

Imperfection is better!

1-clock priced TA with imprecisions on energy level

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Outline of the presentation

- 1 Introduction
- 2 1-clock PTA with imperfect energy level
- 3 Where Presburger arithmetic helps us
- 4 Robust strategies
- 5 A case study
- 6 Conclusion

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Time is necessary

we need a **quantitative notion of time** for modelization:

- the behaviour of most systems actually depends on time,
- modelling has to take it into account

→ Timed Automata, Timed Petri nets...

and also for specifications:

- to faithfully represent the specification,
- untimed specifications are not enough (e.g. bounded response time property)

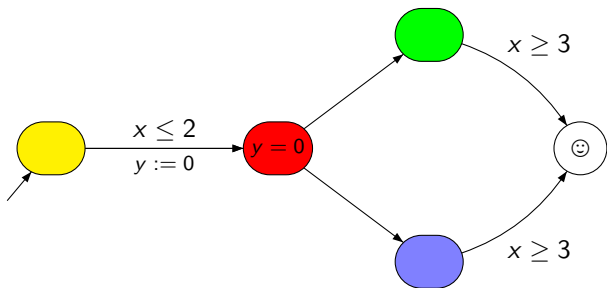
→ TCTL, MTL, TPTL, timed μ -calculus...

But time may not be sufficient

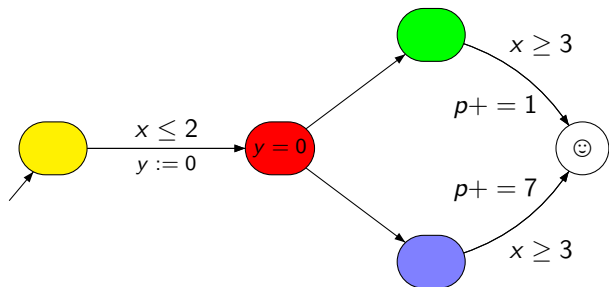
In some cases we don't want to measure time, but rather **energy consumption** to achieve some goal.

- **stopwatch automata**: allows to stop/start some clocks,
→ useful for scheduling
- **hybrid automata**: allows variables whose derivative is not constant,
→ leaking gas burner, water-level monitor...
- **priced (=weighted) timed automata**: similar to linear hybrid automata, but the **behaviour only depends on clock variables**

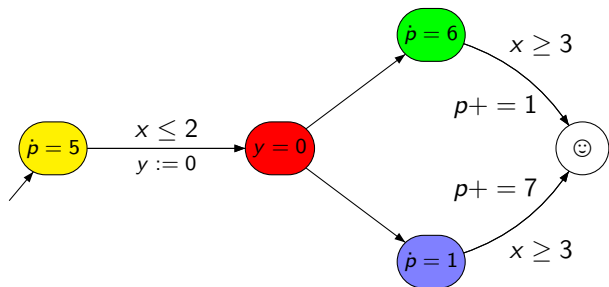
Priced timed automata [ALP01, BFH+01]



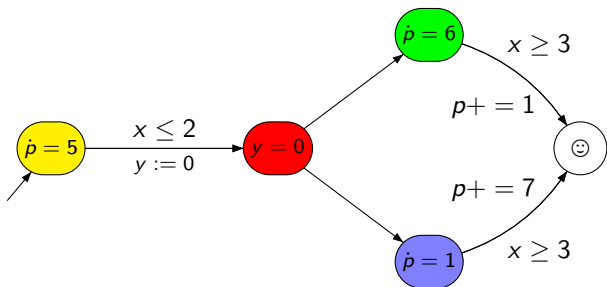
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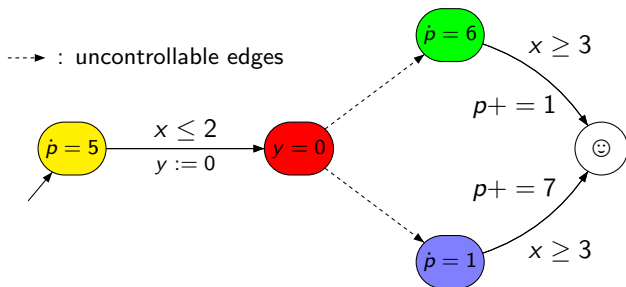


