Towards A ~~Hybrid~~ (Combined?) Approach to Software Verification

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Outline

Introduction: model checking vs. runtime verification (motivations)

Runtime verification for μHML (= μ-calculus)

Extending runtime verification applicability: ~~hybrid~~ (combined?) approach

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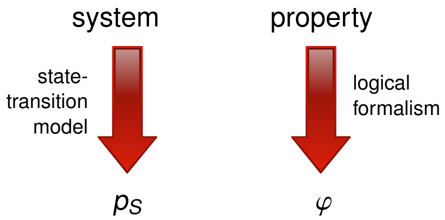
Extending runtime verification applicability: ~~hybrid~~ (combined?) approach

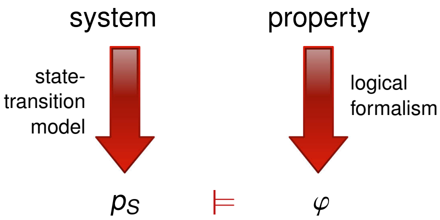
Model checking

system property

Model checking



Model checking



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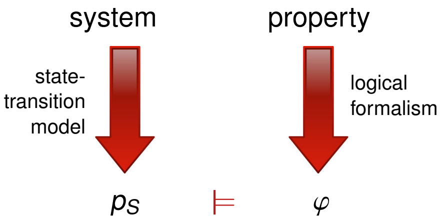

unfeasible for most real-world applications
(state explosion problem)

Runtime verification

monitoring a single partial execution and try to give a verdict

eventually p

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$\neg p$

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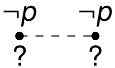

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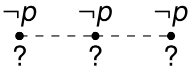

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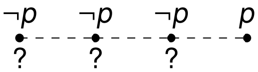

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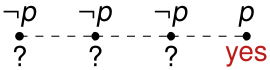

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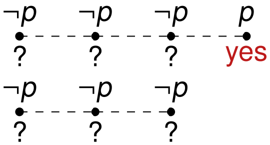

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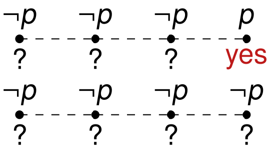

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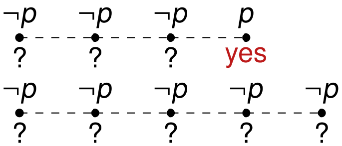

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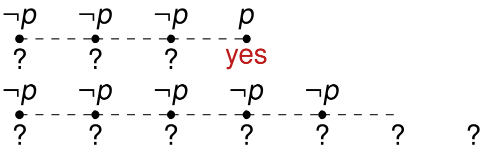

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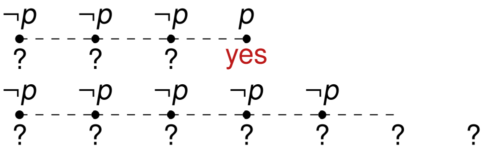

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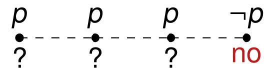
always p



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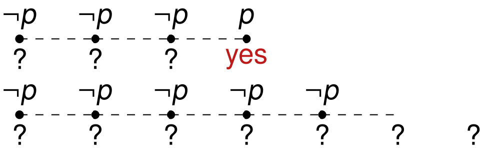

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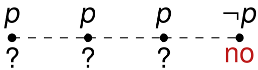

[(p or q) until r]
or (always p)

Runtime verification

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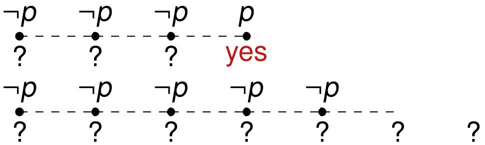

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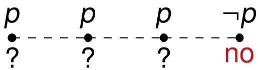

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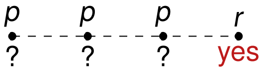

