Model-based Testing and Model Checking for Safety-critical Hierarchical Systems

December 6, 2018

M.Sc. thesis in Computer Science by
Luigi Libero Lucio Starace

Università degli Studi di Napoli Federico II

This thesis work
An overview

- Verification of industrial controllers is the most critical and time-consuming phase in the development life-cycle.

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  - a logic to express linear properties of concurrent hierarchical computations;
  - a model checking procedure for hierarchical machines;

Outline

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Systems Verification

Systems verification
What it is all about

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The process of checking that a system meets certain requirements derived from a given *specification*.

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- Malfunctions may cause financial losses **or worse!**

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When classic techniques fall short

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Traditional verification techniques like testing and code inspection are effective at detecting errors, **but**:

- *hopelessly inadequate to prove their absence*!
- ineffective with complex concurrent systems;
- expensive.

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The model-based approach

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  - model-based testing (automatic test case generation);
  - model checking.

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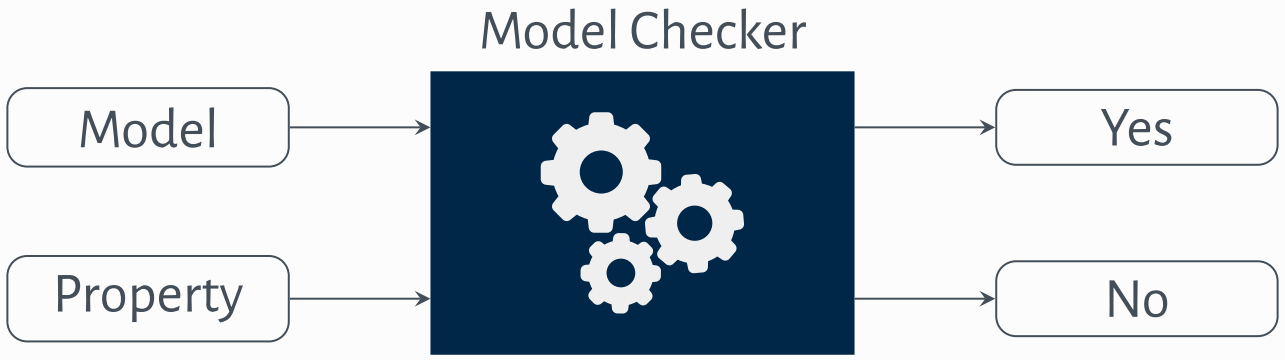

- produces counter-examples;
- can be integrated earlier in the development process.

Previous research

The CRYSTAL project

CRitical sYSTems engineering AcceLeration

- driven by real-world industrial use cases from the automotive, aerospace, rail and health sector;
- produce or improve tool chains to reduce design/verification costs.

ARTEMIS

SEVENTH FRAMEWORK PROGRAMME

Previous research
within the CRYSTAL project

- introduced *Dynamic State Machines* (DSTM);

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- introduced *Dynamic State Machines* (DSTM);
- devised an automatable test case generation procedure for DSTM;

Dynamic State Machines

Dynamic State Machines

A first example

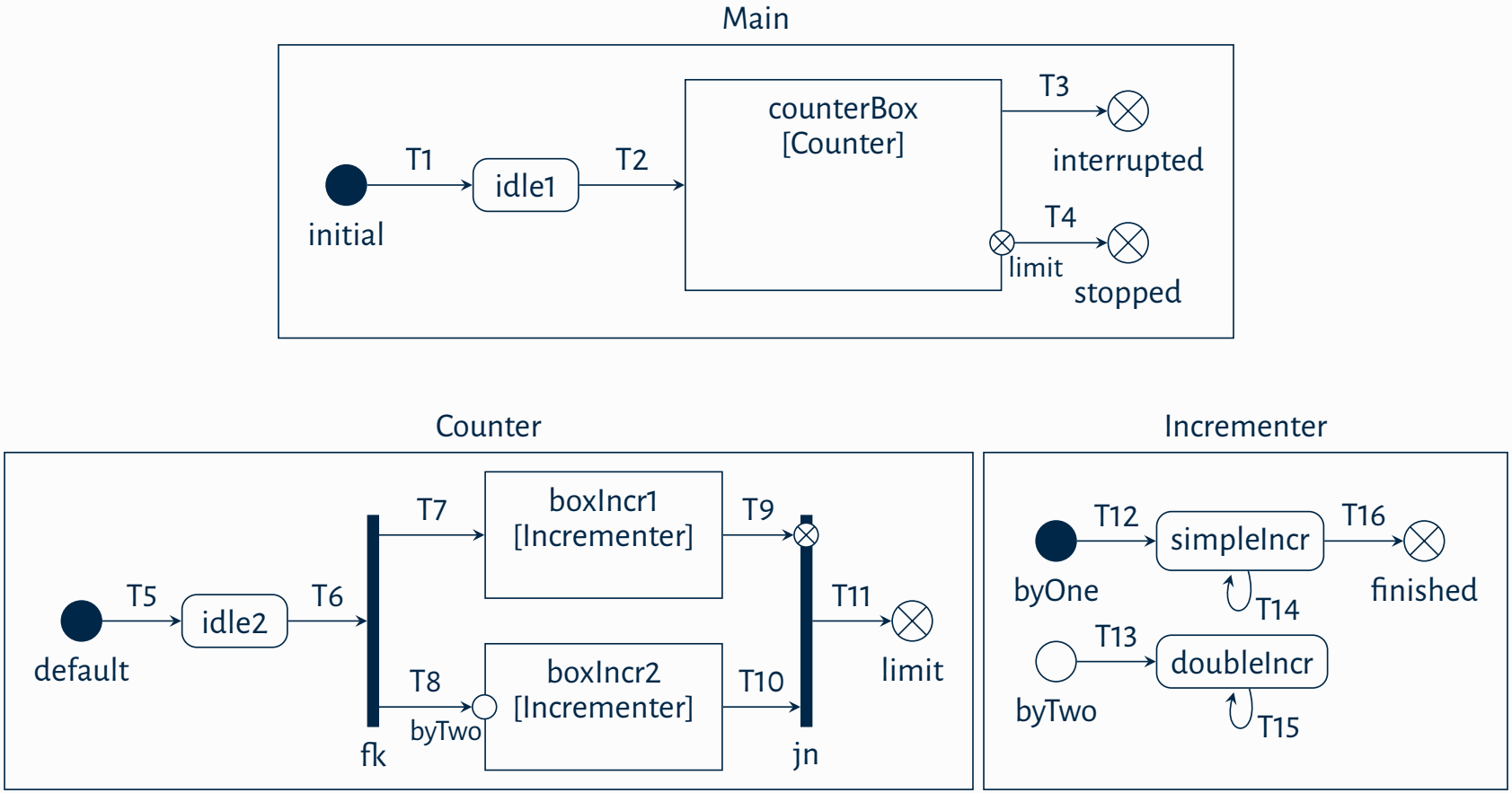
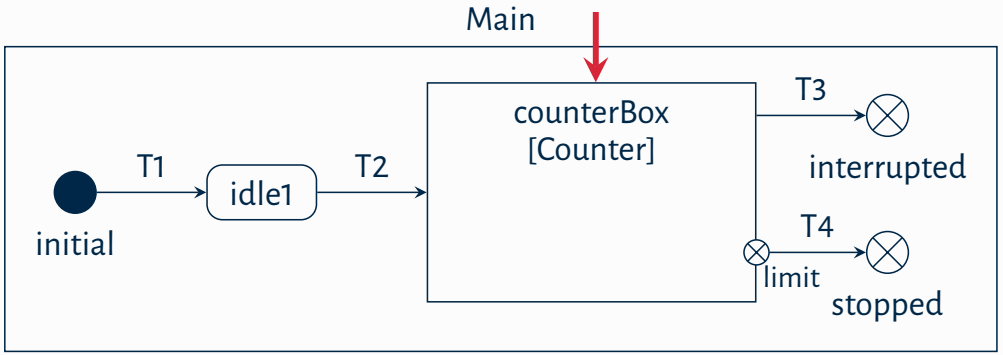
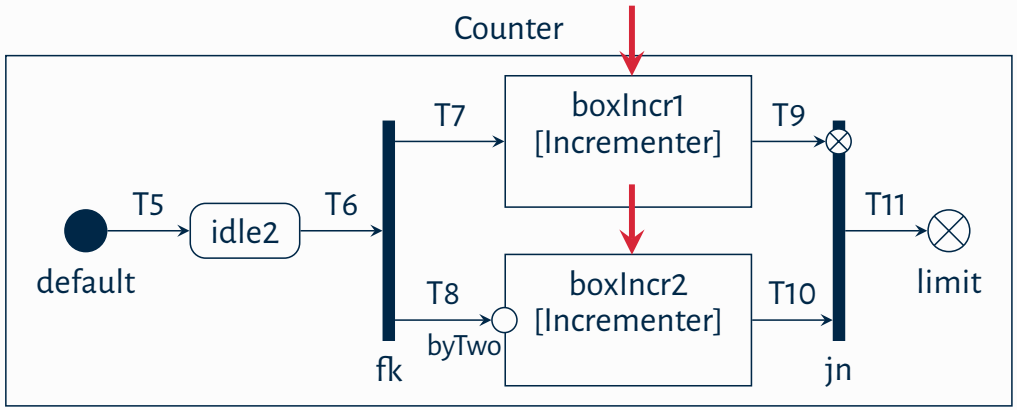


