Iterative Bounded Synthesis for Efficient Cycle Detection in Parametric Timed Automata

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Parametric Timed Automata

Ingredients of PTA (Alur, Henzinger, Vardi '93)

- Finite number of locations ℓ_0, ℓ_1, ℓ_2 . . . . transitions in between
- Clocks x, y, z . . . . advance at the same rate
- Guards, Invariants, Clock resets . . . . specify timing constraints
- Parameters p, q, r . . . . unknown constants used in constraints

Example: the light switch

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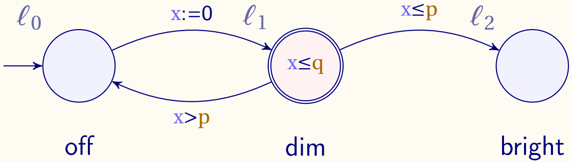

Parametric Synthesis

- Specification and Verification of Real-time systems
- Timing parameters unknown (at design time)
- Goal: synthesise parameter constraints for which requirements hold
- Here: Liveness properties – Büchi conditions

Example: there is an infinite accepting run if and only if $q > p$

Problem statement

- The problem is undecidable for PTA
- How to search an infinite state space for cycles?
- Examples and Semi-algorithms – completeness (in the limit)

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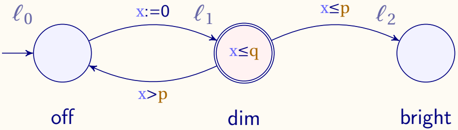

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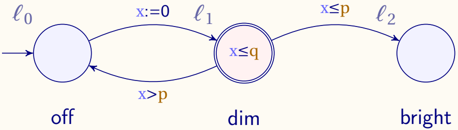

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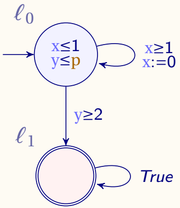

- Exploration using the self-loop on ℓ_0:
  Infinite branch without accepting cycle
- Accepting first strategy:
  Constraint synthesized: $p \geq 2$
- Exploration ends with cumulative pruning

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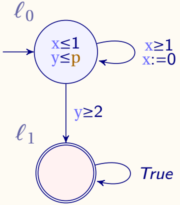
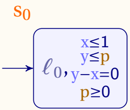


Parametric Zone Graph: (location, convex polyhedron)



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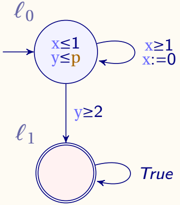

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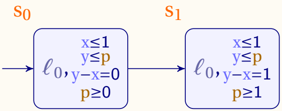

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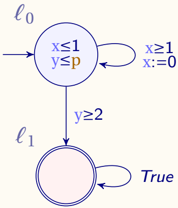

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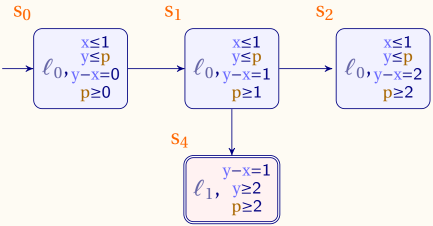

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Accepting-First and Pruning

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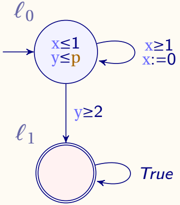

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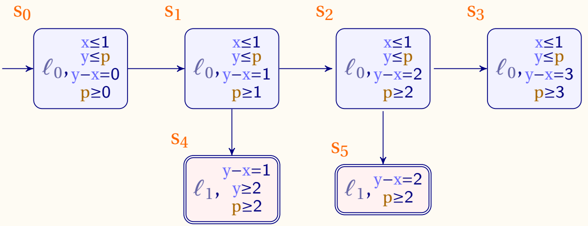

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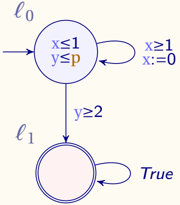

