Assemblée Générale de l'Académie Lorraine des Sciences

Febuary 1st, 2025
Nancy, France

Theoretical and algorithmic contributions to the analysis of safety and security properties in timed systems under uncertainty

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Under the supervision of Étienne André

These works were partially supported by the ANR-NRF research program ProMiS (ANR-19-CE25-0015) and the ANR research program BisoUS (ANR-22-CE48-0012).

Motivation

- Real-time systems:
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A simple example of timing attack

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pwd	c	h	i	c	k	e	n
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Execution time:

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- Problem: The execution time is proportional to the number of consecutive correct characters from the beginning of `attempt`

Methodology

A program

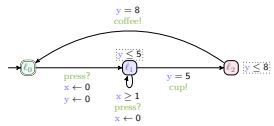
A specification

"The program must be secure"

Methodology

A program

A model



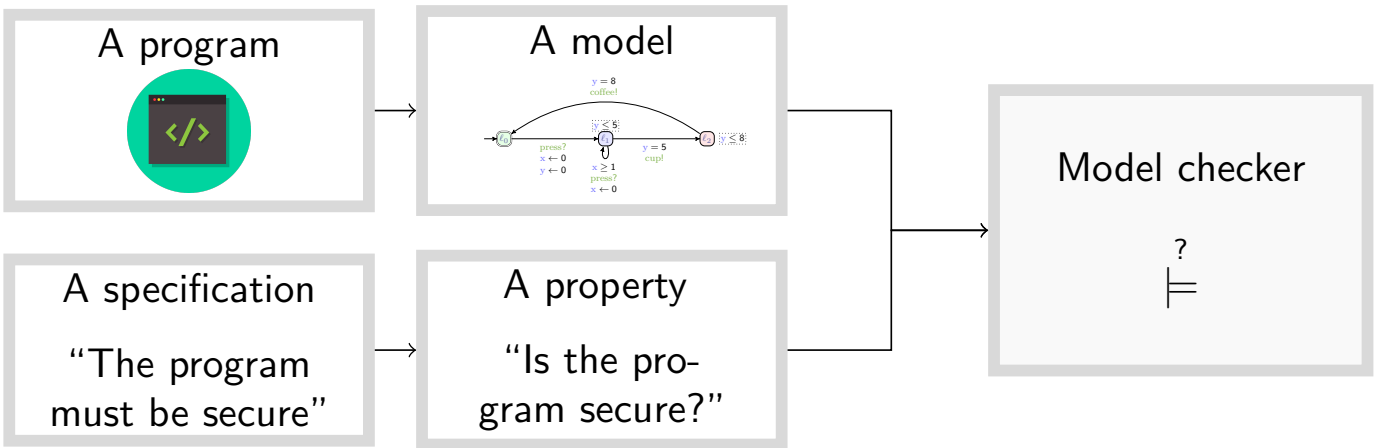
A specification

"The program must be secure"

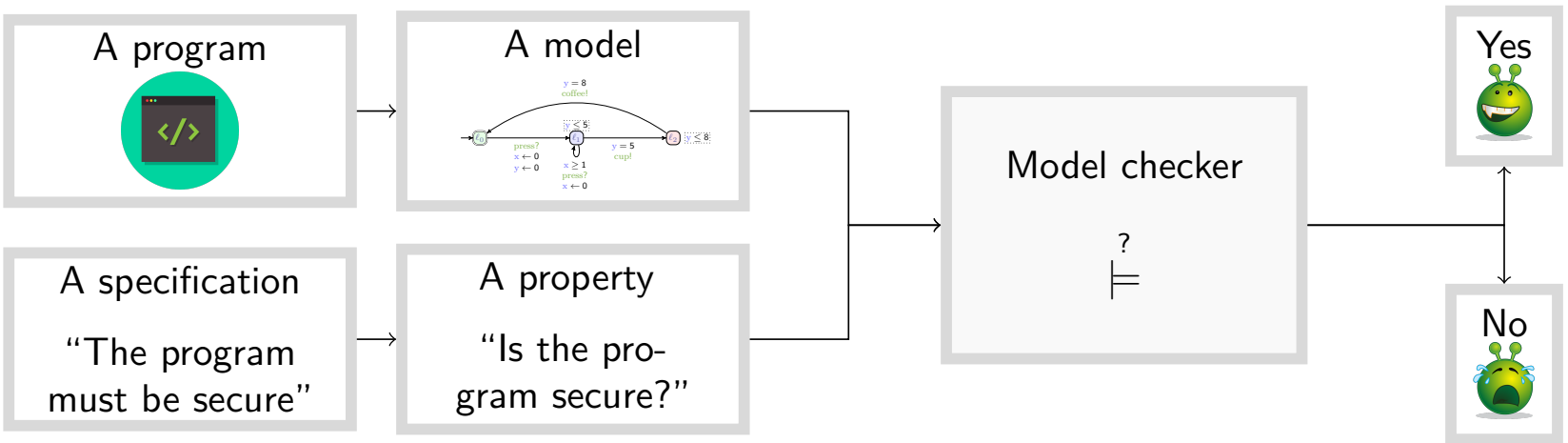
A property

"Is the program secure?"

