

ICTAC '09

IMITATOR: A Tool for Synthesizing Constraints on Timing Bounds of Timed Automata

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Context: Real-Time Concurrent Systems

- Verification of safety property: ensure the **absence** of any **bad behavior** (reachability property)
- A well-known method: CEGAR (Counter-Example Guided Abstraction Refinement [CGJ⁺00])
 - ▶ They use (repeatedly) an example of **bad behavior** in order to **refine** the model of the system
- We present here a **generalization** method
 - ▶ Implementation of the **inverse method** [ACEF09]
 - ▶ We use a given example of **good behavior** in order to **generalize** the model of the system

Outline

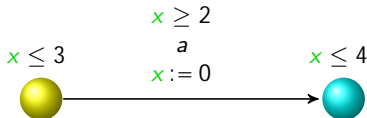
- 1 The Modeling Framework of Parametric Timed Automata
- 2 Presentation of IMITATOR
 - Overview
 - A Motivating Example
 - The General Idea
 - Application to the Example
- 3 Implementation and Case Studies
- 4 Conclusion and Future Works

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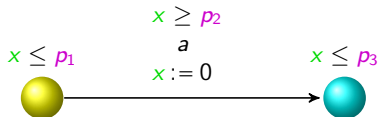
Timed Automata

- Finite state automata (sets of **locations** and **labeled transitions**) augmented with
 - ▶ A set X of **clocks** (i.e., real-valued variables evolving linearly at the same rate)
- Operations
 - ▶ Location **invariant**: property to be verified by the **clocks** to stay at a location
 - ▶ Transition **guard**: property to be verified by the **clocks** to enable a transition
 - ▶ Clock **reset**: clocks can be set to 0 at each transition



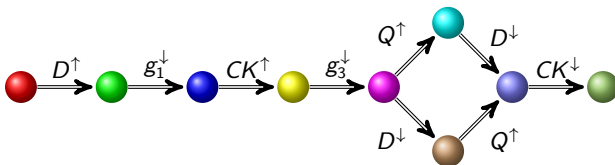
Parametric Timed Automata (PTA)

- Finite state automata (sets of **locations** and **labeled transitions**) augmented with
 - ▶ A set X of **clocks** (i.e., real-valued variables evolving linearly at the same rate)
 - ▶ A set P of **parameters** (i.e., unknown constants), used in guards and invariants
- Operations
 - ▶ Location **invariant**: property to be verified by the **clocks** and the **parameters** to stay at a location
 - ▶ Transition **guard**: property to be verified by the **clocks** and the **parameters** to enable a transition
 - ▶ Clock **reset**: clocks can be set to 0 at each transition



States and Traces

- **Symbolic state** of a PTA: couple (q, C) , where
 - ▶ q is a location,
 - ▶ C is a **constraint** (conjunction of inequalities) over the **parameters**
- **Trace** (or run) over a PTA: finite alternating sequence of **locations** and transitions



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Inputs and Outputs (1/2)



Inputs and Outputs (2/2)

- **Input**

- ▶ A PTA \mathcal{A}
- ▶ A **reference instantiation** π_0 of all the parameters of \mathcal{A}
 - ★ Exemplifying a good behavior
(all traces under π_0 represent good behaviors)

π_0

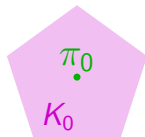
Inputs and Outputs (2/2)

- **Input**

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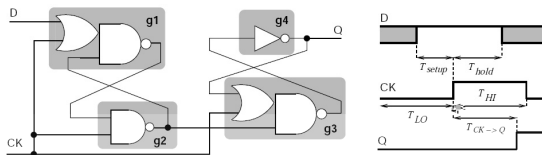
- **Output:** generalization

- ▶ A **constraint** K_0 on the parameters such that
 - ★ $\pi_0 \models K_0$
 - ★ For all instantiation $\pi \models K_0$, the set of traces under π is the same as the set of traces under π_0



An Example of Circuit (1/2)

- Memory circuit [CC07]



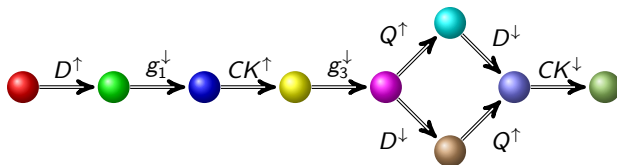
- 4 elements: G_1, G_2, G_3, G_4
- 2 input signals (D and CK), 1 output signal (Q)
- 4 internal signals: g_1, g_2, g_3, g_4 (output of each element)
- Timed parameters of the system
 - Traversal delays of the gates by the electric current
 - ★ Parametric interval; example for element g_1 : $[\delta_1^-, \delta_1^+]$
 - Stabilization time of input signal D
 - ★ T_{Setup}, T_{Hold}
 - CK low and high durations
 - ★ T_{LO}, T_{HI}

An Example of Circuit (2/2)

