

Parametric Time Broadcast Protocols

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Motivation

Our framework allows to model **Networks** of **identical** systems.

⇒ *Communication protocols*

- ▶ Expressive (Timing features)
- ▶ Abstract (Parameters)

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Goal: Parametric model checking

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Goal: Parametric model checking

Real motivation: Models mixing 2 types of parameters

Outline

Introduction

Background

Broadcast Protocol Networks and Timed Automata

Parametric Time Broadcast Protocol Networks

Decidability for bounded PTBP

Reconfigurable semantics

Clique semantics

L/U-PTBP

Conclusion

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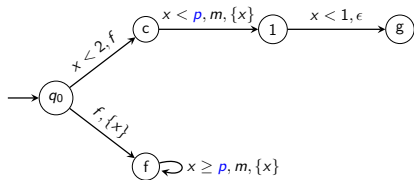
L/U-PTBP

Conclusion

(Parametric) Timed Automata

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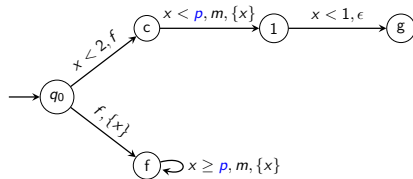
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- ▶ Guarded transitions
- ▶ (Invariants)
- ▶ Timing Parameters p



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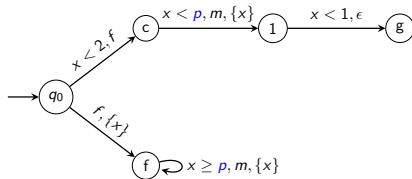


Does there exist a value of p such that g is reachable?

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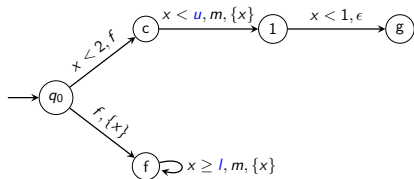
Undecidable in the general setting (1 clock compared to 1 parameter)

(L/U)-PTA

L/U-PTA

L/U-PTA are PTA where parameters are partitioned into

- ▶ Lower-bound parameters (L)
- ▶ Upper-bound parameters (U)

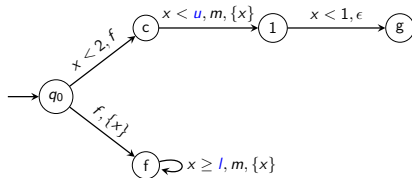


(L/U)-PTA

L/U-PTA

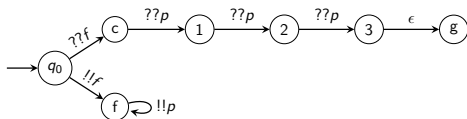
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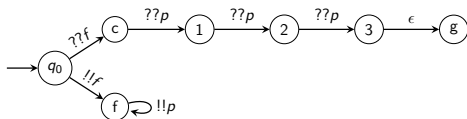
In this context, some reachability problems become decidable.

Broadcast Protocol Networks



- ▶ Parametric number of identical processes n
- ▶ Communicating
- ▶ Arbitrary communication topologies:
 - ▶ Reconfigurable: Non-det Receiver set
 - ▶ Clique: All processes receive
 - ▶ ...

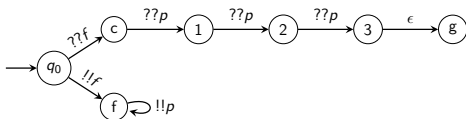
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Does there exist a value of n such that g is reachable
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Undecidable in general, but not for cliques

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Parametric Time Broadcast Protocol Networks

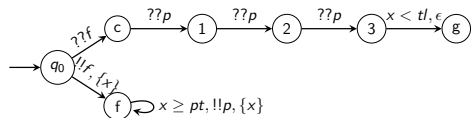
Definition (PTBP Network)

A **Parametric Time Broadcast Protocol Network** is a *Broadcast Protocol Network*, with a *parametric number* of identical processes, which are all modeled using a *Parametric Timed Automaton*.