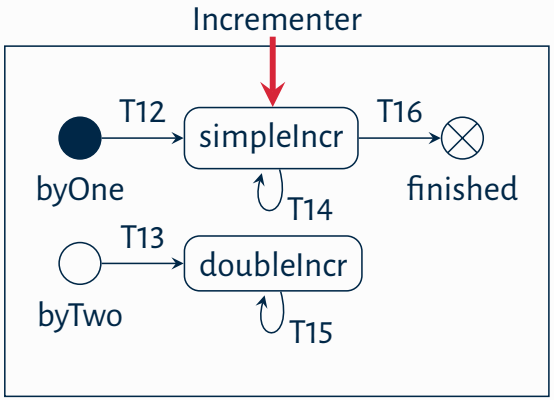
Figure: A simple DSTM specification

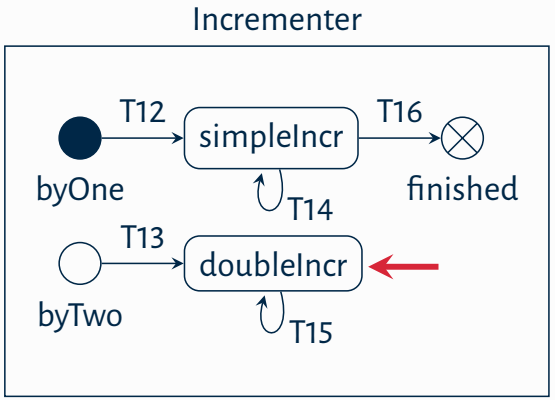
Dynamic State Machines

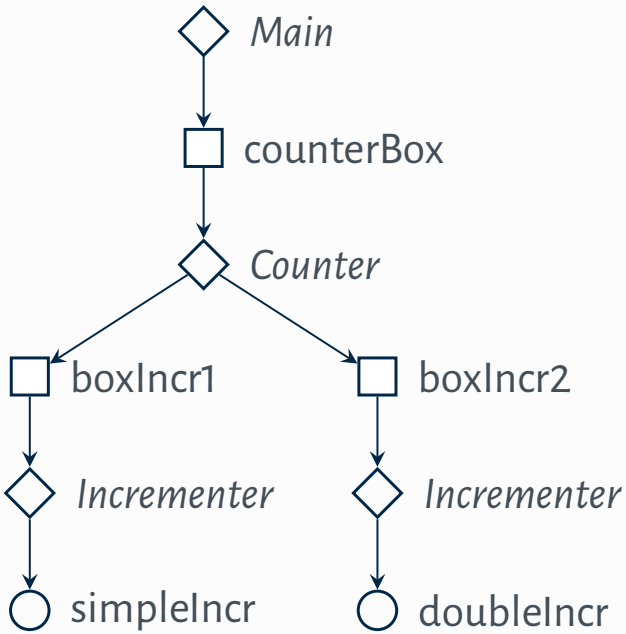
In action







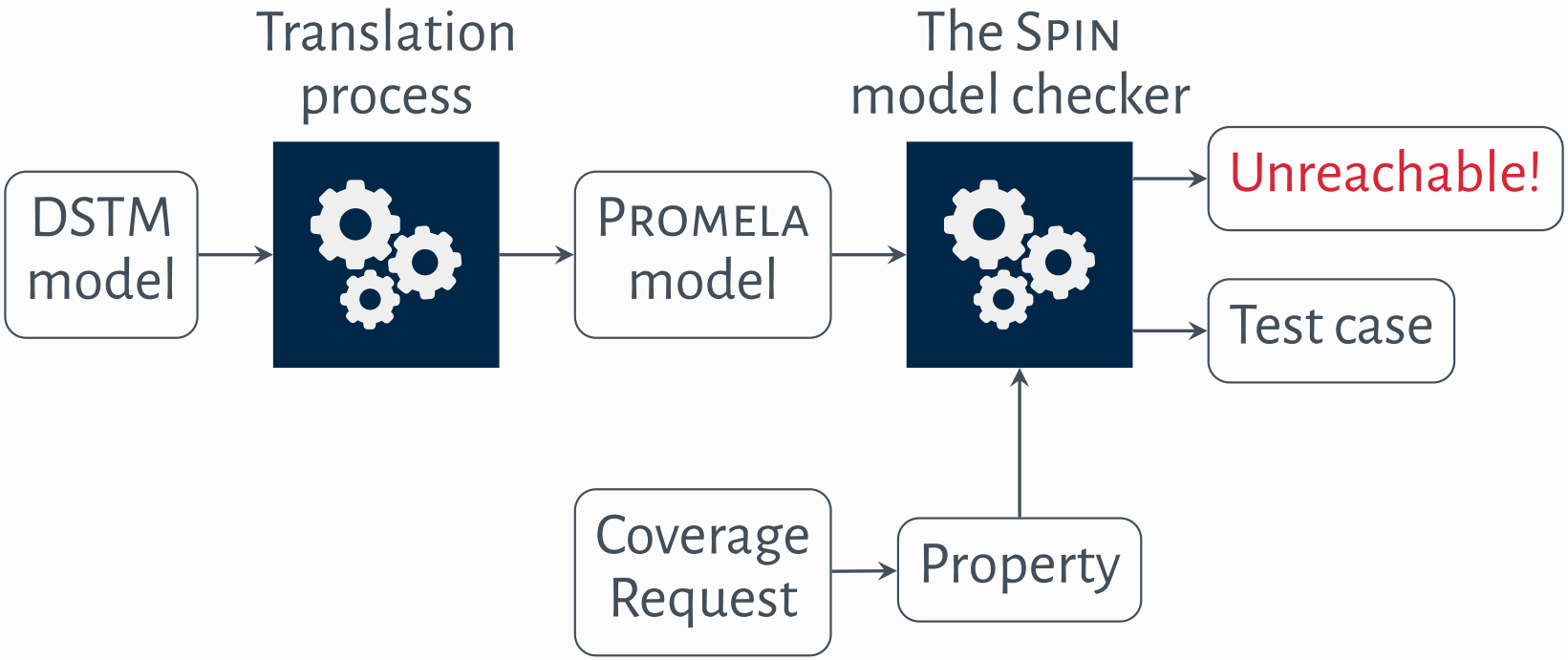




Model-based testing on DSTM models

Model-based testing

Generating test-cases from DSTM models



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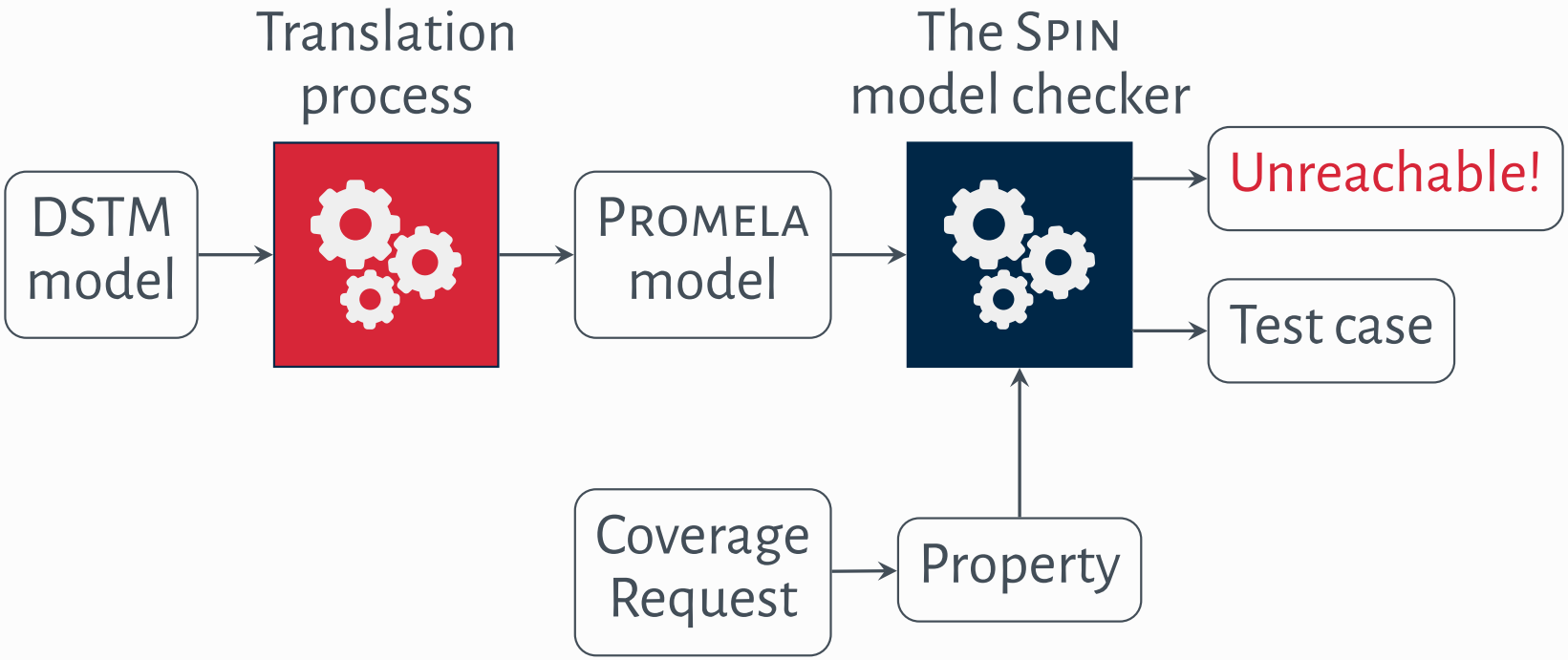

Hierarchical Linear-time Temporal Logic with Interrupts

Linear-time Temporal Logic (LTL)

Reasoning about linear time

$$\phi := p \in \mathcal{P} \mid \neg\phi \mid \phi \vee \phi$$

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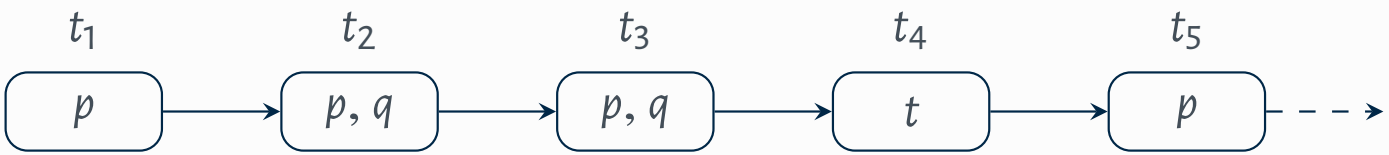

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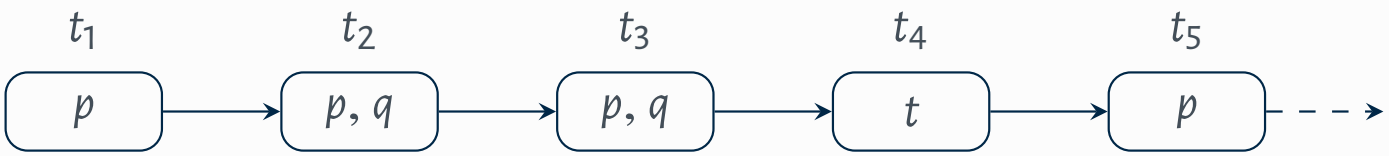

Some examples:

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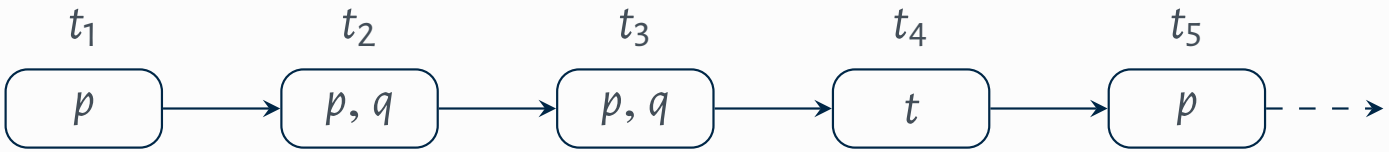

Some examples:

- $\mathtt{X}(p \wedge q)$ (Next)

