV = property as formula φ + current program trace”

Formula φ

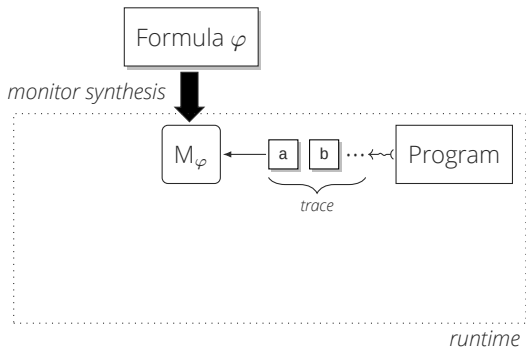
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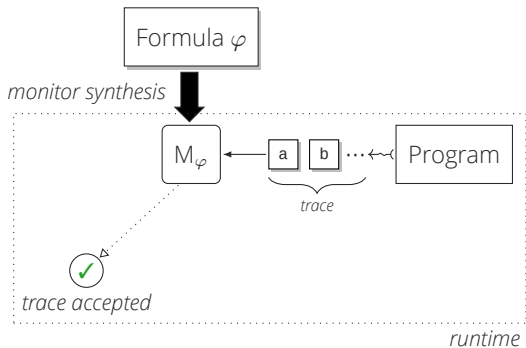
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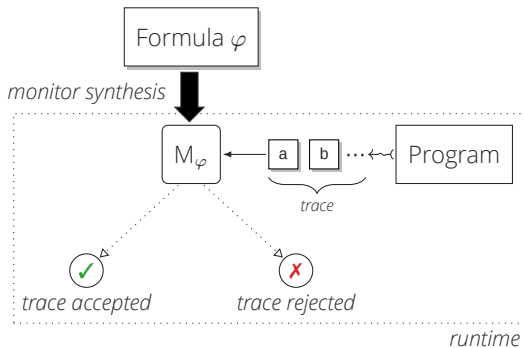
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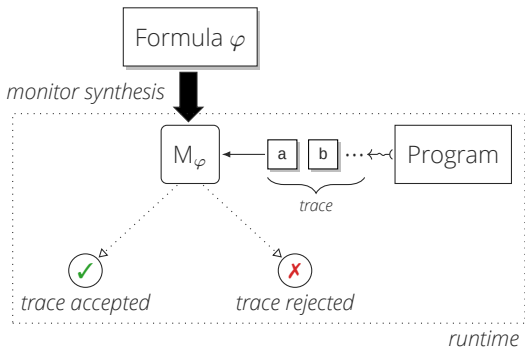
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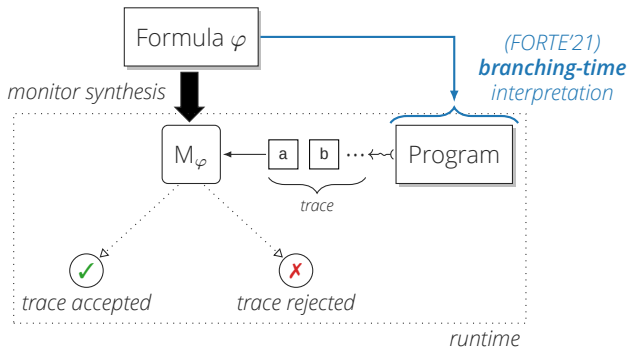
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Our monitor verdicts **cannot be changed** once given

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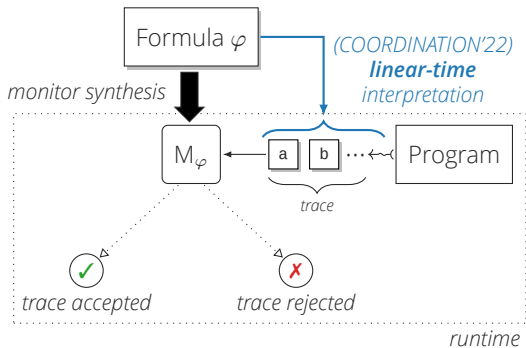
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Our monitor verdicts **cannot be changed** once given

The aspects of modular RV

Monitorability of the logic

Establishing the set of properties that can be runtime checked

Correctness of monitors

Ensuring that the monitor represents the specified property φ

φ

M_φ

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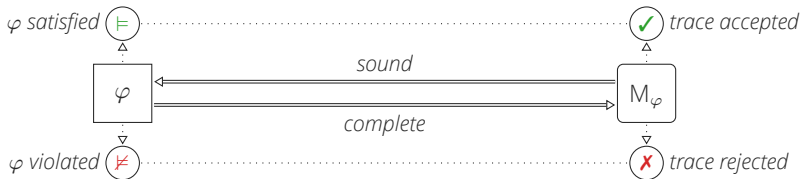
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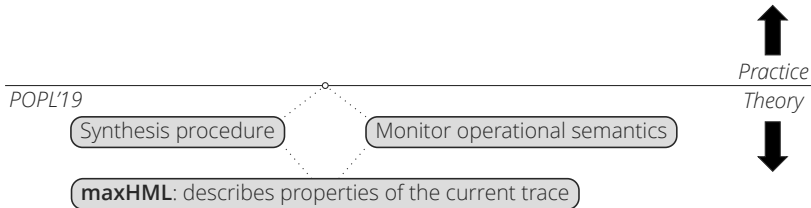
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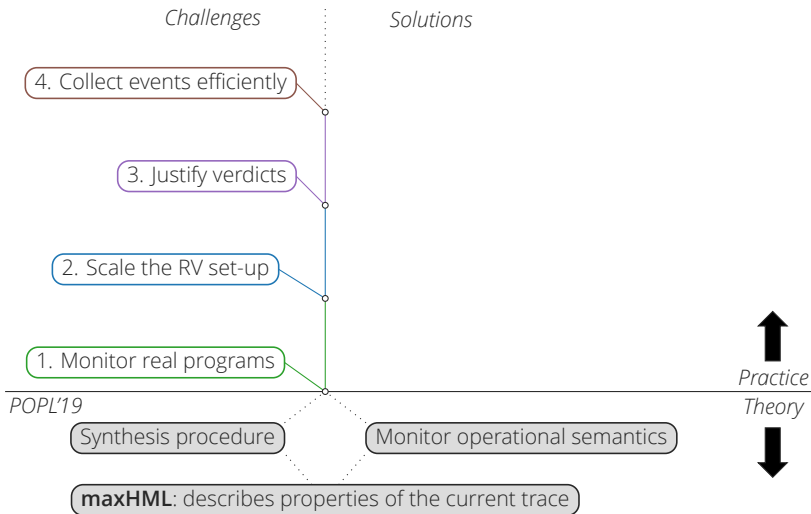
Ensuring that the monitor represents the specified property φ