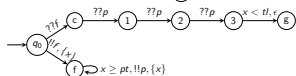
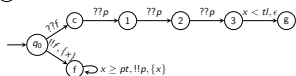
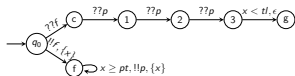
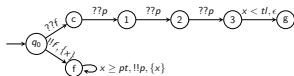
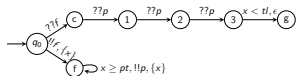
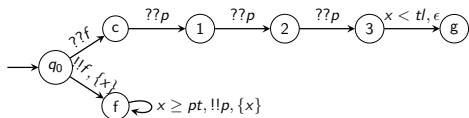
- ▶ Two types of parameters:
 - ▶ Timing
 - ▶ Number of processes
- ▶ Transitions are of three types:
 - ▶ internal: ϵ
 - ▶ emissions: $!!m$
 - ▶ receptions: $??m$

In the following, we assume that all timing parameters are **bounded**.

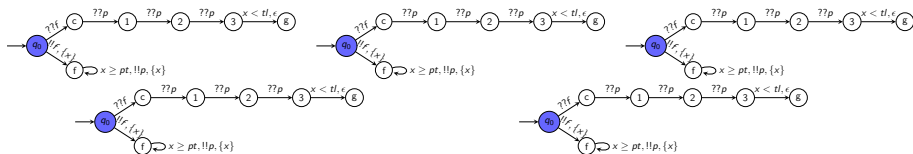
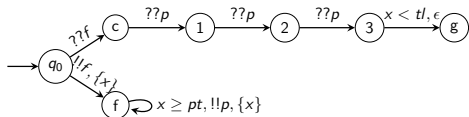
PTBP Network - Example



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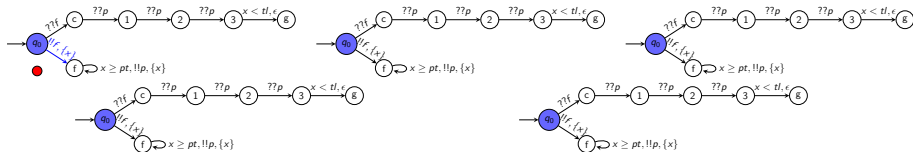
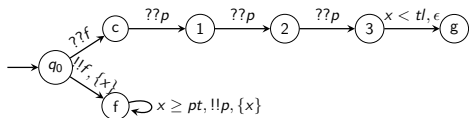


PTBP Network - Example



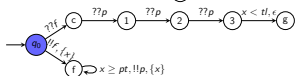
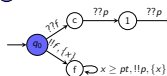
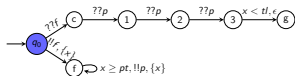
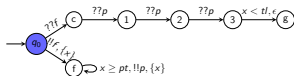
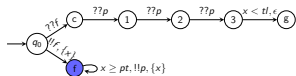
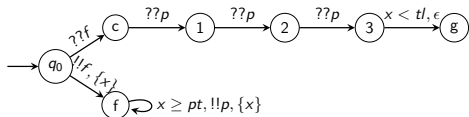
$$\begin{pmatrix} q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \end{pmatrix}$$

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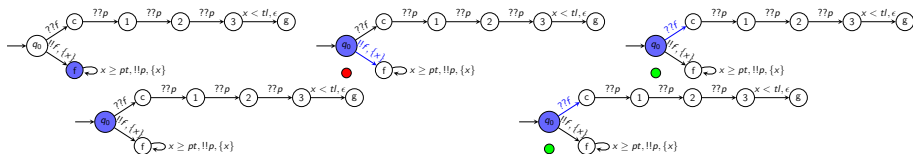
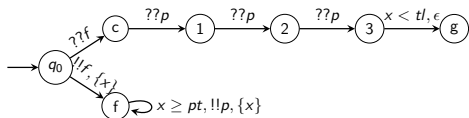
$$\begin{pmatrix} q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \end{pmatrix} \xrightarrow{0.1.1.f, \emptyset}$$