Main known results:

- Optimal infinite behaviours are computable (in PSPACE) minimal cost for reaching \odot
- Model Checking logic WCTL: $EF_{p \leq 10} \odot$, $AG_{t=2}(EF_{p \leq 6} \odot)$
 - decidable over PTAs with ≤ 1 clocks (in PSPACE)
 - undecidable over PTAs with ≥ 3 clocks

Note: Prices and price rates are non-negative

Priced timed games



Main known results:

- Computing (almost) optimal strategies for 1-clock turn-based PTGs is decidable
- It is undecidable for PTGs with ≥ 3 clocks

Note: Again, prices and price rates are non-negative

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Energy is not only consumed, but can be regained.

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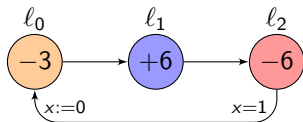
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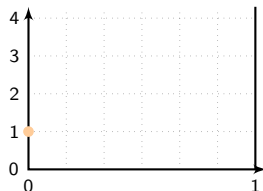
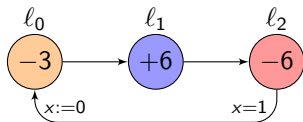


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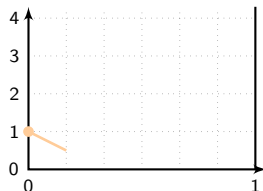
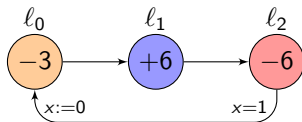
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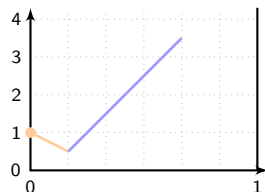
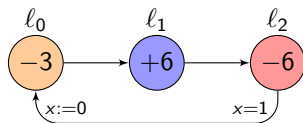
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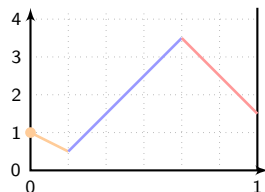
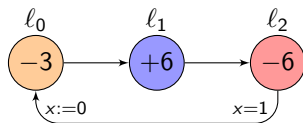
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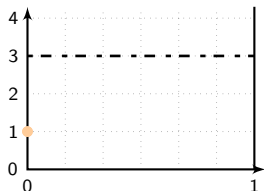
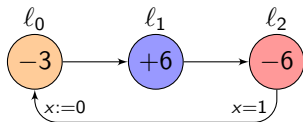
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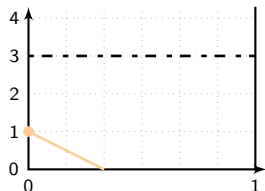
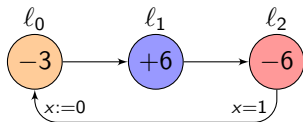
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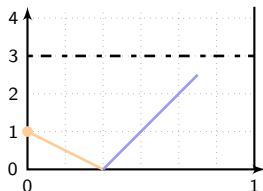
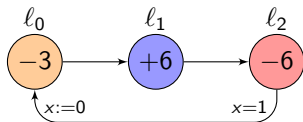
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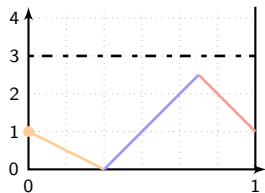
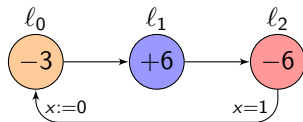
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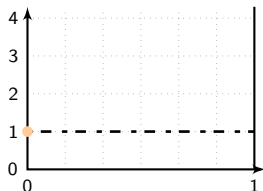
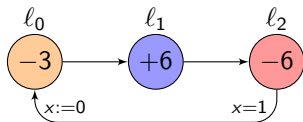
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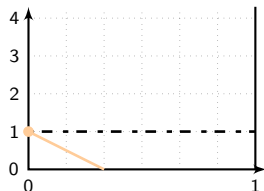
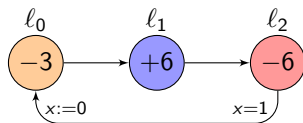
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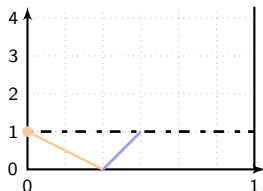
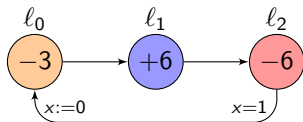
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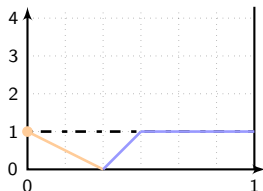
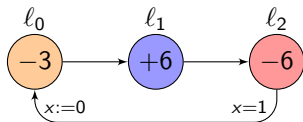
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Existing results for the perfect 1-clock case

