Expressing structural temporal properties of safety critical hierarchical systems

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September 10, 2021

Safety Critical Systems

- A system is **Safety Critical** if its failure could lead to **unacceptable consequences**.
- Typical examples include:
  - medical care devices
  - Aircraft controllers
  - Railway traffic controllers
  - Nuclear plants
  - Many more

Safety Critical Systems

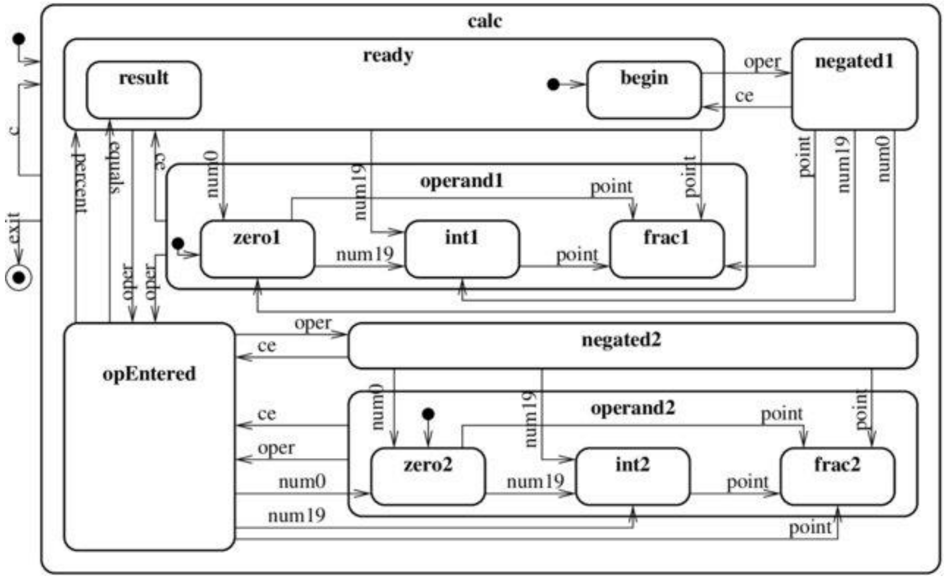
- A way broader class of systems has the potential for unacceptable consequences of failure
- A malfunction in telephone exchange system could have serious consequences as well!
- General trend towards **more complex**, interconnected, **software-intensive** safety critical systems
- It is **imperative** to guarantee high safety standards

Formal Methods

- A way to ensure high safety standards is using **formal methods**
  - *applied mathematics for modelling and analysing ICT systems*
- Key steps to apply formal methods include **specification** of
  - The System to be designed (via **modelling** languages)
  - The Properties that such system must satisfy

Hierarchical Models

- The notion of **hierarchy** arises naturally to deal with the increasing complexity of these systems
  - Popular hierarhical modelling languages include **Statechart**, **Simulink**
- System is described as a collection of **modules** in a tree-like hierarchy



Example of a Statechart, from [1]

[1] Pinter, Gergely, and Istvan Majzik. "Impact of statechart implementation techniques on the effectiveness of fault detection mechanisms." *Proceedings. 30th Euromicro Conference, 2004.*. IEEE, 2004.

Motivations

- A lot of work has been done on defining **hierarchical modelling** languages, and towards integration with model-driven development frameworks.
- Less work, on the other hand, has been directed towards languages to express relevant **behavioural properties** of hierarchical models

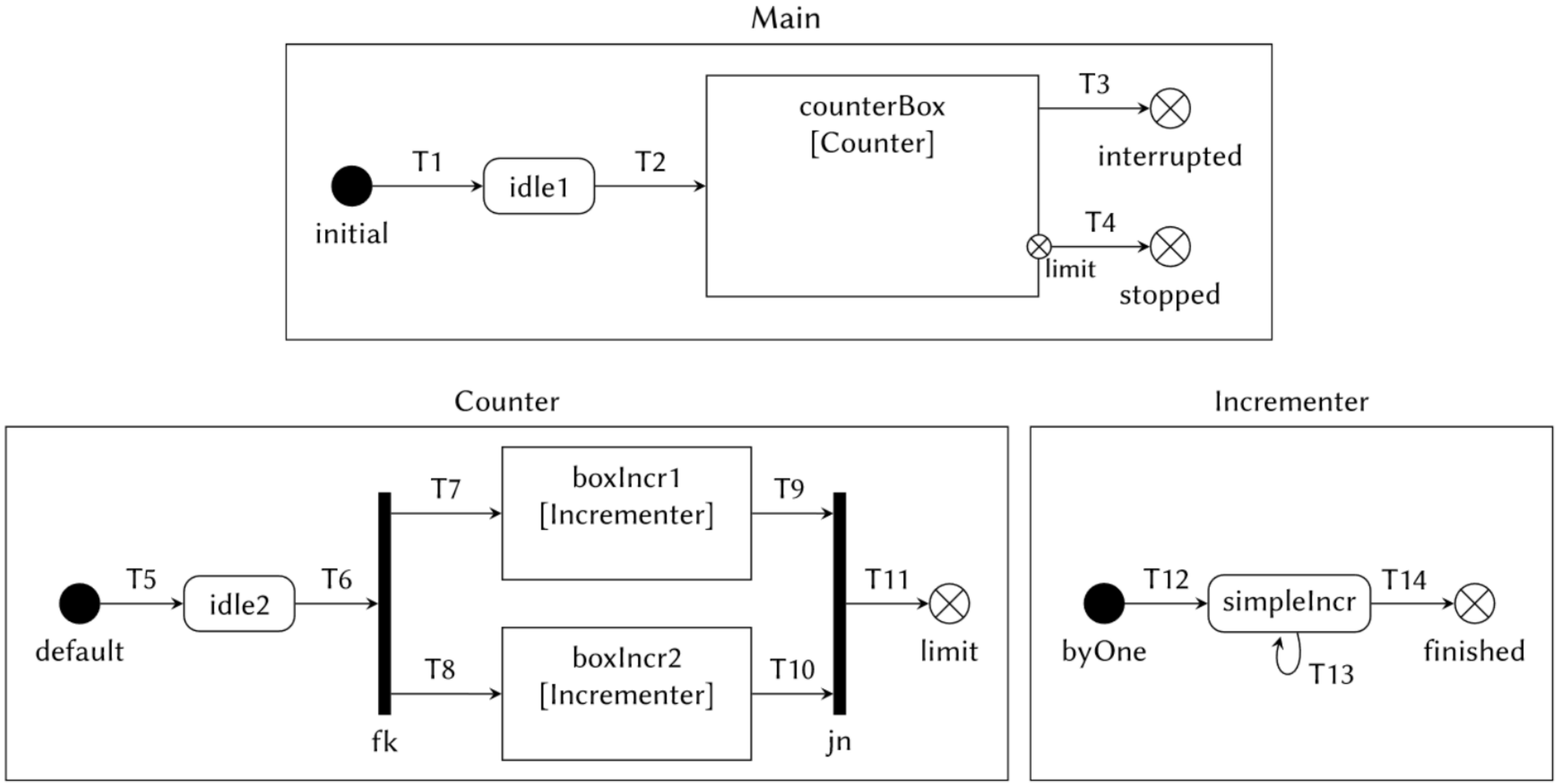
Goals

In this work, we propose HLTL, a logical formalism designed to express temporal structural properties of hierarchical models

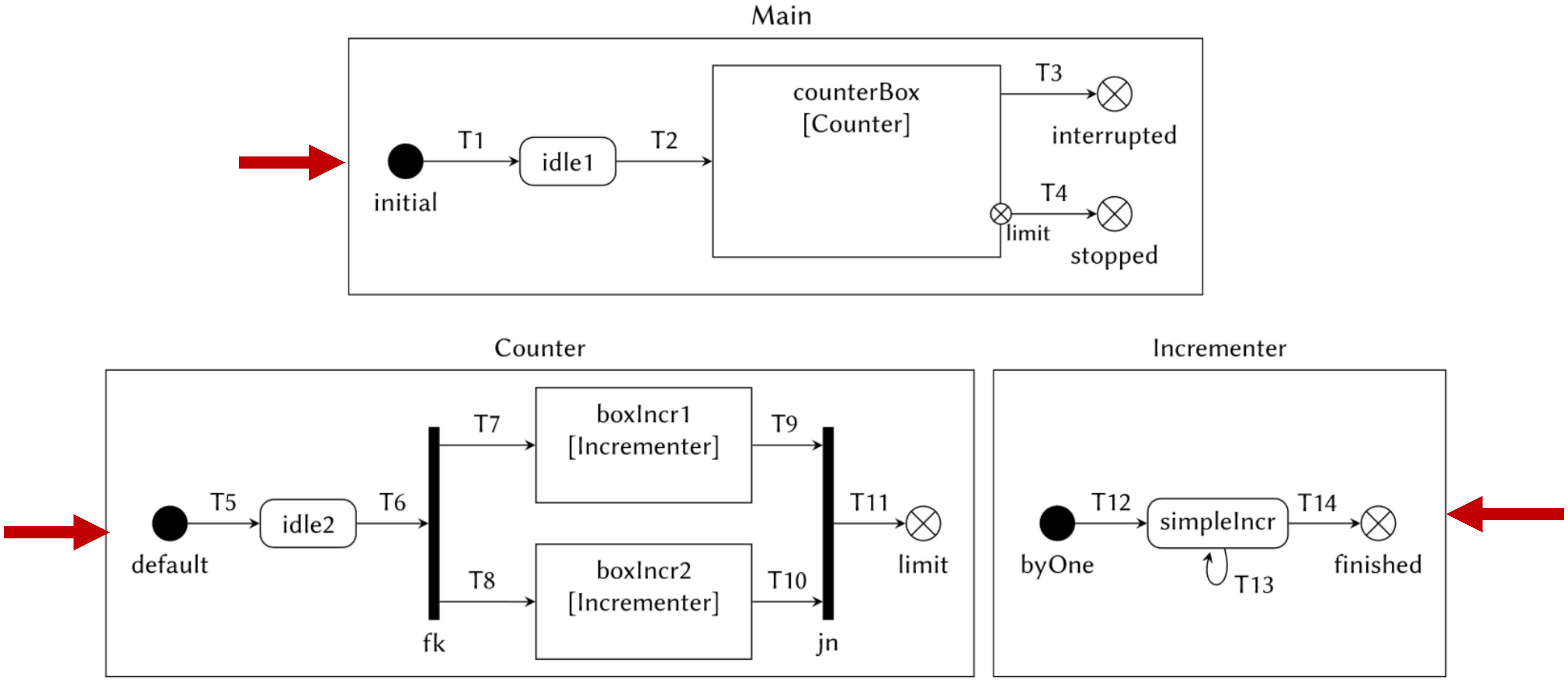
- Firstly we'll introduce Dynamic State Machines (DSTMs), a hierarchical modelling language
- Then, we'll introduce the formalism we propose