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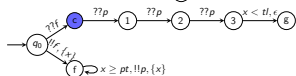
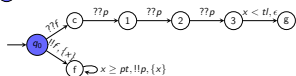
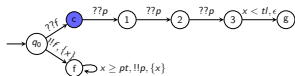
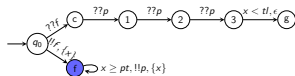
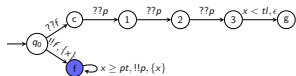
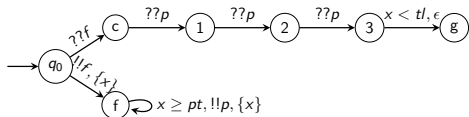
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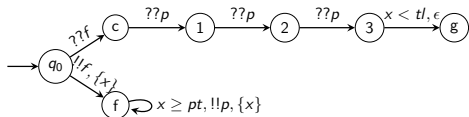
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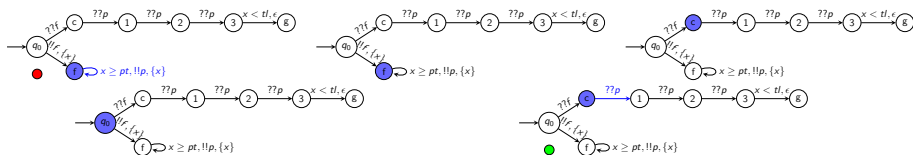


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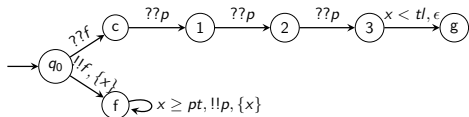


► $pt \geq 5.4$

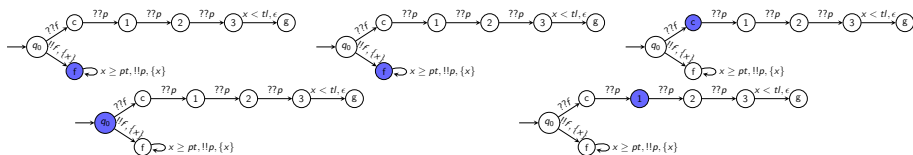


$$\begin{pmatrix} q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \end{pmatrix} \xrightarrow{0.1.1, f, 0} \begin{pmatrix} f, 0 \\ q_0, 0.1 \\ q_0, 0.1 \\ q_0, 0.1 \\ q_0, 0.1 \end{pmatrix} \xrightarrow{4.1.2, f, \{3,5\}} \begin{pmatrix} f, 4.1 \\ f, 0 \\ c, 4.2 \\ q_0, 4.2 \\ c, 4.2 \end{pmatrix} \xrightarrow{1.3.1, p, \{5\}}$$

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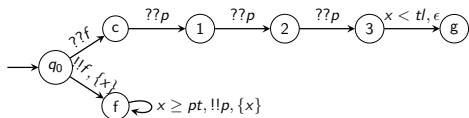


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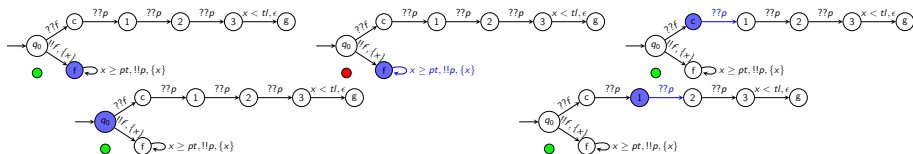
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PTBP Network - Example



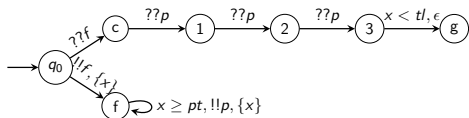
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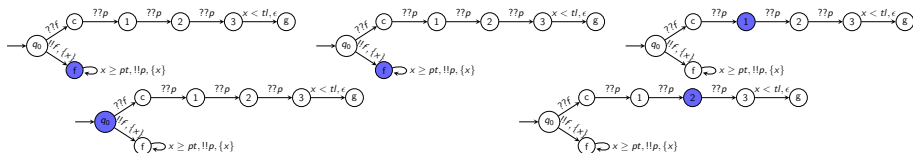


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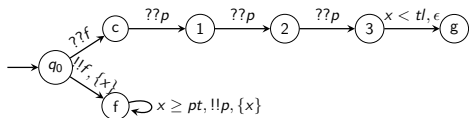