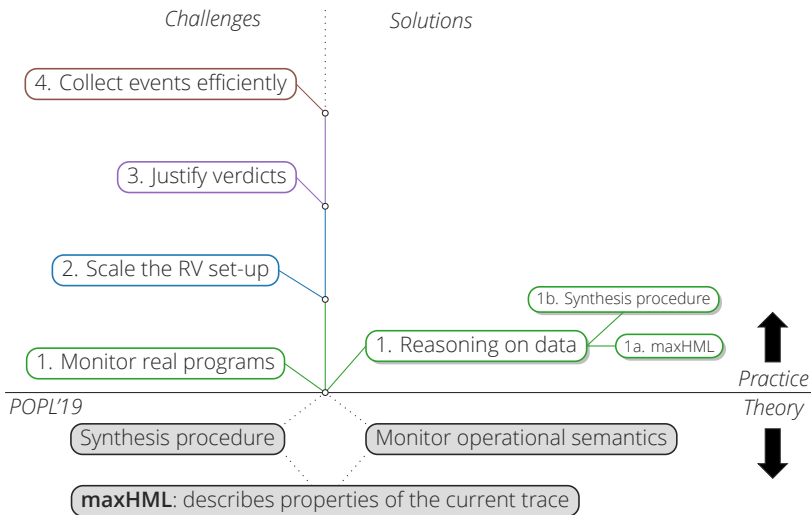
Making the theory come alive



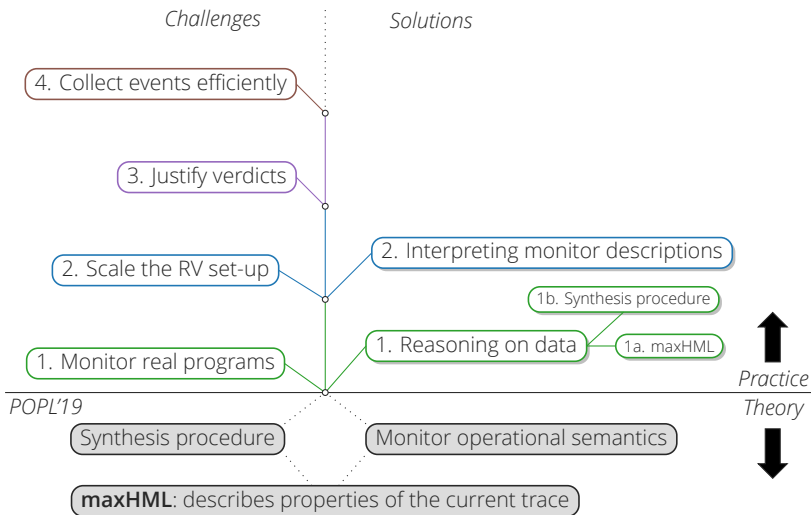
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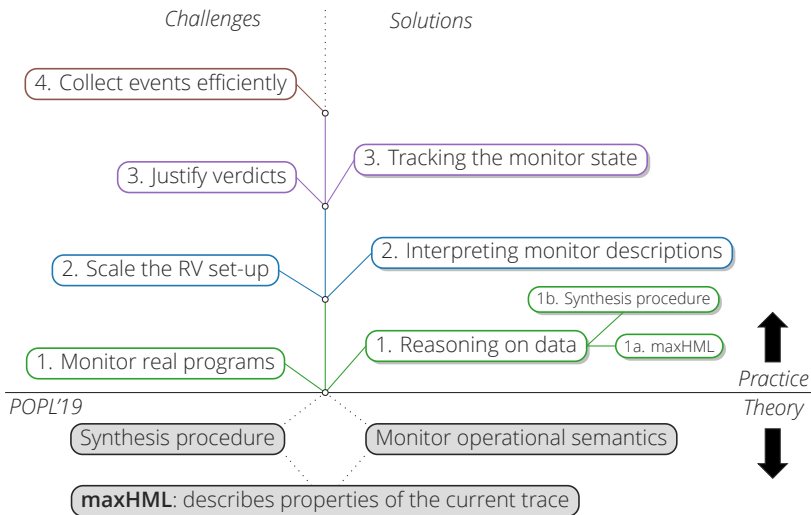
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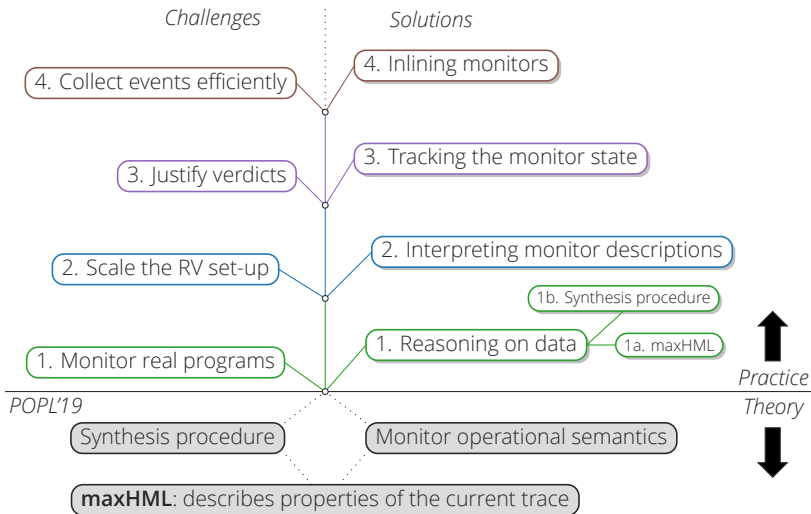
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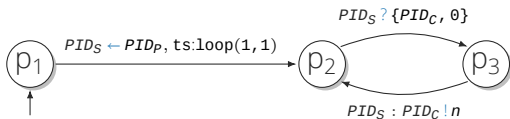
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Making the theory come alive



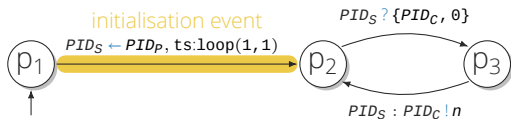
Token Server: An example in Erlang



Erlang token server (ts.erl)