A hierarchical modelling language: Dynamic State Machines (DSTMs)

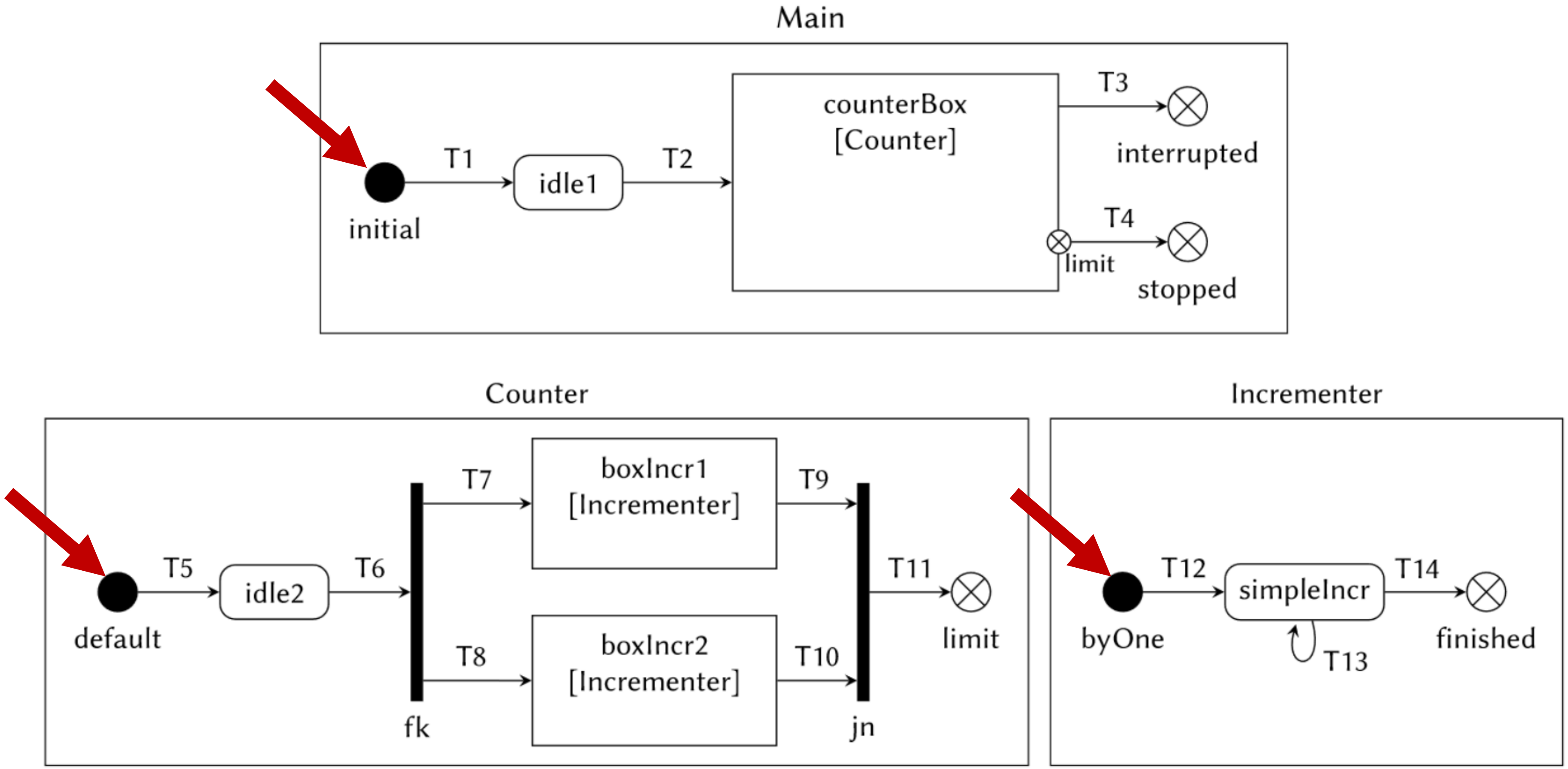
DSTM Syntax


Main
initial
T1
idle1
T2
counterBox
[Counter]
T3
interrupted
T4
limit
stopped
Counter
default
T5
idle2
T6
fk
T7
T8
boxIncr1
[Incrementer]
boxIncr2
[Incrementer]
T9
T10
jn
T11
limit
Incrementer
byOne
T12
simpleIncr
T13
T14
finished