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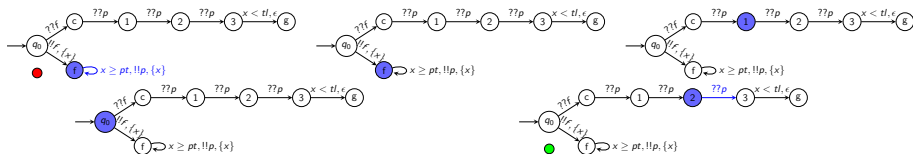


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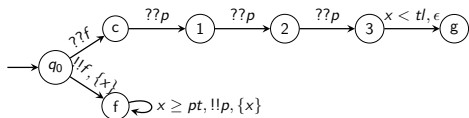


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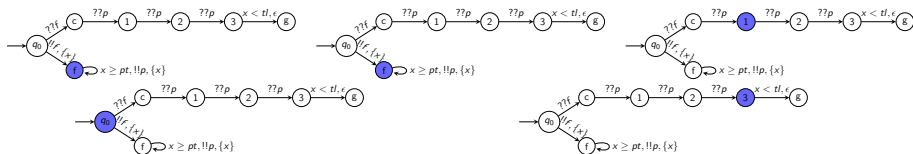


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PTBP Network - Example

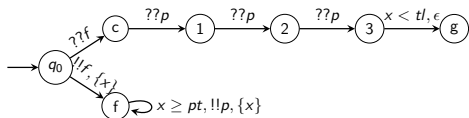


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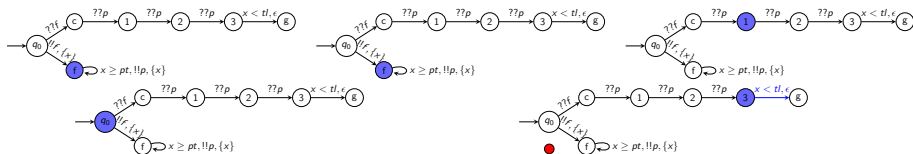


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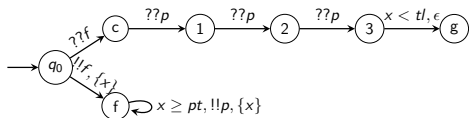


- ▶ $pt \geq 5.4$
- ▶ $pt \geq 3.1$
- ▶ $pt \geq 3$
- ▶ $tl \leq 8.5$

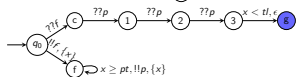
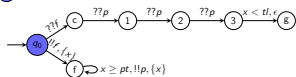
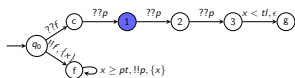
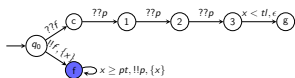
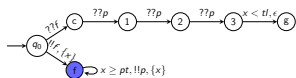


$$\begin{pmatrix} q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \end{pmatrix} \xrightarrow{0.1.1, f, 0} \begin{pmatrix} f, 0 \\ q_0, 0.1 \\ q_0, 0.1 \\ q_0, 0.1 \\ q_0, 0.1 \end{pmatrix} \xrightarrow{4.1.2, f, \{3,5\}} \begin{pmatrix} f, 4.1 \\ f, 0 \\ c, 4.2 \\ q_0, 4.2 \\ c, 4.2 \end{pmatrix} \xrightarrow{1.3.1, p, \{5\}} \begin{pmatrix} f, 0 \\ f, 1.3 \\ c, 5.5 \\ q_0, 5.5 \\ 1, 5.5 \end{pmatrix} \xrightarrow{1.8.2, p, \{1,3,4,5\}} \begin{pmatrix} f, 1.8 \\ f, 0 \\ 1, 7.3 \\ q_0, 7.3 \\ 2, 7.3 \end{pmatrix} \xrightarrow{1.2.1, p, \{5\}} \begin{pmatrix} f, 0 \\ f, 1.2 \\ 1, 8.5 \\ q_0, 8.5 \\ 3, 8.5 \end{pmatrix} \xrightarrow{0.5, \epsilon, 0}$$