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1 start(Tok) -> spawn(ts, loop, [Tok, Tok]).
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3 loop(OwnTok, NextTok) ->
4     receive
5         {Clt, \emptyset} ->
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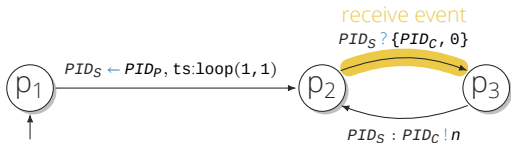
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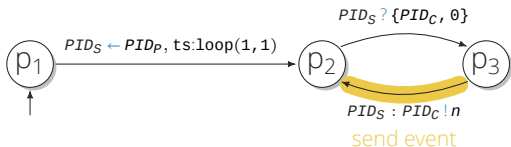
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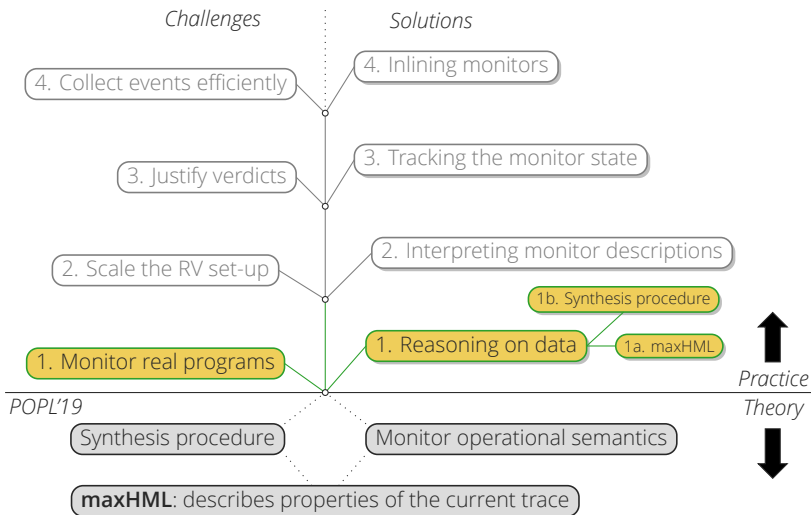
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Making the theory come alive



1. Reasoning on data

Formulae $[\{P \text{ when } C\}] \varphi$ in the logic use **symbolic actions**

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Formulae $[\{P \text{ when } C\}] \varphi$ in the logic use **symbolic actions**

$[\{P \text{ when } C\}] \varphi$

pattern P **matches** the shape of a trace event:

- \leftarrow initialisation event pattern
- $!$ send event pattern
- $?$ receive event pattern

1. Reasoning on data

Formulae $[\{P \text{ when } C\}] \varphi$ in the logic use **symbolic actions**

$[\{P \text{ when } C\}] \varphi$



C is a **decidable** Boolean constraint expression:

- $Var1, Var2, etc.$ data variables
- $1, \{1, b\}, etc.$ data values
- $==, /=, >, etc.$ Boolean and relational operators

1. Reasoning on data

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binds the free variables



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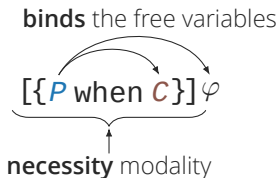
$\{P \text{ when } C\}$ defines a set of concrete of program events

An event is in this set when:

1. P matches the event, instantiating the variables in C , **and**
2. C is satisfied

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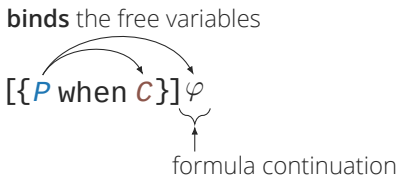
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$[\{P \text{ when } C\}] \text{ff}$

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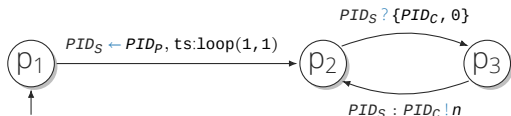
event does not match P or if it does, C is not satisfied

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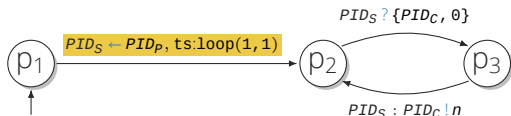
1a. $\max\text{HML}$: an example trace property