Methodology



Methodology



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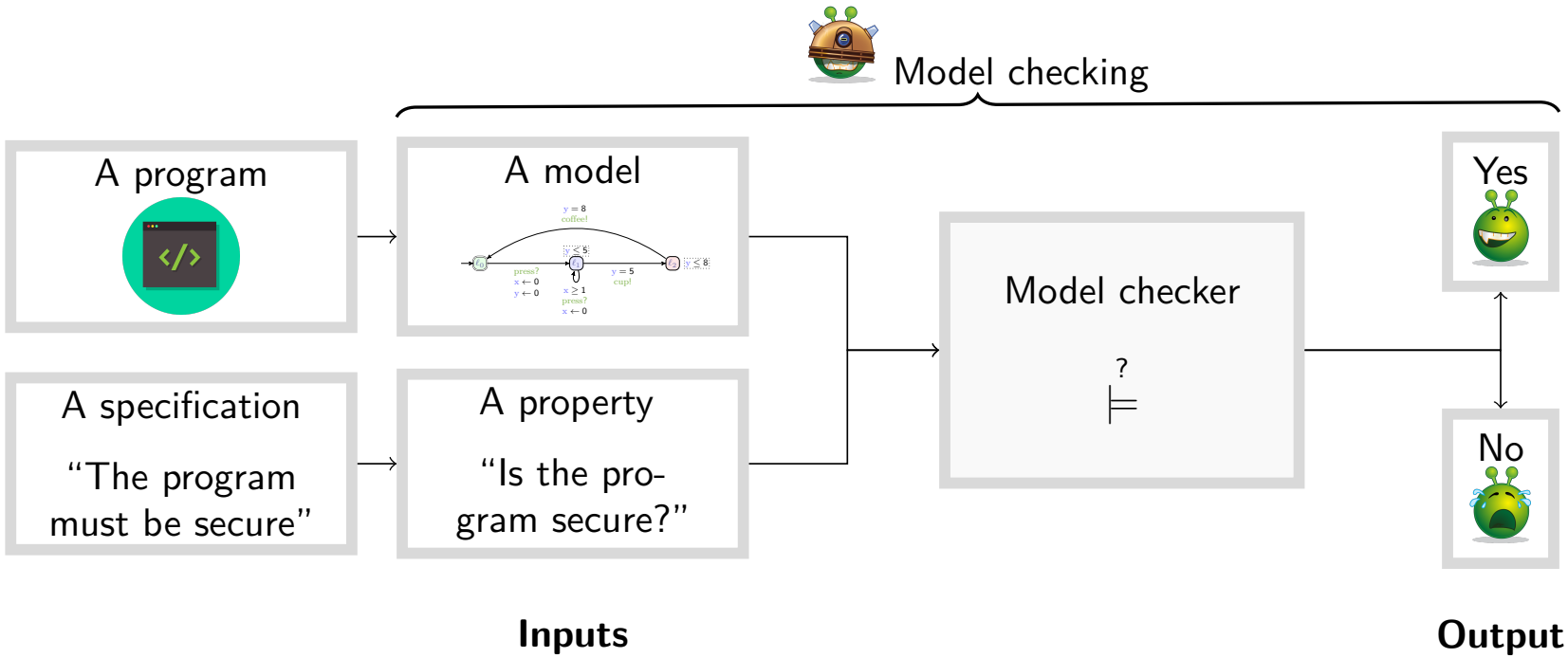
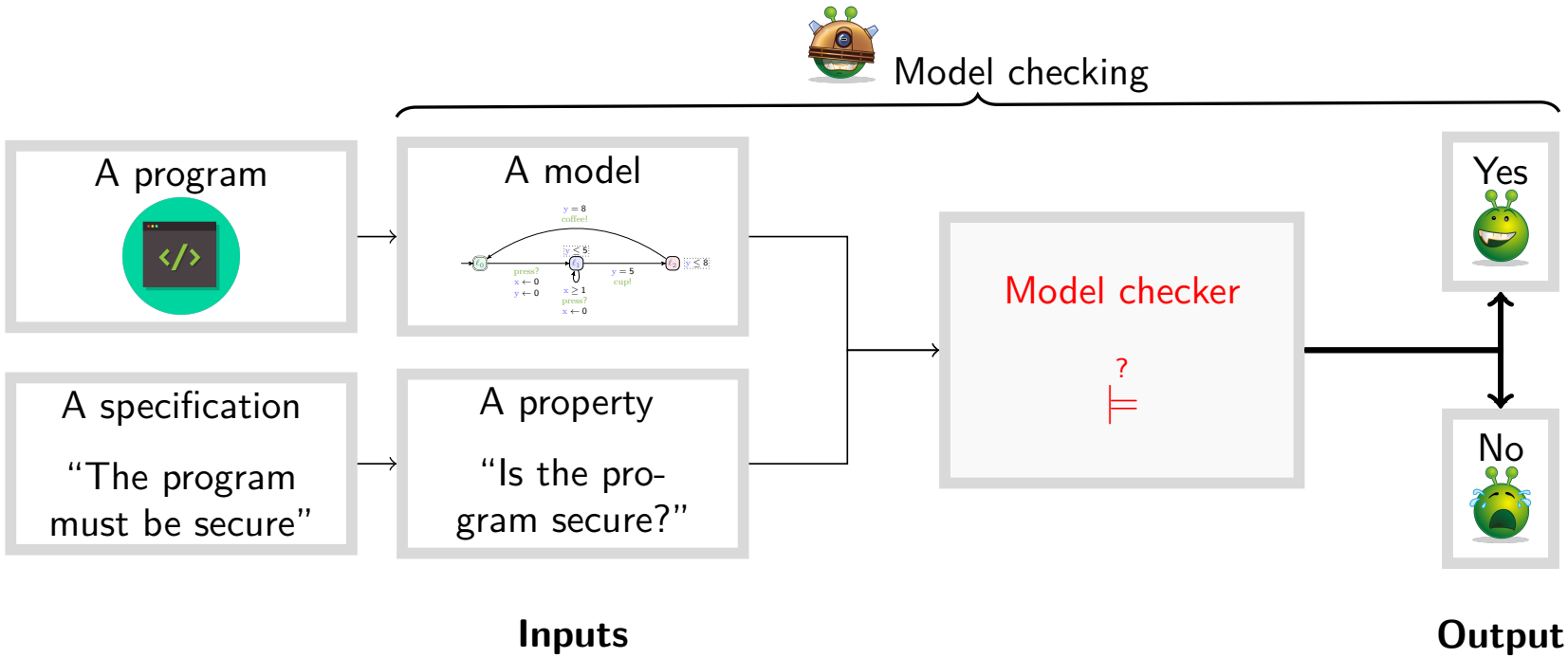