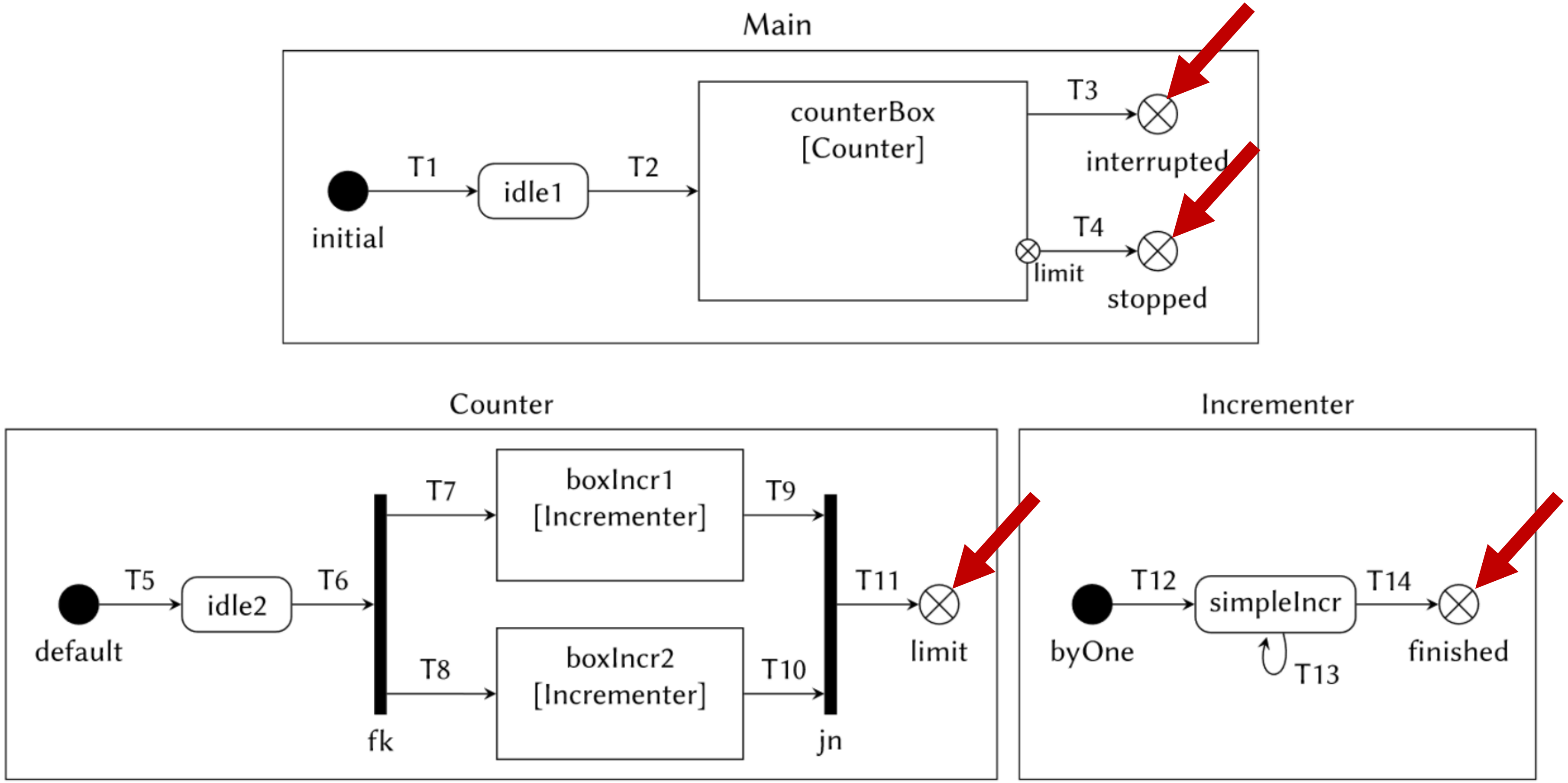
Machines or modules



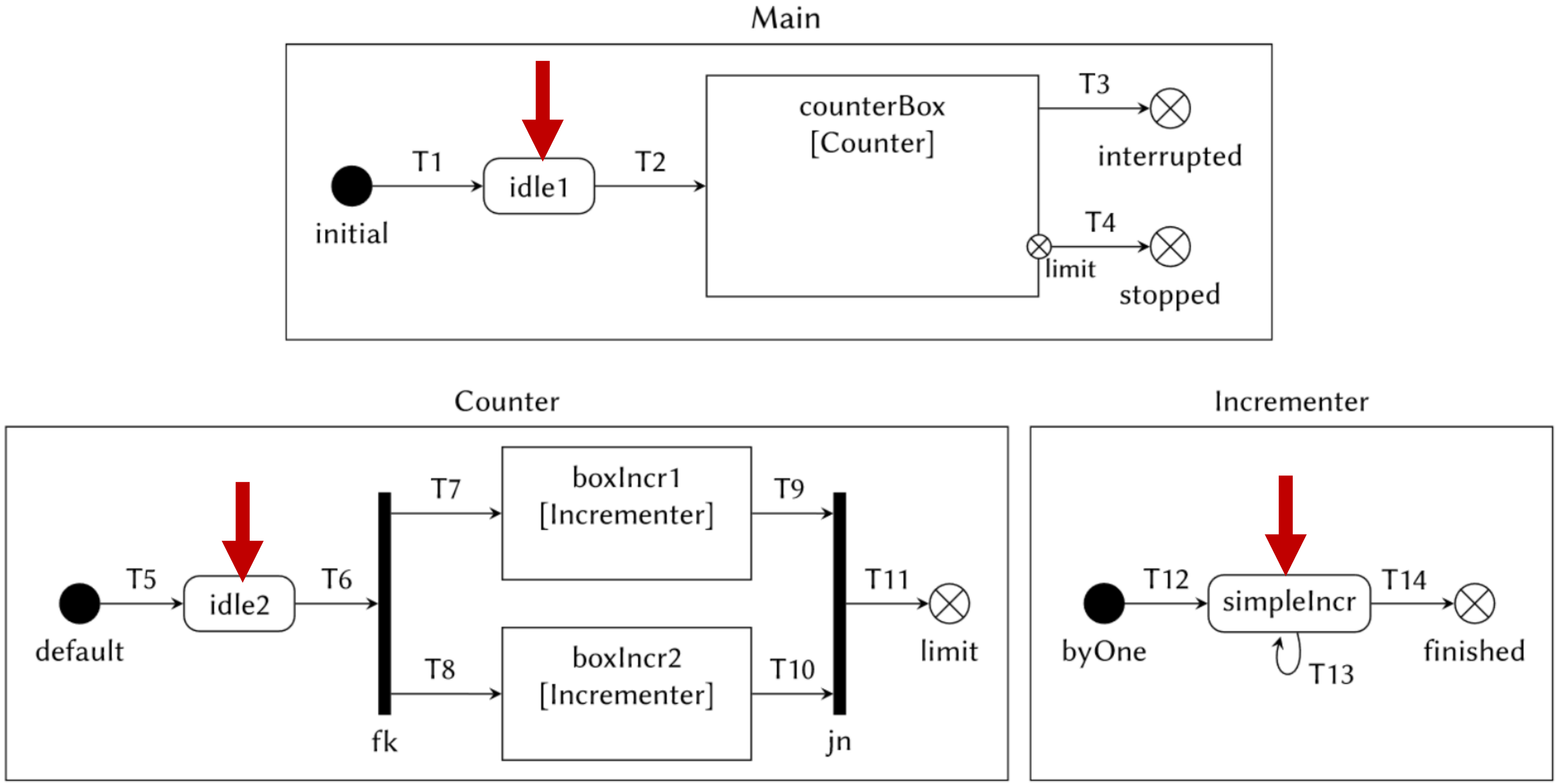
Entering nodes



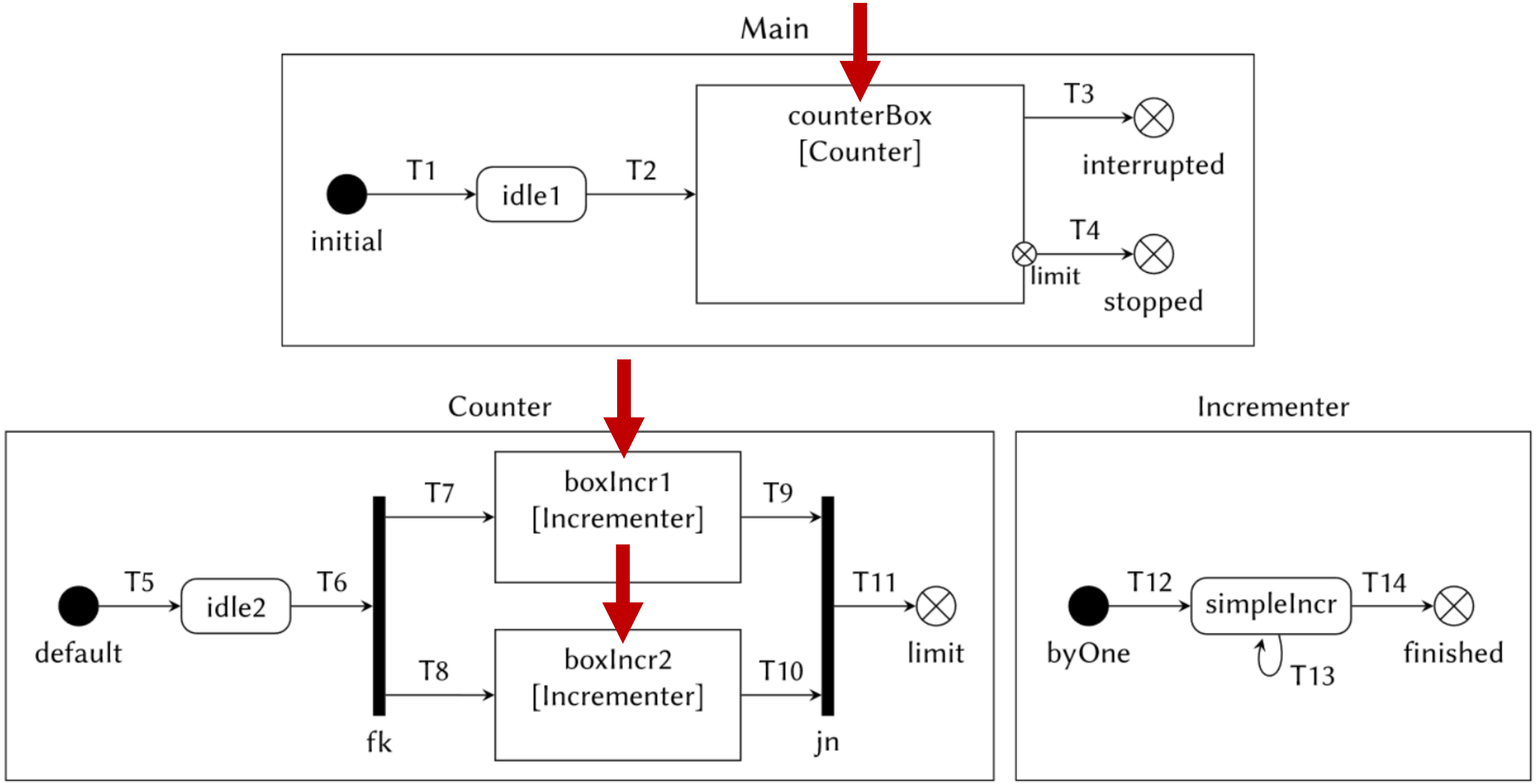
Exiting nodes



Simple states



Boxes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T8
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T10
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default
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Incrementer
T12
simpleIncr