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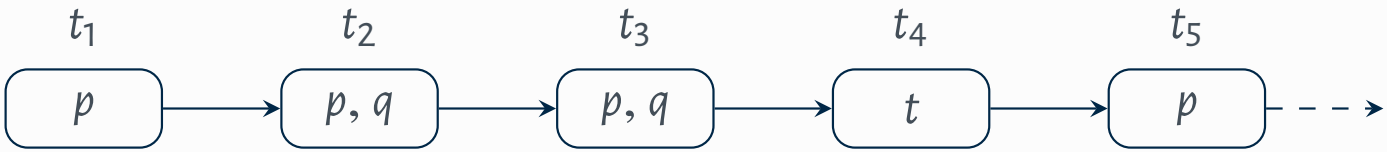
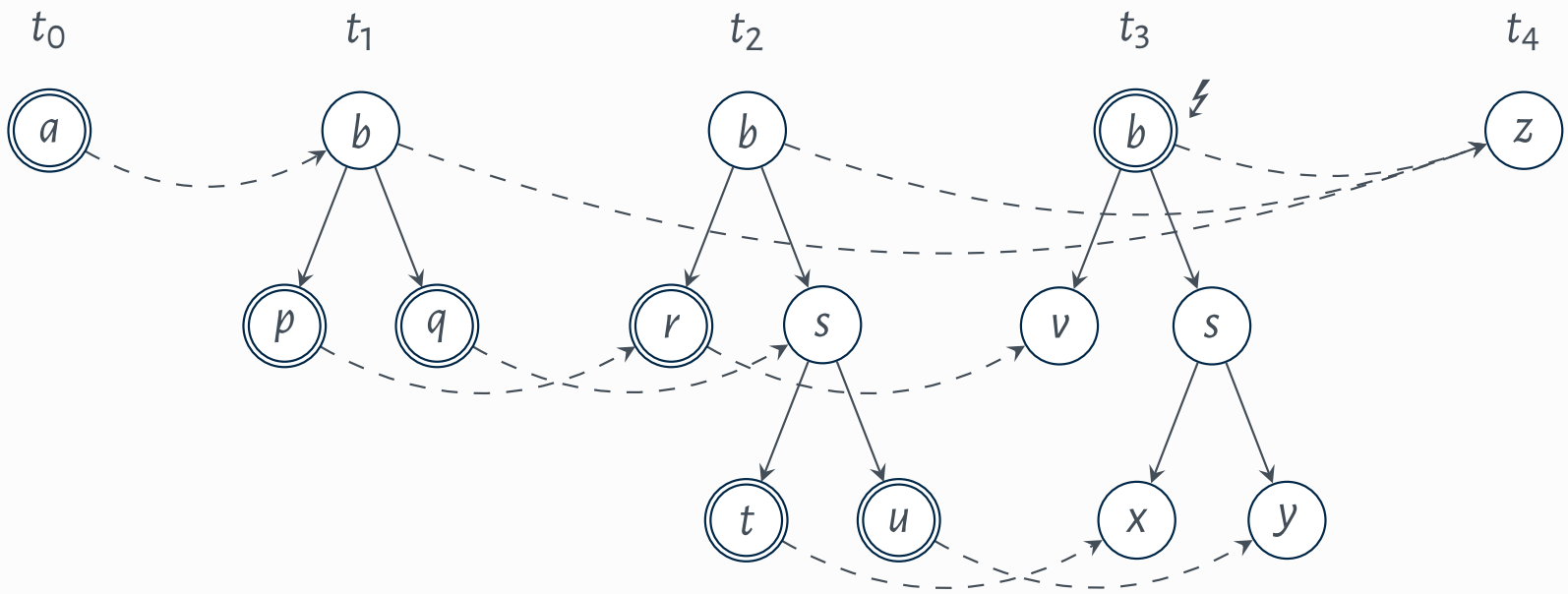


Some examples:

- $\mathtt{X}(p \wedge q)$ (Next)
- $p\,\mathtt{U}\,t$ (Until)

Hierarchical LTL with Interrupts

A novel extension of the well-known LTL



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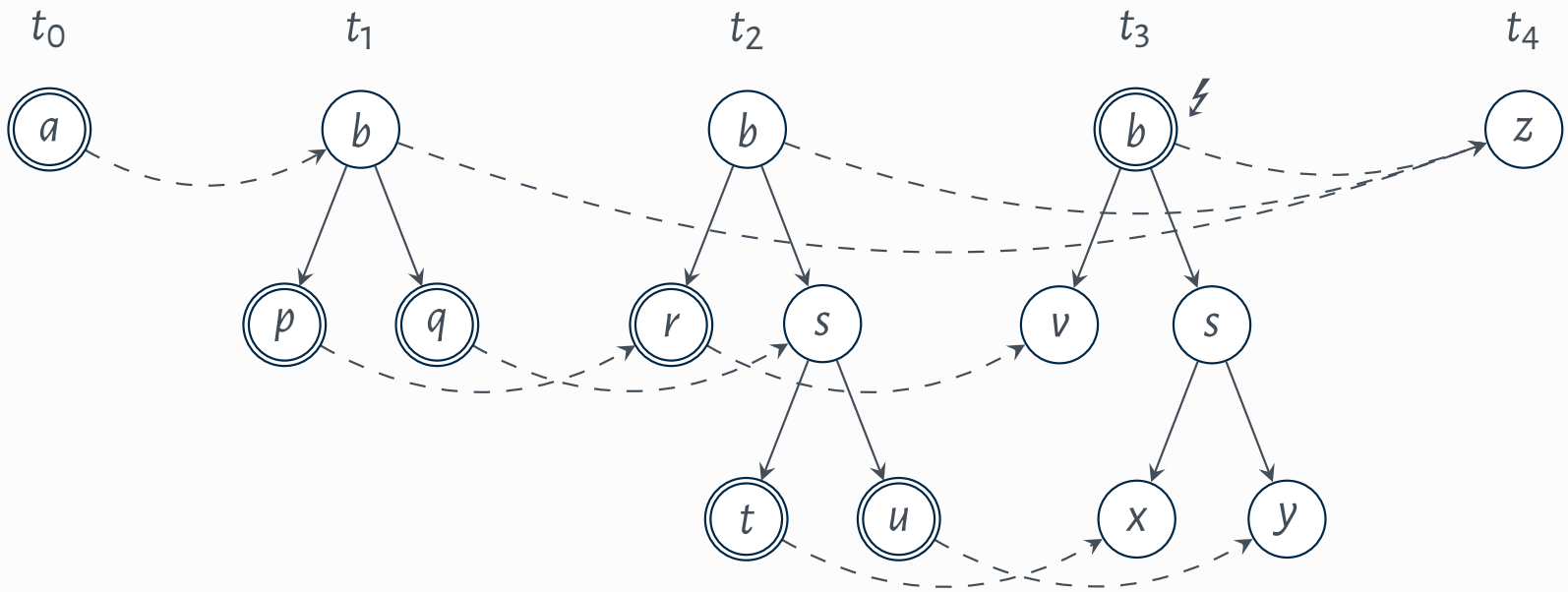

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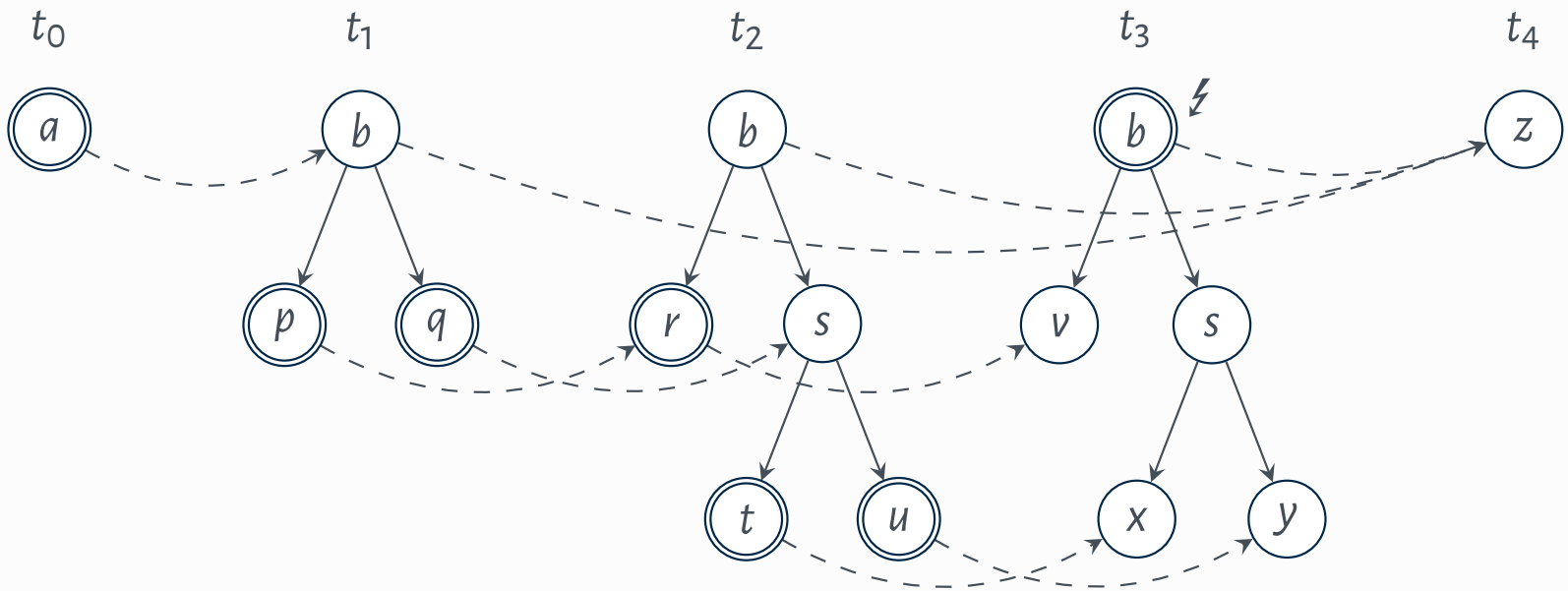

- LTL-like operators to reason about the evolution of a module;
- new operators to contextualize formulae in the hierarchy of modules.

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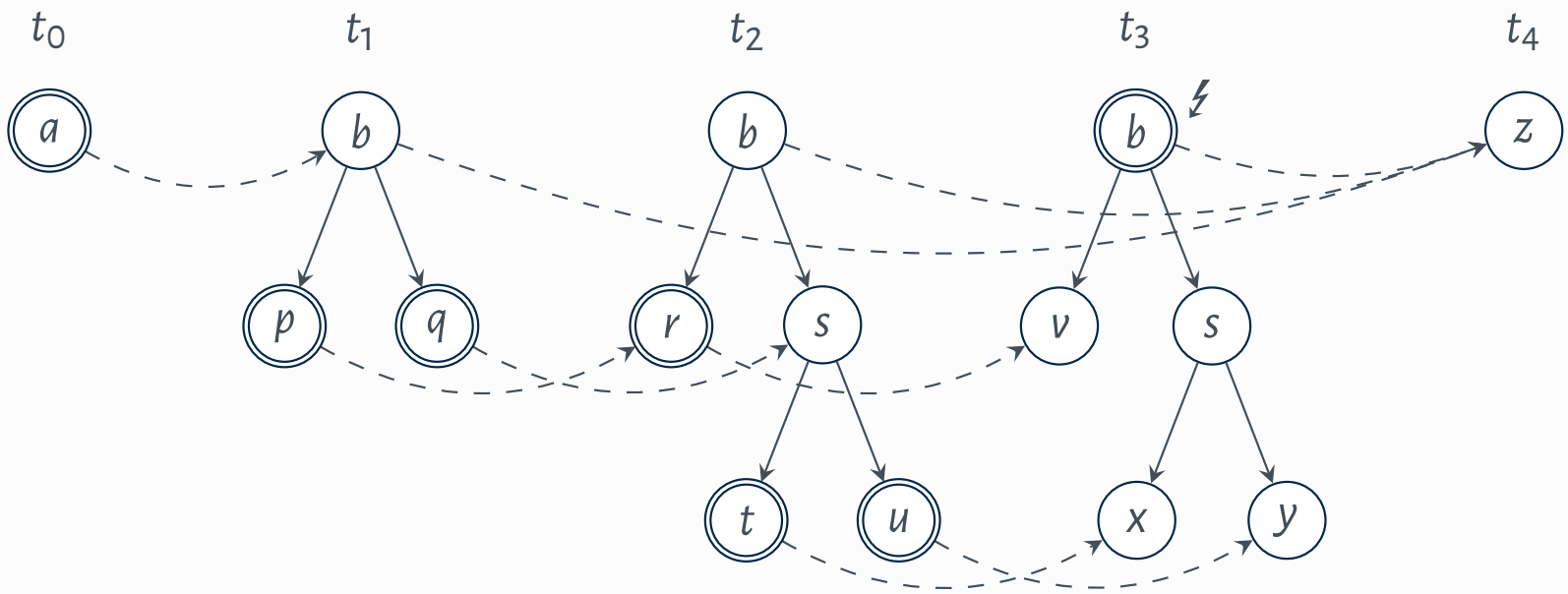