The server private token is not leaked in client replies

- 1
- 2
- 3
- 4
- 5
- 6

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```
1 [{"_ ← _, ts:loop(OwnTok, _)}]
```

2

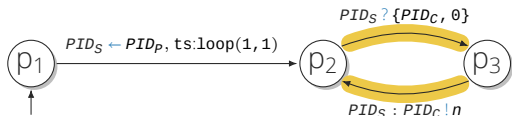
3

4

5

6

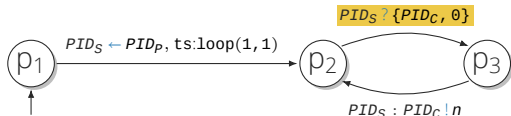
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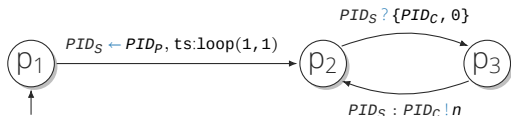
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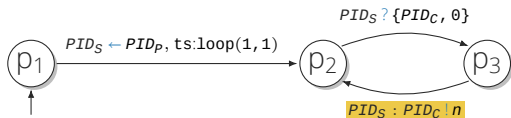
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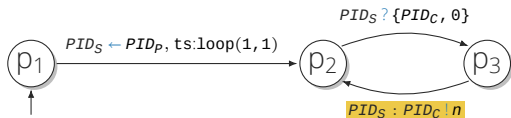
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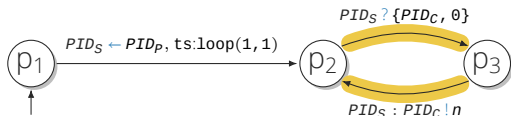

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1b. *Synthesis procedure*

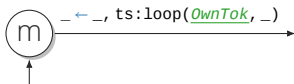
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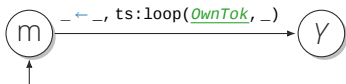
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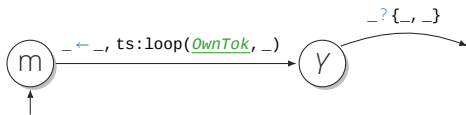
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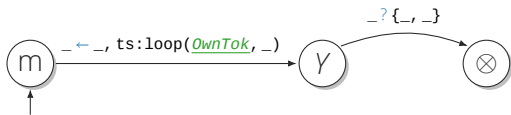
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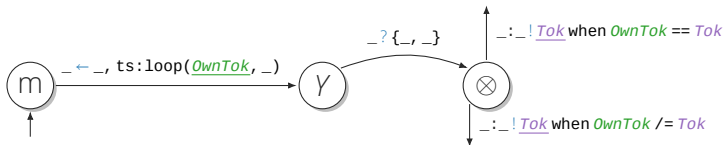
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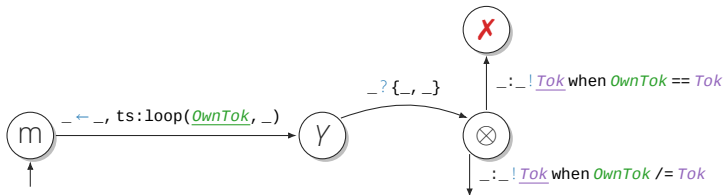