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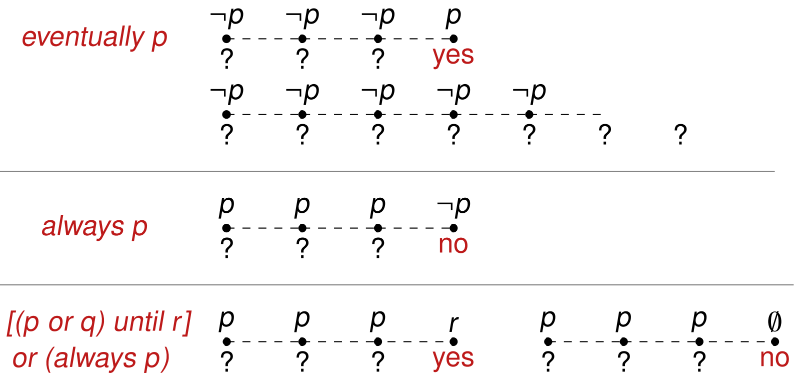

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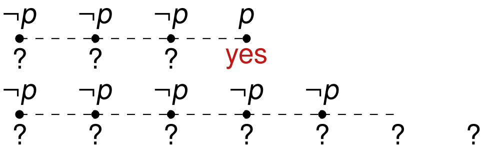

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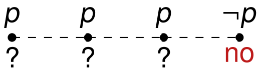

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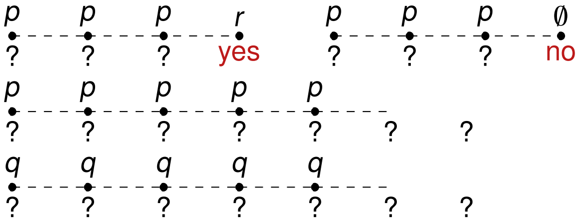

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Monitorability

Definition (monitorability)

φ is monitorable := φ is suitable to be runtime verified

:= either

there exists

a finite witness for satisfaction

whenever φ is true

or

there exists

a finite witness for violation

whenever φ is false

The branching time logic μHML

$\varphi, \phi \in \mu\text{HML} ::=$

tt	(truth)	$\mid$ ff	(falsehood)
$\mid \varphi \vee \phi$	(disjunction)	$\mid \varphi \wedge \phi$	(conjunction)
$\mid \langle\alpha\rangle\varphi$	(possibility)	$\mid [\alpha]\varphi$	(necessity)
$\mid \min X.\varphi$	(min. fixpoint)	$\mid \max X.\varphi$	(max. fixpoin)
$\mid X$	(rec. variable)		

The maximal monitorable subset

$$\pi, \varpi \in \text{cHML} ::= \text{tt} \quad \mid \text{ff} \quad \mid \pi \vee \varpi \quad \mid \langle\alpha\rangle\pi \quad \mid \min X.\pi \quad \mid X$$

$$\theta, \vartheta \in \text{sHML} ::= \text{tt} \quad \mid \text{ff} \quad \mid \theta \wedge \vartheta \quad \mid [\alpha]\theta \quad \mid \max X.\theta \quad \mid X$$

Francalanza, Aceto, Ingólfsdóttir, **On verifying Hennessy-Milner logic with recursion at runtime**. In Runtime Verification, 2015

The branching time logic μHML

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Monitorability: examples

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Examples

$\langle a \rangle$tt

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Examples

$\langle a \rangle \text{tt}$ $\qquad$ $[a]\text{ff}$

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Examples

$\langle a \rangle \text{tt}$ $\qquad$ $[a]\text{ff}$ $\qquad$ $\langle a \rangle \text{tt} \vee \langle b \rangle \text{tt}$

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$\langle a \rangle \text{tt}$ $\qquad$ $[a]\text{ff}$ $\qquad$ $\langle a \rangle \text{tt} \vee \langle b \rangle \text{tt}$ $\qquad$ $\langle a \rangle (\langle b \rangle \text{tt} \vee [c]\text{ff})$

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Examples

$\langle a\rangle\mathsf{tt}$ $\quad$ $[a]\mathsf{ff}$ $\quad$ $\langle a\rangle\mathsf{tt} \vee \langle b\rangle\mathsf{tt}$ $\quad$ ~~$\langle a\rangle(\langle b\rangle\mathsf{tt} \vee [c]\mathsf{ff})$~~

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Where runtime verification can reach so far

$\langle a \rangle(\langle b \rangle \mathrm{tt} \vee [c]\mathrm{ff})$: not monitorable, do model checking