[BFLMS08], [BFLM10]

	exist. problem	univ. problem	games
L	$\in PTIME$	$\in PTIME$?
L+W	$\in PTIME$	$\in PTIME$?
L+U	?	?	undecidable

Note: PTIME membership results hold if there are no discrete costs (EXPTIME otherwise).

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→ We will introduce imperfect information on the energy level to solve a L+U problem

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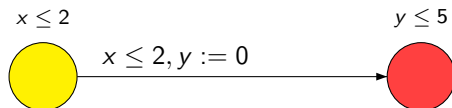
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1-clock PTA with imperfect energy level

- The **exact value of the energy level (=price)** is not known in general
- The energy level is only observed when firing so-called **update transitions**
- Derivative of the price is defined by a **non-punctual interval**

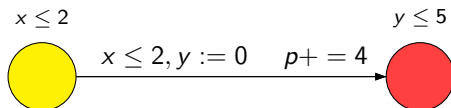
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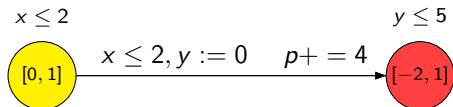
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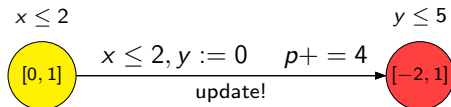
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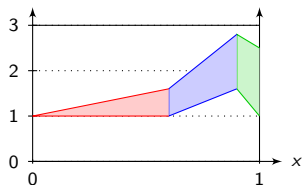
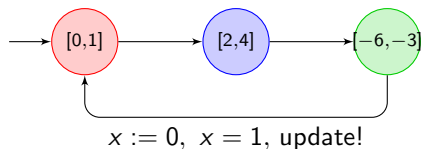


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- The dynamics of the price is defined as in rectangular hybrid automata: $\dot{p} \in [0, 1]$
- Transitions with “update!” mean that after having fired this transition, the exact value of the energy level is observed.

1-clock PTA with imperfect energy level (2)

We see this model as a two-player game:

- the **controller** chooses the transitions and the **delays**.
- the **environment** chooses the **rate** of the energy



The controller only observes the energy level after having fired “update!” transitions.

More formally

A *strategy* for the controller represents here a mapping:
Finite prefixes of runs \longrightarrow Discrete transitions \cup Delays

A strategy is *admissible* if it respects the imperfect information:
if two runs give the same observation, then the strategy
must give the same decision.

A strategy is *winning* if all its outcomes are safe runs.

Problem: Given a 1cPTA with imp. energy level, an initial state s_0 and a safe interval S , does there exist a winning admissible alternating strategy?

Theorem

Under some assumptions on 1c-PTAs, this problem is decidable.

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Outline of the proof

We build a Presburger formula with real variables which characterizes the existence of a winning admissible strategy.

