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Online

Guaranteeing Timed Opacity using Parametric Timed Model Checking

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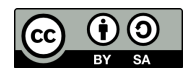

Context: timing attacks

- 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

```
1 # input pwd     : Real password
2 # input attempt: Tentative password
3 for i = 0 to min(len(pwd, len(attempt)) - 1 do
4     if pwd[i] =/= attempt[i] then
5         return false
6 done
7 return true
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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?

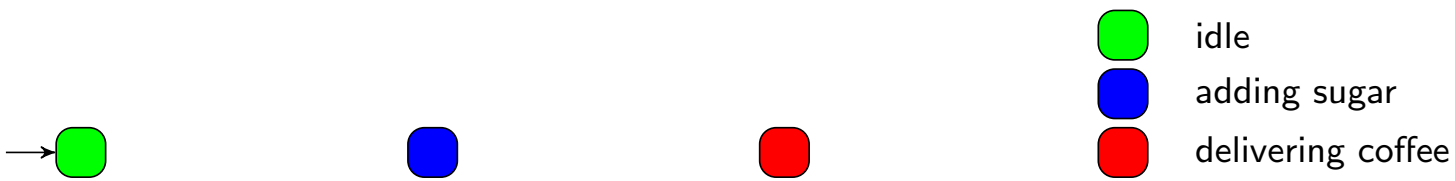
Time-opacity synthesis

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

Outline

Timed automaton (TA)

- Finite state automaton (sets of locations)



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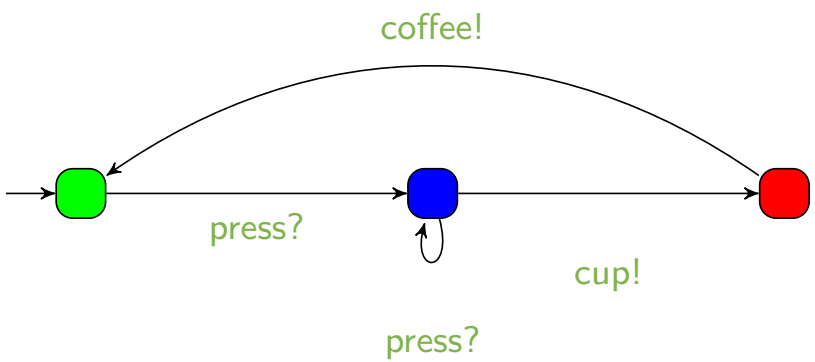
