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Online

Guaranteeing Timed Opacity using Parametric Timed Model Checking

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Context: timing attacks

- Principle: deduce private information from timing data (execution time)

Issues:

- May depend on the implementation (or, even worse, be introduced by the compiler)
- A relatively trivial solution: make the program last always its maximum execution time
  Drawback: loss of efficiency

$\rightsquigarrow$ Non-trivial problem

A simple example of timing attack

```
# input pwd     : Real password
# input attempt: Tentative password
for i = 0 to min(len(pwd, len(attempt)) - 1 do
    if pwd[i] =/= attempt[i] then
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pwd	c	h	i	c	k	e	n
attempt	c	h	e	e	s	e	

Execution time:

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Execution time: $\epsilon + \epsilon + \epsilon$

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

Informal problems

Question: can we exhibit secure execution times?

Time-opacity computation

Exhibit execution times for which it is not possible to infer information on the internal behavior

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Further question: can we also tune internal timing constants to make the system resisting to timing attacks?

Time-opacity synthesis

Exhibit execution times and internal timing constants for which it is not possible to infer information on the internal behavior

Outline

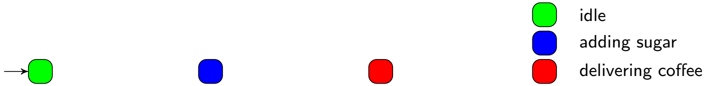
Formalism and Computation results

Toward parameter synthesis

Perspectives

Timed automaton (TA)

- Finite state automaton (sets of locations)



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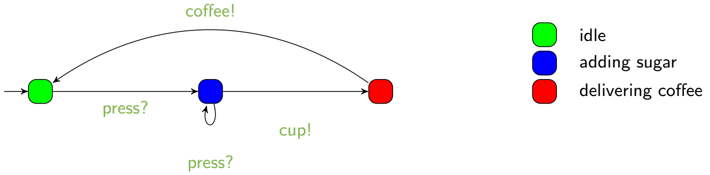

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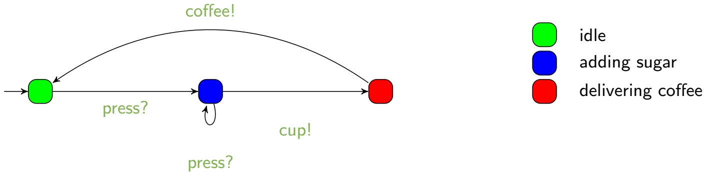
  - Real-valued variables evolving linearly at the same rate



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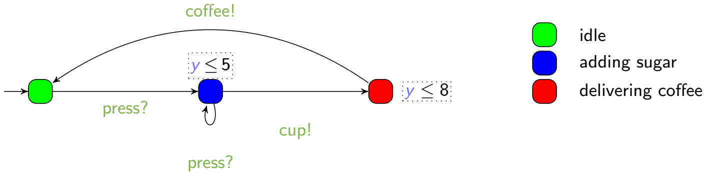
  - Location invariant: property to be verified to stay at a location



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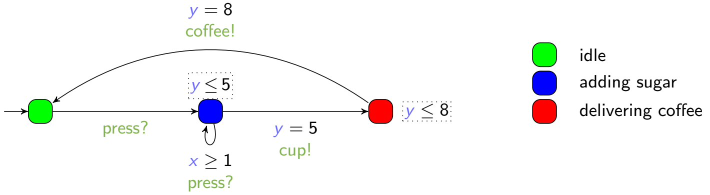

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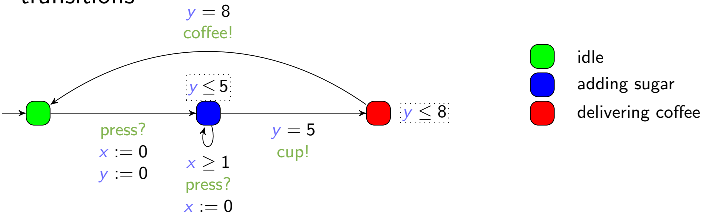
  - Location invariant: property to be verified to stay at a location
  - Transition guard: property to be verified to enable a transition
  - Clock reset: some of the clocks can be set to 0 along transitions



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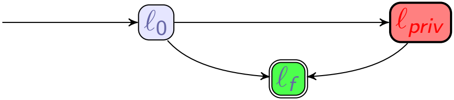
Formalization

Hypotheses: [AS19]

- A start location ℓ_0 and an end location ℓ_f
- A special private location ℓ_{priv}



Definition (timed opacity)

The system is opaque w.r.t. ℓ_{priv} on the way to ℓ_f for a duration d if there exist two runs to ℓ_f of duration d

