Core Course

Introduction to Model Checking

https://clegra.github.io/mc/mc.html

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Model Checking

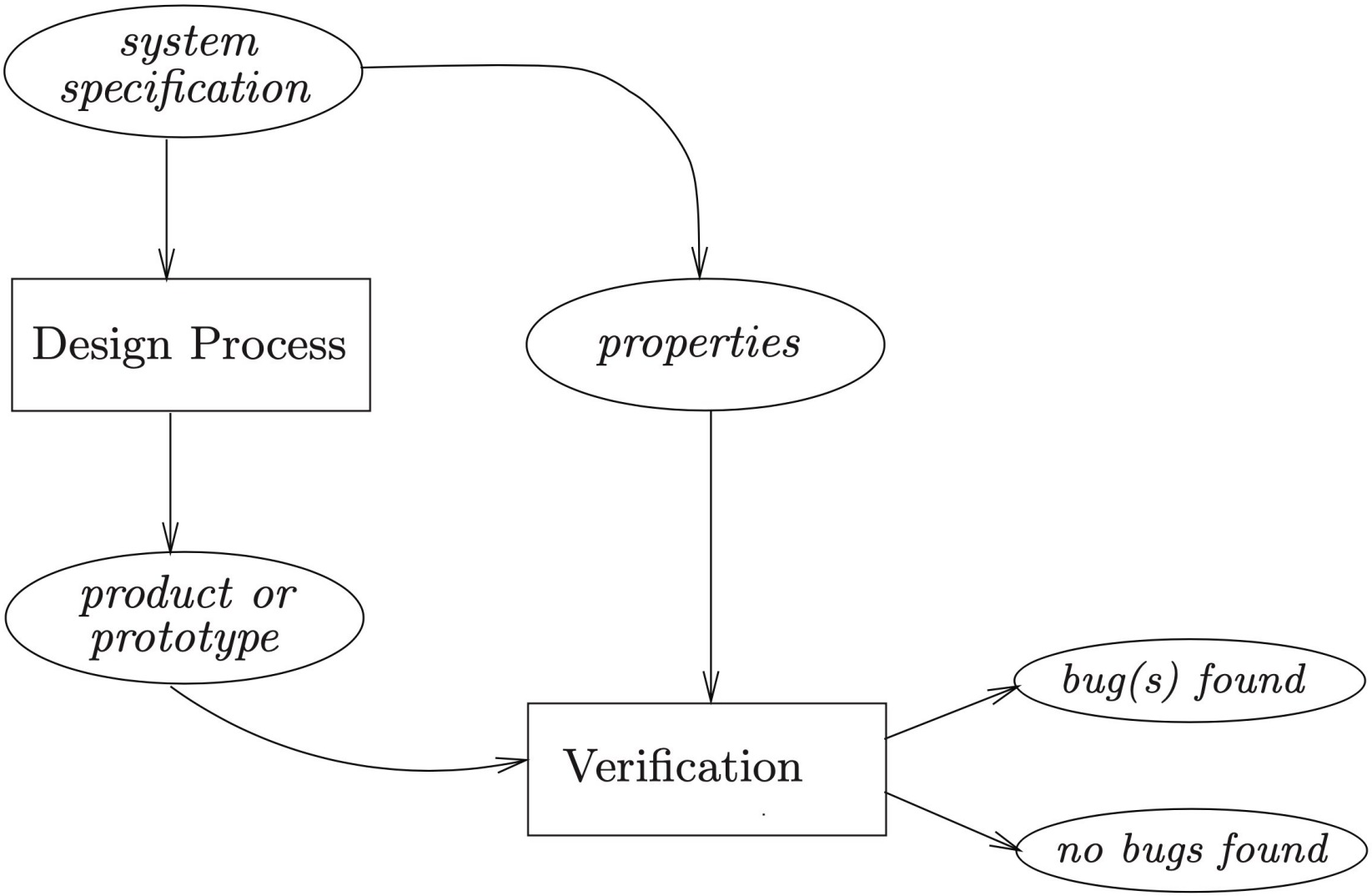
. . . is an effective automatable technique:

- *to expose potential software design errors;*
- *that, given a finite-state model of a system and a formal property, systematically checks whether this property holds for that model.*