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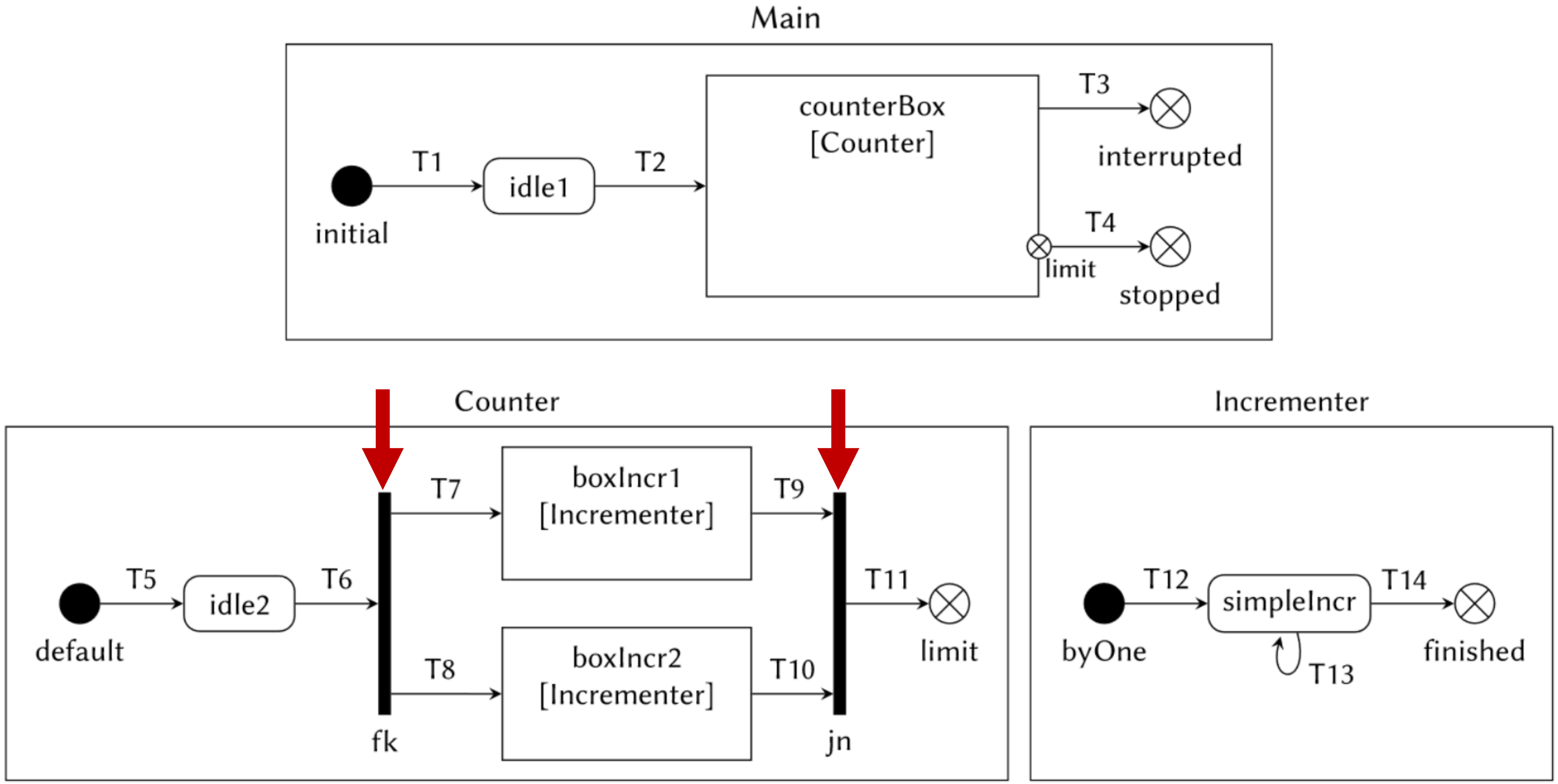
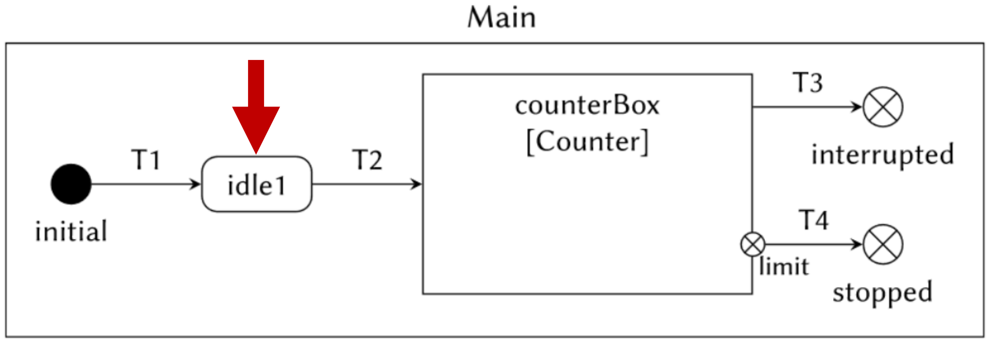
Forks and Joins

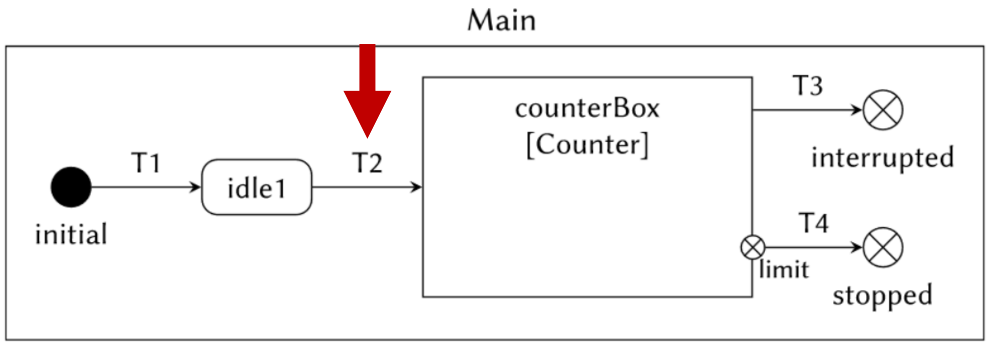


DSTM Semantics by Example



Main
State: idle1

DSTM Semantics by Example



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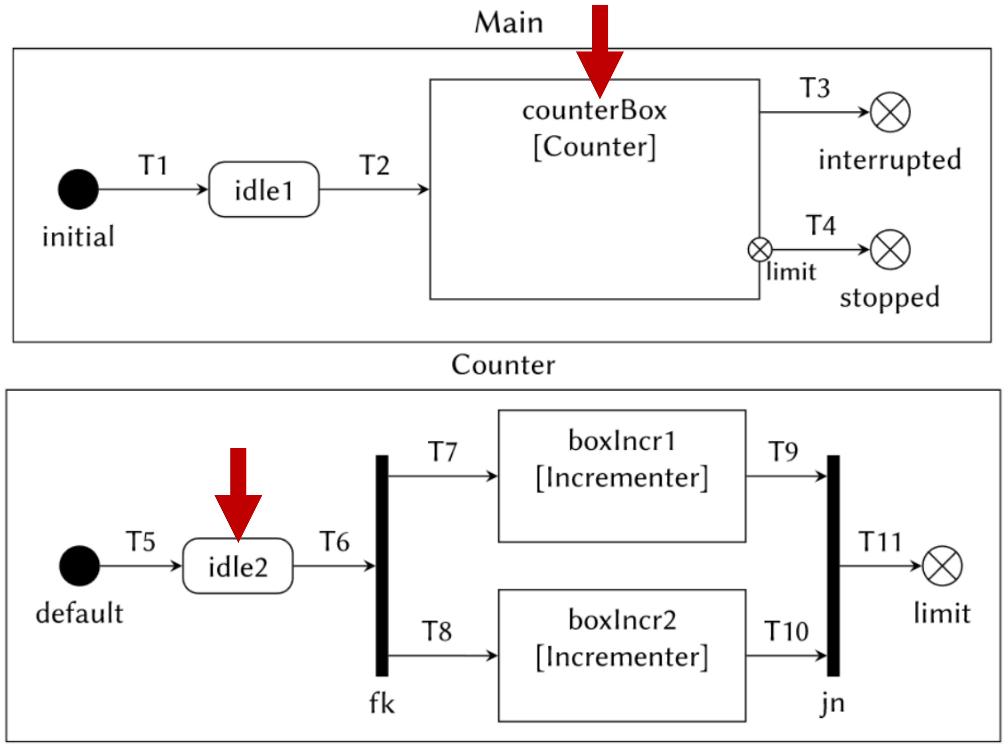
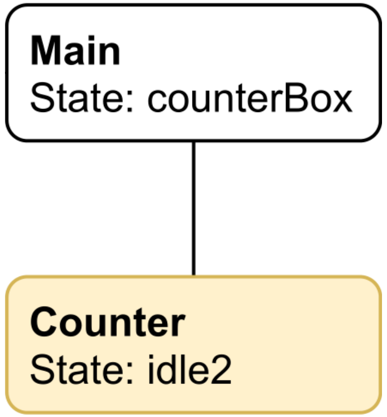
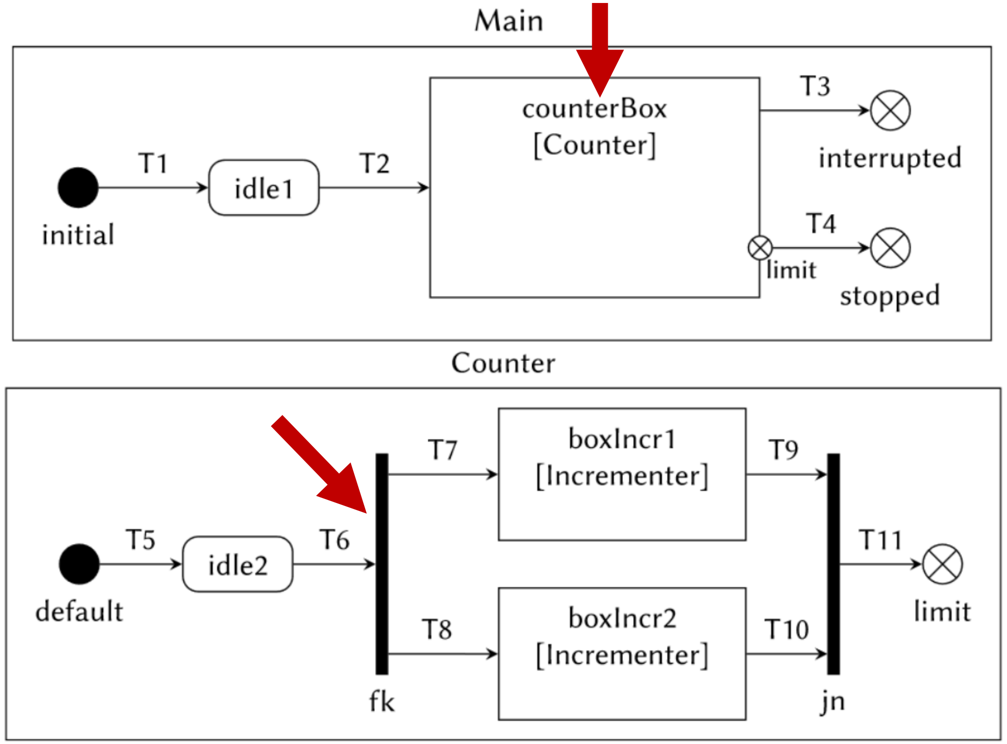