1. one passing by ℓ_{priv}
2. one *not* passing by ℓ_{priv}

[AS19] Étienne André and Jun Sun. "Parametric Timed Model Checking for Guaranteeing Timed Opacity". In: *ATVA* (Oct. 28–31, 2019). Ed. by Yu-Fang Chen, Chih-Hong Cheng, and Javier Esparza. Vol. 11781. Lecture Notes in Computer Science. Taipei, Taiwan: Springer, 2019, pp. 115–130. DOI: 10.1007/978-3-030-31784-3_7

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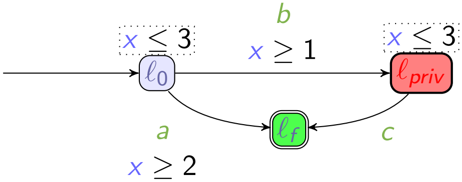

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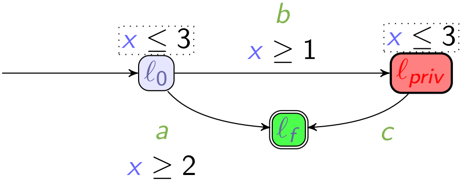

- There exist two runs of duration $d = 2$:

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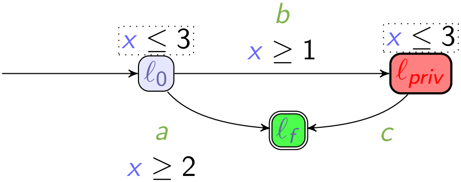

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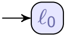

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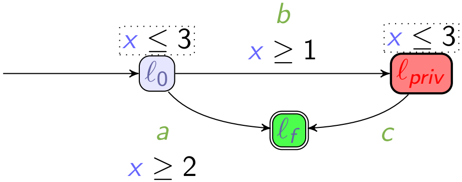

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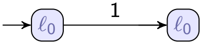

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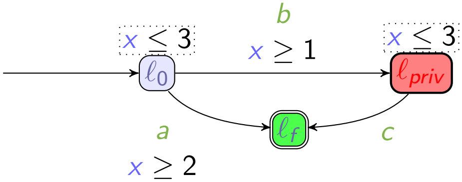

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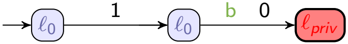

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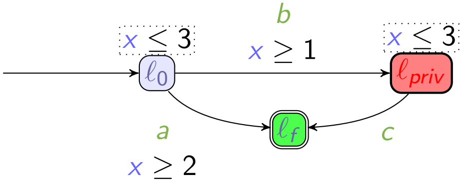

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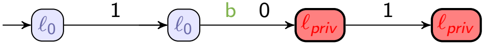

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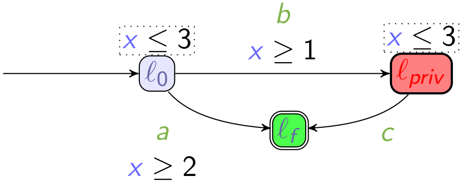

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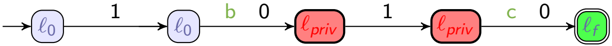

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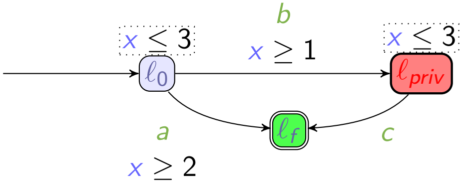

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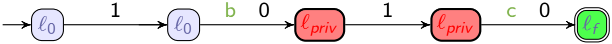

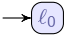

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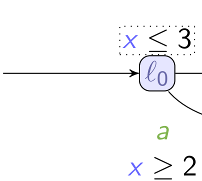

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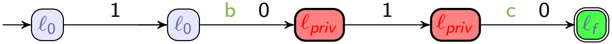

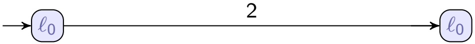

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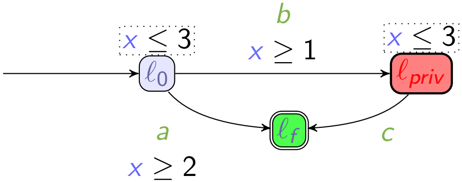

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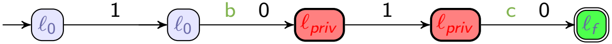

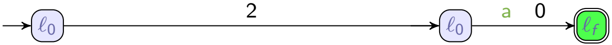

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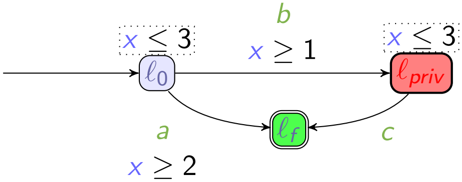

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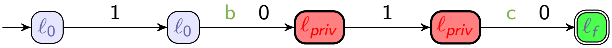
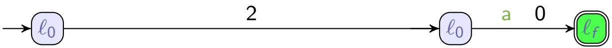
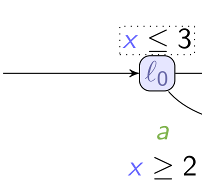




We say that the system is opaque w.r.t. ℓ_{priv} on the way to ℓ_f for a duration $d = 2$

Example



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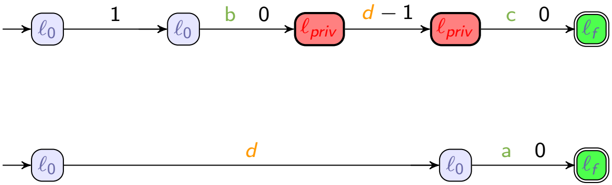

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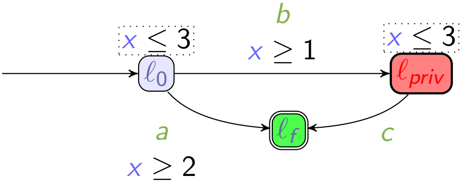

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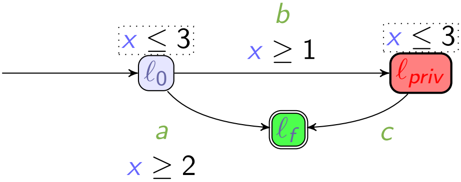