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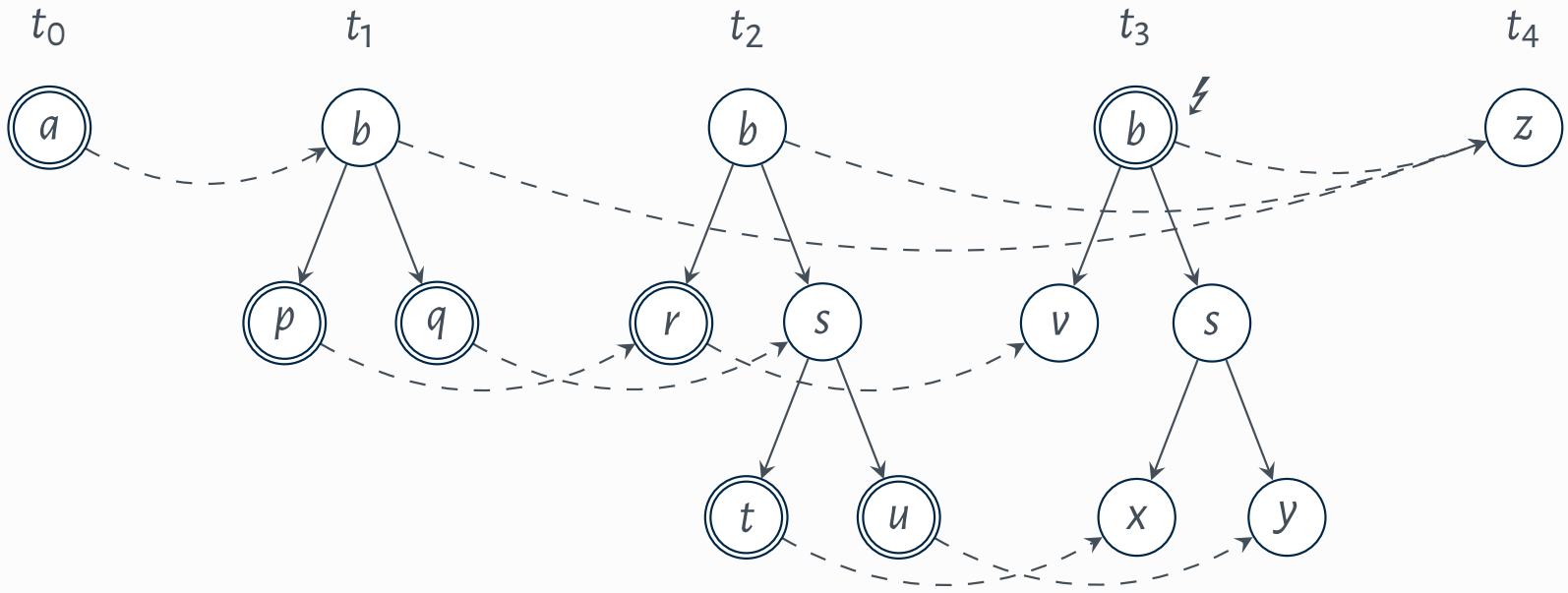

New operators:

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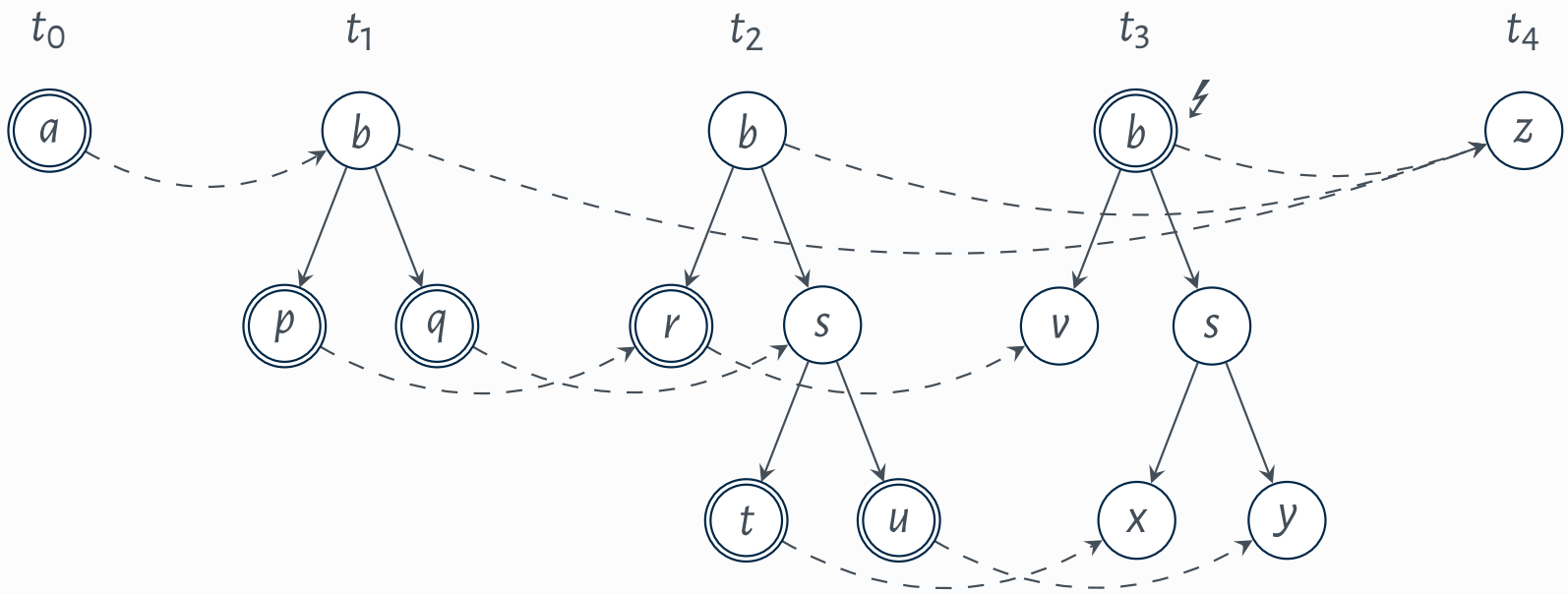

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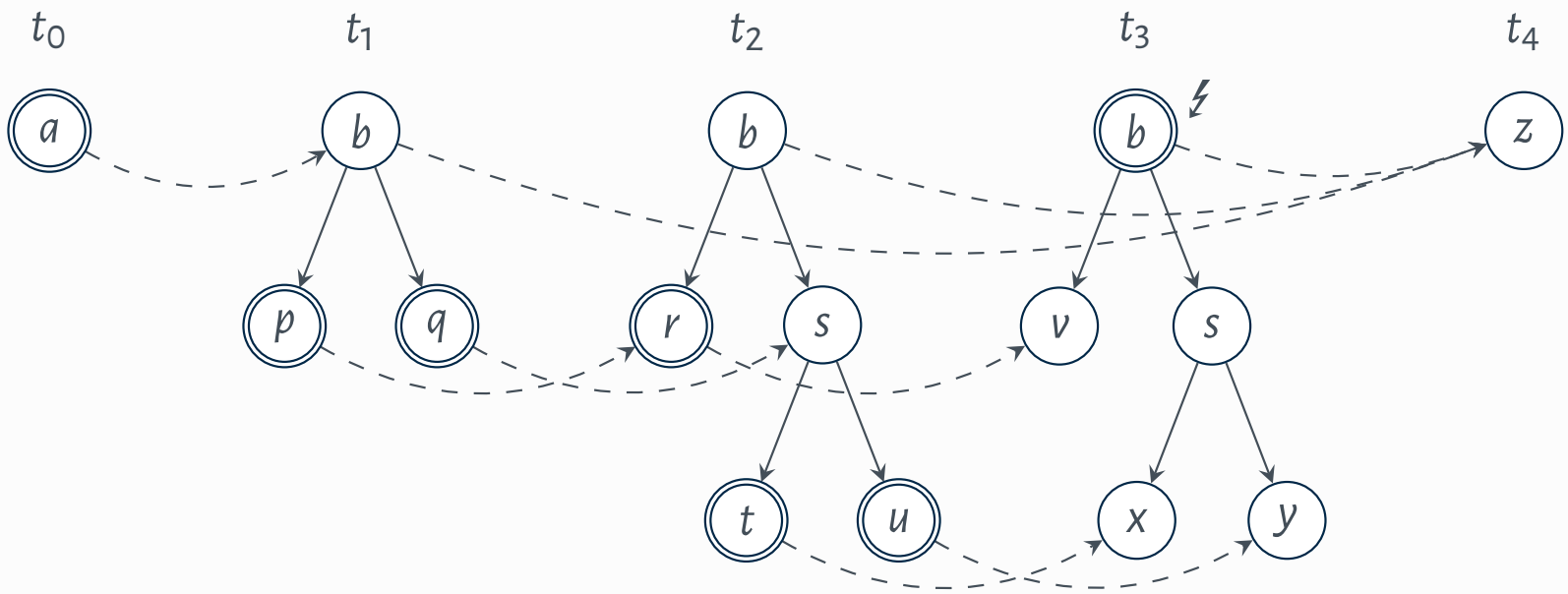