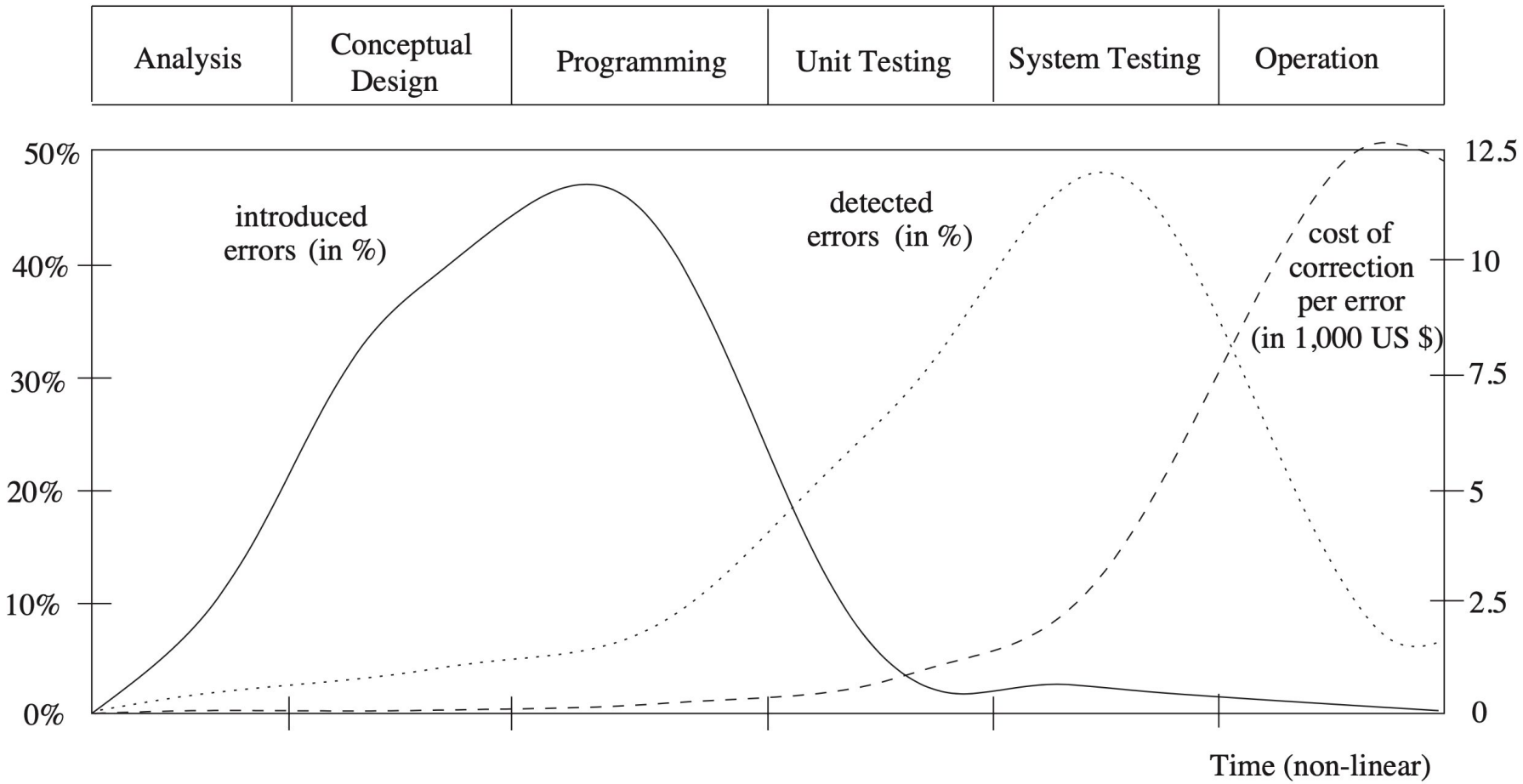
Strengths:

- widely applied in industry
  for: embedded systems, software engineering, hardware design, explainable AI
- supports partial verification (of system parts)
- provides diagnostic information for debugging
- has sound mathematical underpinning (logic and process theory)