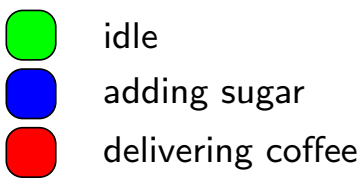
Timed automaton (TA)

- Finite state automaton (sets of locations and actions)





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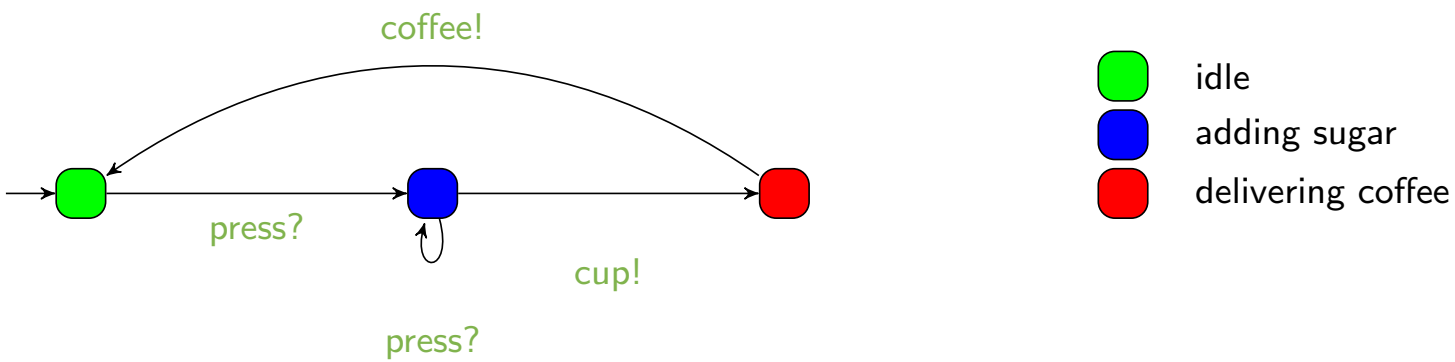
  - Real-valued variables evolving linearly at the same rate



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- Features
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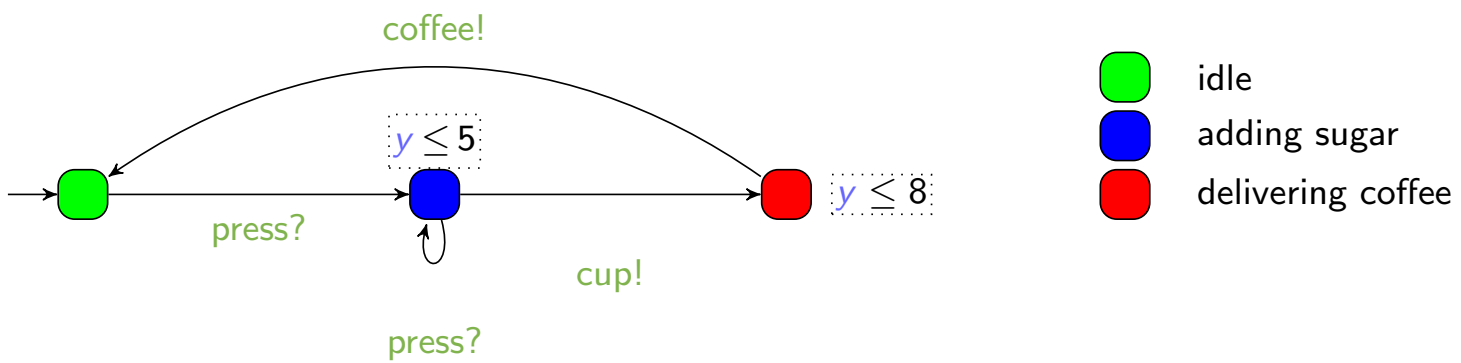

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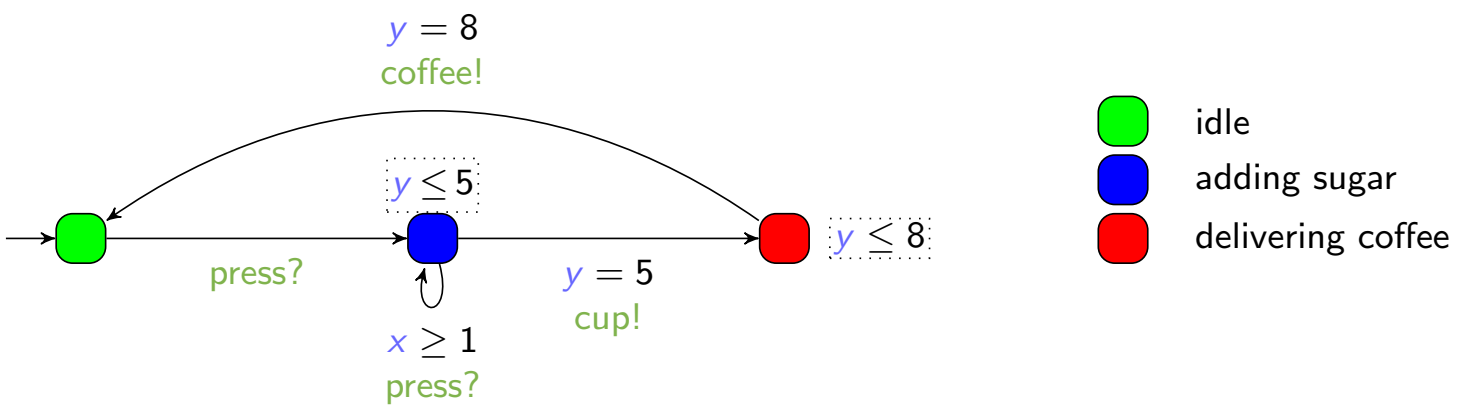

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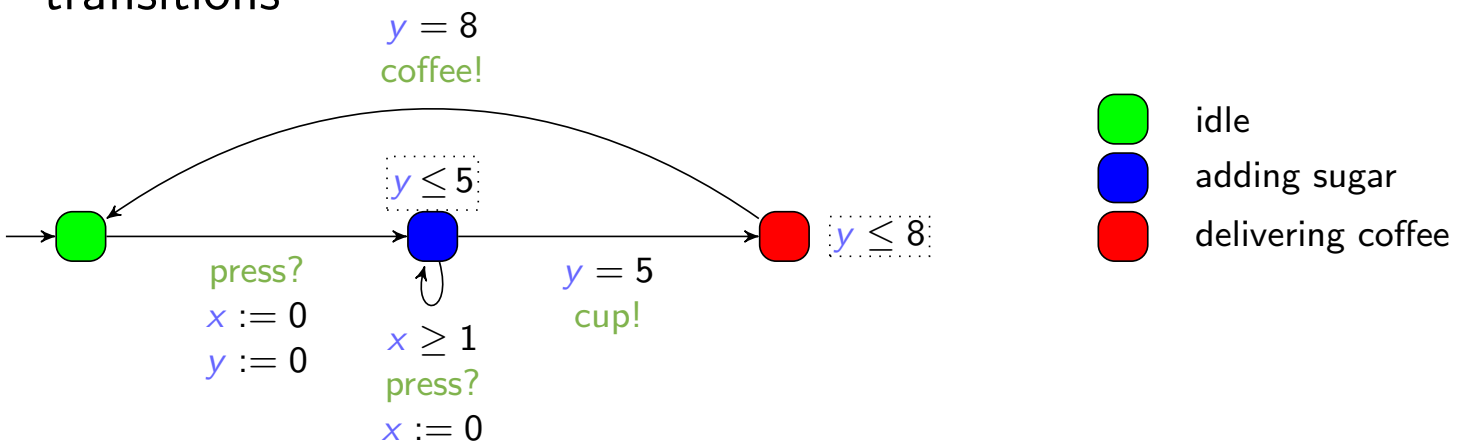
  - Transition guard: property to be verified to enable a transition
  - Clock reset: some of the clocks can be set to 0 along transitions



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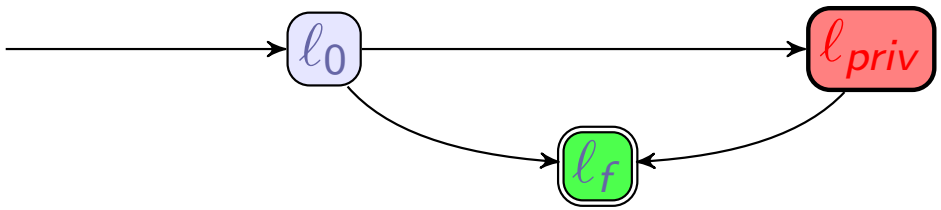
Formalization