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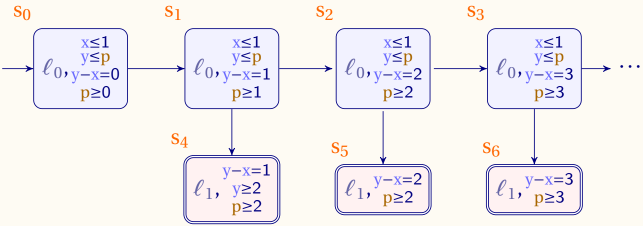

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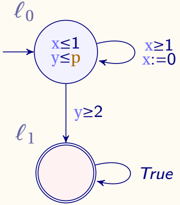

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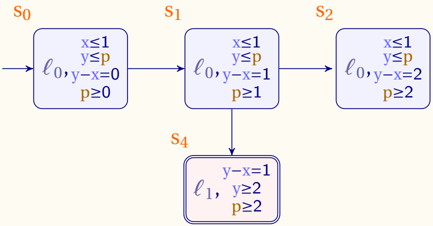

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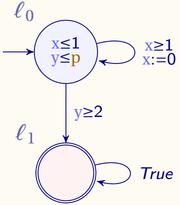

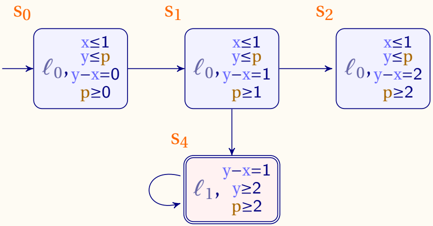

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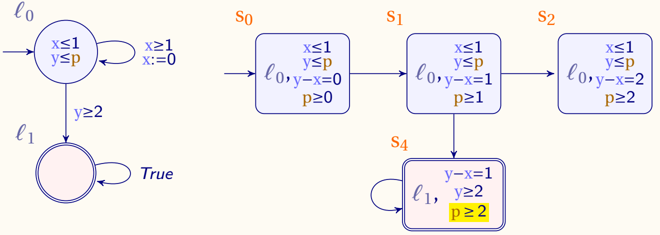

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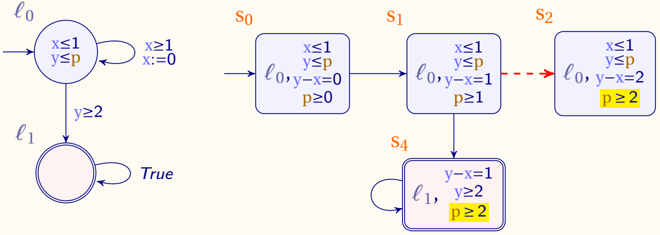

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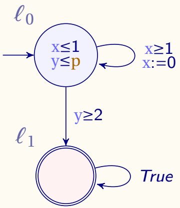
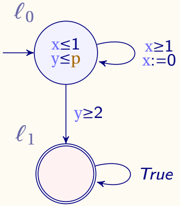
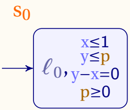
Layering Strategy



- Exploration by layers, having the same constraints on parameters
- The constraints zones decrease along a path
- Constraint synthesized at ℓ_1
- Exploration ends with cumulative pruning





- Exploration by layers, having the same constraints on parameters
- The constraints zones decrease along a path
- Constraint synthesized at s_0
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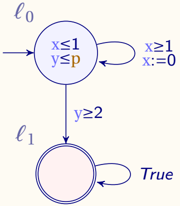

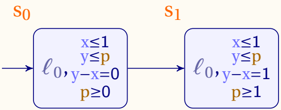

- Exploration by layers, having the same constraints on parameters
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- Constraint synthesized at s_5
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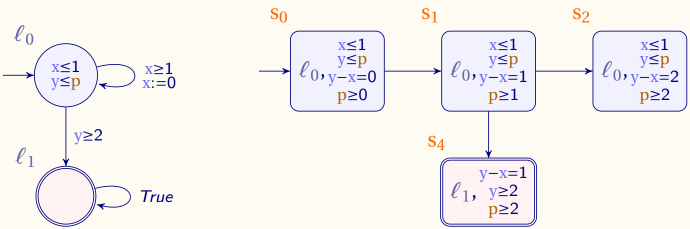