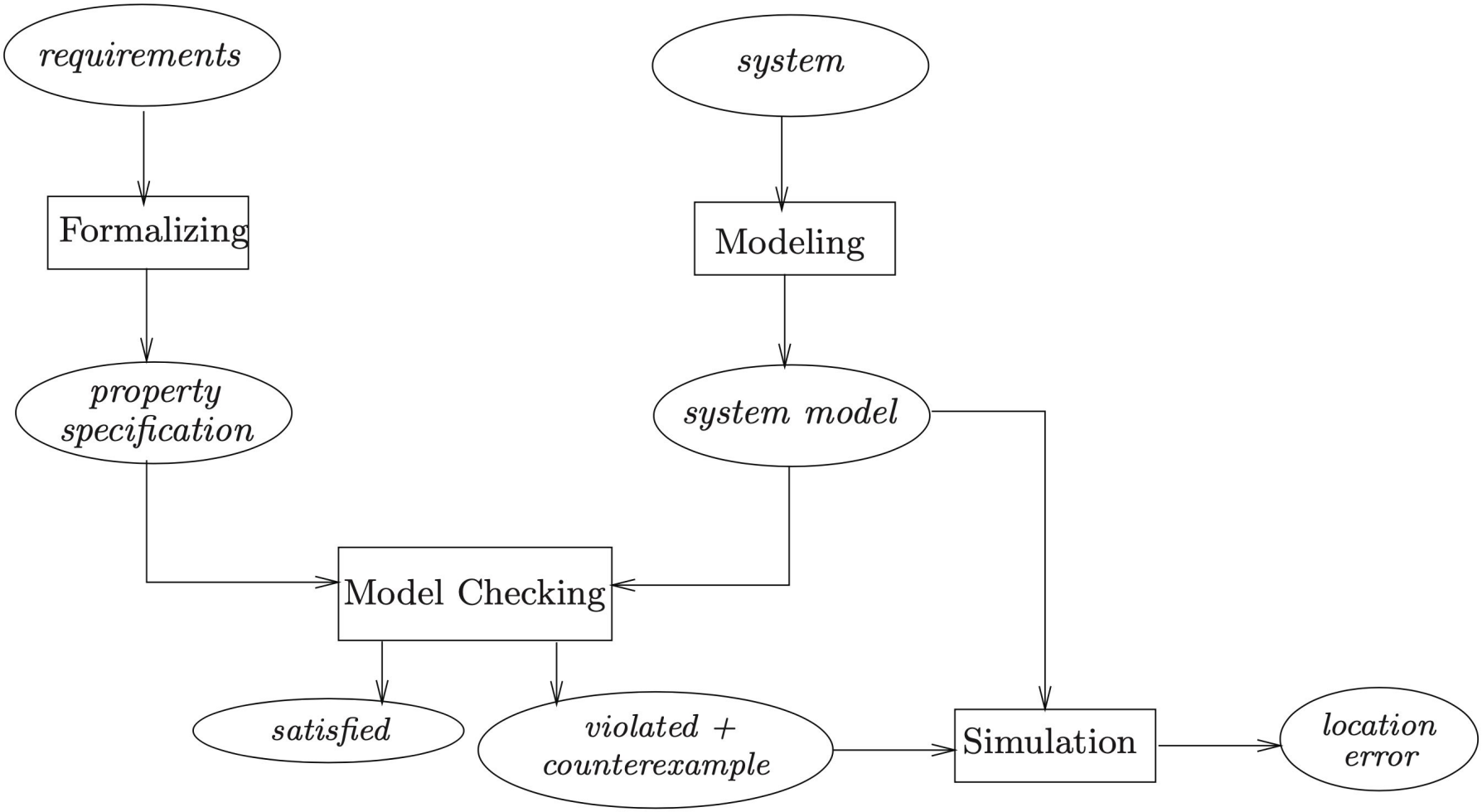
Hard-/Software Verification (traditionally)