- We are given an instantiation of the parameters

$$\begin{array}{cccc}
 T_{HI} = 20 & T_{LO} = 15 & T_{Setup} = 10 & T_{Hold} = 15 \\
 \delta_1^- = 1 & \delta_1^+ = 1 & \delta_3^- = 5 & \delta_3^+ = 6 \\
 \delta_2^- = 8 & \delta_2^+ = 10 & \delta_4^- = 3 & \delta_4^+ = 5
 \end{array}$$

- ▶ This instantiation point guarantees some (good) behavior



- We are looking for other instantiations of the parameters leading to the same (good) behavior

The General Idea of IMITATOR

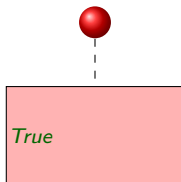
Start with $K_0 = True$

- 1 Compute the set S of reachable symbolic states under K_0
- 2 Refine K_0 by removing a π_0 -incompatible state from S
 - ▶ Select a π_0 -incompatible state (q, C) within S (i.e., $\pi_0 \not\models C$)
 - ▶ Select a π_0 -incompatible inequality J within C (i.e., $\pi_0 \not\models J$)
 - ▶ Add $\neg J$ to K_0
- 3 Go to (1)

Application to the Memory Circuit Example

 $\pi_0 :$

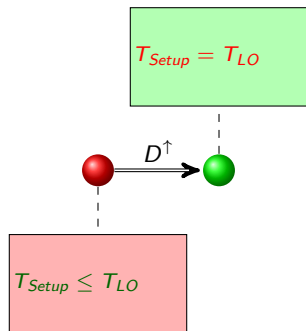
$\delta_1^- = 1$	$\delta_1^+ = 1$	$T_{HI} = 20$
$\delta_2^- = 8$	$\delta_2^+ = 10$	$T_{LO} = 15$
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$\delta_4^- = 3$	$\delta_4^+ = 5$	$T_{Hold} = 15$

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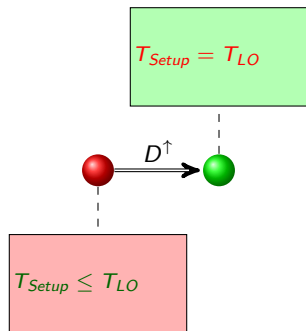
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$$K_0 = T_{Setup} < T_{LO}$$

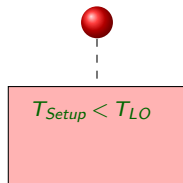


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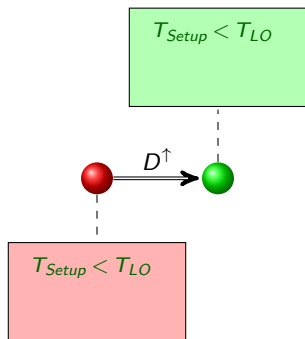


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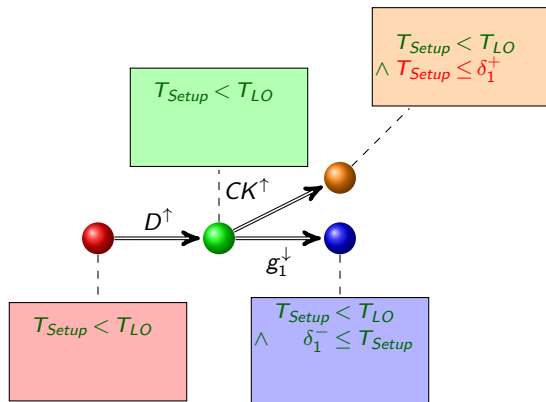
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Application to the Memory Circuit Example

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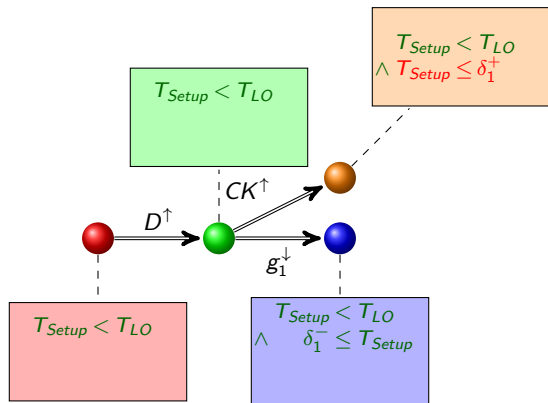
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$$\wedge T_{Setup} > \delta_1^+$$