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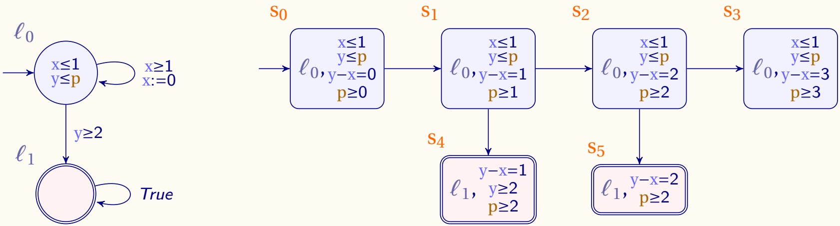

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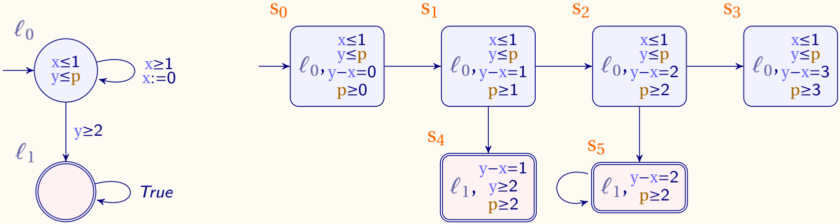

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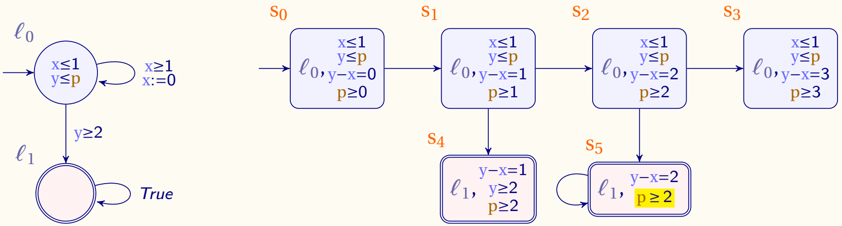

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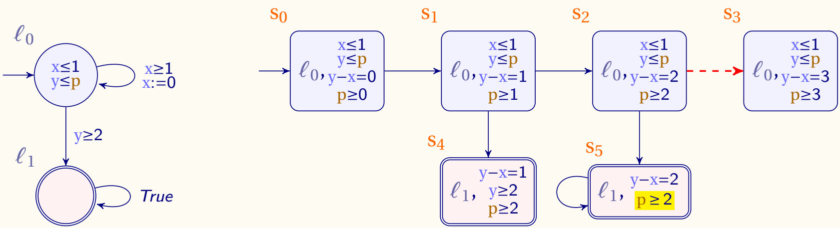

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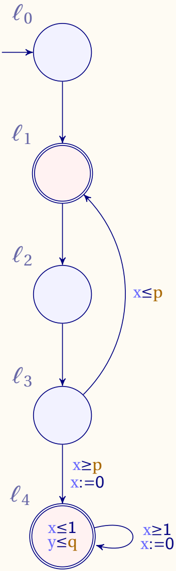
Look-Ahead Strategy



- From s_4, it is possible to engage in an infinite run .... not a lasso!
- Look-ahead strategy: s_3 has an accepting successor "on the stack"
- Constraint $p \geq 0 \land q \geq 0$ is synthesized immediately
- Cumulative pruning prunes away the infinite run starting in s_4