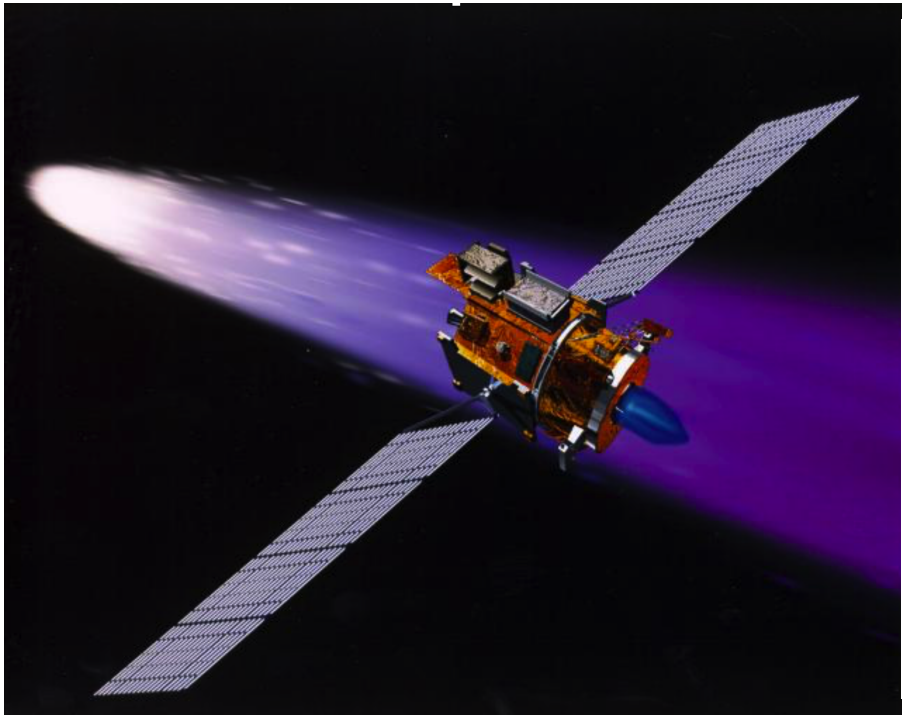
Error introduction, detection, and repair costs

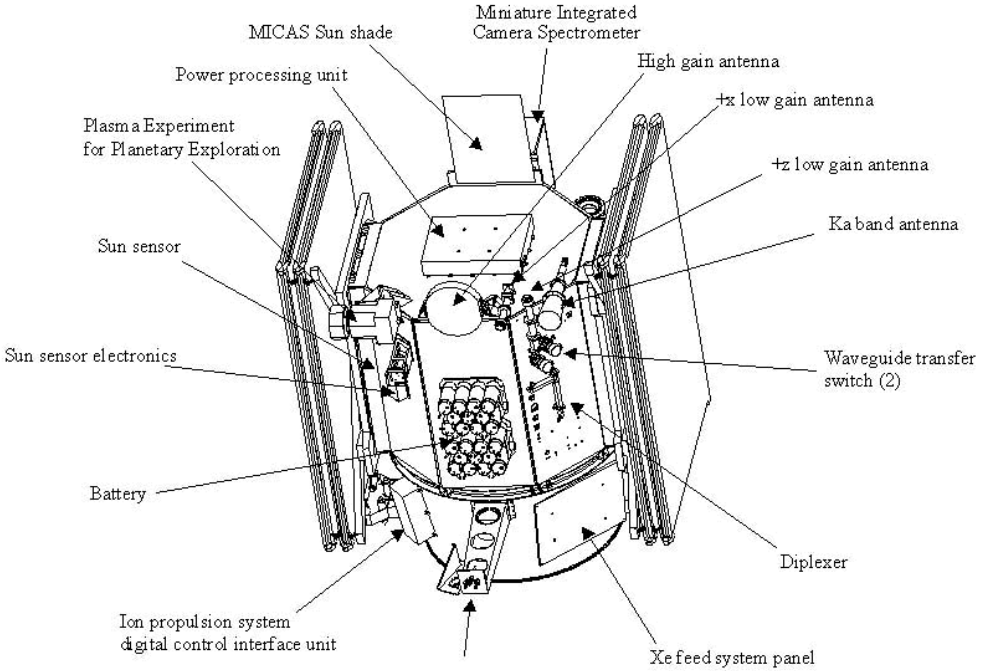


Model checking



Deep Space 1





- Flyby of asteroid 9969 Braille (1999)
- Entered the coma of Comet Borrelly (2001)
- Model checking discovered 5 concurrency errors

Example (program concurrency/non-determinism)