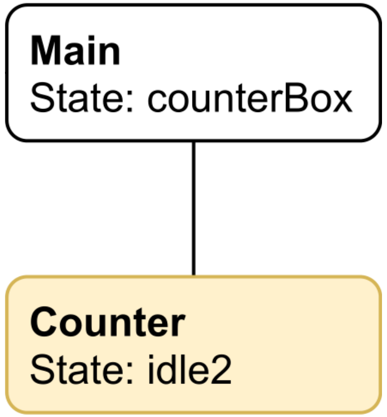


Main
State: counterBox

Counter
State: idle2

DSTM Semantics by Example





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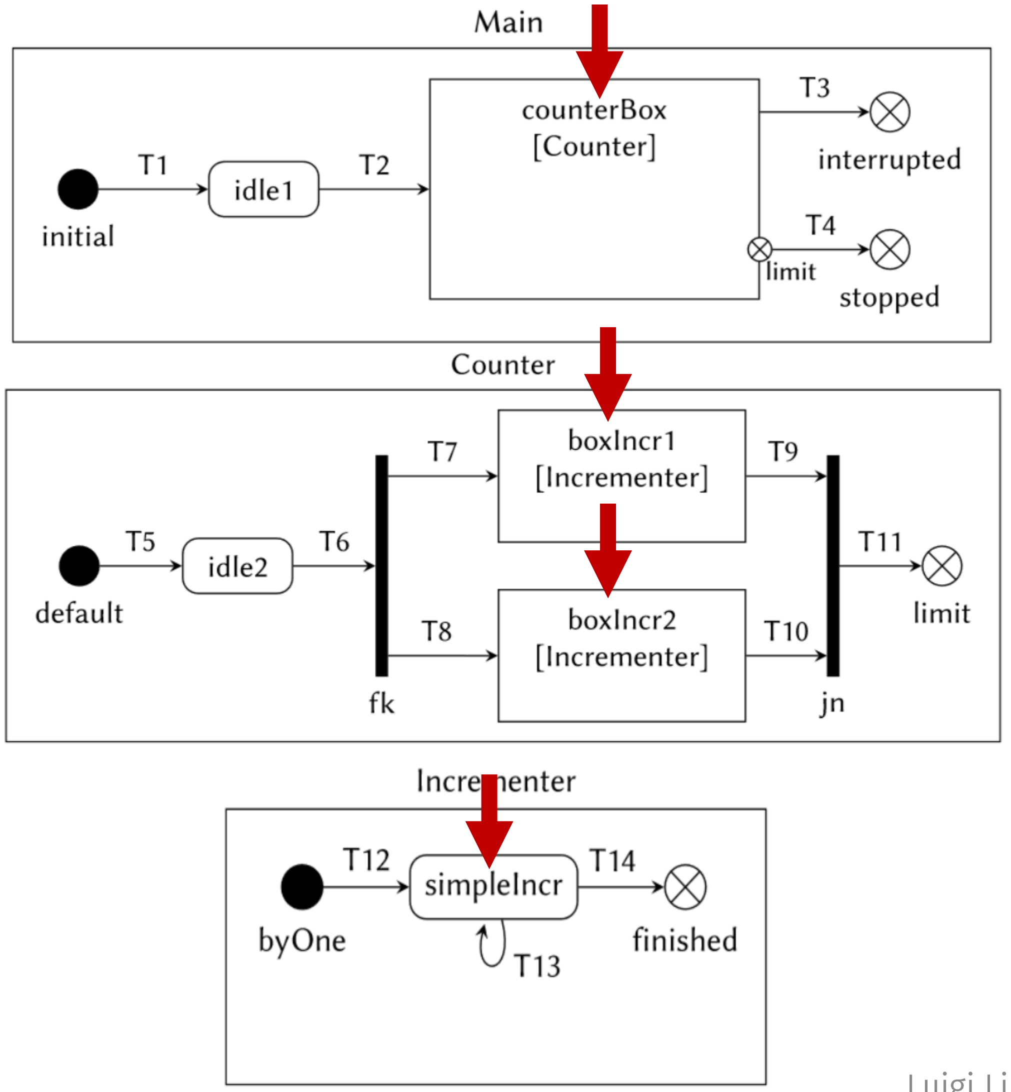
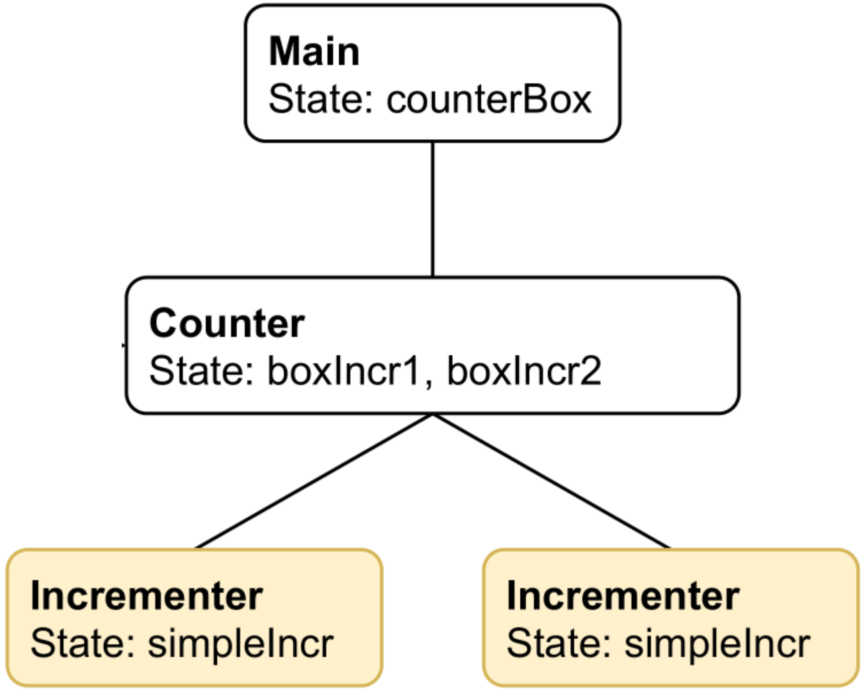




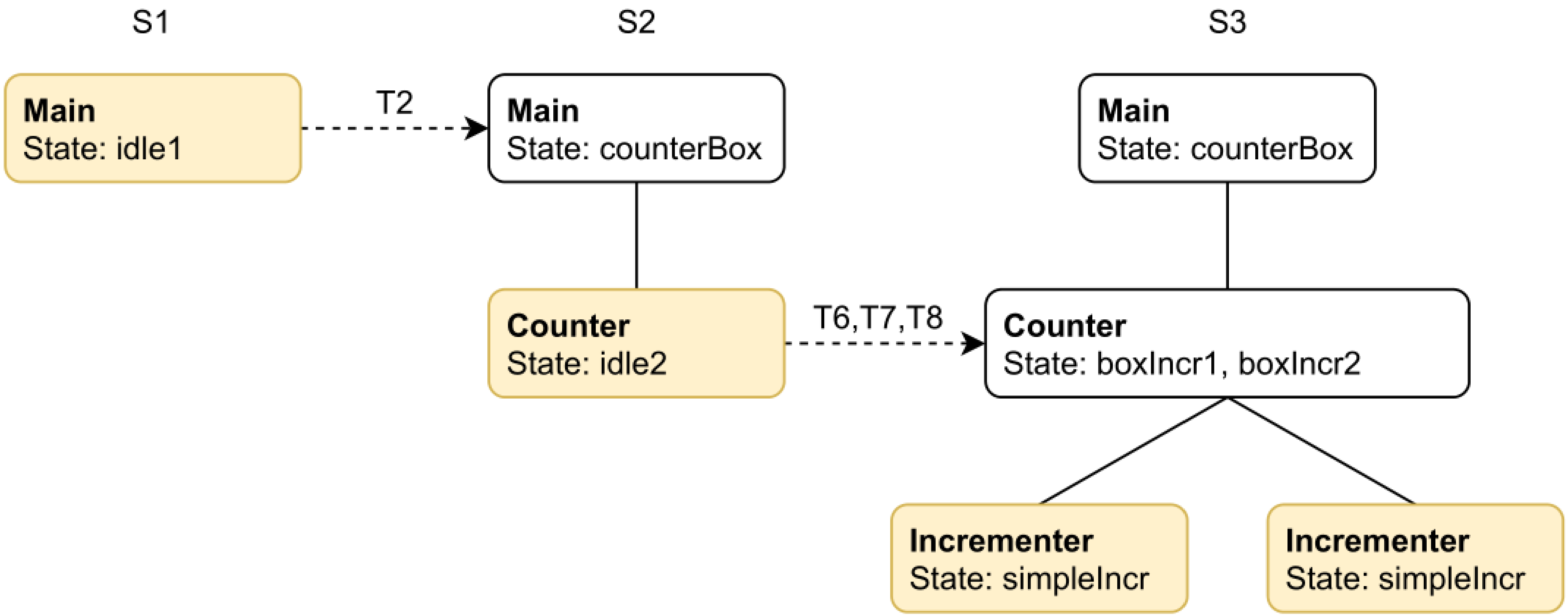
Main
State: counterBox

Counter
State: boxIncr1, boxIncr2

Incrementer
State: simpleIncr

Incrementer
State: simpleIncr

Hierarchical Computations



Reasoning about computations

- How can we **predicate** over such hierarchical computations?