PTBP Network - Example



- ▶ $pt \geq 5.4$
- ▶ $pt \geq 3.1$
- ▶ $pt \geq 3$
- ▶ $tl \leq 8.5$



$$\begin{pmatrix} q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \\ q_0, 0 \end{pmatrix} \xrightarrow{0.1, 1, f, 0} \begin{pmatrix} f, 0 \\ q_0, 0.1 \\ q_0, 0.1 \\ q_0, 0.1 \\ q_0, 0.1 \end{pmatrix} \xrightarrow{4.1, 2, f, \{3, 5\}} \begin{pmatrix} f, 4.1 \\ f, 0 \\ c, 4.2 \\ q_0, 4.2 \\ c, 4.2 \end{pmatrix} \xrightarrow{1.3, 1, p, \{5\}} \begin{pmatrix} f, 0 \\ f, 1.3 \\ c, 5.5 \\ q_0, 5.5 \\ 1, 5.5 \end{pmatrix} \xrightarrow{1.8, 2, p, \{1, 3, 4, 5\}} \begin{pmatrix} f, 1.8 \\ f, 0 \\ 1, 7.3 \\ q_0, 7.3 \\ 2, 7.3 \end{pmatrix} \xrightarrow{1.2, 1, p, \{5\}} \begin{pmatrix} f, 0 \\ f, 1.2 \\ 1, 8.5 \\ q_0, 8.5 \\ 3, 8.5 \end{pmatrix} \xrightarrow{0.5, \epsilon, 0} \begin{pmatrix} f, 0 \\ f, 1.2 \\ 1, 8.5 \\ q_0, 8.5 \\ g, 8.5 \end{pmatrix}$$

Considered Problems

We consider *Parametric Reachability* problems, i.e. **“Does there exist a network size N satisfying a given reachability property”?**

4 potential declinations:

\exists -EF-emptiness: $\exists N \in \mathbb{N}, \exists p \in \text{bounds}, \exists \rho \in \text{Execs}, \rho \models \diamond q_f$

\exists -EF-universality: $\exists N \in \mathbb{N}, \forall p \in \text{bounds}, \exists \rho \in \text{Execs}, \rho \models \diamond q_f$

\exists -AF-emptiness: $\exists N \in \mathbb{N}, \exists p \in \text{bounds}, \forall \rho \in \text{Execs}, \rho \models \diamond q_f$

\exists -AF-universality: $\exists N \in \mathbb{N}, \forall p \in \text{bounds}, \forall \rho \in \text{Execs}, \rho \models \diamond q_f$

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AF-problems in Reconfigurable semantics

AF-Problems in Reconfigurable Semantics

\exists -AF-emptiness and \exists -AF-universality are **decidable** for 1 clock PTBP but **undecidable** for (L/U)-PTBP with 3 clocks or more.

Intuition: In this context, AF problems are equivalent to the same problems in networks of size 1 (because receiver sets can be empty).

EF-problems in Reconfigurable semantics

We knew from timed networks (trivial encoding):

Without timing parameters

- ▶ \exists -EF is **decidable** for PTBP without parameters and with one clock per process and **undecidable** with two clocks per process.
- ▶ \exists -EF-emptiness and \exists -EF-universality problems are **undecidable** for PTBP with two clocks.

EF-problems in Reconfigurable semantics

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- ▶ \exists -EF-emptiness and \exists -EF-universality problems are **undecidable** for PTBP with two clocks.

We prove that

EF-Problems in Reconfigurable Semantics

The \exists -EF-emptiness and \exists -EF-universality problems are **undecidable** for PTBP with at least one clock.

Proof: Reduction of the halting and boundedness problems for two-counter machine.

Undecidability in Clique semantics

From previous work, we know that

AF-Problems in the Clique semantics

The \exists -AF problem is **undecidable** for PTBP with no clock in the clique semantics.

Intuition: Reduction of the halting problem of a two-counter machine. The values of the counters are encoded by the number of processes in given states.

EF-Problems in Clique Semantics

The \exists -EF-emptiness and \exists -EF-universality problems are **undecidable** for PTBP with at least one clock.

Same proof as for reconfigurable semantics

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1-clock L/U PTBP

Since the problems are undecidable in timed Networks for 2 clocks with no parameters, we focus on L/U-PTBP with a single clock.