Programs Inc, Dec, and Reset cooperate, and use a shared variable x:

```
proc Inc
  while true
    do
      if x < 200
        then x := x + 1
      fi
    od
```

```
proc Dec
  while true
    do
      if x > 0
        then x := x - 1
      fi
    od
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proc Reset
  while true
    do
      if x = 200
        then x := 0
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Question: Is $0 \leq x \leq 200$ always guaranteed?

Modeling (by labeled transition systems)

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proc Inc
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      if x < 200
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Modeling (by labeled transition systems)

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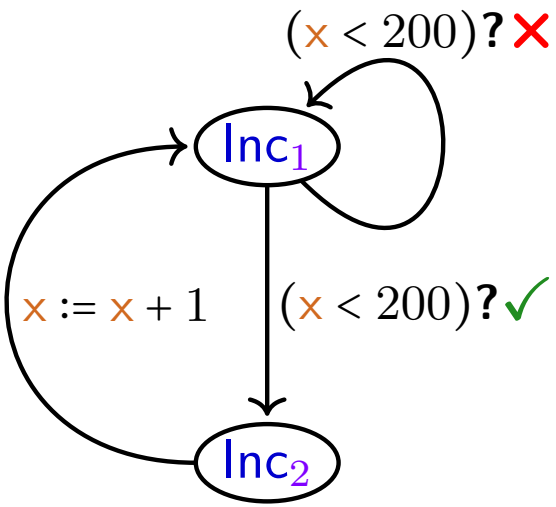
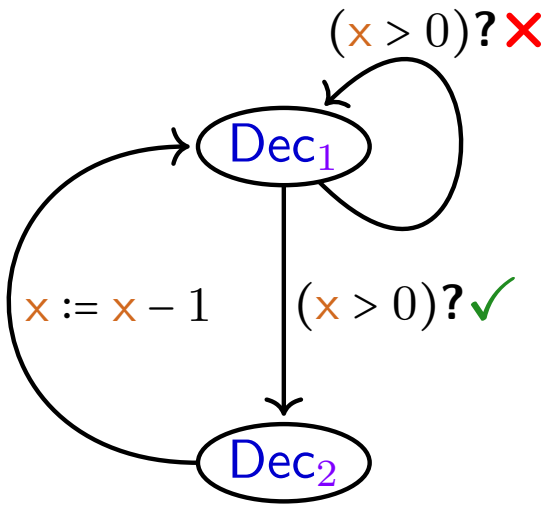
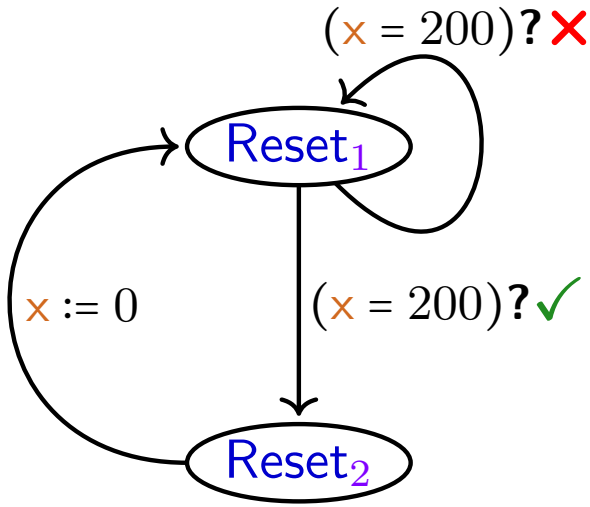
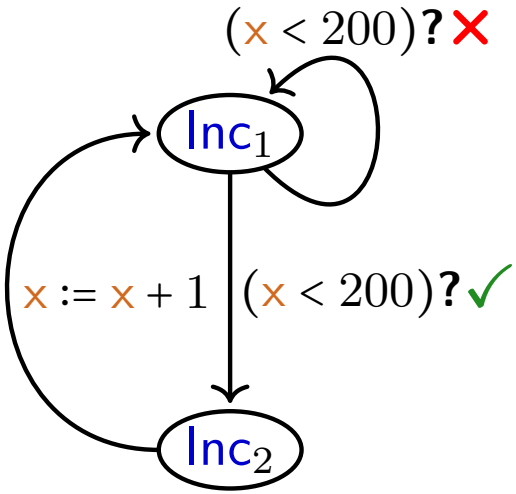


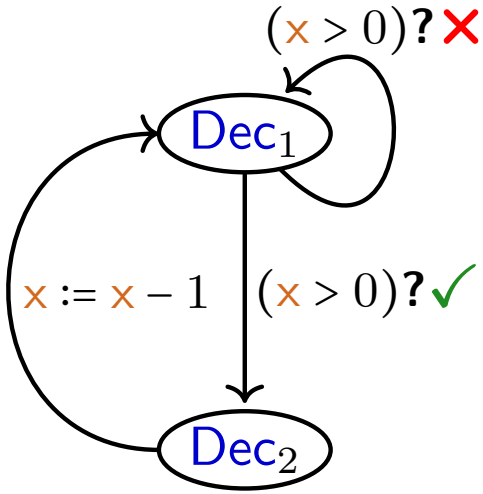


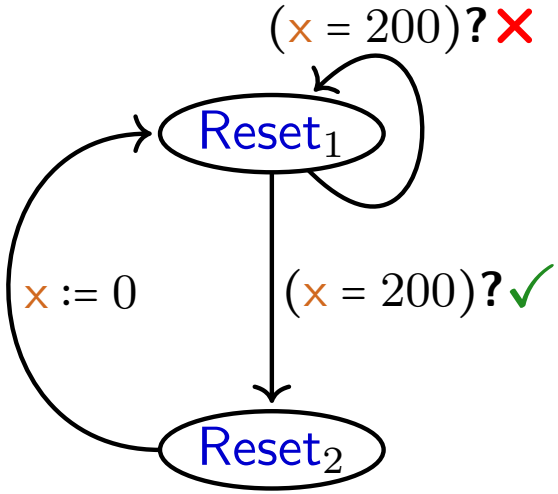


Labeled transition systems (LTSs)