Temporal Logics

- How can be **predicate** over such hierarchical computations?
- Formalisms to express properties of system behaviours (sequences of system states)
- Extensions of standard propositional logics with **temporal modalities**
- LTL is a widely-used temporal logic, and it is very effective when reasoning about sequences of flat, unstructured states

Dealing with Hierarchical Computations

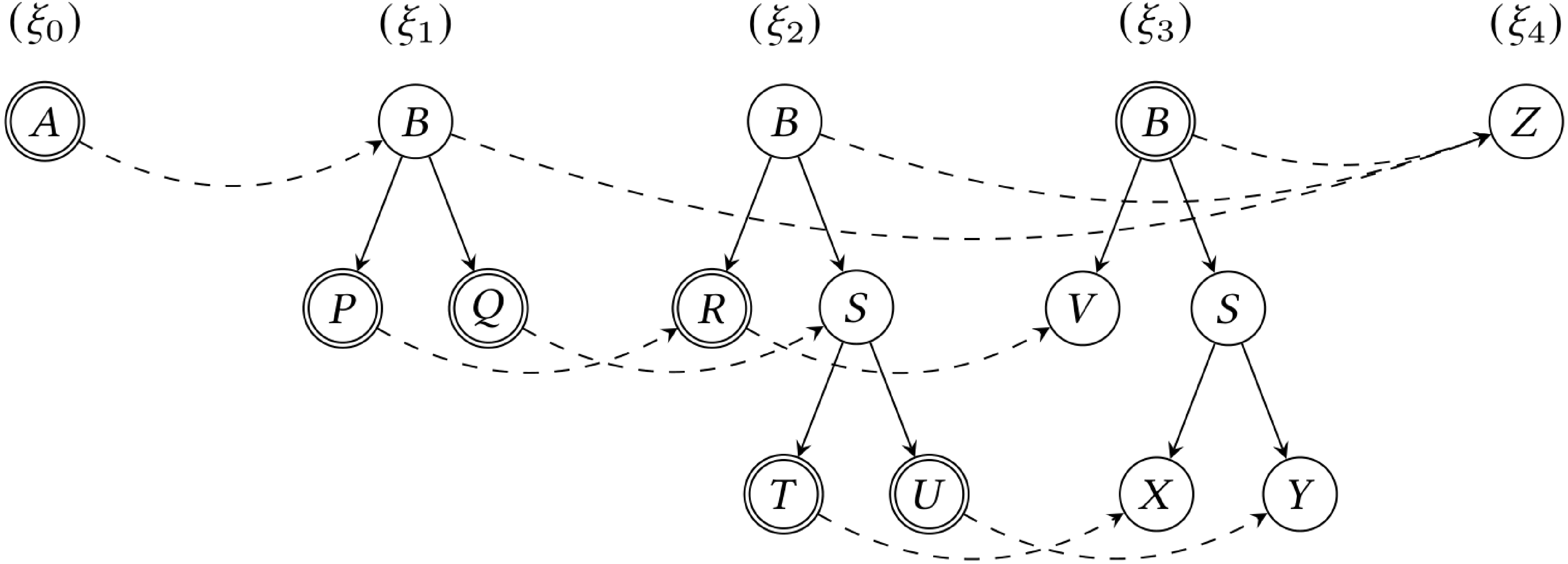
- In hierarchical computations, states are not flat, they have an intrinsic, tree-like hierarchical structure
- LTL cannot predicate naturally over this intrinsic structure
- We extended LTL with operators that allow to **contextualize formulae in the hierarchical structure** of states
- We called this extension Hierarchical LTL (**HLTL**)

Hierarchical Linear-time Temporal Logic

An **HLTL** formula is defined inductively as follows:

$\phi \coloneqq \top \mid p \in P \mid \neg\phi \mid \phi_1 \vee \phi_2 \mid \phi_1 \wedge \phi_2$	Standard Propositional Logic
$\mid X(\phi) \mid \phi_1 U \phi_2$	LTL operators
$\mid\leftarrow(\phi)\mid\rightarrow(\phi)\mid\downarrow_n(\phi)$	HLTL operators

HLTL by Example



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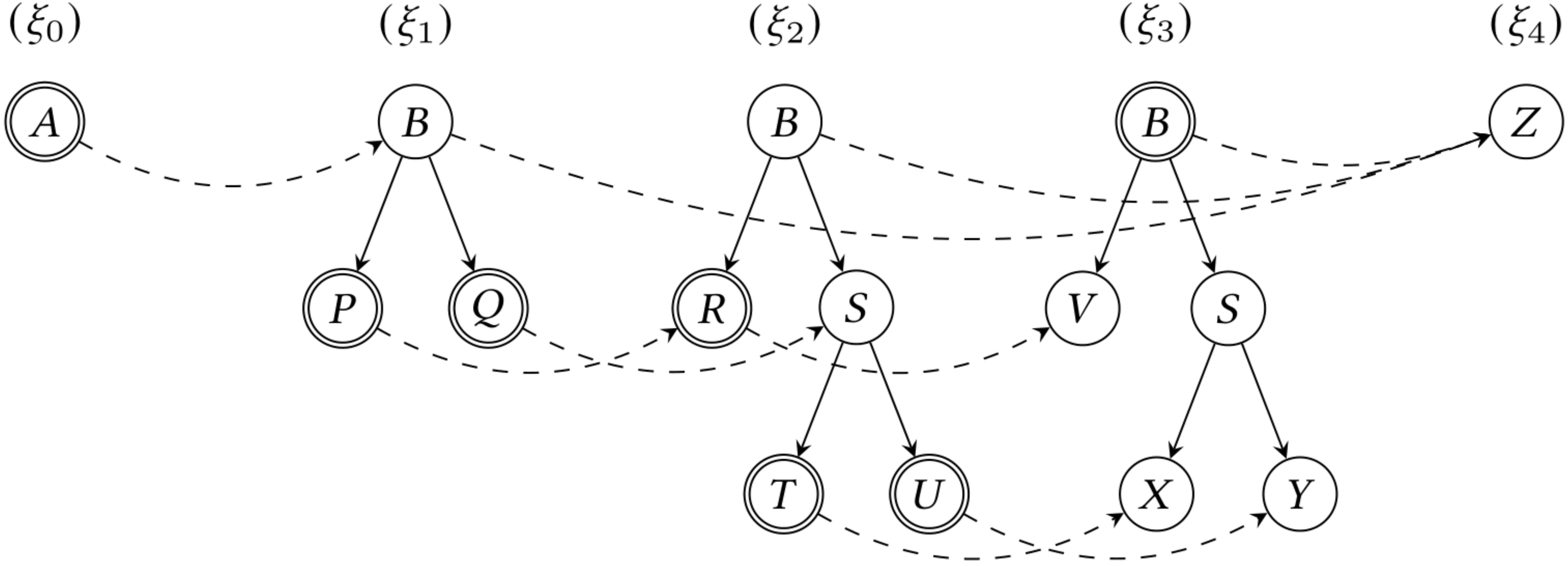
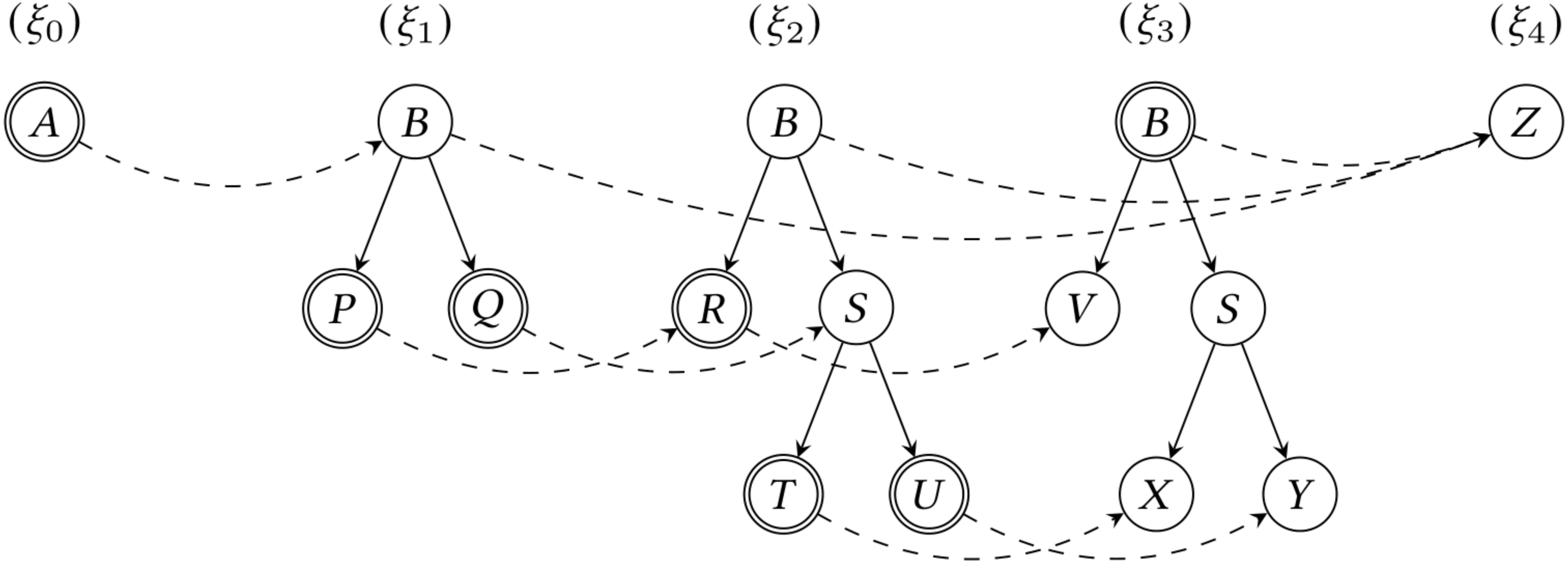