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Why are they interesting?

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Why are they interesting?

Monotonicity

In L/U-PTBP, increasing the value of U-parameters and decreasing the value of L-parameters does not remove behaviors (preserves reachability).

Decidable EF-problems for L/U-PTBP with 1 clock

Recall that the EF-Problem is decidable for PTBP with a single clock and no timing parameters. As a consequence,

Decidability of (some) EF-Problems

- ▶ The \exists -EF-universality problem is **decidable** for closed bounded L/U-PTBP with one clock in both semantics.
- ▶ The \exists -EF-emptiness problem is **decidable** for (open or closed) bounded L/U-PTBP with one clock in both semantics.

Intuition: Replace the parameters by their maximal (U-parameters) and/or minimal (L-parameters) values. Use monotonicity to solve the problems.

Undecidable EF-problems for L/U-PTBP with 1 clock

When the parameters are open-bounded, or unbounded, \exists -EF-universality becomes undecidable.

Undecidability for open-bounded/unbounded L/U-PTBP

- ▶ The \exists -EF-universality problem is **undecidable** for open bounded L/U-PTBP with one clock in the clique semantics.
- ▶ \exists -EF-universality in the clique semantics is **undecidable** already with a single clock for U-PTBP with open bounds on the left, and L-PTBP with infinity as right bound.

Intuition: Reduction from the halting problem of a two-counter machine.

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Conclusion and Future Work

	1-c	2-c	3-c	1-L/U		2-L/U	3-L/U
				cb	ob		
\exists -EF-empt.	<i>Th3</i>			L5		<i>L1</i>	
\exists -EF-univ.	<i>Th3</i>			L4 <i>open</i>		<i>L1</i>	
\exists -AF	Th1 <i>open</i>	<i>Th1</i>	<i>Th1</i>	Th1	<i>open</i>	<i>Th1</i>	

(a) Reconfigurable semantics

	PTBP	L/U		L or U	
		cb	ob	cb	ob
\exists -EF-empt.	<i>L2</i>	L5		L5	
\exists -EF-univ.	<i>L2</i>	L4 <i>Th5</i>	L4 <i>L6</i>		
\exists -AF	<i>Th4</i>				

(b) Clique semantics for 1 clock

Table: Summary of our contributions

Conclusion and Future Work

	1-c	2-c	3-c	1-L/U		2-L/U	3-L/U
				cb	ob		
\exists -EF-empt.	<i>Th3</i>			L5		<i>L1</i>	
\exists -EF-univ.	<i>Th3</i>			L4 <i>open</i>		<i>L1</i>	
\exists -AF	Th1 <i>open</i>	<i>Th1</i>	<i>Th1</i>	Th1		<i>open</i>	<i>Th1</i>

(a) Reconfigurable semantics

	PTBP	L/U		L or U	
		cb	ob	cb	ob
\exists -EF-empt.	<i>L2</i>	L5		L5	
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(b) Clique semantics for 1 clock

Table: Summary of our contributions

- ▶ Open problems (2-clocks, reconfigurable is well-known)
- ▶ Exact Synthesis for decidable subclasses
- ▶ Other communication topologies/semantics
- ▶ Universality for network sizes

Conclusion and Future Work

	1-c	2-c	3-c	1-L/U		2-L/U	3-L/U
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\exists -EF-empt.	<i>Th3</i>			L5		<i>L1</i>	
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\exists -AF	Th1 <i>open</i>	<i>Th1</i>	Th1	Th1 <i>open</i>		<i>Th1</i>	

(a) Reconfigurable semantics

	PTBP	L/U		L or U	
		cb	ob	cb	ob
\exists -EF-empt.	<i>L2</i>	L5		L5	
\exists -EF-univ.	<i>L2</i>	L4 <i>Th5</i>	L4 <i>L6</i>		
\exists -AF	<i>Th4</i>				

(b) Clique semantics for 1 clock

Table: Summary of our contributions

- ▶ Open problems (2-clocks, reconfigurable is well-known)
- ▶ Exact Synthesis for decidable subclasses
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Thank you for your Attention