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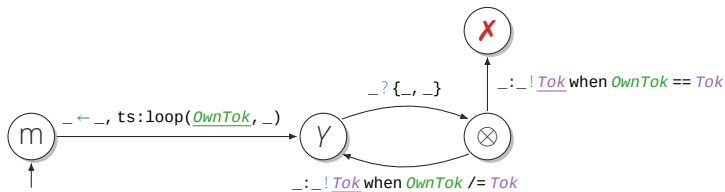
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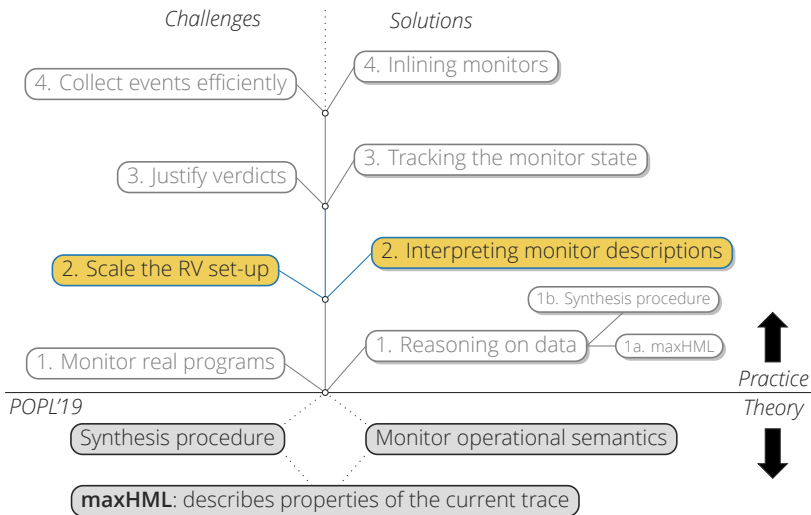
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Making the theory come alive



2. Interpreting monitor descriptions

Our algorithm determinises monitors **on-the-fly**

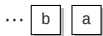
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Scalability: we **emulate** disjunctive and conjunctive parallelism

monitor description



+



program trace



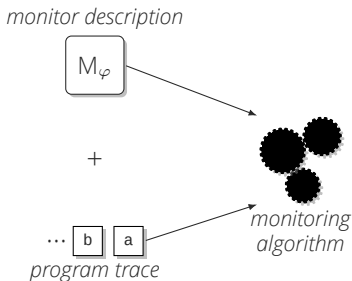
*monitoring
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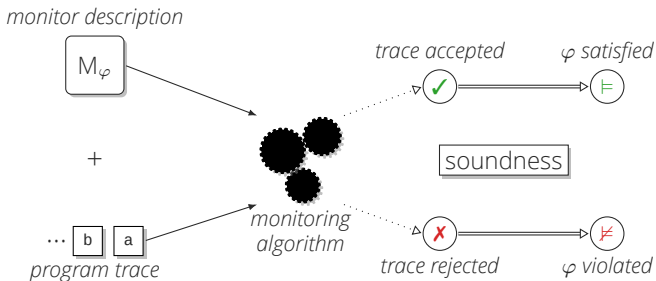


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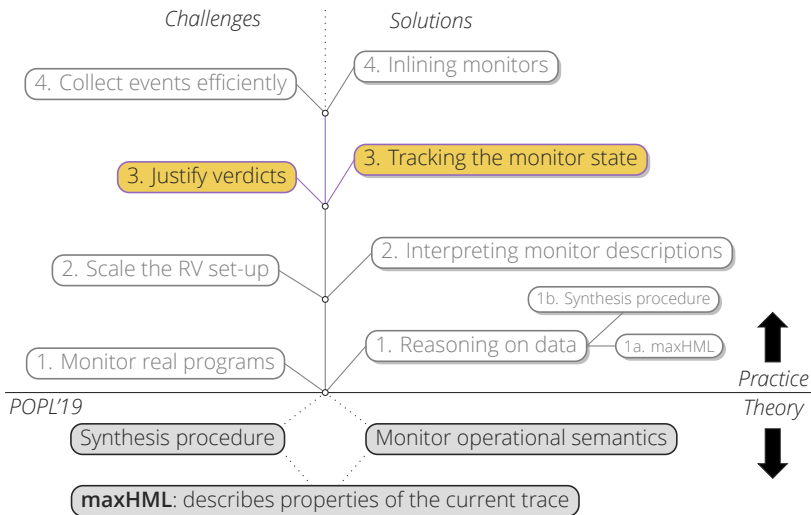
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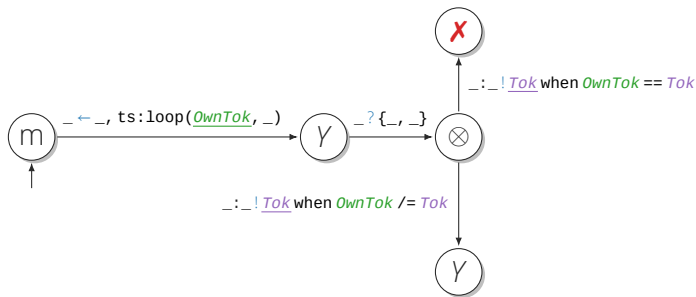


Making the theory come alive



3. Tracking the monitor state

“ Explainability = tracking monitor state + applied rules ”

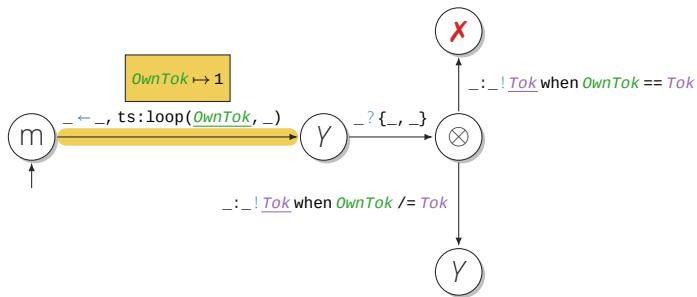


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token server trace (simplified)

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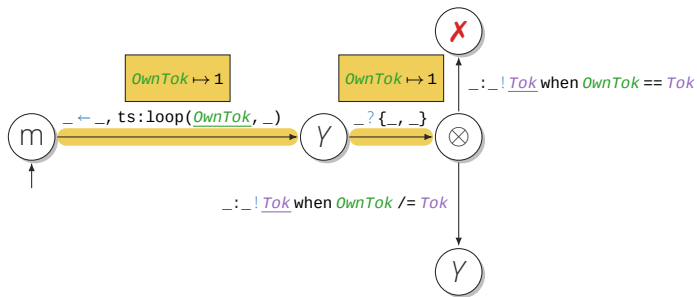