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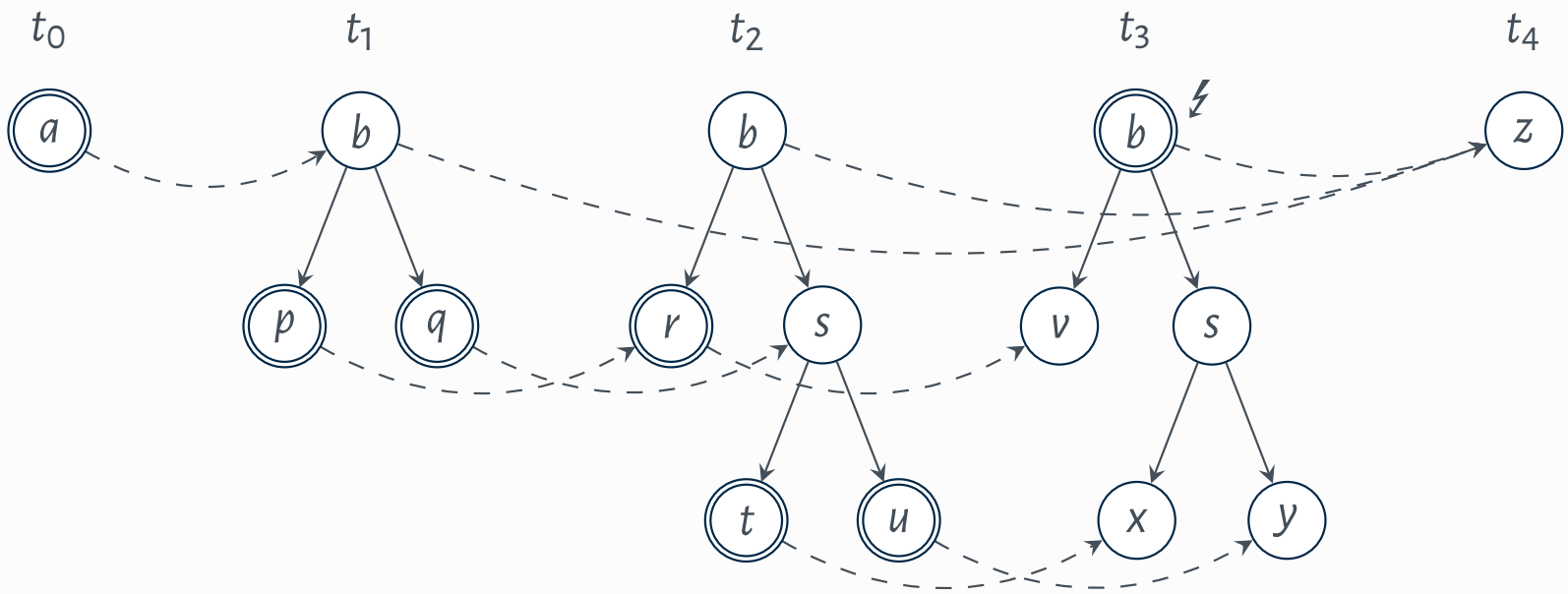

Some examples:

- $\mathrm{X}_{\lightning}(z)$;
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Communicating Hierarchical Automata

Simplifying DSTM

Communicating Hierarchical Automata with Interrupts (CHA$^{\lightning}$)

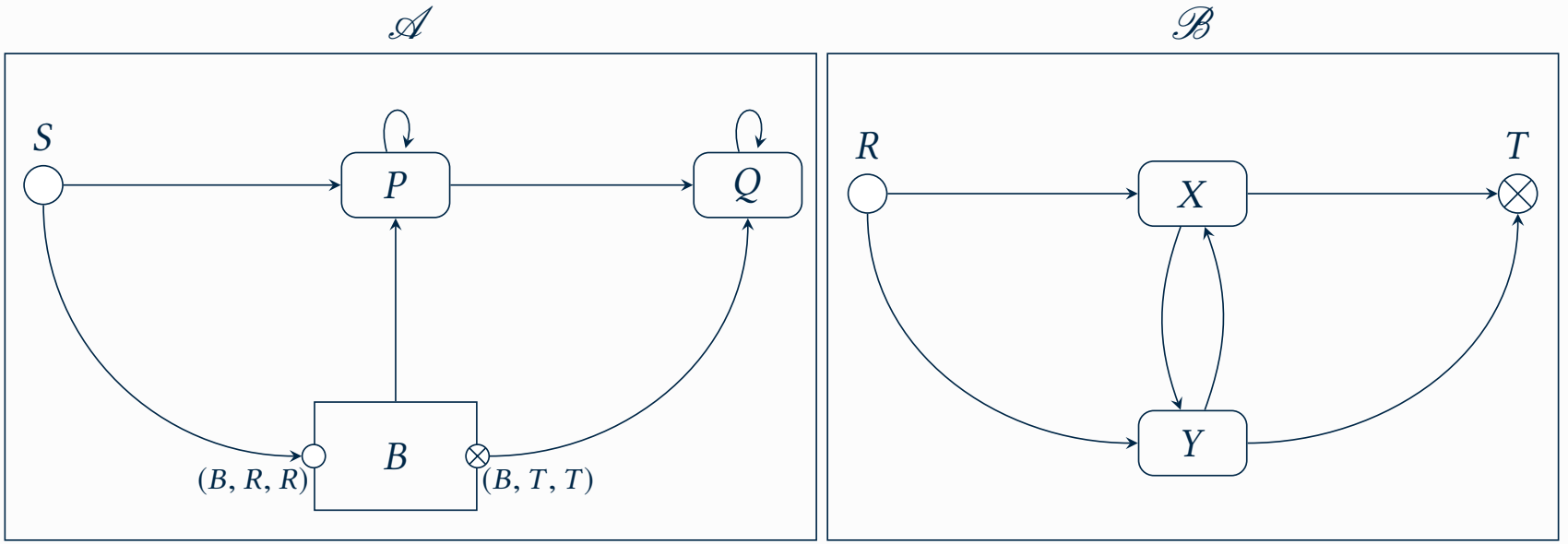

Figure: A simple CHA$^{\lightning}$

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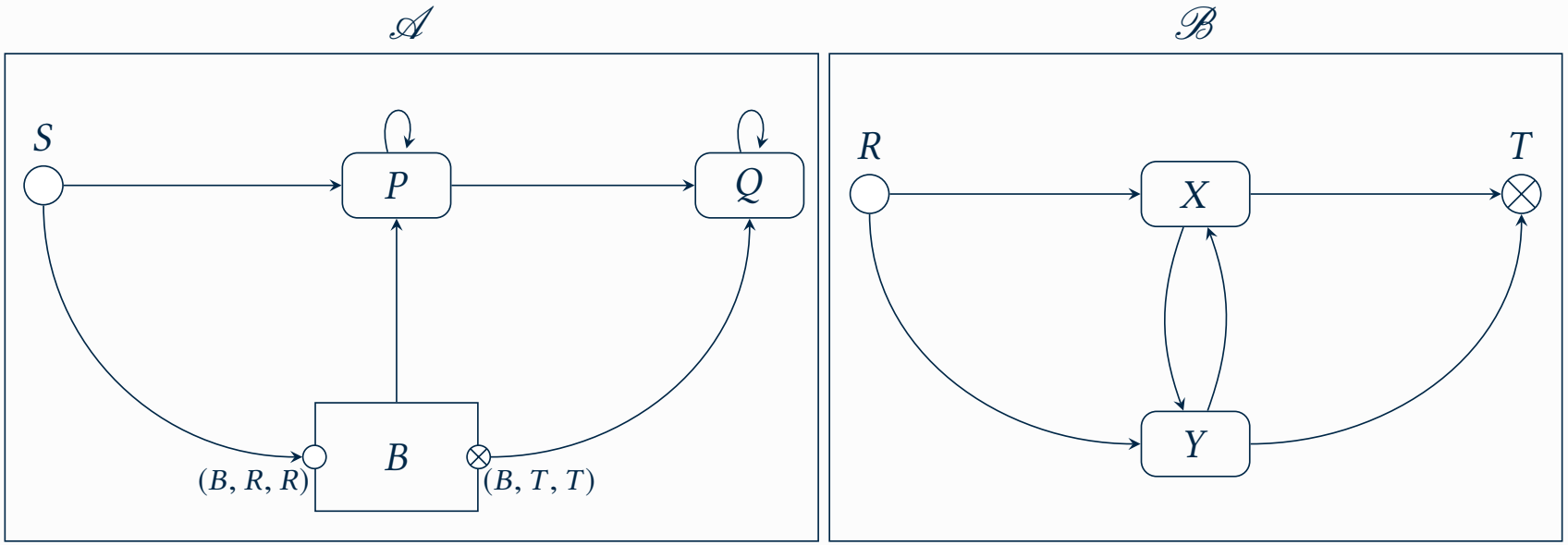


Figure: A simple CHA$^{\lightning}$

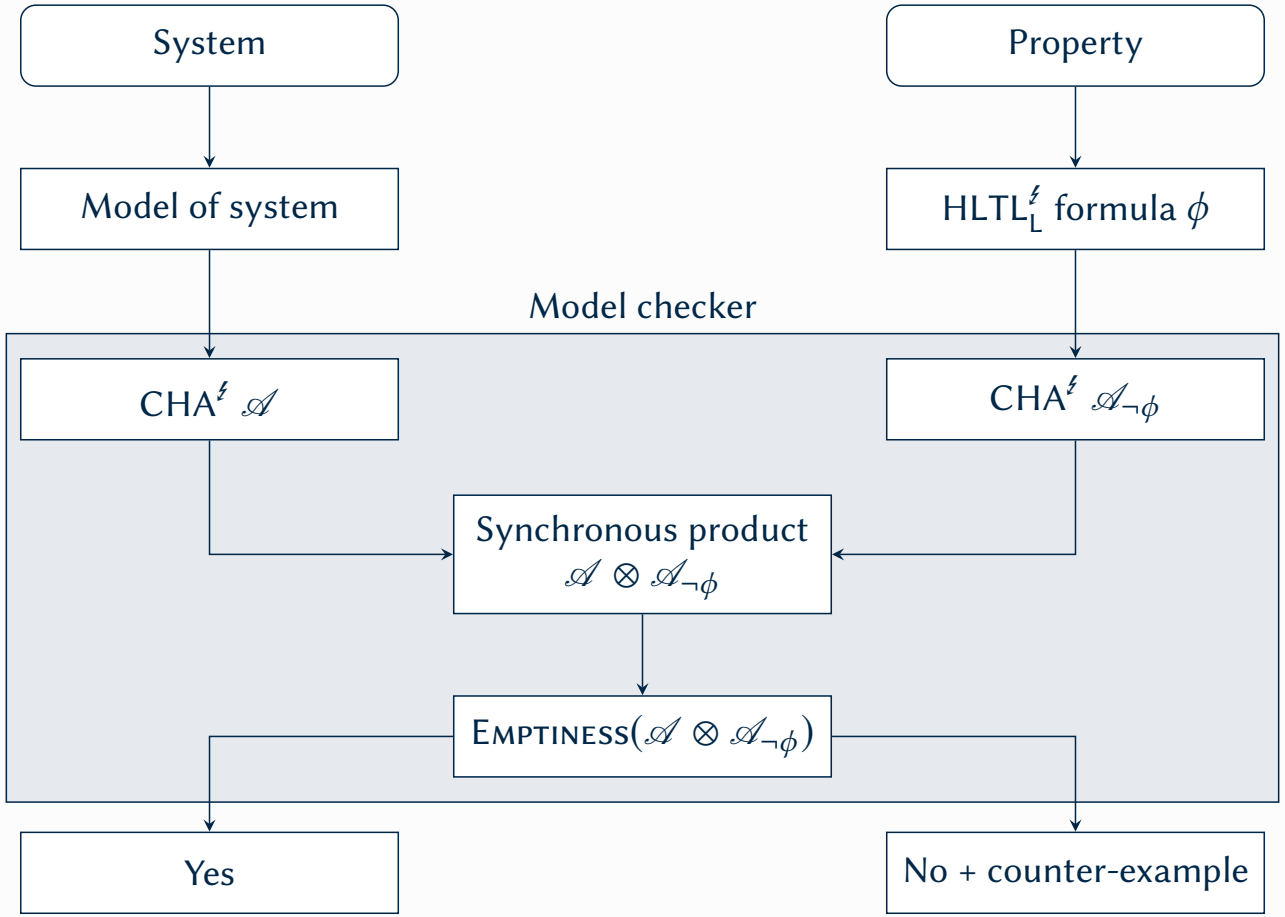
Differences with DSTM:

- no recursion;
- no forks/joins;

Model checking

The model checking procedure

Overview



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Further work:

- extend results to DSTM;
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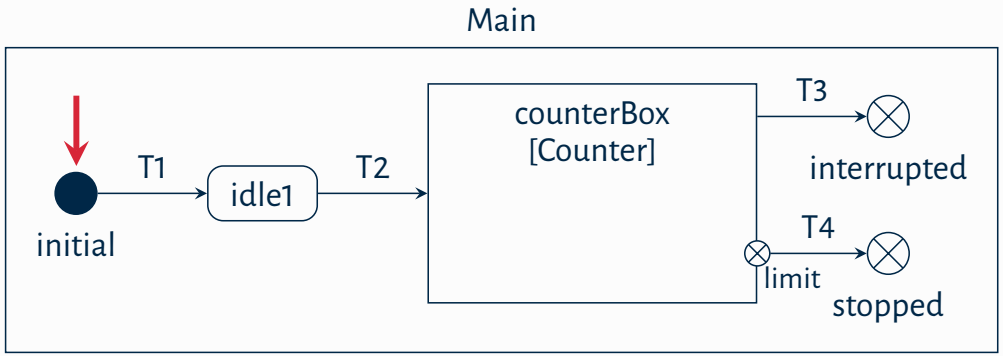
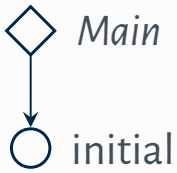
Thank you for your time!