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monitorable:
do runtime verification

not monitorable:
do model checking

An (RV/MC)decomposition

$$\varphi \equiv \varphi_{RV} \overset{\wedge}{\underset{\vee}{}} \varphi_{MC}$$

Universal: $\wedge$, $[\alpha]$, max X

Existential: $\vee$, $\langle\alpha\rangle$, min X

Skip

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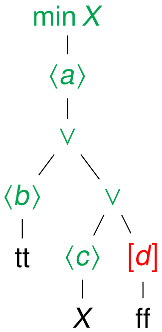
$\min X.\langle a\rangle(\langle b\rangle tt \vee \langle c\rangle X \vee [d]ff)$



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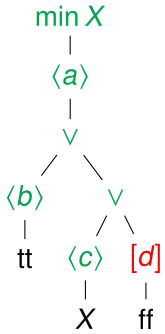
$$\equiv$$

$$\big(\min X.\langle a\rangle(\langle b\rangle \mathrm{tt} \vee \langle c\rangle X)\big) \vee \boxed{\;?\;}$$



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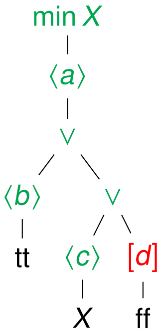

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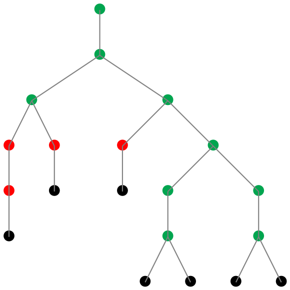
The decomposition procedure



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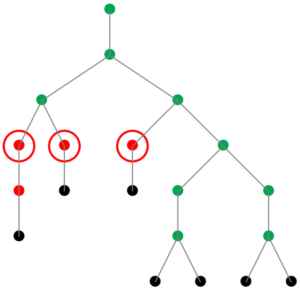

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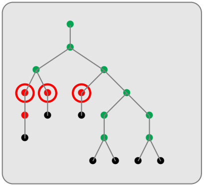
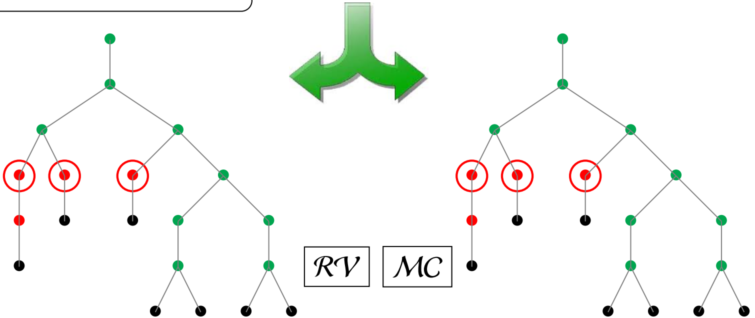


1. Remove subtrees rooted in high univ. nodes
2. Remove new leaves



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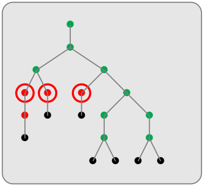

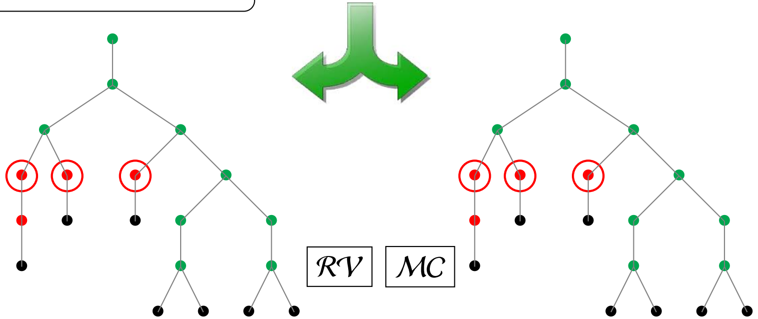

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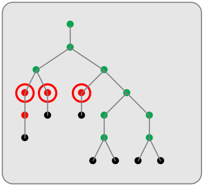