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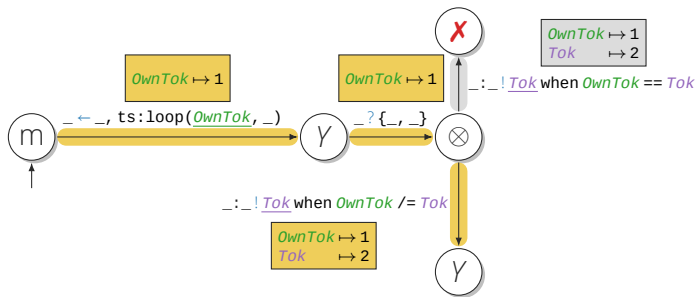
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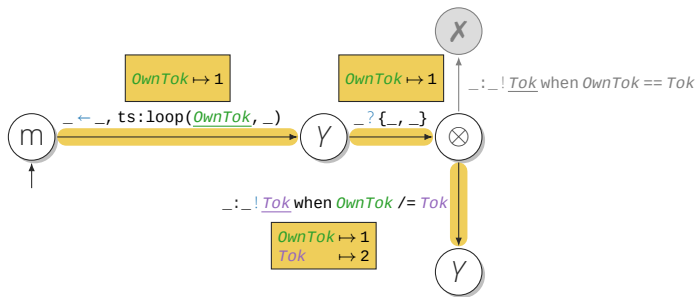
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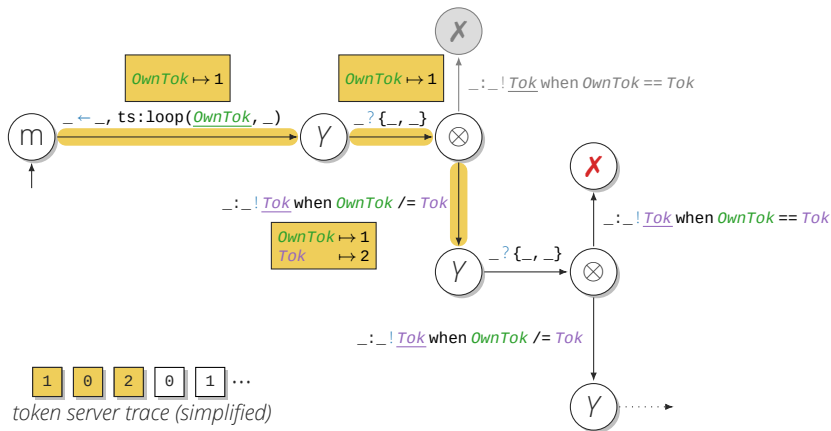
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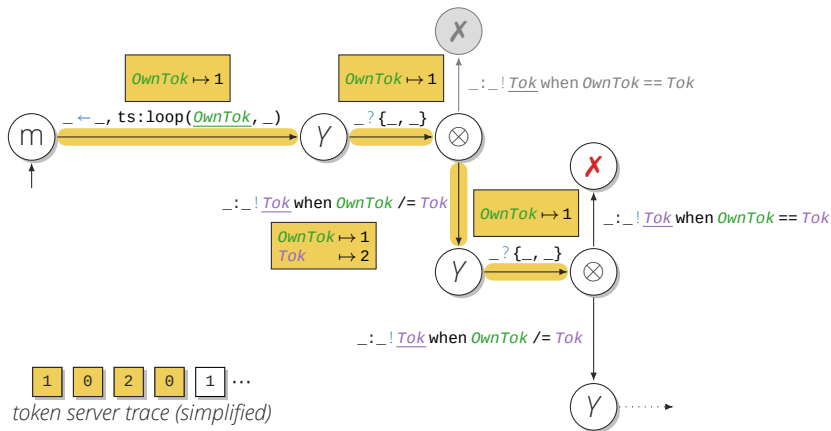
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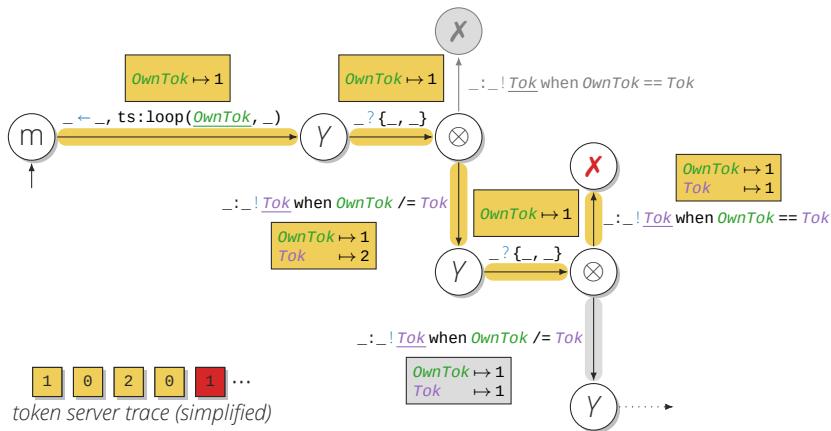
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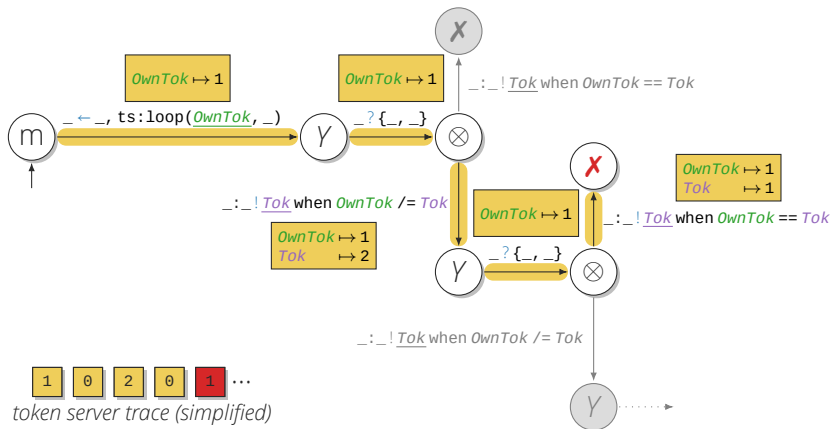
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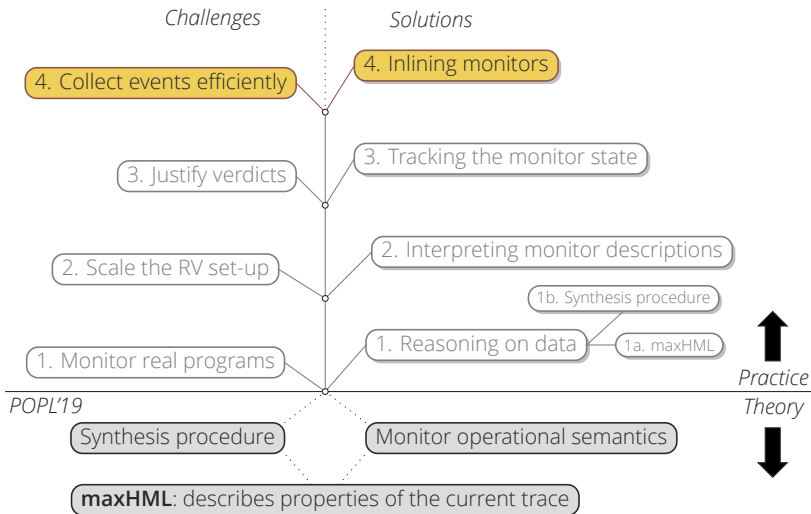


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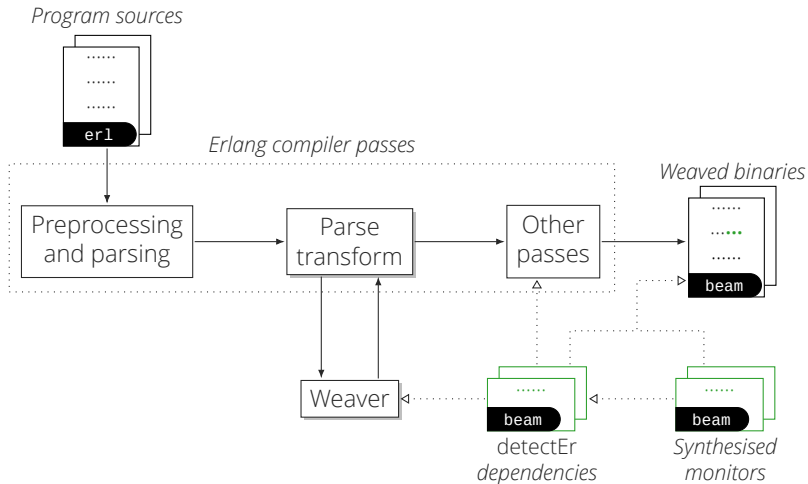
“ Explainability = tracking monitor state + applied rules ”



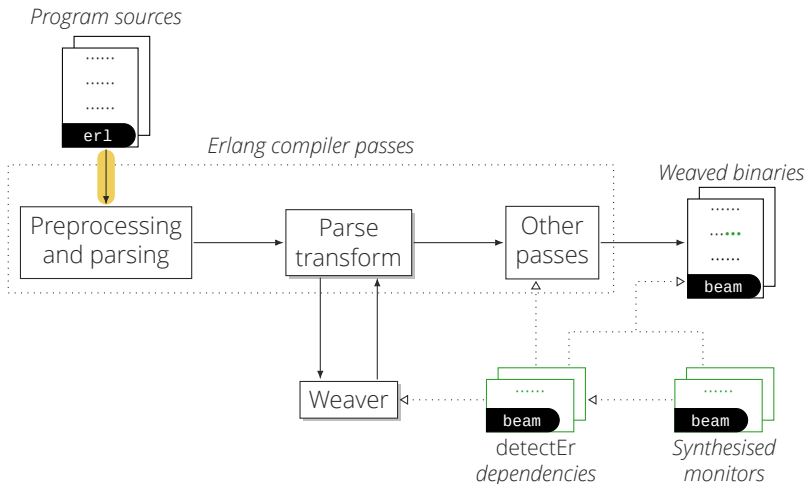
Making the theory come alive



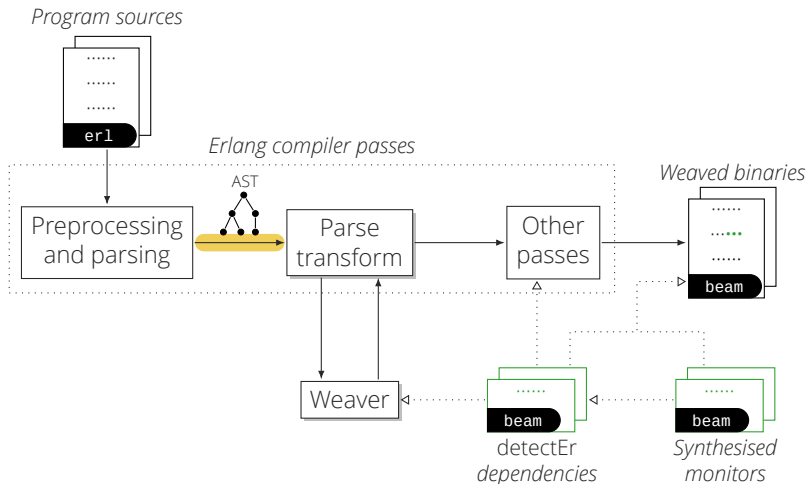
4. Inlining monitors



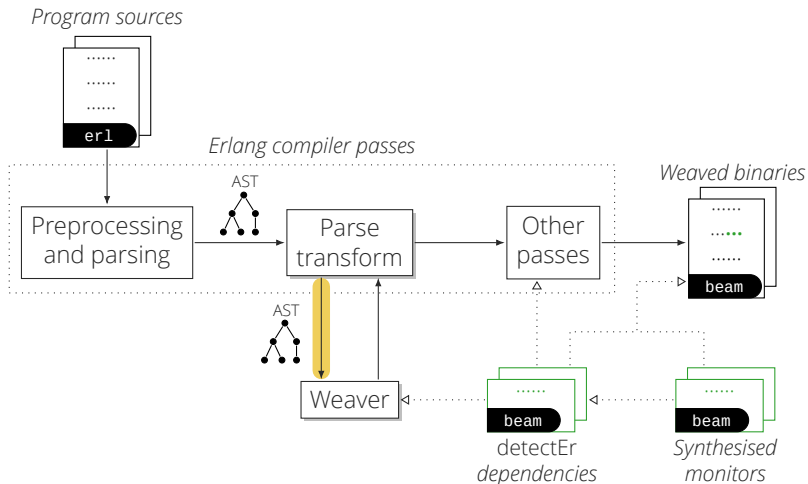
4. Inlining monitors



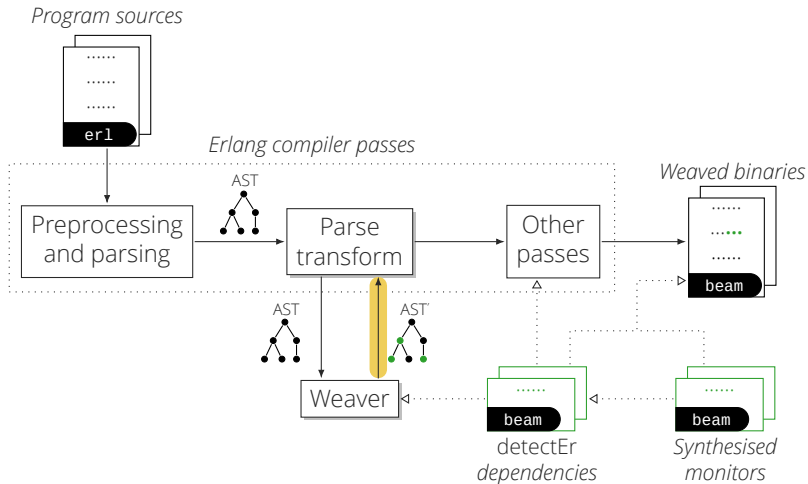
4. Inlining monitors



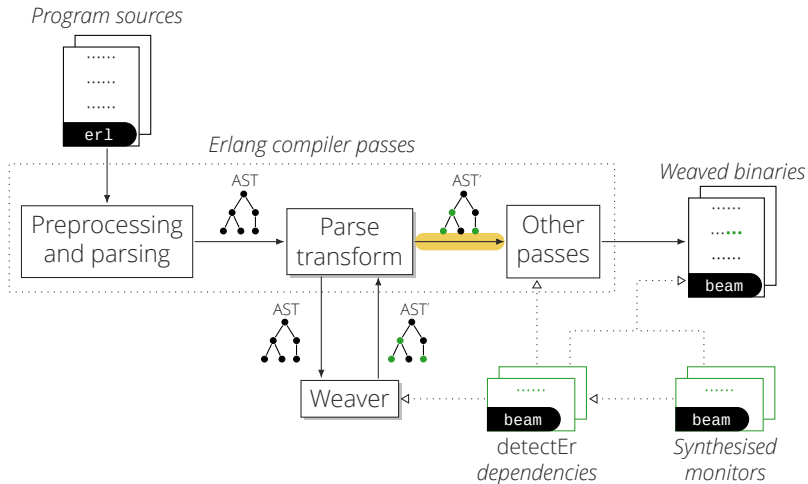
4. Inlining monitors



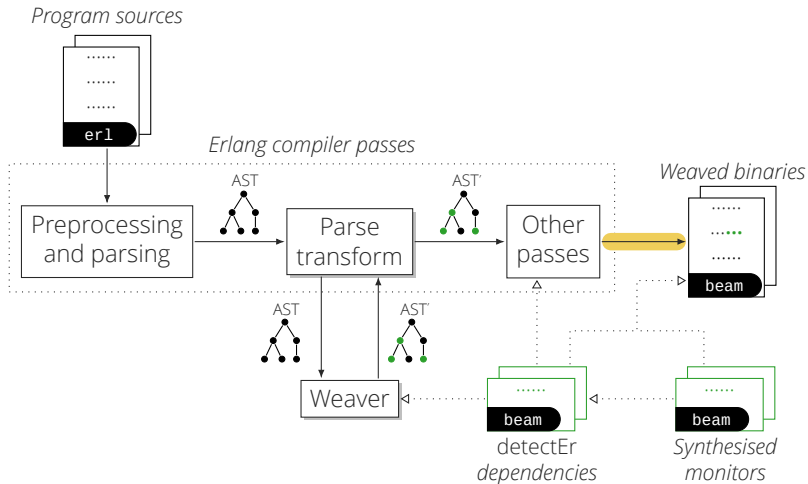