Backup slides

Dynamic State Machines
In action





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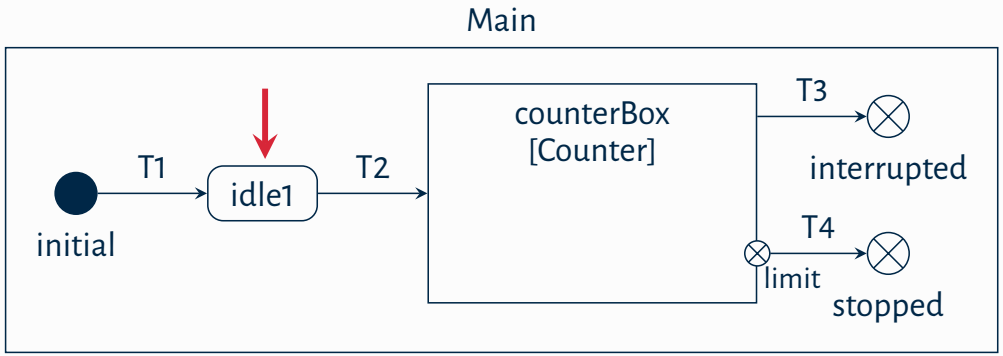

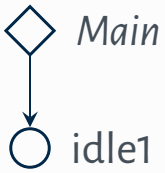

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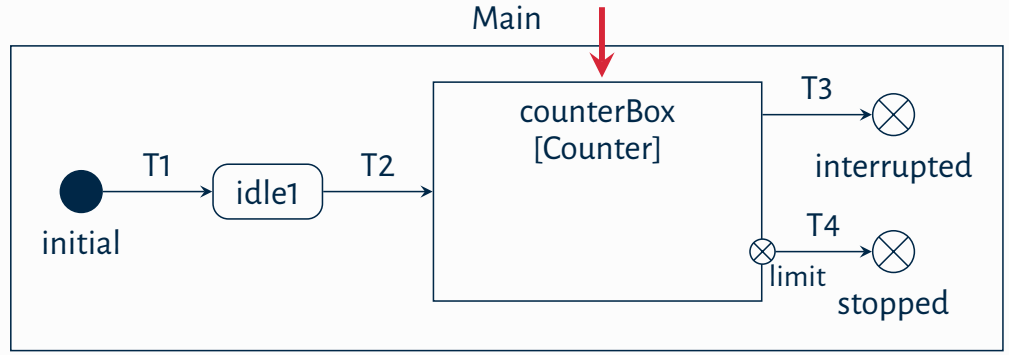

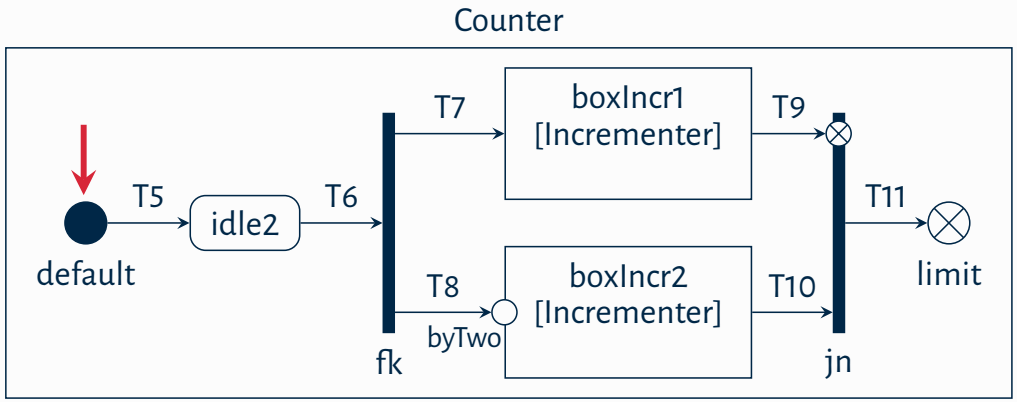

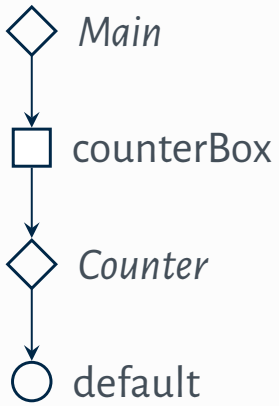

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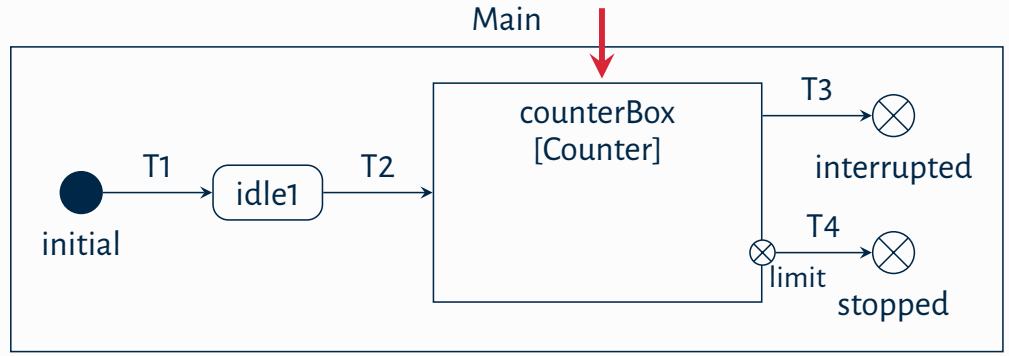