Hypotheses: [AS19]

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



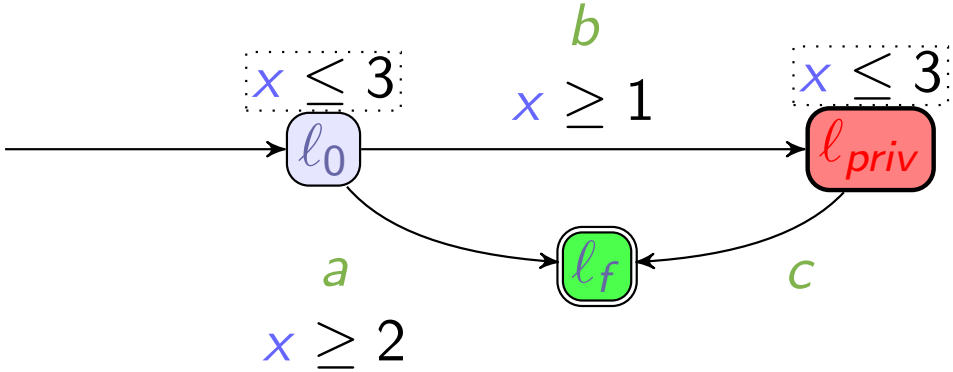
Definition (timed opacity)

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

Example



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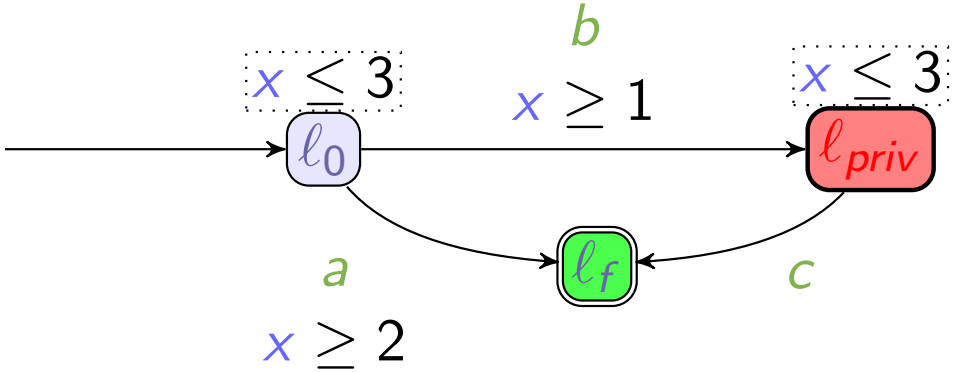

- There exist two runs of duration $d = 2$:

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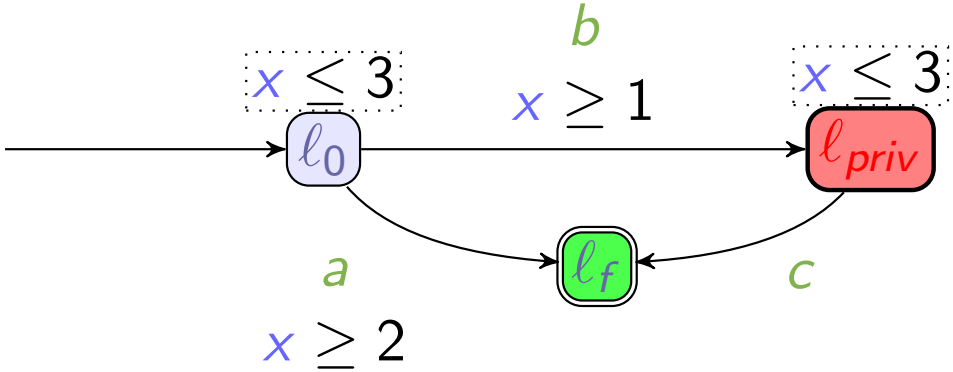

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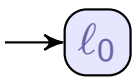

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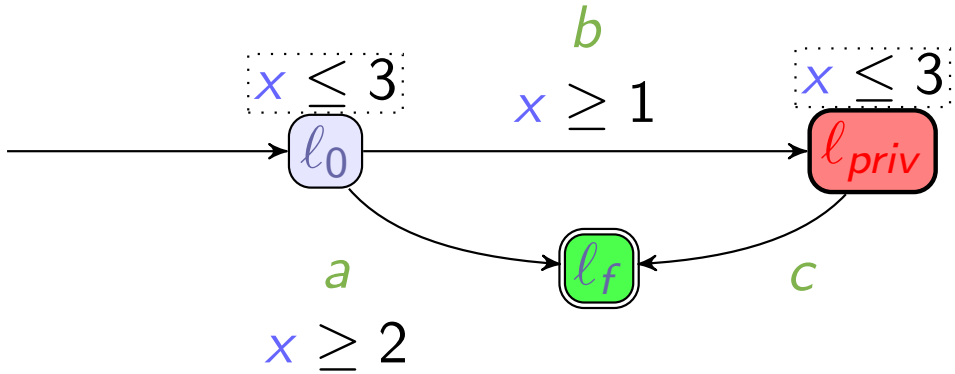

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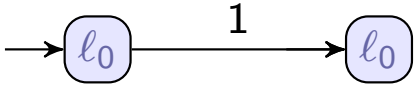

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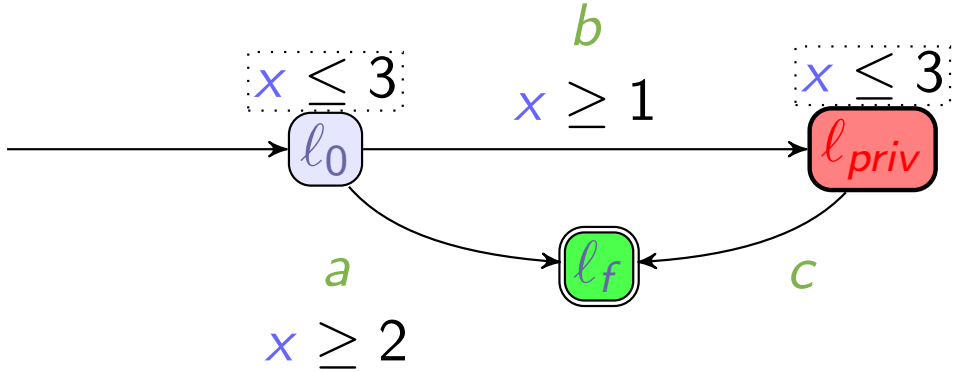

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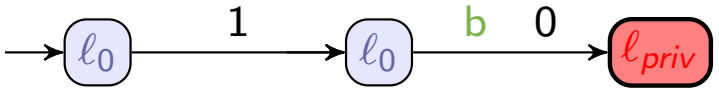