4. Inlining monitors



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4. Inlining monitors



Contributions and summary

An extended monitorable logic and monitors that handle **data**

An algorithm that follows the monitor **operational semantics**

Verdict **explainability** based on monitor reductions

One tool to monitor linear- and branching-time specifications

Future directions and improvements

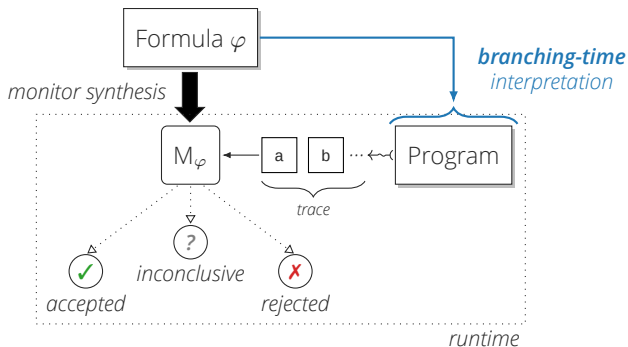
- Bound on the number of states managed by the algorithm
- Leverage the outline instrumentation provided by detectEr
- Empirical study of runtime overhead

<https://duncanatt.github.io/detector>

Thank you

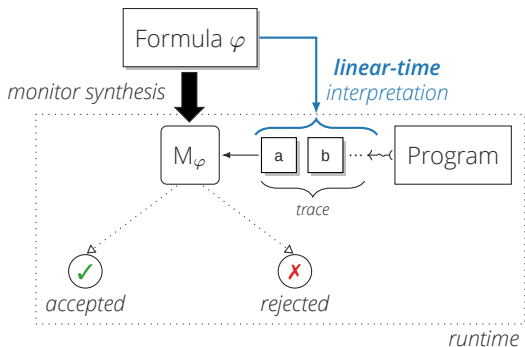
The monitoring set-up

Logic formulae describe properties of the **program**



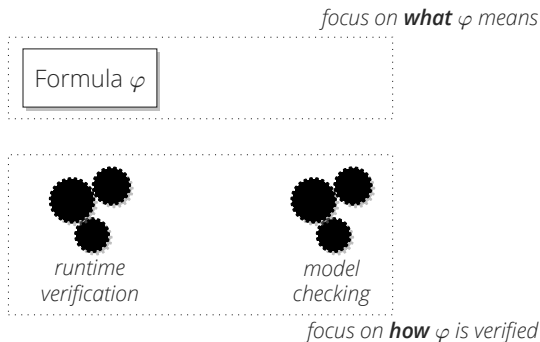
The monitoring set-up

Logic formulae describe properties of **traces** of the program



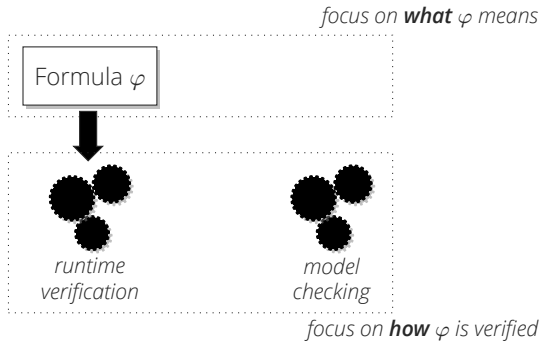
A modular approach to verification

“ The meaning of φ is agnostic of the verification method ”



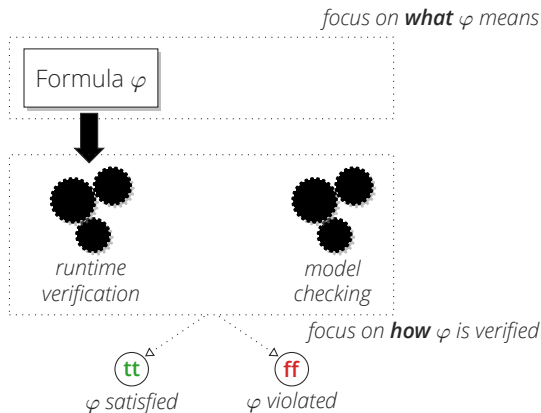
A modular approach to verification

“ *The meaning of φ is agnostic of the verification method* ”



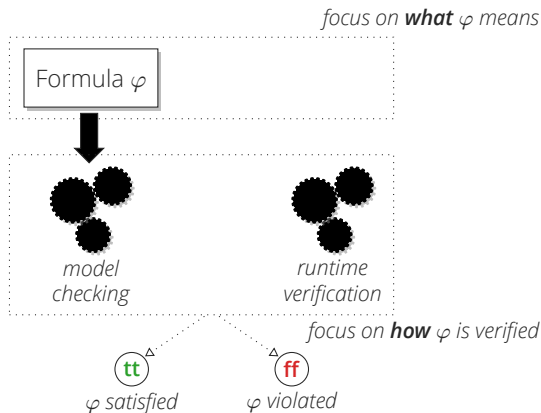