Formalizing properties (in temporal logic)







$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \stackrel{?}{\models} \quad \Box(0 \leq x \wedge x \leq 200)$ (Linear-TL formula)

Counterexample (offending execution trace)

$$\langle x = 199 \,;\, \mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \rangle$$

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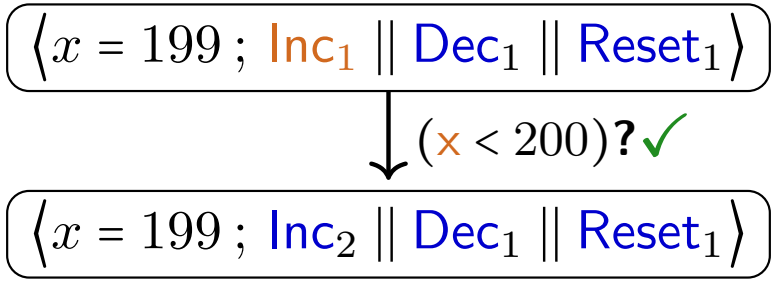

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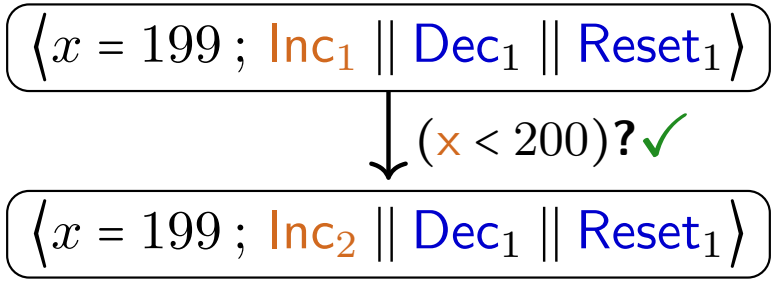

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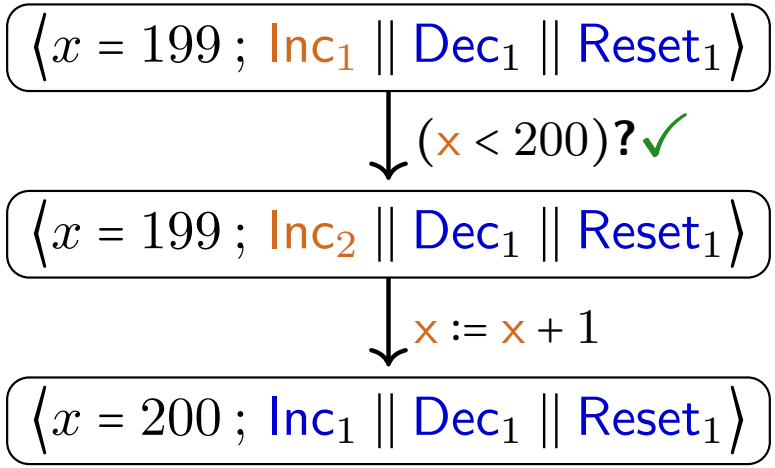