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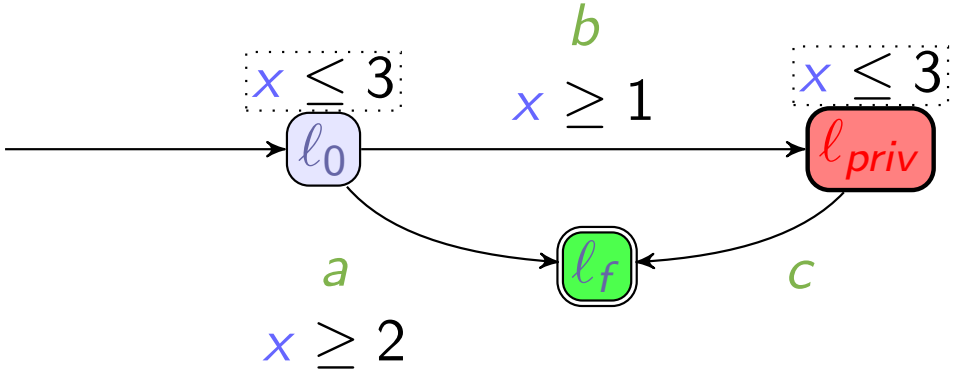

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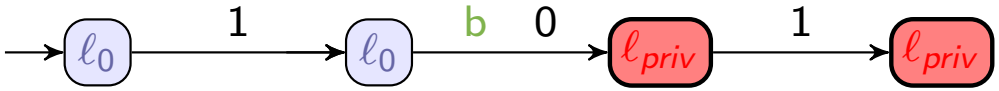

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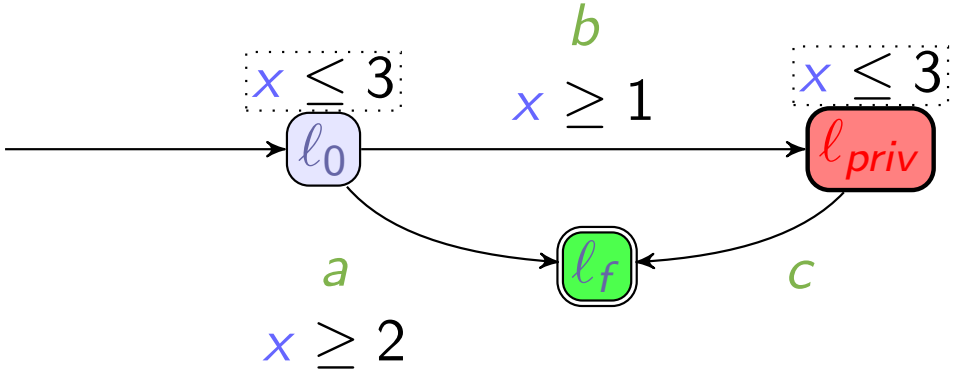

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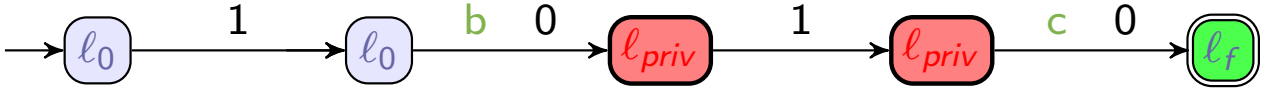

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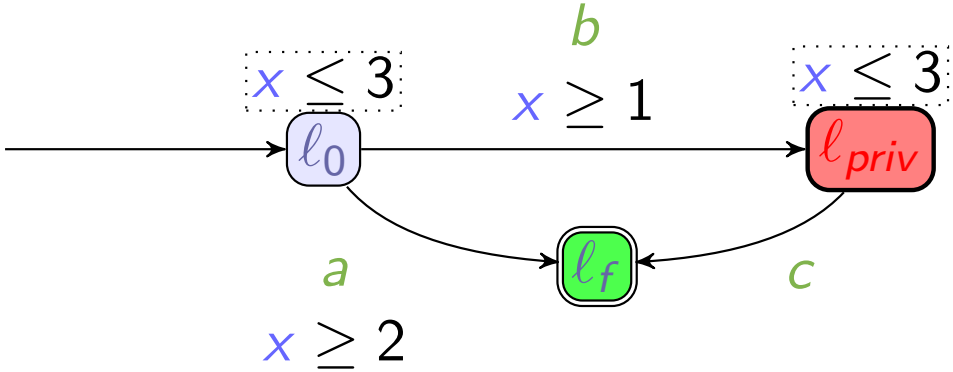

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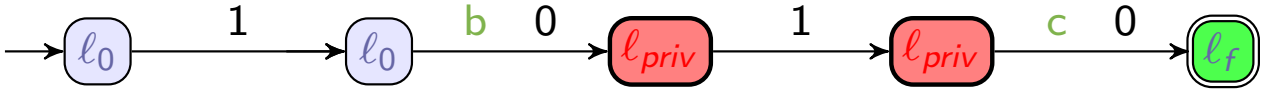

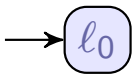

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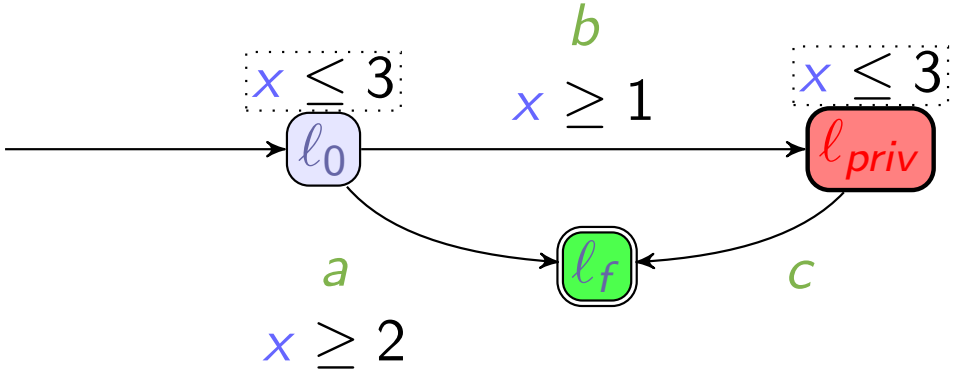

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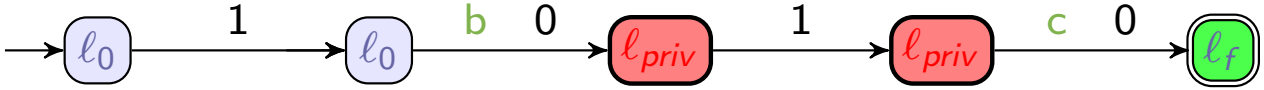

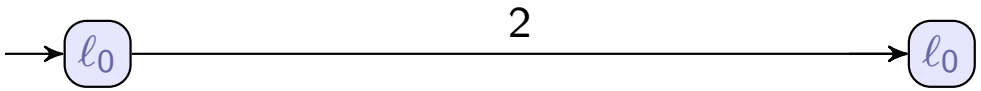