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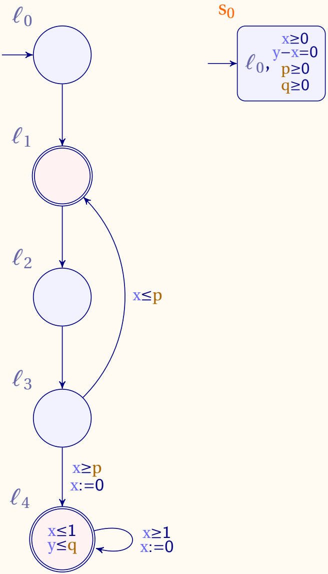

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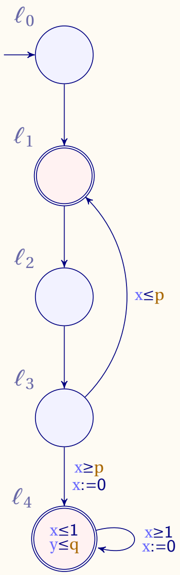

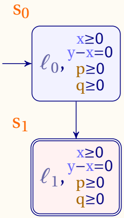

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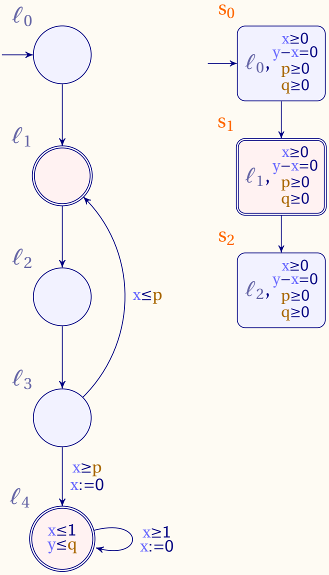

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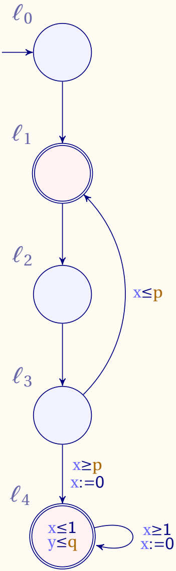

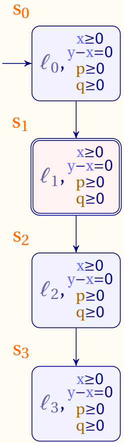

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Look-ahead strategy: s_9 has an accepting successor "on the stack"

Constraint $p \geq 0 \wedge q \geq 0$ is synthesized immediately

Cumulative pruning prunes away the infinite run starting in s_4

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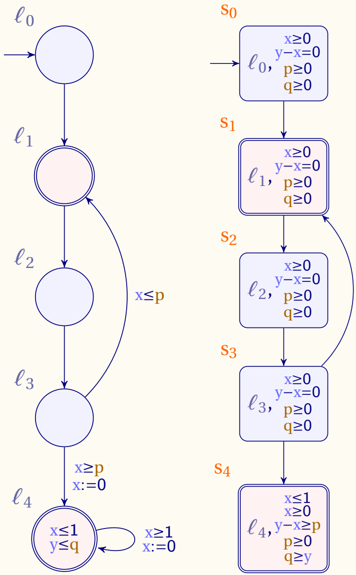

From s_0, it is possible to engage in an infinite run .... not a lasso!

Look-ahead strategy: s_1 has an accepting successor "on the stack"

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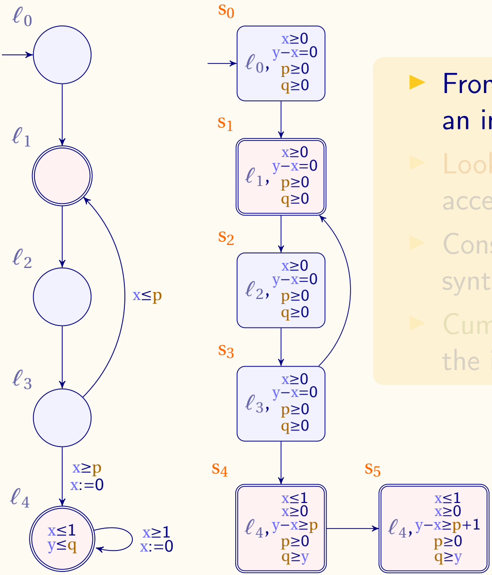