If one has a winning predicate, one can express that in a given configuration, there exists a move which only leads to winning states.

Key ingredient: we use imperfect information to show that winning configurations can be gathered into a finite number of intervals.

→ The Presburger formula expresses the existence of these intervals.

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→ The Presburger formula expresses the existence of these intervals.

Our Hypothesis:

- each cycle carries at least one “update!” transition,
- when the energy is observed, the clock is reset, and it is compared to a positive lower bound.

How imperfect information helps

In the following we consider “meta-transitions” that consist in sequence of non-update transitions ending by an update transition.

Using our hypothesis on the model, we prove:

Lemma

There exists a positive value $\Delta > 0$ such that after having fired a meta-transition, the imprecision on the value of the energy is at least Δ .

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Corollary

Let S be a safe interval. If a configuration is winning and has an entering meta-transition, then there exists a winning interval of size at least Δ containing it.

As a consequence, in each location, winning configurations are included in at most $N := \lceil \frac{|S|}{\Delta} \rceil$ intervals.

Construction of the formula

Let e be an energy level, t be a meta-transition and $\vec{\tau}$ be a vector of timestamps for t . We define the following operators:

- the predicate $Safe(e, t, \vec{\tau})$
- the interval $Outcomes(e, t, \vec{\tau})$

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We consider variables $a_{i,j}, b_{i,j}$, with $1 \leq i \leq n$ and $1 \leq j \leq N$.

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Let $q \in Q$. We define the **winning predicate**:

$$Win(q, e) \iff \bigvee_{q \xrightarrow{t} q_k} \exists \vec{\tau} \text{ s.t. } \left\{ \begin{array}{l} Safe(e, t, \vec{\tau}) \\ \bigwedge_{\ell=1}^N Outcomes(e, t, \vec{\tau}) \subseteq [a_{k,\ell}, b_{k,\ell}] \end{array} \right.$$

Construction of the formula (2)

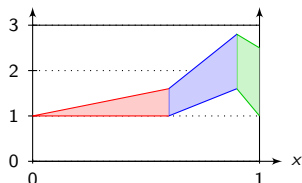
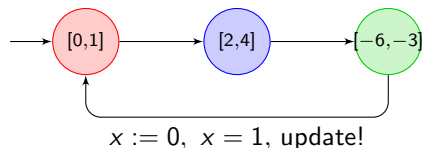
Let q_0 (resp. e_0) denote the initial location (resp. energy).

We define the Presburger formula as follows:

$$\Phi(q_0, e_0) = \exists_{i=1}^n \exists_{j=1}^N a_{i,j}, b_{i,j} \text{ s.t. } \left\{ \begin{array}{l} \bigwedge_{i,j} [a_{i,j}, b_{i,j}] \subseteq S \\ \wedge \text{Win}(q_0, e_0) \\ \bigwedge_{i,j} \forall e, a_{i,j} \leq e \leq b_{i,j} \Rightarrow \text{Win}(q_i, e) \end{array} \right.$$

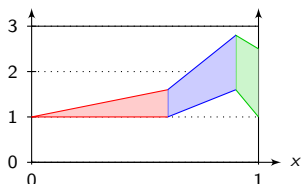
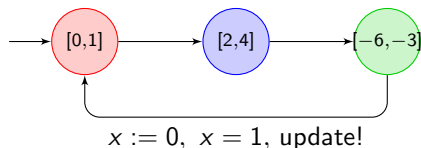
Bonus: Using Fourier-Motzkin elimination, we end up with the set of initial values of the energy for which there exists a winning strategy.

Example



There is only one meta-transition: the cycle. Its minimal imprecision is $\Delta = 1$. We thus obtain $N = \frac{3}{1} = 3$.