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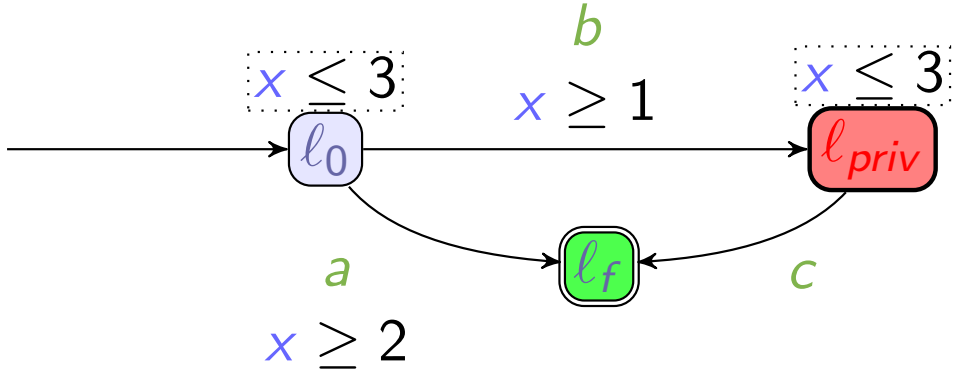

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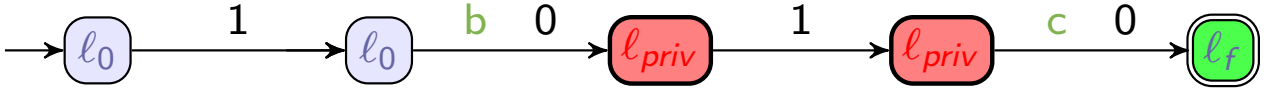

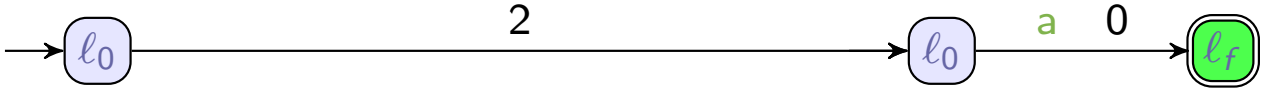

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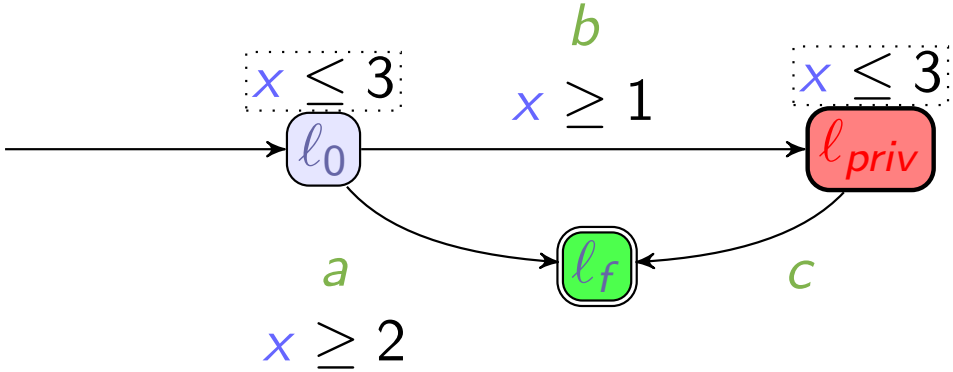

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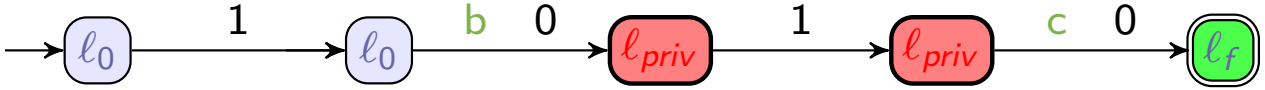

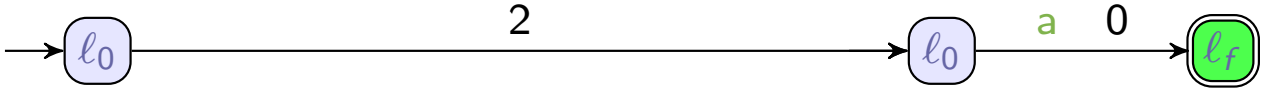

We say that the system is opaque w.r.t. ℓ_{priv} on the way to ℓ_f for a duration $d = 2$

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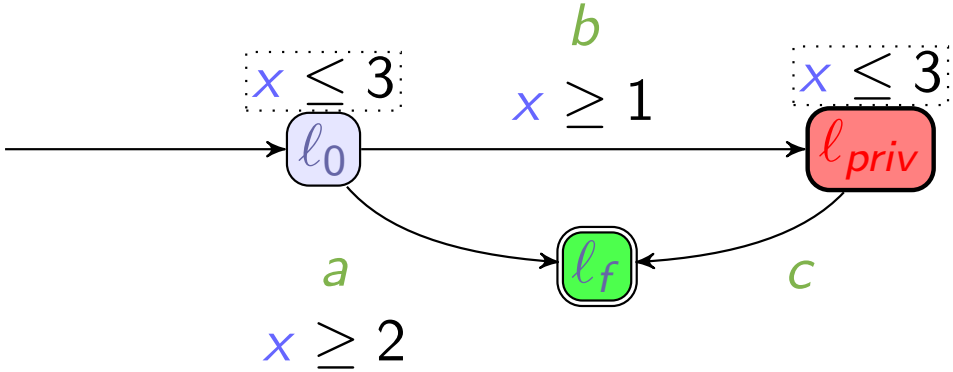

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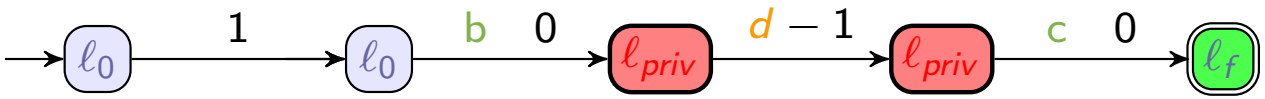

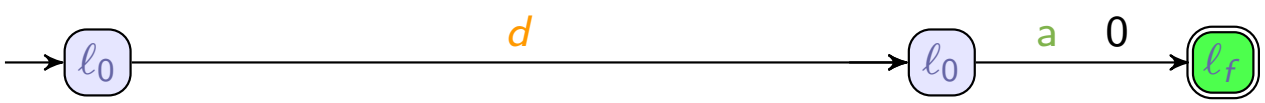

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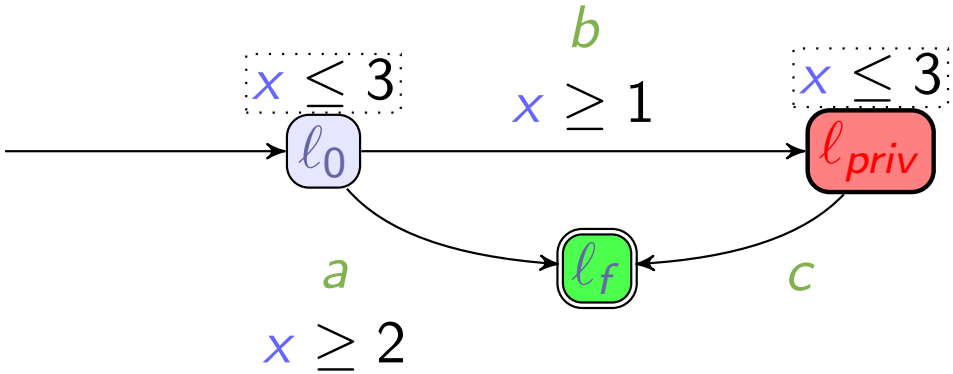

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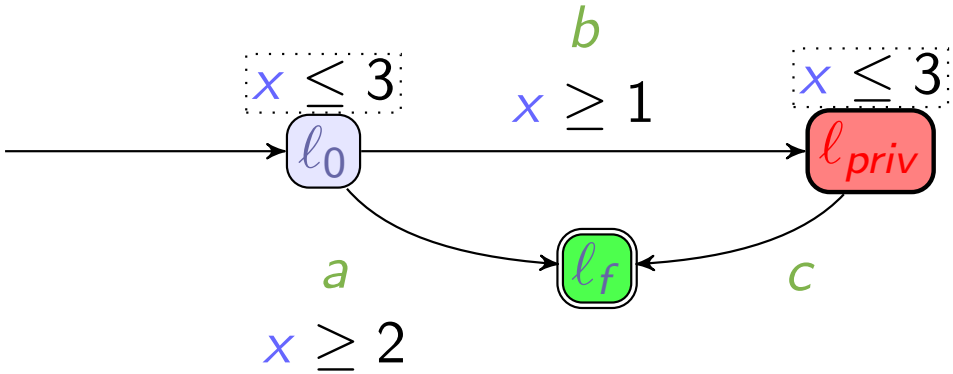