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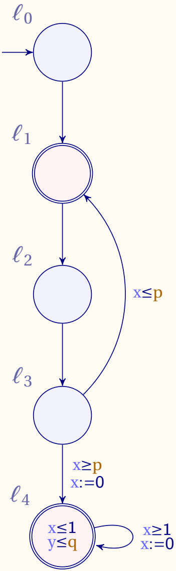

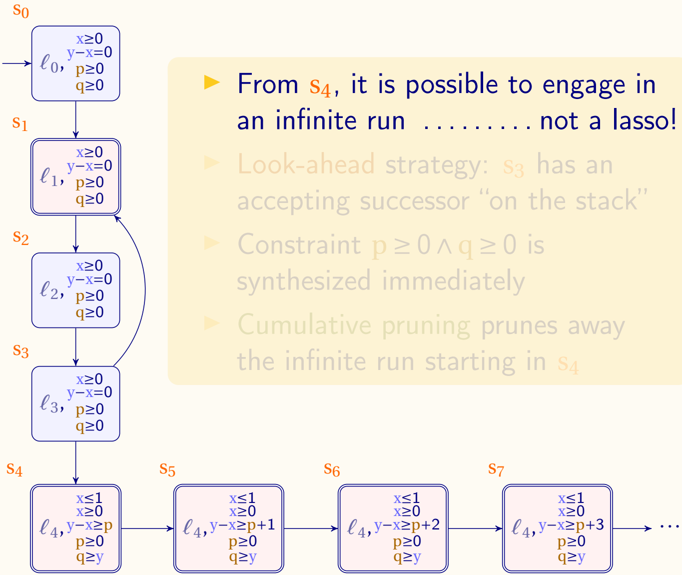

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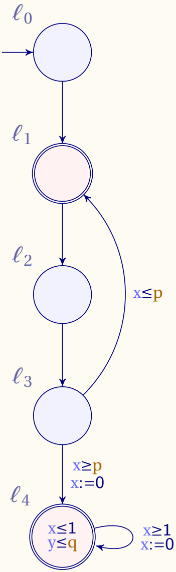

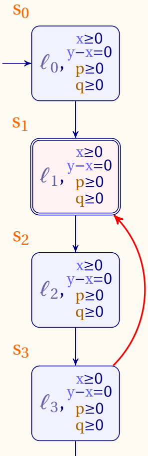

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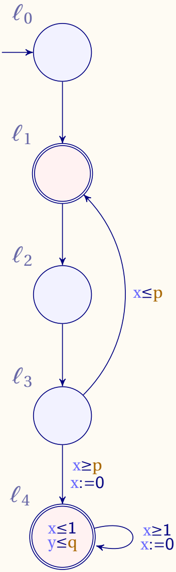

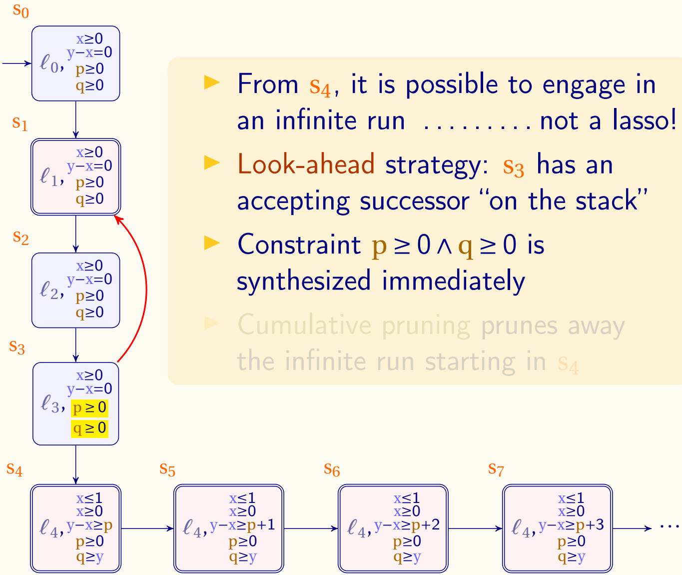

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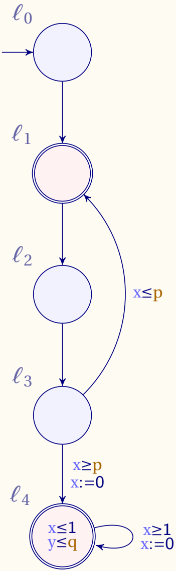