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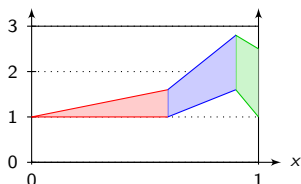
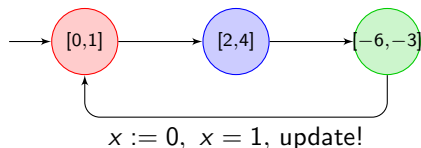


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$$\text{Safe}(e, t, \vec{\tau}) \iff \begin{cases} 0 \leq e & \wedge e \leq 3 \\ \wedge 0 \leq e & \wedge e + \tau_1 \leq 3 \\ \wedge 0 \leq e + 2\tau_2 & \wedge e + \tau_1 + 4\tau_2 \leq 3 \\ \wedge 0 \leq e + 2\tau_2 - 6\tau_3 & \wedge e + \tau_1 + 4\tau_2 - 3\tau_3 \leq 3 \end{cases}$$

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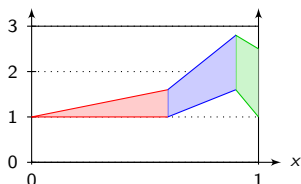
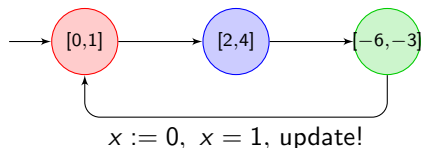
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$$\text{Outcomes}(e, t, \vec{\tau}) = [e + 2\tau_2 - 6\tau_3, e + \tau_1 + 4\tau_2 - 3\tau_3]$$

Example



There is only one meta-transition: the cycle. Its minimal imprecision is $\Delta = 1$. We thus obtain $N = \frac{3}{1} = 3$.

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Here we end up with the constraint $0 \leq e_0 \leq \frac{12}{5}$

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- 2 1-clock PTA with imperfect energy level
- 3 Where Presburger arithmetic helps us
- 4 Robust strategies**
- 5 A case study
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Recall that a **strategy** is a **sequence of transitions and timestamps**.

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We can **modify operators** $\text{Safe}(e, t, \vec{\tau})$ and $\text{Outcomes}(e, t, \vec{\tau})$ to include this perturbation:

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→ definition of Win_δ

→ definition of $\Phi_\delta(q_0, e_0)$

New Presburger formula

For a fixed value of δ , the Presburger formula $\Phi_\delta(q_0, e_0)$ characterizes the initial values of the energy which own δ -robust winning strategies.

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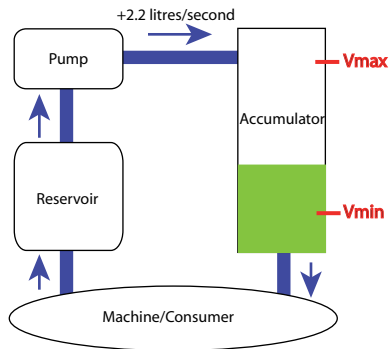
→ Consider the formula $\Phi_{robust}(q_0, e_0) \stackrel{def}{=} \exists \delta > 0 \mid \Phi_\delta(q_0, e_0)$

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A case study

The study of L+U energy problems has been motivated by a collaboration within the [european research project Quasimodo](#).



Synthesis of a pump controller for an oil-accumulator system.

L+U: The oil volume must stay within a **safety interval**.

Infinite run: The machine repeats a cycle of production of plastic cells forever.

A case study (2)

The oil level can be modelled as a price:

- it is a linear hybrid variable,
- it can both increase (pump on) and decrease (machine consumes oil)
- price rates are not singletons: there are imprecisions in the machine rates.

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→ We have to **develop a tool** to perform this analysis!

We plan to rely on the SMT solver Z3 of Nikolaj Bjorner.

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Conclusion

Contributions:

- decidability for a **L+U** problem
- **Presburger arithmetic** as a new tool for energy constraints problems
- extends for free to **robustness** issues

Challenges/Perspectives:

- extraction of **strategies**
- develop a **tool** (case study)
- works also for **1-clock prices timed games**
- other extensions? (**multiple costs, optimization...**)
- exact **complexity** of the procedure?