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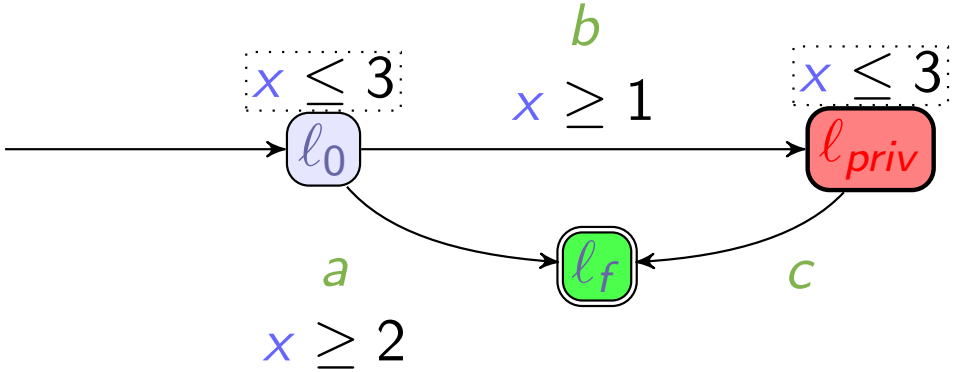

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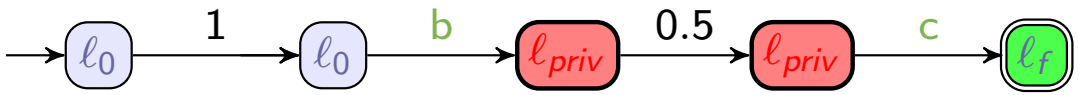
  There exists a run of duration 1.5 passing by ℓ_{priv}



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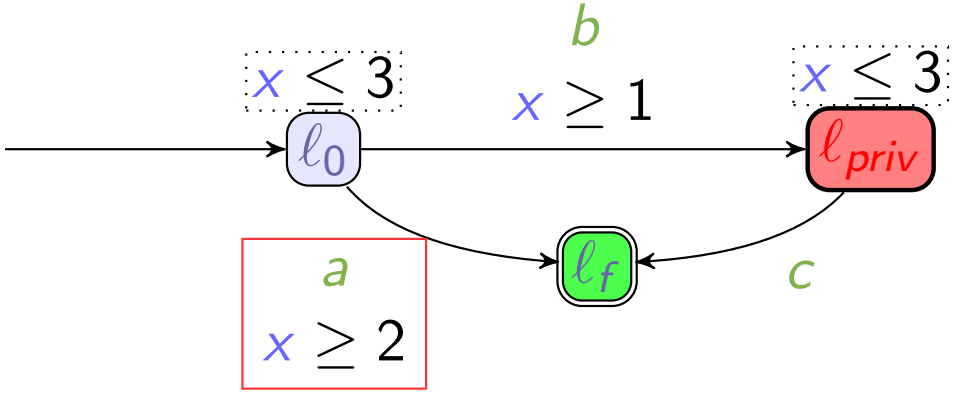

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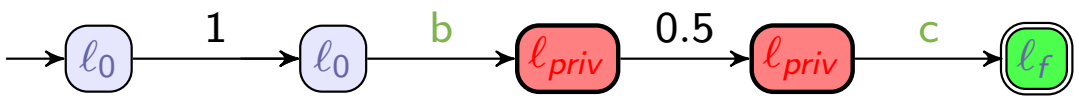
We say that the system is opaque w.r.t. ℓ_{priv} on the way to ℓ_f for all durations in [2,3]

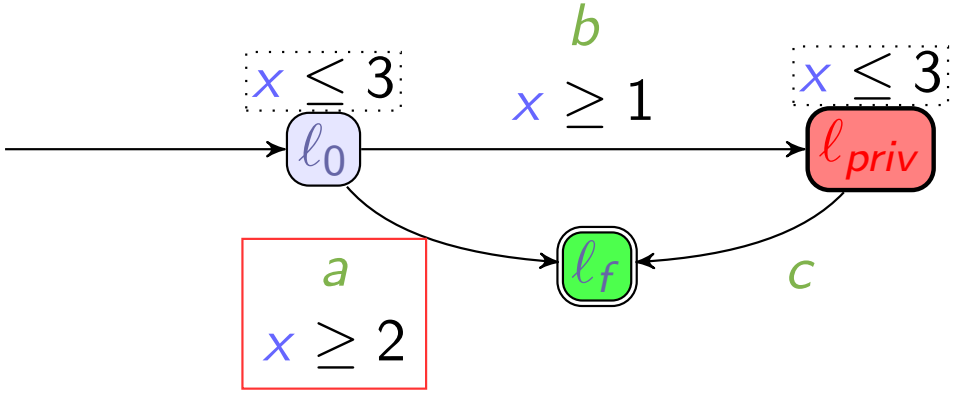
- But

  There exists a run of duration 1.5 passing by ℓ_{priv}



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

Example



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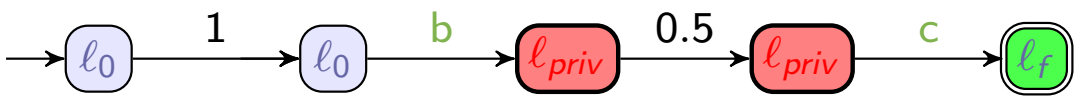

  It is not possible to reach ℓ_f with a path of duration 1.5 not passing by ℓ_{priv}