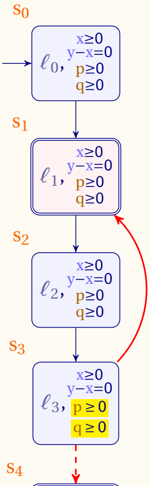

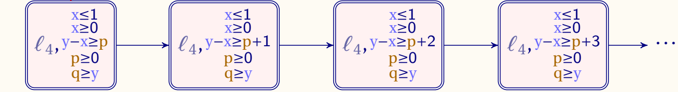

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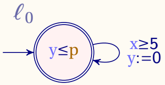
Subsumption Strategy



- s_1 is subsumed by s_2, so s_2 simulates s_1
- There must be an infinite accepting run when $p \geq 5$!
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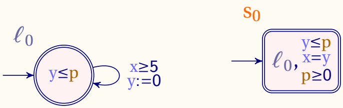

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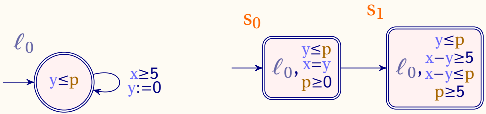

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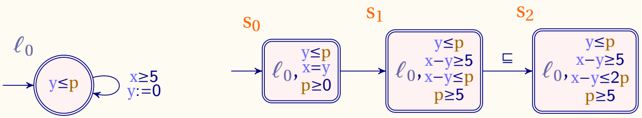

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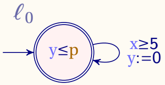

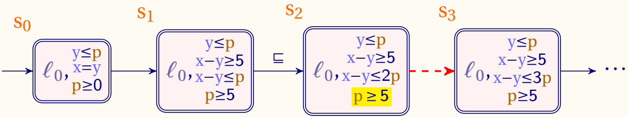

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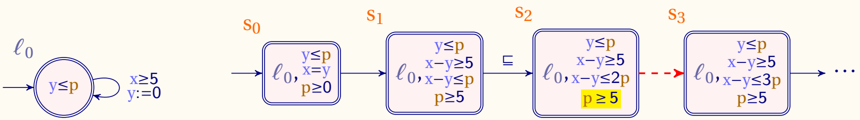

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  - Cumulative Pruning
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- Three scenarios:
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- Evaluated and compared all strategies on 26 benchmarks[3]

- Applied to a case study: Bounded Retransmission Protocol
  - Synthesized more liberal constraints than in previous work (D'Argenio, Vaandrager)

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TACAS ★ Artifact ★ AEC ★ Evaluated ★ Consistent ★ Complete ★ Well Documented ★ Easy to Reuse ★

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Correctness in the limit (ideal)

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Pathological Cases

Solution set is not a finite set of convex polyhedra

The set of solutions is not a finite union: $p = 1 \vee p = 2 \vee p = 3 \vee \cdots$

An infinite accepting run that is not feasible

The PZG has an infinite accepting run, but its constraint $\bigcap_i (p \geq i) = \emptyset$

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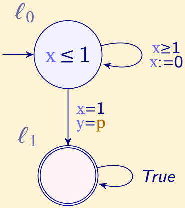

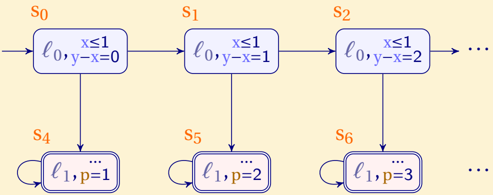

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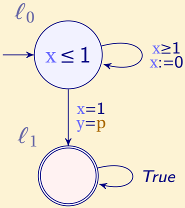