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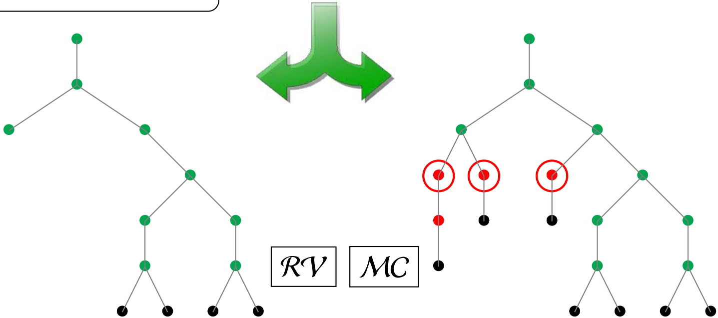

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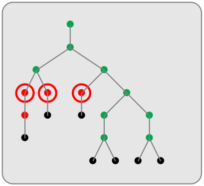

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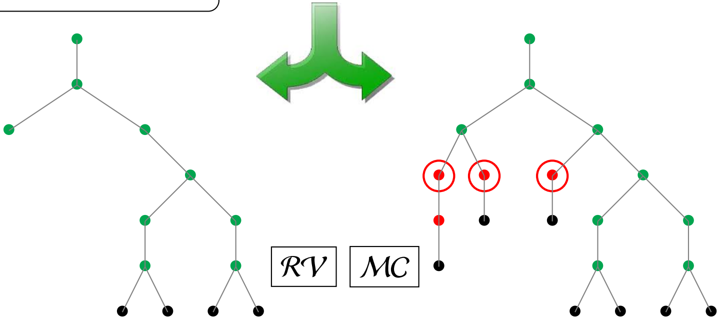

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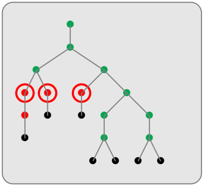

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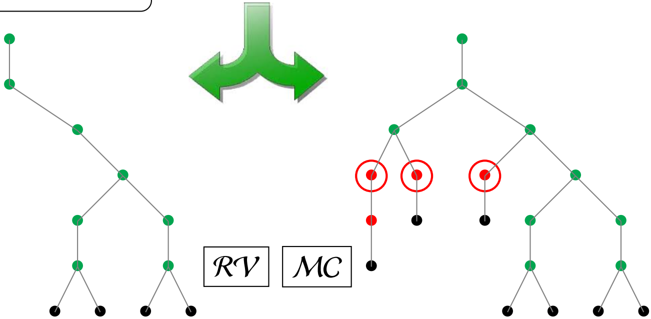

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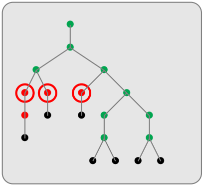

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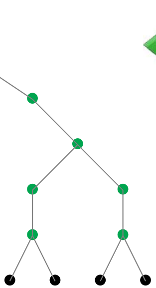
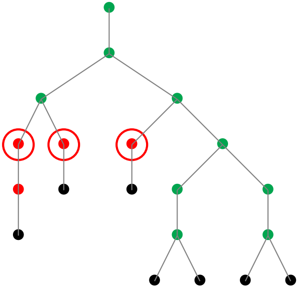
1. Collect subtrees rooted in high univ. nodes
2. Closure under bindings



$\mathcal{RV}$ $\mathcal{MC}$



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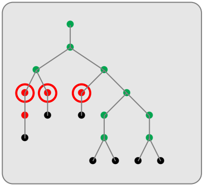

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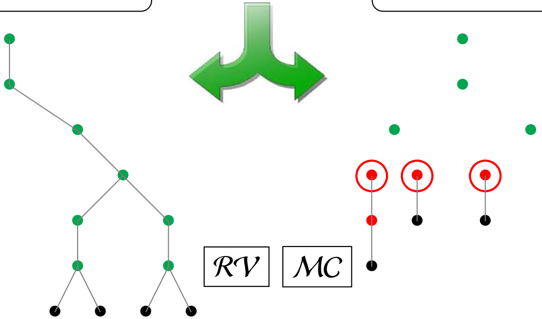

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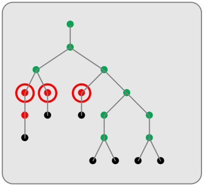