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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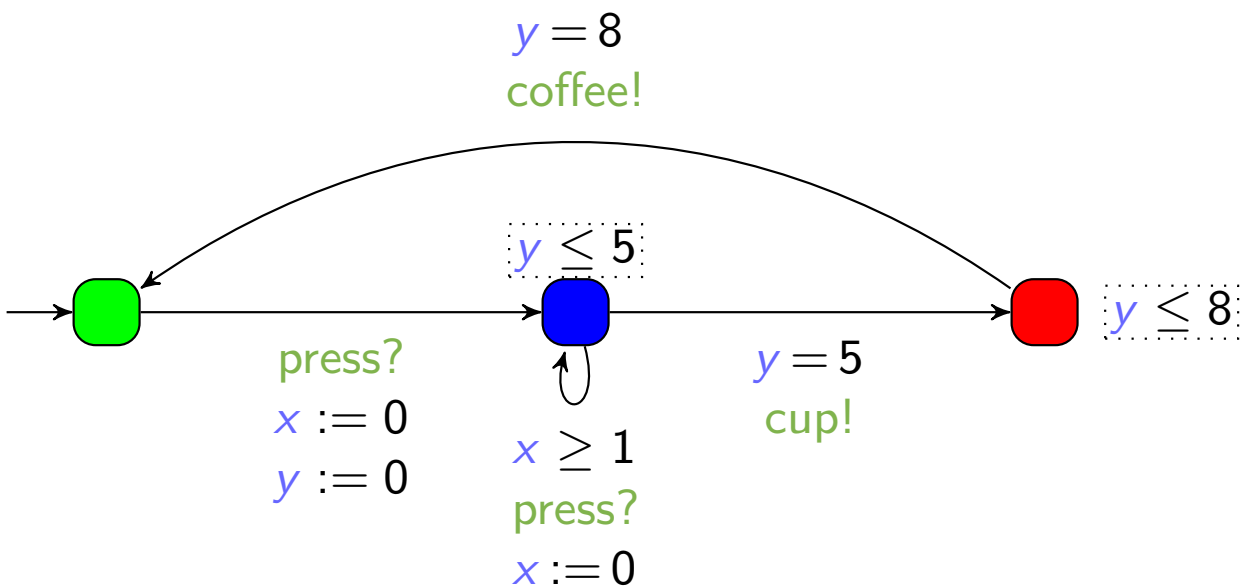
Outline

Parametric Timed Automaton (PTA)

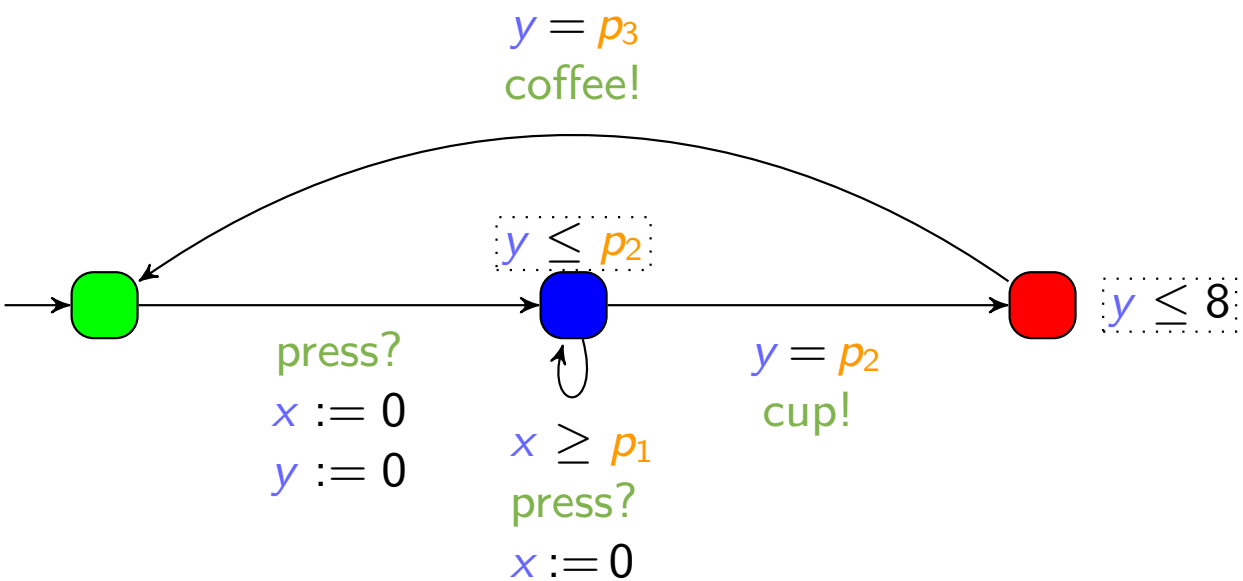
- Timed automaton (sets of locations, actions and clocks)



[AHV93] Rajeev Alur, Thomas A. Henzinger, and Moshe Y. Vardi. "Parametric real-time reasoning". In: *STOC*. ed. by S. Rao Kosaraju, David S. Johnson, and Alok Aggarwal. San Diego, California, United States: ACM, 1993, pp. 592–601. ISBN: 0-89791-591-7. DOI: 10.1145/167088.167242

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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Overview of our theoretical results

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

[And+]

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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
  - The synthesis is uncomptable in pratice

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[And+]

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

- Some restricted problems remain open
  e. g., PTA with one clock
- Study more restritive sub-classes, with the hope to exhibit a decidable one

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  e. g., PTA with one clock
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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

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

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Rajeev Alur and David L. Dill. "A theory of timed automata". In: *Theoretical Computer Science* 126.2 (Apr. 1994), pp. 183–235. ISSN: 0304-3975. DOI: 10.1016/0304-3975(94)90010-8.

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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.