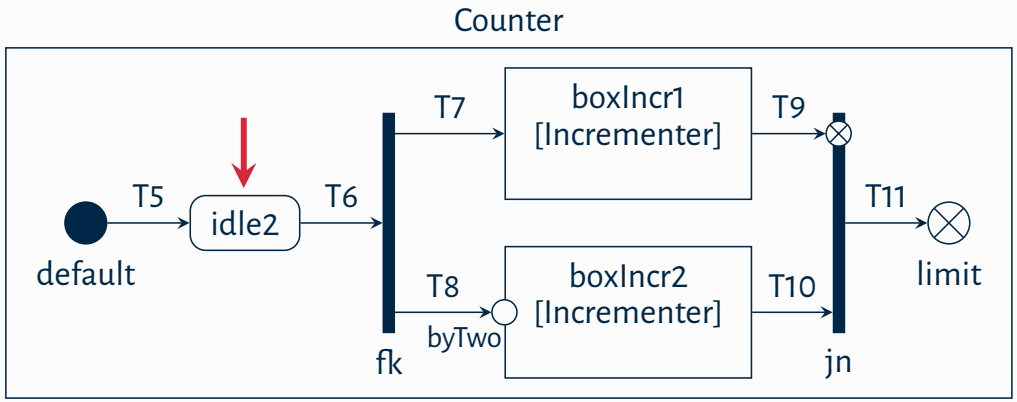

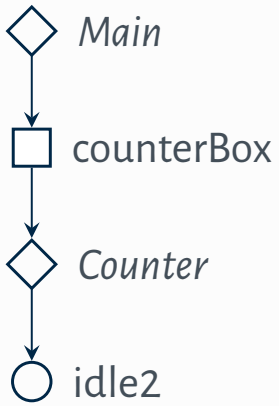

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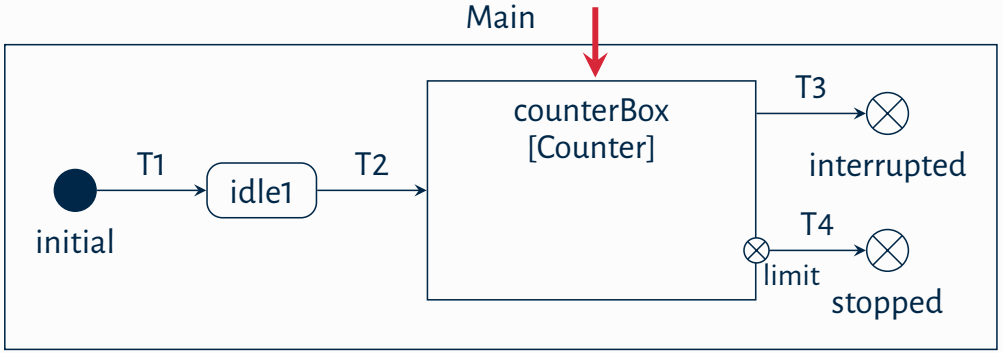
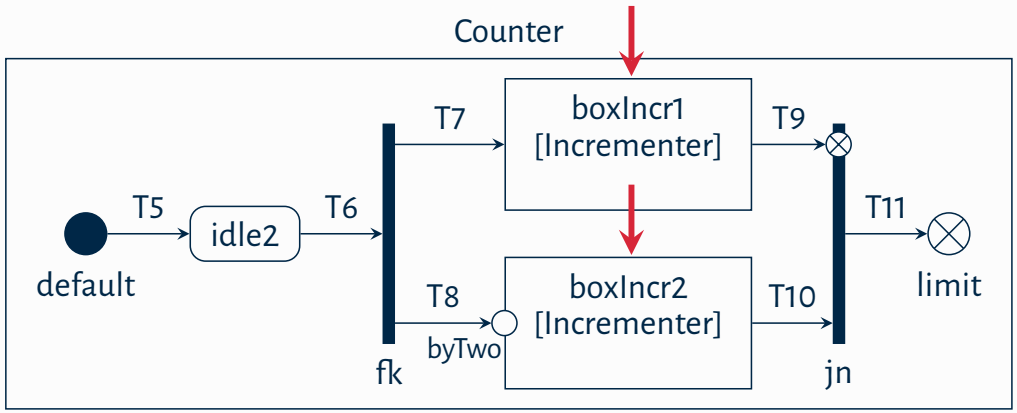
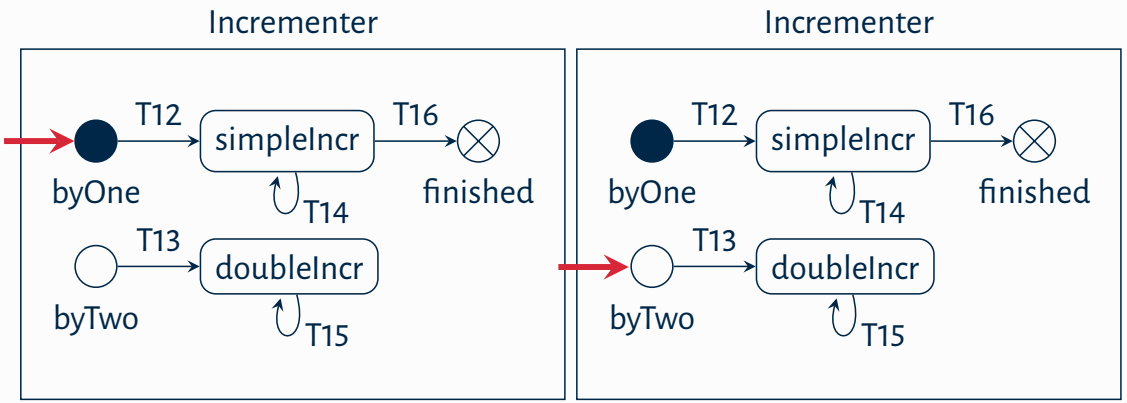
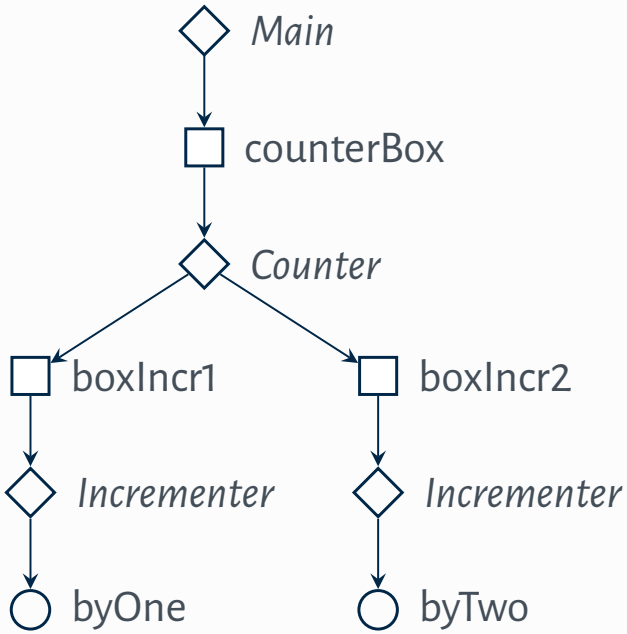