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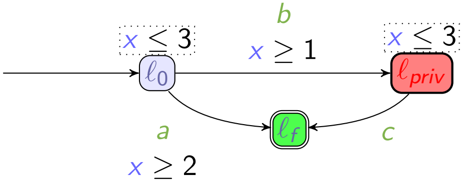

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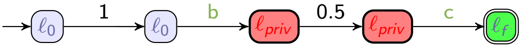

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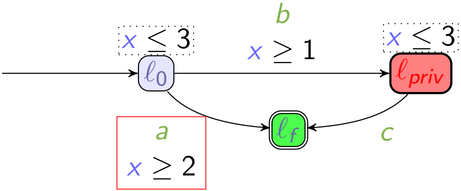

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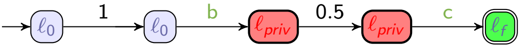

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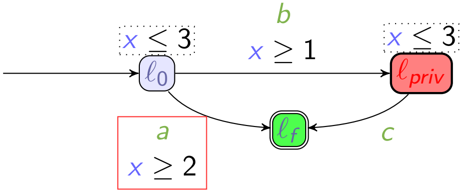

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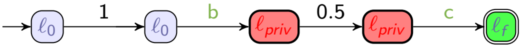

  It is not possible to reach ℓ_f with a path of duration 1.5 not passing by ℓ_{priv}

We say that the system is *not* fully opaque w.r.t. ℓ_{priv} on the way to ℓ_f

Problem 1: timed-opacity computation

Theorem The durations d such that the system is opaque can be effectively computed and defined

[And+] Étienne André, Didier Lime, Dylan Marinho, and Jun Sun. "Guaranteeing Timed Opacity using Parametric Timed Model Checking". submitted

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Proof: based on the region graph and RA-arithmetic (see [And+])

Exact complexity: unproved (EXPSPACE upper bound proved, but exponential hardness seems likely)

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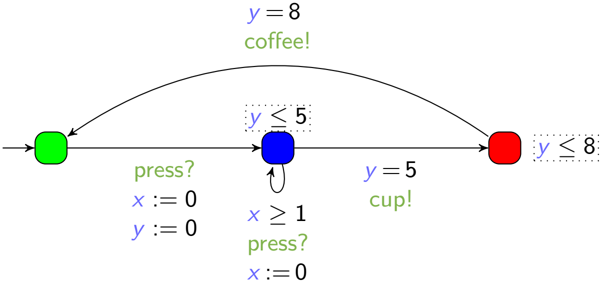
Outline

Parametric Timed Automaton (PTA)

- Timed automaton (sets of locations, actions and clocks)



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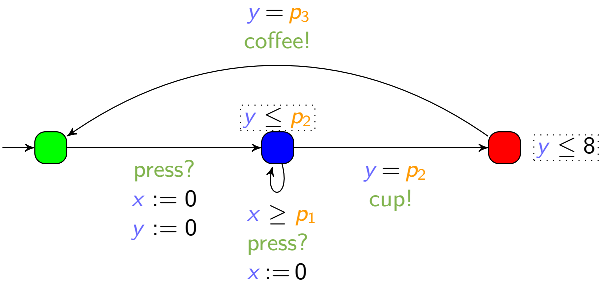
Parametric Timed Automaton (PTA)

- Timed automaton (sets of locations, actions and clocks) augmented with a set P of parameters [AHV93]
  - Unknown constants compared to a clock in guards and invariants



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- General case: The mere existence of a parameter valuation for which there exists a duration for which timed-opacity is achieved is undecidable

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- Study of a subclass known for being "at the frontier" of decidability (L/U-PTA)
  - The existence of valuations for timed opacity w.r.t. some execution times is decidable
  - The existence of valuations for full timed opacity is undecidable
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We adopt a "best-effort" approach for the general case of PTAs

- Approach not guaranteed to terminate in theory

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Outline

Perspectives

On the theoretical side

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On the pratical side

- Have an automatic translation of programs to PTAs
  → Some experiments were done, but on Java programs manually translated to PTAs
- Repairing a non-opaque system
  → Preliminary ideas in [And+][a], but not fixed

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