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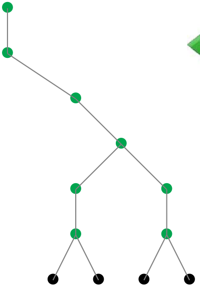

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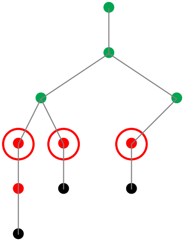
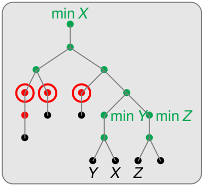
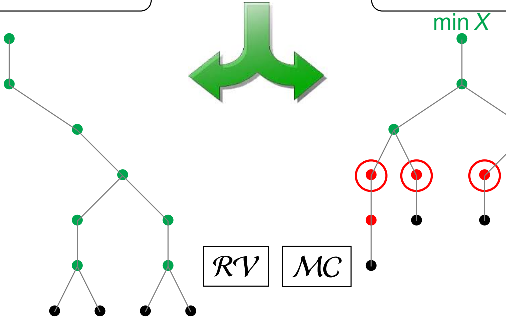


The decomposition procedure



1. Remove subtrees rooted in high univ. nodes
2. Remove new leaves

1. Collect subtrees rooted in high univ. nodes
2. Closure under bindings



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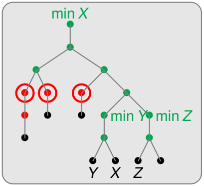

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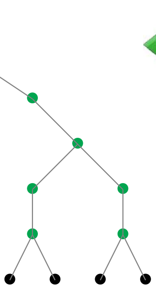

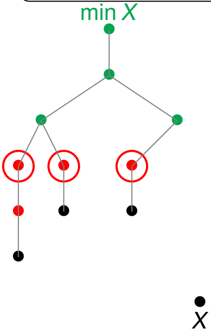

$\mathcal{RV}$ $\mathcal{MC}$

Skip

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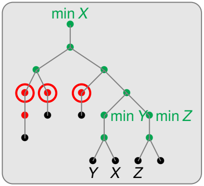

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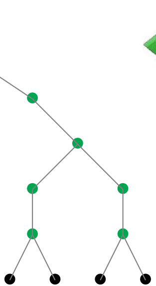

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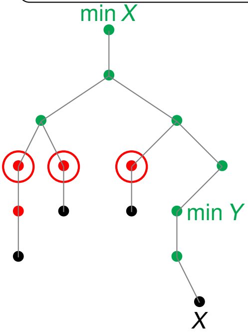

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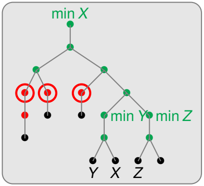

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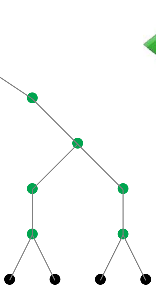

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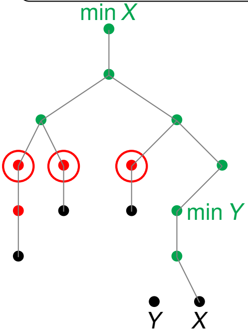

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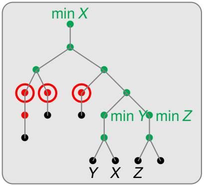

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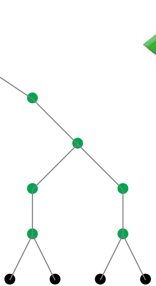

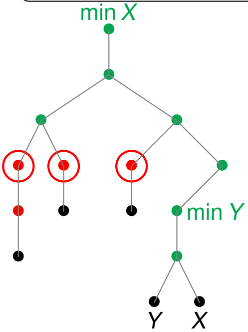

$\mathcal{RV}$ $\mathcal{MC}$

Skip

(RV/MC)-decomposition at work

$$\min X.\langle a\rangle(\langle b\rangle \mathrm{tt} \vee \langle c\rangle X \vee [d]\mathrm{ff})$$
$$\equiv$$
$$\Big(\min X.\langle a\rangle(\langle b\rangle \mathrm{tt} \vee \langle c\rangle X)\Big) \vee \Big(\min X.\langle a\rangle([d]\mathrm{ff} \vee \langle c\rangle X)\Big)$$