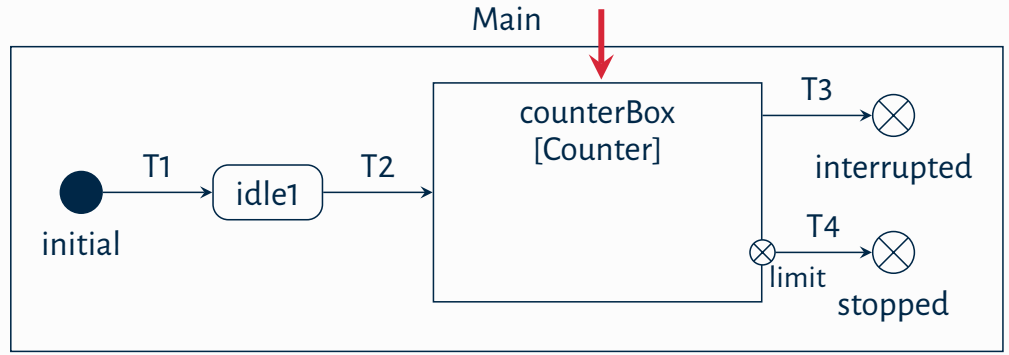


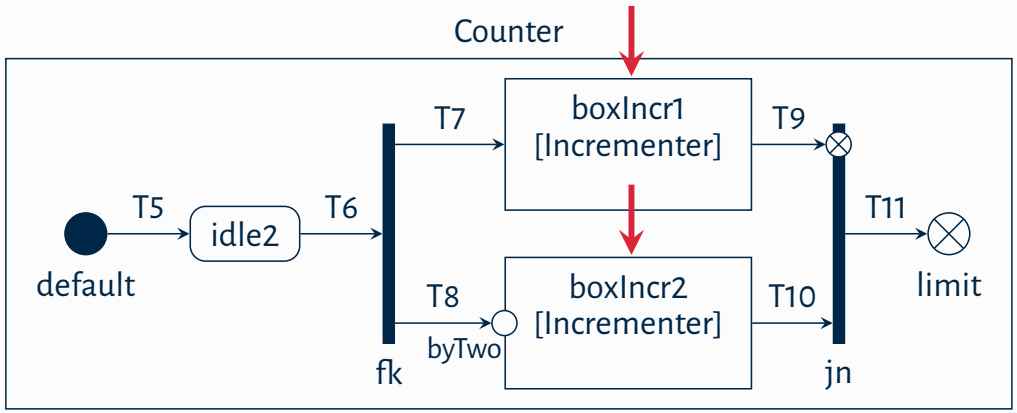


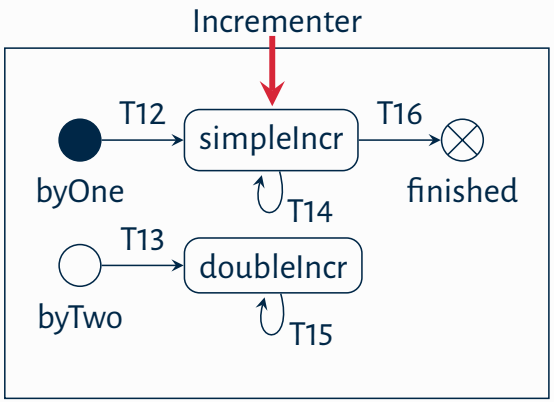


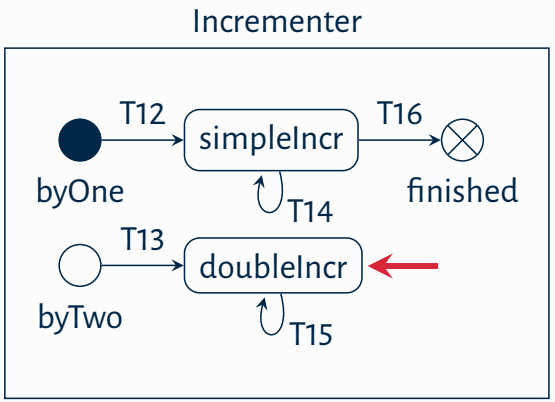
Dynamic State Machines

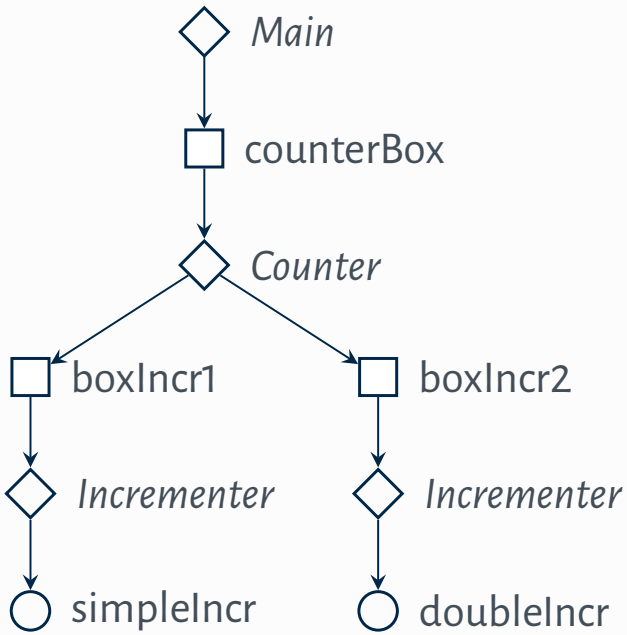
In action





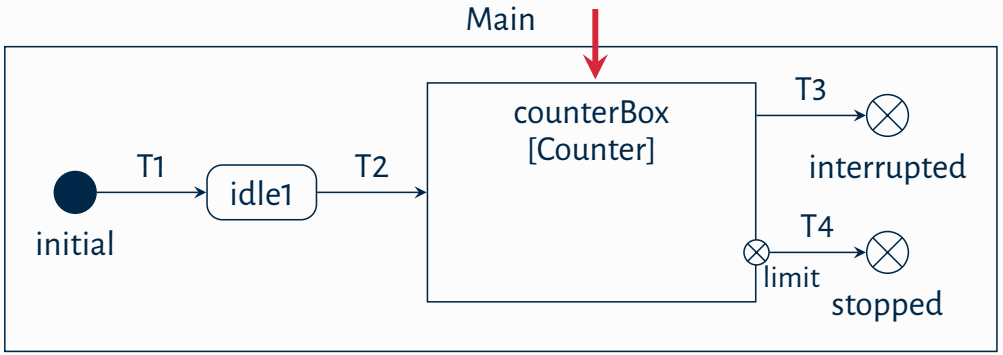


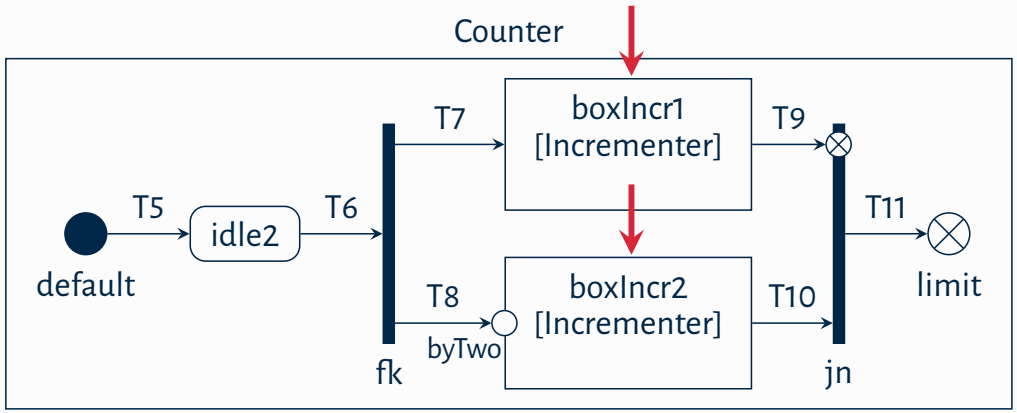


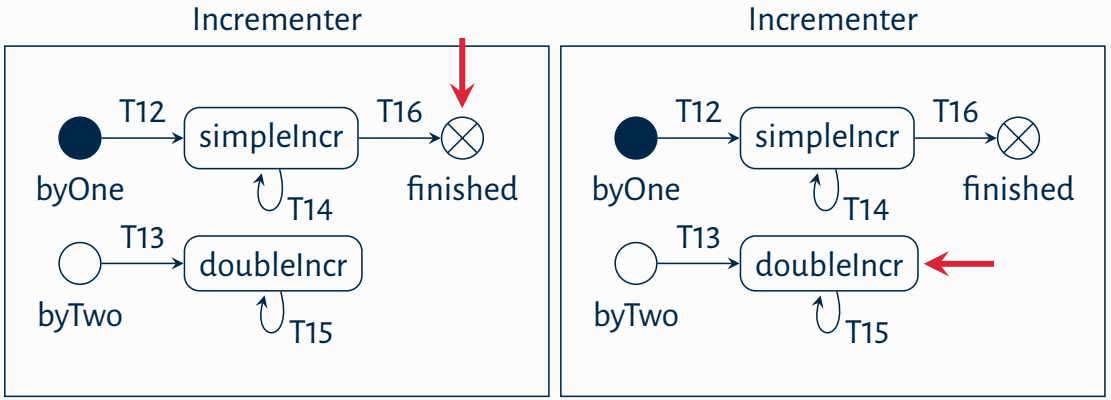


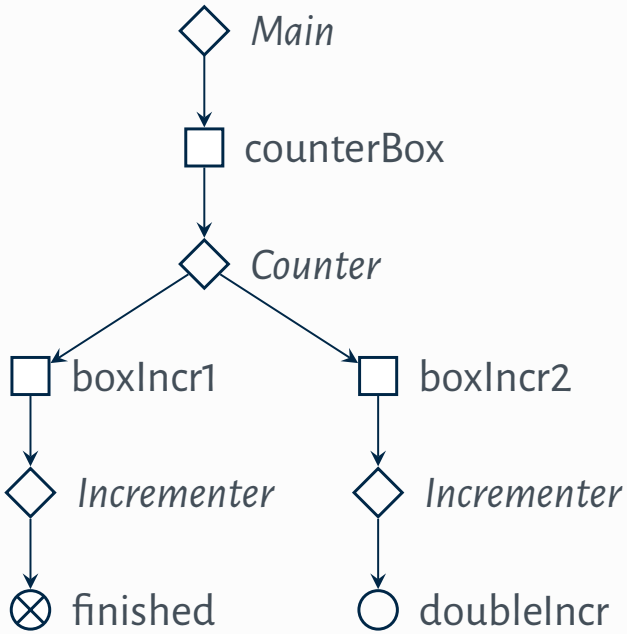
Dynamic State Machines

In action



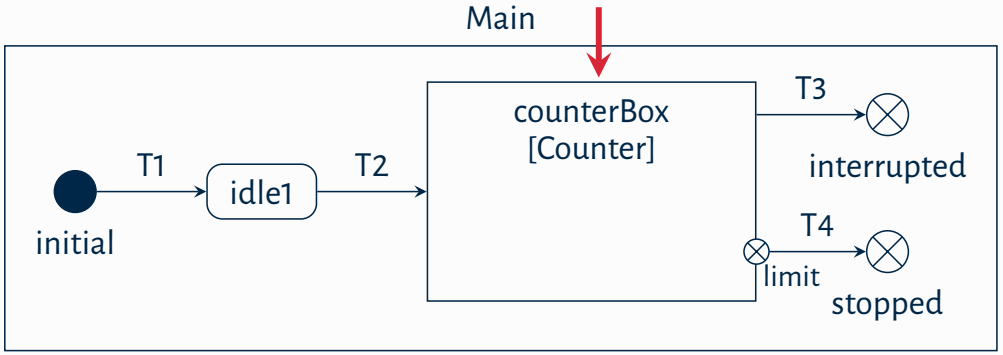


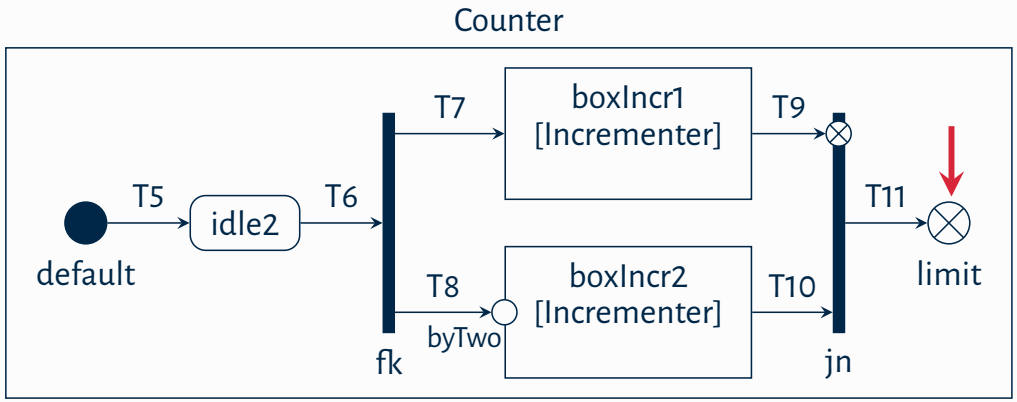


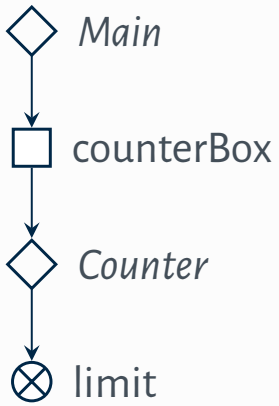


Dynamic State Machines

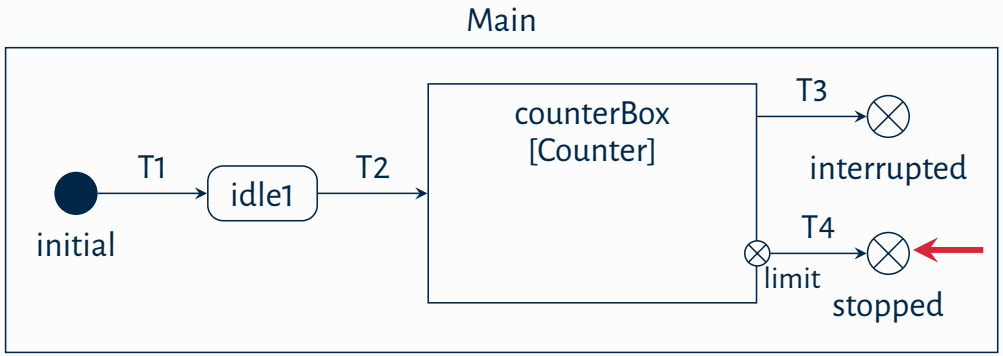
In action

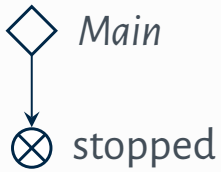






Dynamic State Machines
In action





Dynamic State Machines

A dynamic instantiation example

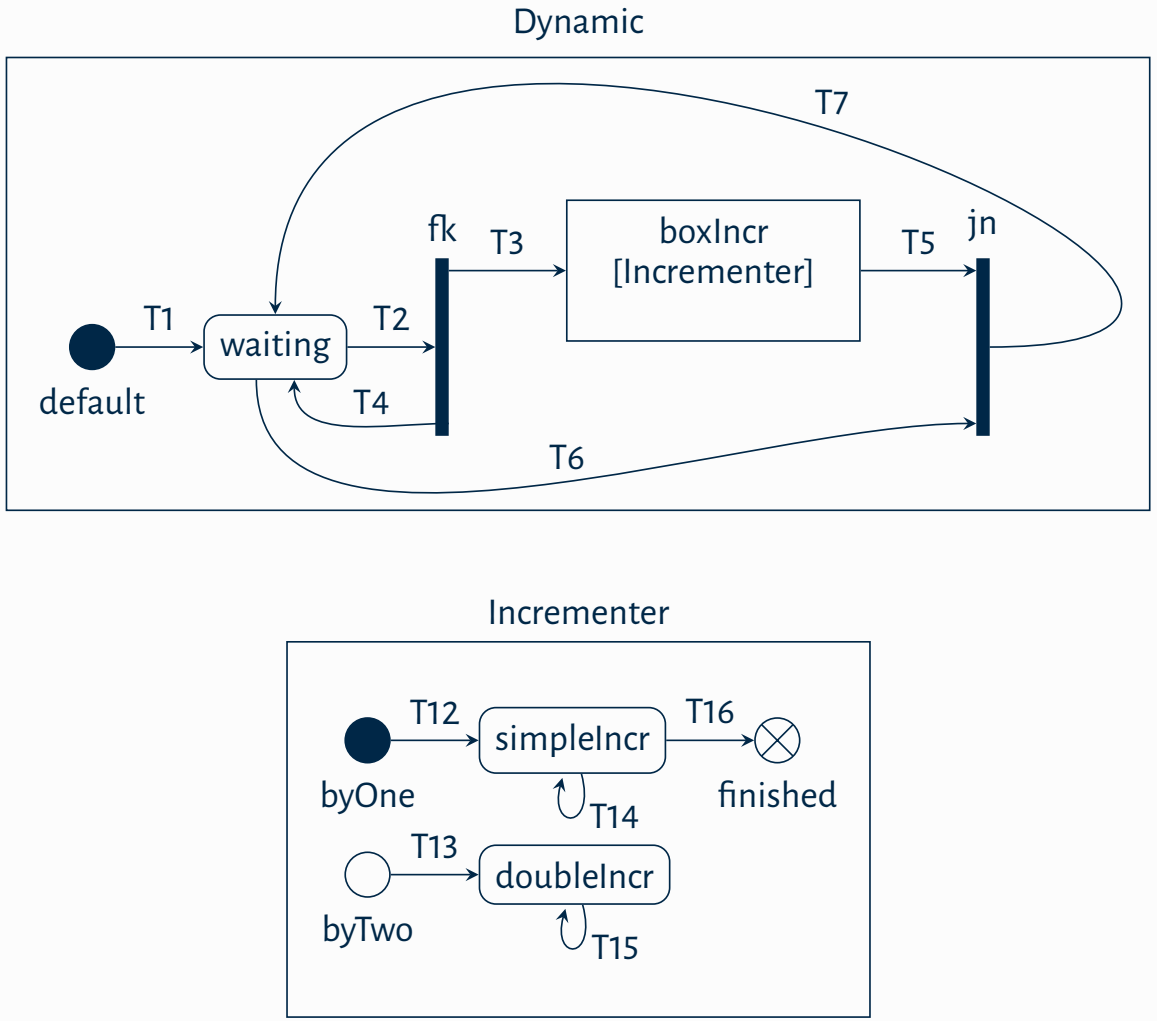


Figure: A dynamic DSTM specification

Deciding Emptiness for CSA

The Emptiness procedure

Emptiness problem

Given a CHA$^{\lightning}$, is there any accepting computation?

Main intuition:

- bottom-up summarization;

Deciding Satisfiability for HLTL$^{\lightning}$ formulae

The Satisfiability procedure

Satisfiability problem

Given a HLTL$^{\lightning}$ formula ϕ, is there any hierarchical computation satisfying ϕ?

Main intuitions:

- build a CHA$^{\lightning}$ accepting hierarchical words satisfying the formula;
- non-trivial extension of the Vardi-Wolper approach for LTL;
- check for the emptiness of the automaton;

The model checking procedure

Overview