A modular approach to verification

“The meaning of φ is agnostic of the verification method”



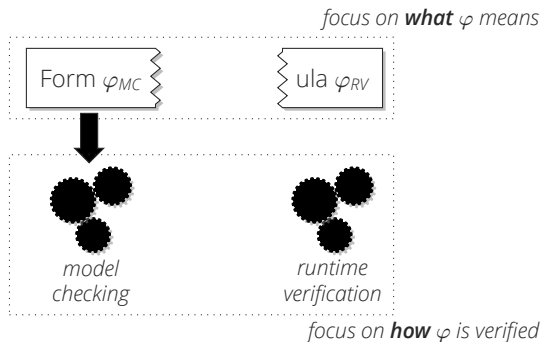
A modular approach to verification

“The meaning of φ is agnostic of the verification method”



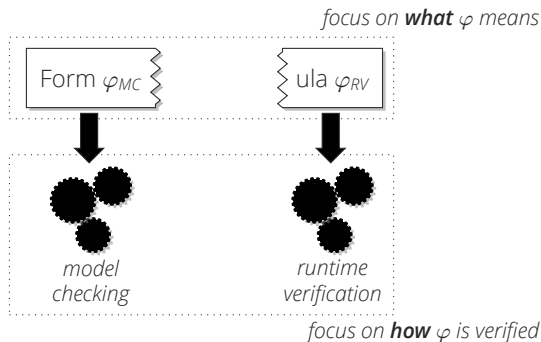
A modular approach to verification

“ The meaning of φ is agnostic of the verification method ”



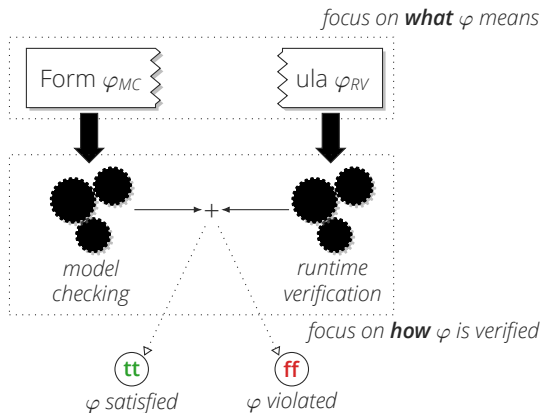
A modular approach to verification

“ The meaning of φ is agnostic of the verification method ”



A modular approach to verification

“The meaning of φ is agnostic of the verification method”



Some encodings

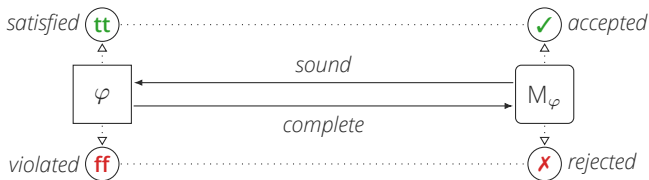
$$\text{Inv}(\varphi) \triangleq X = \varphi \wedge [\text{Act}]X$$

$$\text{Pos}(\varphi) \triangleq X = \varphi \vee \langle \text{Act} \rangle X$$

$m \triangleq \alpha.\text{yes} + \text{no}$ is unsound because for $p \triangleq \alpha.0$ we have $\text{acc}(p, m)$ and $\text{rej}(p, m)$

How does modularity impact RV?

“Monitorability: what set of properties can be runtime checked?”



Non-negotiable requirements for monitors

- Correct w.r.t. formulae in the monitorable logic fragment
- Operate properly as software entities
- Induce low runtime overhead