Outline



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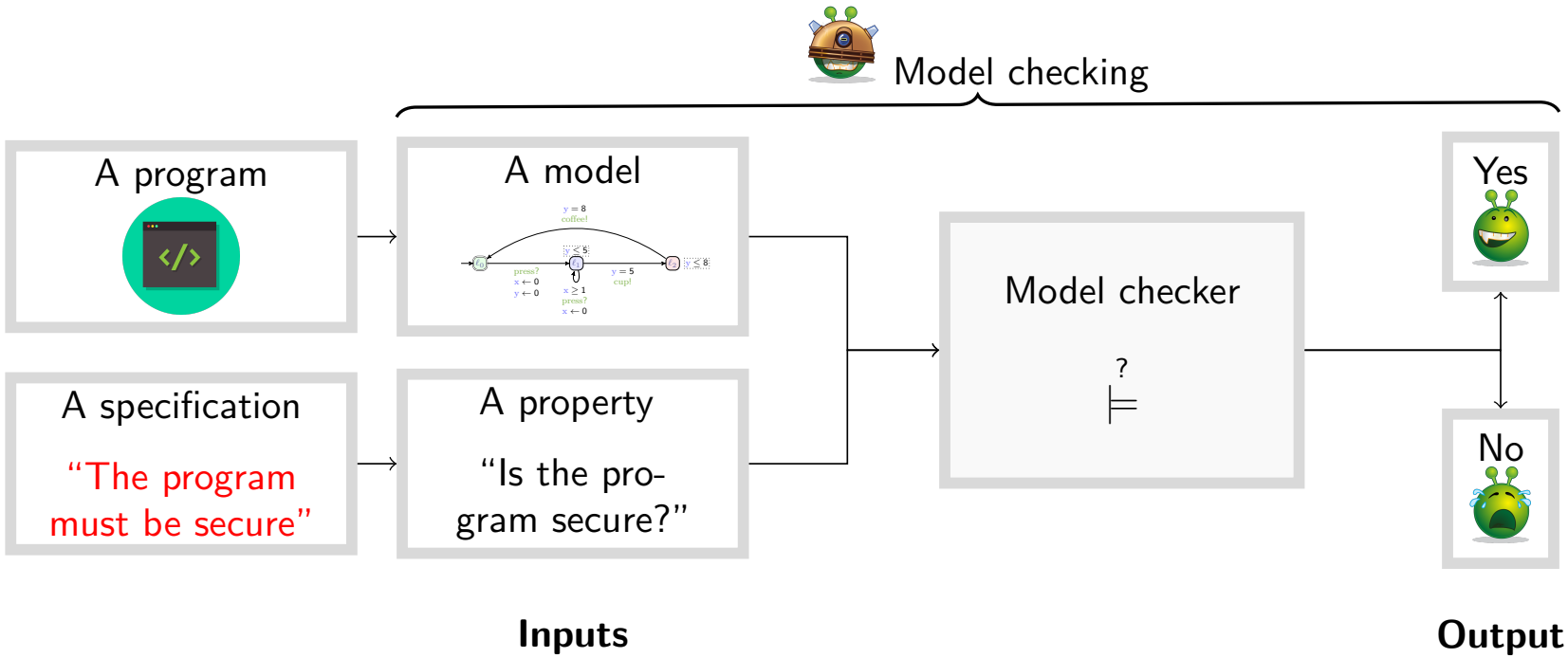