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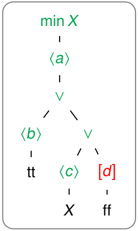

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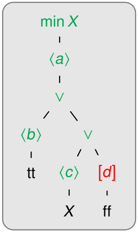

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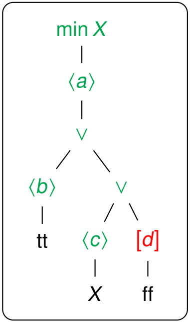

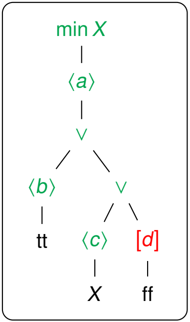

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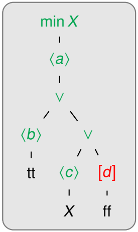

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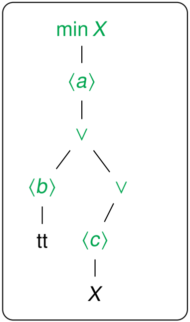

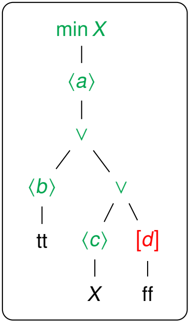

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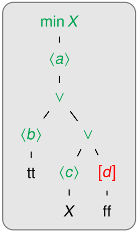

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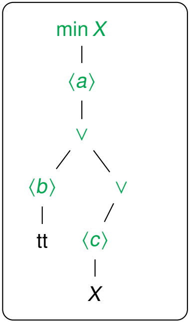

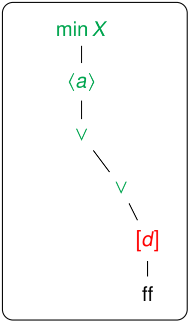

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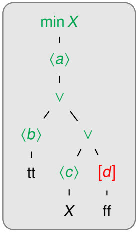

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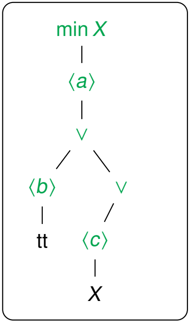

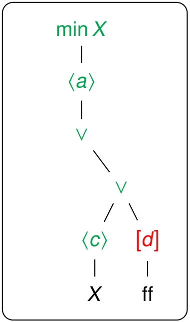

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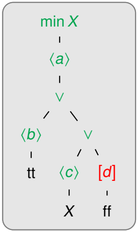

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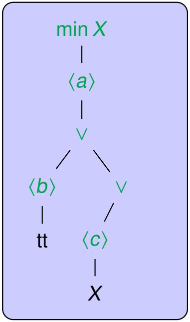

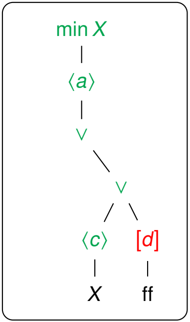

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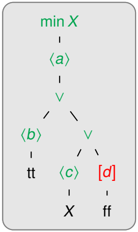

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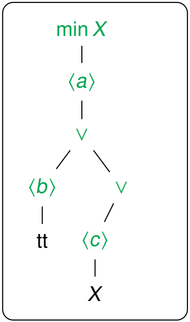

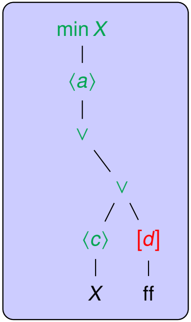

Correctness

Claim (correctness)

- $\varphi \equiv \varphi_{\mathcal{RV}} \vee \varphi_{\mathcal{MC}}$ (existential)
- $\varphi \equiv \varphi_{\mathcal{RV}} \wedge \varphi_{\mathcal{MC}}$ (universal)

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Conclusions and future direction

Contribution

- A decomposition of μHML formulae into:
  - a runtime verification formula
  - a model checking formula
- Runtime verification is applicable to a larger set of formulae

Future work

- Formal correctness proof
- Empirical tests for efficiency
- Extending the approach to other formalisms
- Expressiveness study of induced μHML fragments/hierarchy

The end

Thank you