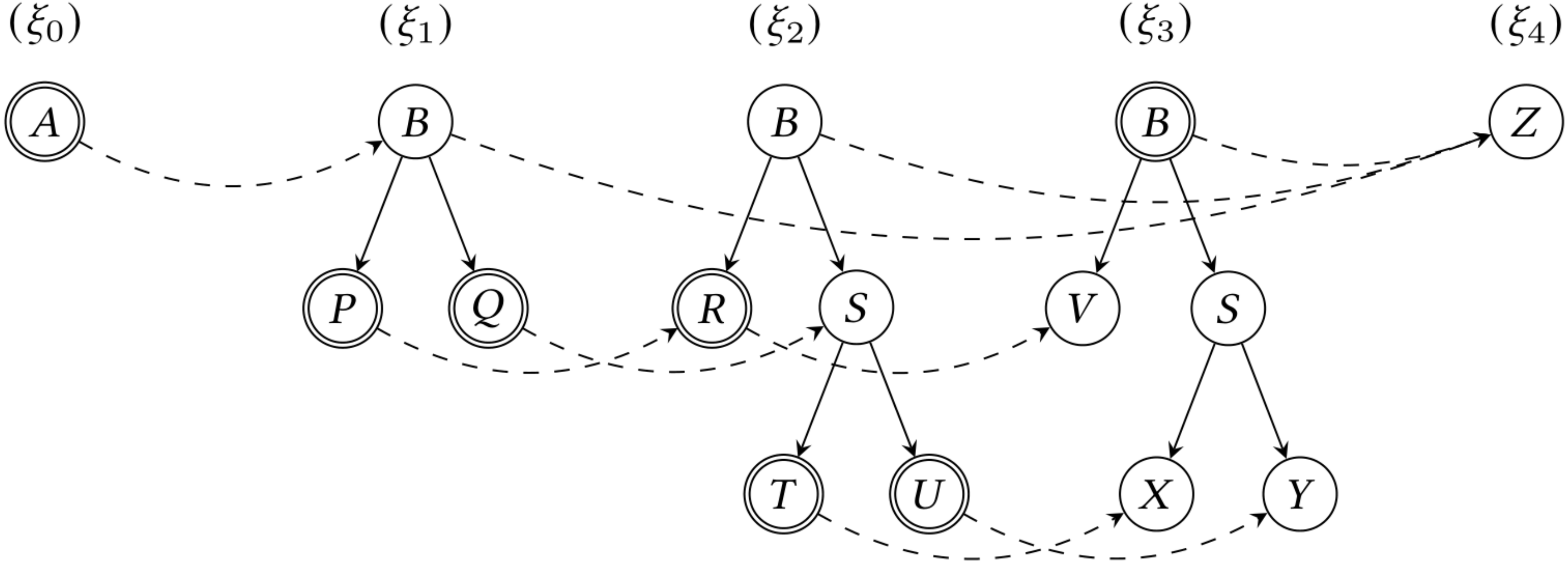
$$X(\downarrow_2 (Q))$$

HLTL by Example



$$X\left(\downarrow_1 \left(P \wedge \rightarrow (Q)\right)\right)$$

HLTL by Example



$$X\left(\downarrow_1 \left(P \wedge X(R)\right)\right)$$

Conclusions and Future Works

- We have presented and formalized **HLTL**
- In future works:
  - Devise a **model checking** procedure
  - Integrate HLTL within the modelling framework for Dynamic State Machines presented in [2]

[2] Benerecetti, M., Gentile, U., Marrone, S., Nardone, R., Peron, A., Starace, L.L.L., Vittorini, V.: From dynamic state machines to Promela. In: Model Checking Software. pp. 56–73. Springer International Publishing, Cham (2019)

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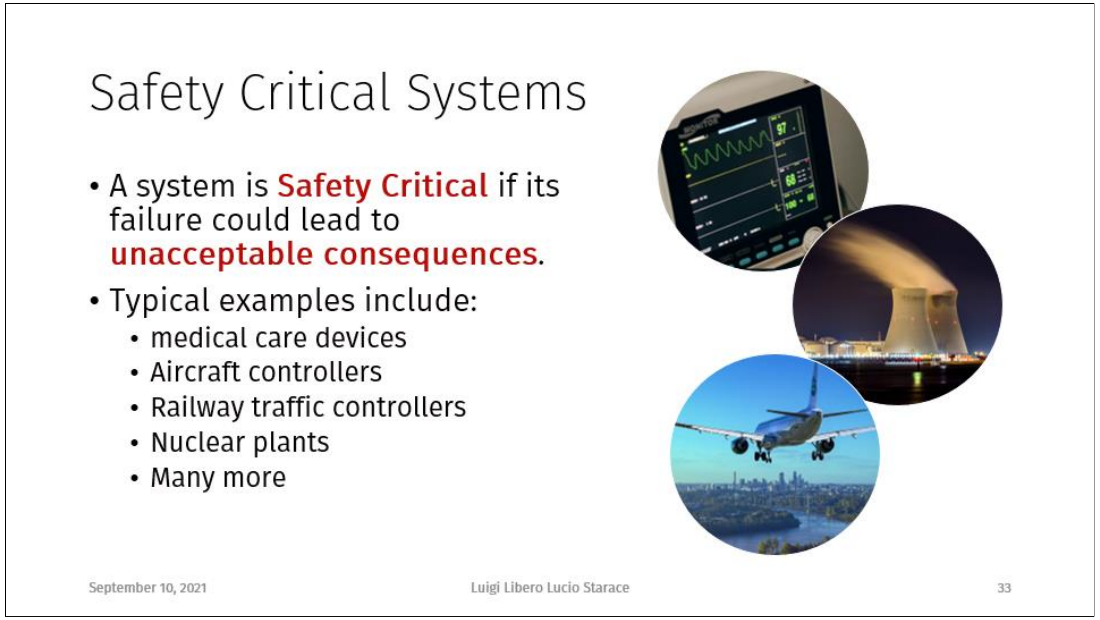

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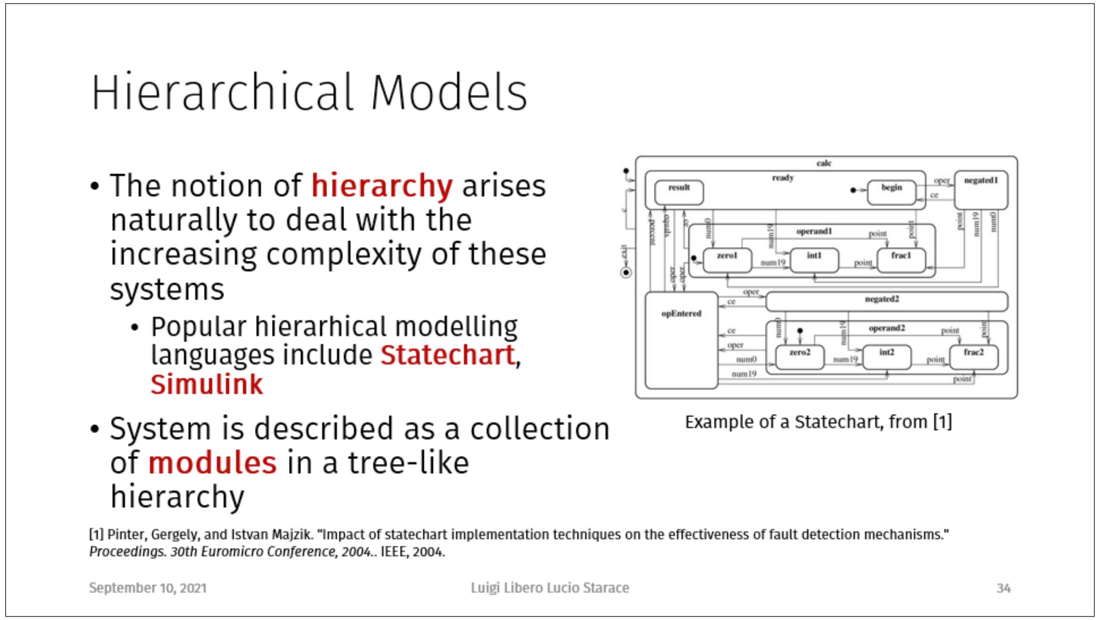

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calc
ready
result
begin
negated1
operand1
zero1
int1
frac1
opEntered
negated2
operand2
zero2
int2
frac2
oper
ce
point
num0
num19
percent
equals
exit