Outline

1. Contribution: Efficient verification (Manuscript, Part I)
2. Contribution: Execution-time opacity (Manuscript, Part II)

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- The verification of systems modeled by PTAs is difficult (undecidability, state-space explosion, ...)

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Contributions

- Benchmark library [TAP21]
- Zone merging algorithm [FORMATS22]

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Contributions

- ET-opacity definition, decidability results and experiments [TOSEM22]
- Expiring ET-opacity definition and decidability results [ICECCS23]
- Untimed control [FTSCS22]

Our attacker model

Attacker capabilities

- Has access to the model (white box)
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Attacker goal

- Wants to deduce some private information based on these observations
  $\rightarrow$ visit of a private location

Outline

Conclusion

Efficient verification

- A new benchmark library (119 models, 216 properties) [TAP21]
- Zone merging algorithm for PTA verification [FORMATS22]

Execution-time opacity

- Formalization and decidability results of ET-opacity [TOSEM22]
- Extension with secrets with expiration date [ICECCS23]
- Untimed control, implementation of strategFTO [FTSCS22]

Publications

[FORMATS22] Étienne André, Dylan Marinho, Laure Petrucci, and Jaco van de Pol. "Efficient Convex Zone Merging in Parametric Timed Automata". In: FORMATS (2022). LNCS. Springer, 2022.

[FTSCS22] Étienne André, Shapagat Bolat, Engel Lefaucheux, and Dylan Marinho. "strategFTO: Untimed control for timed opacity". In: FTSCS (2022). ACM, 2022.

[ICECCS23] Étienne André, Engel Lefaucheux, and Dylan Marinho. "Expiring opacity problems in parametric timed automata". In: ICECCS (2023). Springer, 2023.

[TAP21] Étienne André, Dylan Marinho, and Jaco van de Pol. "A Benchmarks Library for Extended Parametric Timed Automata". In: TAP (2021). LNCS. Springer, 2021.

[TICSA23] Étienne André, Engel Lefaucheux, Didier Lime, Dylan Marinho, and Jun Sun. "Configuring Timing Parameters to Ensure Execution-Time Opacity in Timed Automata". In: TICSA. 2023.

[TOSEM22] Étienne André, Didier Lime, Dylan Marinho, and Jun Sun. "Guaranteeing Timed Opacity using Parametric Timed Model Checking". In: ACM TOSEM 31 (2022).

References I

[FORMATS22] Étienne André, Dylan Marinho, Laure Petrucci, and Jaco van de Pol. "Efficient Convex Zone Merging in Parametric Timed Automata". In: FORMATS (2022). LNCS. Springer, 2022.

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[ICECCS23] Étienne André, Engel Lefaucheux, and Dylan Marinho. "Expiring opacity problems in parametric timed automata". In: ICECCS (2023). Springer, 2023.

References II

[TAP21] Étienne André, Dylan Marinho, and Jaco van de Pol. "A Benchmarks Library for Extended Parametric Timed Automata". In: TAP (2021). LNCS. Springer, 2021.

[TOSEM22] Étienne André, Didier Lime, Dylan Marinho, and Jun Sun. "Guaranteeing Timed Opacity using Parametric Timed Model Checking". In: ACM TOSEM 31 (2022).

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