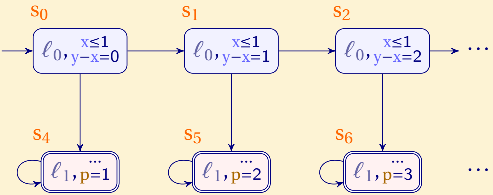

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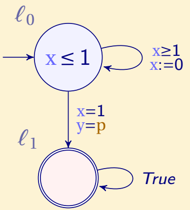

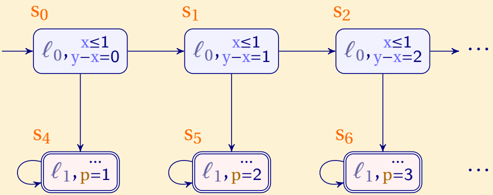

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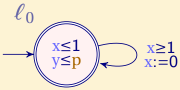

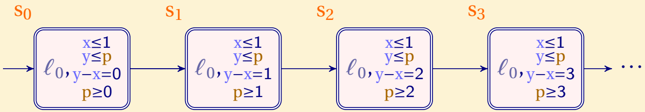

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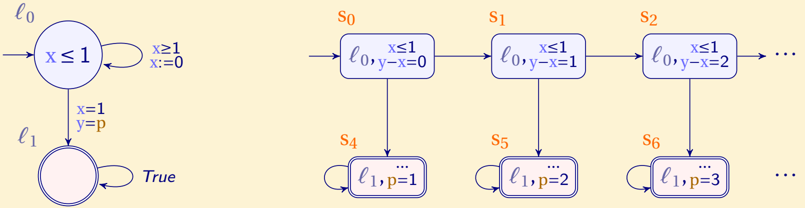

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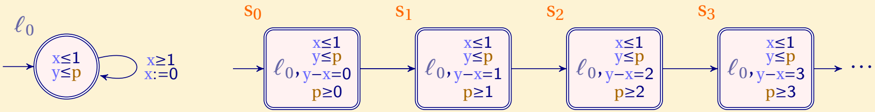

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Summary of the Results

Algorithm	terminates	partially sound	partially complete	sound in the limit	complete in limit	complete for lassos	$\mathscr{A}_1$	$\mathscr{A}_2$	$\mathscr{A}_3$	$\mathscr{A}_4$	$\mathscr{A}_5$	$\mathscr{A}_6$
NDFS + strategies	×	✓	✓	✓	×	×	✓	×	×	(✓)	(L)	×
BFS + SCC	×	✓	✓	✓	×	✓	✓	×	×	(✓)	(✓)	×
Bound + deepening	×	✓	✓	✓	×	✓	✓	✓	×	(✓)	✓	×
Bounded (fixed n)	✓	✓	×	✓	×	×						
Naïve enumQ	××	(✓)	(✓)	✓	✓	✓						

Naïve enumeration:

- Enumerate all rational parameter values .... (Cantor)
- Check the resulting Timed Automaton for cycles .... (Alur & Dill)

Sender

- requests to transmit a large data package (size N=2)
- transmits data, with alternating bit and indications (lossy channel)
- retransmits messages not acknowledged (bound MAX=2)

Receiver

- reports the received packets to the other user
- sends acknowledgements back through a lossy channel

Timing parameters

TD	time delay of the communication channels
TS	time between subsequent transmissions by the sender
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The channels will not be used simultaneously

Exact constraint (2 s): $TS > 2 * TD$ (R1)

The receiver starts each session with a frame with “first-bit” indication

- Add (R1) to the initial constraint of the model
- Exact constraint (R2) (1 s):
  $SYNC + TS >= TR + TD \ \& \ TS > 2 * TD \ \& \ TR > 4 * TS + 3 * TD$

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