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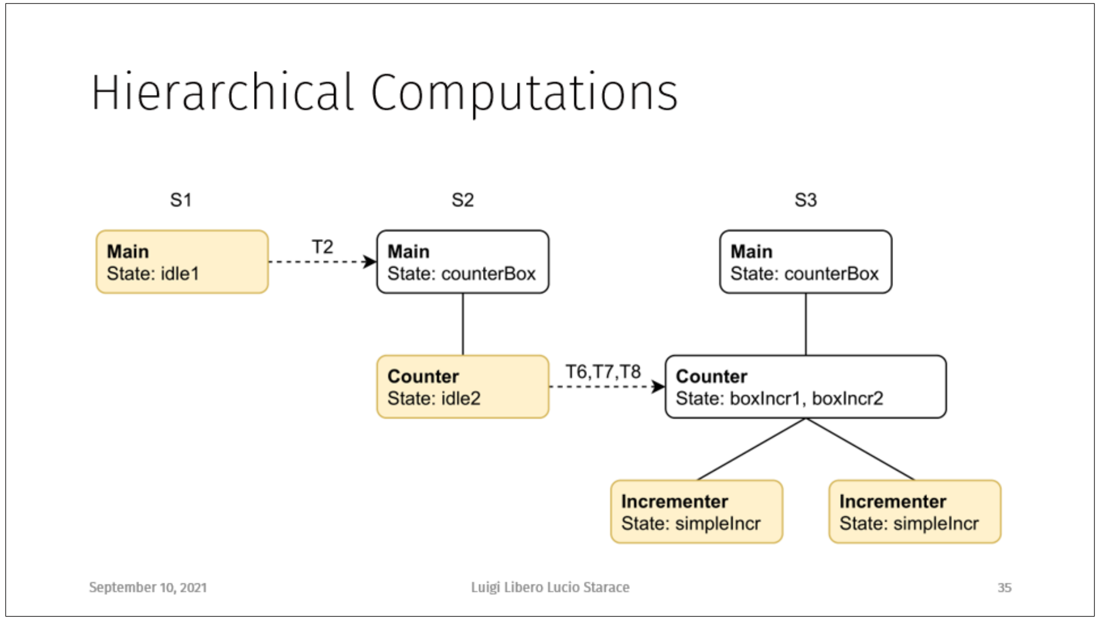

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S1

Main
State: idle1

T2

S2

Main
State: counterBox

Counter
State: idle2

T6,T7,T8

S3

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Counter
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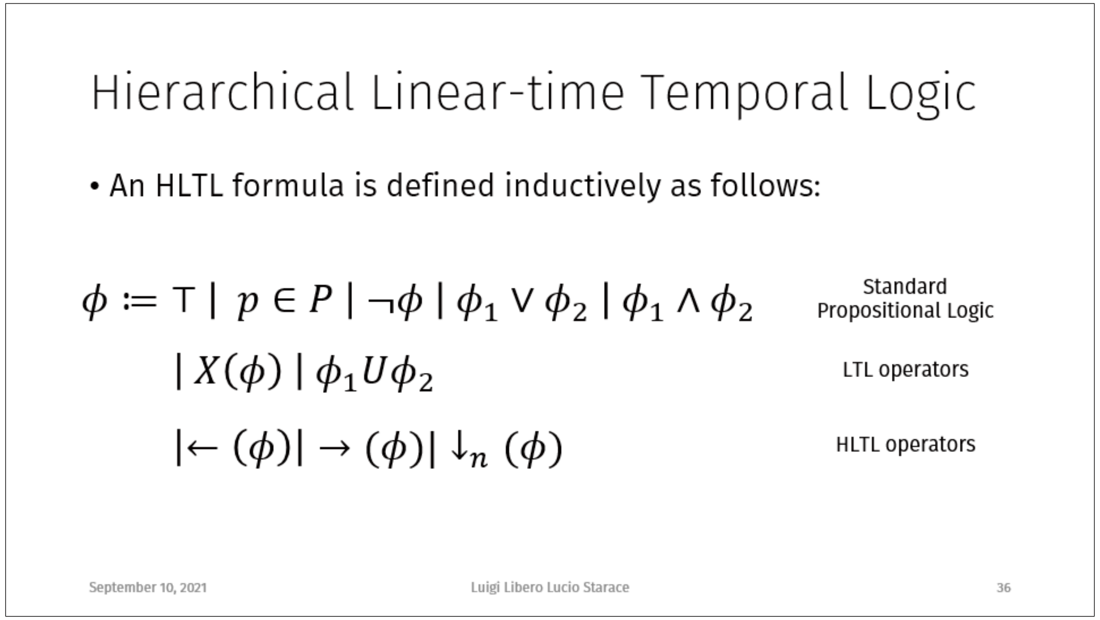

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HLTL operators

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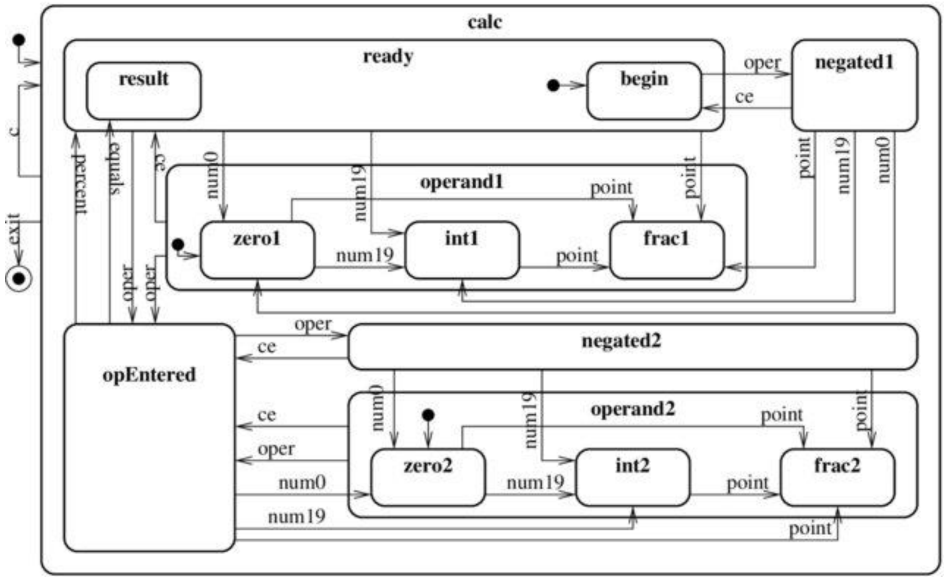

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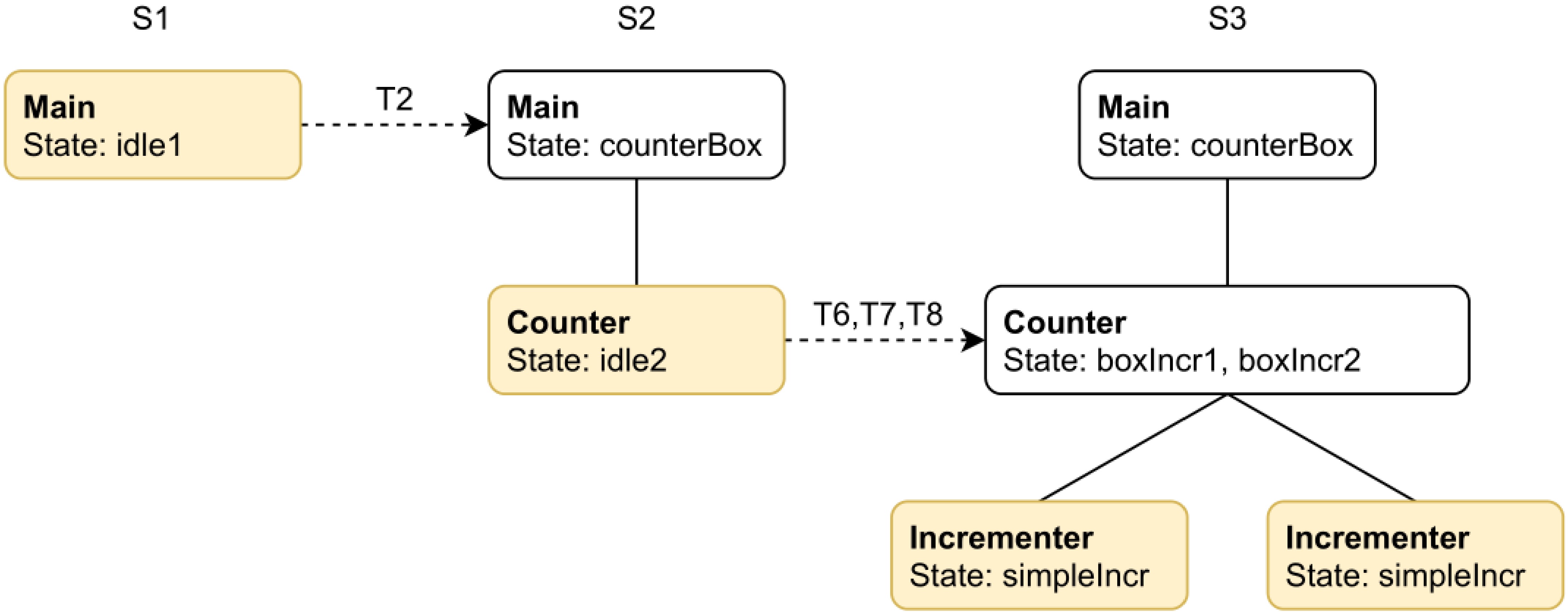

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