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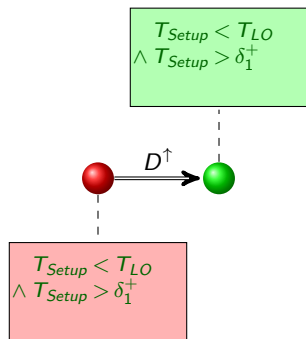
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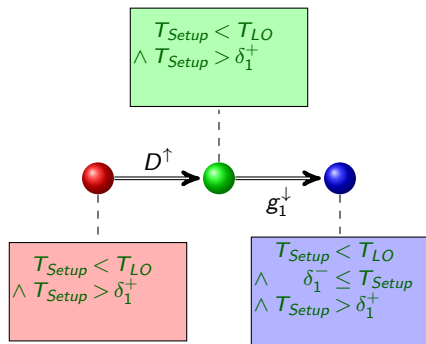
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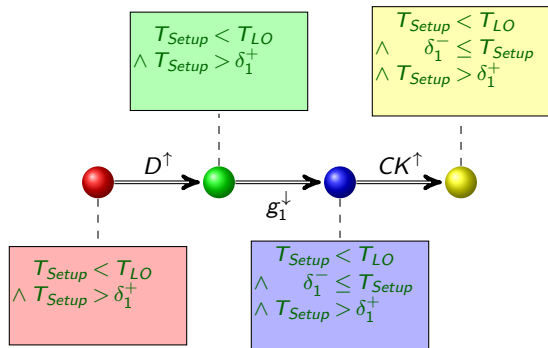
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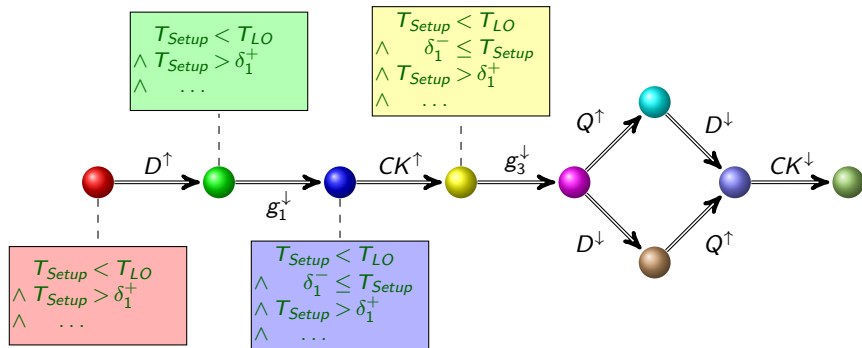
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 $K_0 =$

$$\begin{aligned}
 & T_{Setup} < T_{LO} \quad \wedge \quad \delta_3^+ + \delta_4^+ < T_{HI} \\
 & \wedge T_{Setup} > \delta_1^+ \quad \wedge \quad \delta_3^+ + \delta_4^+ \geq T_{Hold} \\
 & \wedge \quad \delta_3^+ < T_{Hold} \quad \wedge \quad \delta_3^- + \delta_4^- \leq T_{Hold} \\
 & \wedge \quad \delta_1^- > 0
 \end{aligned}$$



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Implementation

- IMITATOR: program written in Python
 - ▶ IMITATOR: “Inverse Method for Inferring Time Abstract Behavior”
 - ▶ 1500 lines of code
 - ▶ 4 man-months of work
 - ▶ Calls the parametric model checker HYTECH [HHWT95]
 - ★ Tool written in C
 - ★ Used by IMITATOR for the computation of the *Post* operation
- IMITATOR is available on its Web page
 - ▶ <http://www.lsv.ens-cachan.fr/~andre/IMITATOR>

Case Studies

- Some real cases treated
 - ▶ SPSMALL [CEFX09]: memory circuit (ST-Microelectronics)
 - ★ Allow to optimize input timing bounds
 - ▶ SIMOP [AAC⁺09]: model of manufacturing system with sensors and controllers communicating through a network
 - ★ Allow to define zones of good behavior
- Computation times of various case studies [AEF09]
 - ▶ Experiences conducted on an Intel Quad Core 3 Ghz with 3.2 Gb

Example	# of PTAs	loc. per PTA	# of clocks	# of param.	# of iter.	Post*	K ₀	CPU time
Flip-flop [CC07]	5	[4, 16]	5	12	8	11	7	2 s
RCP [SS01]	5	[6, 11]	6	5	18	154	2	70 s
CSMA/CD [NSY92]	3	[6, 7]	4	3	21	294	3	108 s
SPSMALL [CEFX09]	10	[3, 8]	10	22	31	31	23	78 min
SIMOP [AAC ⁺ 09]	5	[6, 16]	9	16	51	848	7	419 min

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Final Remarks

- **Inverse method** implemented in IMITATOR
 - ▶ Modeling of a system with **parametric timed automata**
 - ▶ Starting with an **instantiation point** π_0 of the system, IMITATOR generates a **constraint** K_0 **on the parameters** guaranteeing the same set of traces

- **Advantages**
 - ▶ Sufficient termination conditions
 - ▶ Useful to optimize timing bounds of systems
 - ▶ Powerful even on **fully parameterized** big systems
 - ★ Can handle dozens of parameters

- **Drawbacks**
 - ▶ The zone (set of points) generated by the constraint is rather small compared to exhaustive point by point methods
 - ▶ The generated constraint is not **maximal**: it is possible to find valuations $\pi \not\models K_0$ s.t. the set of traces under π and π_0 are the same

Future Works

- Improve the constraint K_0
 - ▶ Goal: generate a maximal constraint K_0
 - ★ The maximal K_0 may exist under a disjunctive form only
 - ▶ Use IMITATOR in an incremental way
 - ★ Given a constraint K generated by IMITATOR, run IMITATOR again on a new point $\pi \not\models K$
- Increase the scalability
 - ▶ Write an *ad hoc* tool instead of using HYTECH
 - ▶ Use a library of polyhedra

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