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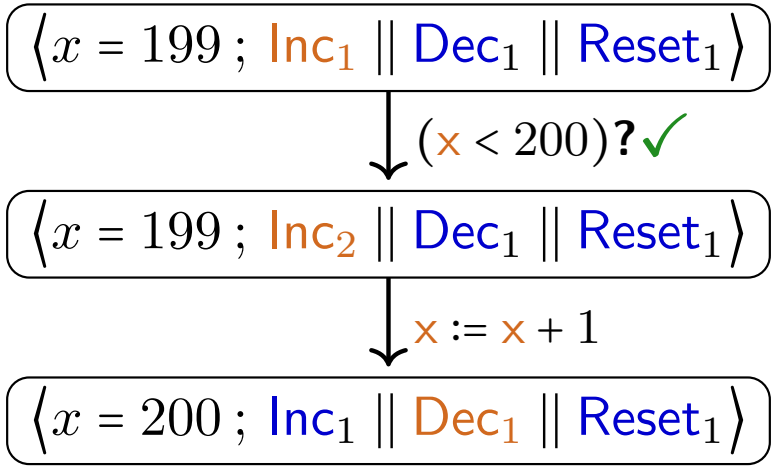

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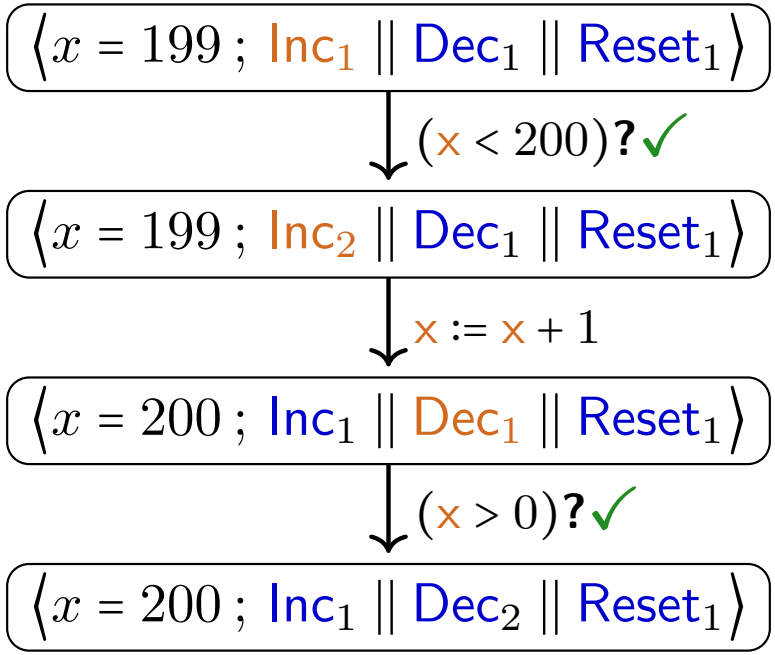

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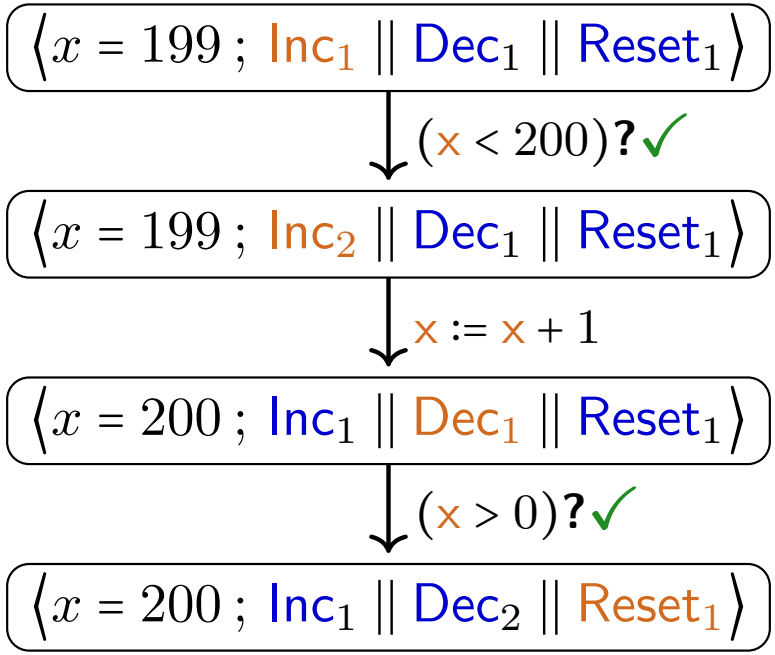

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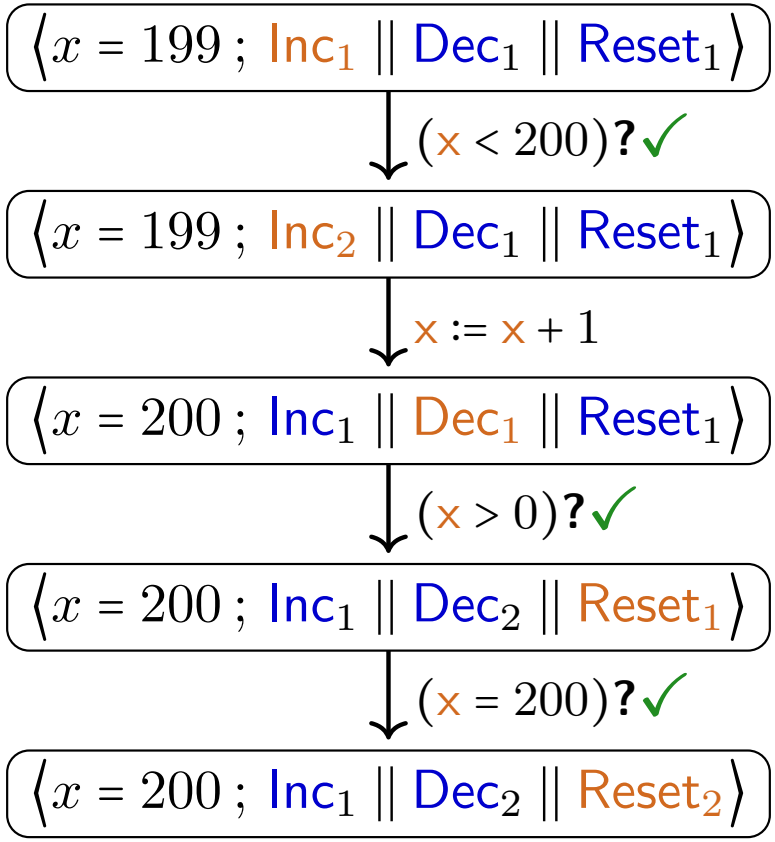

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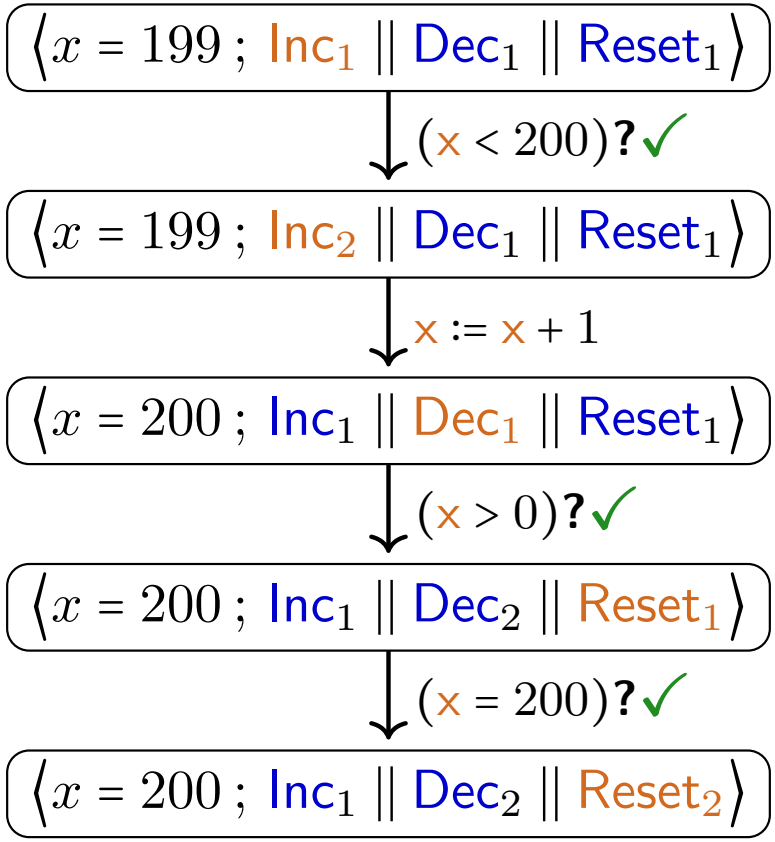

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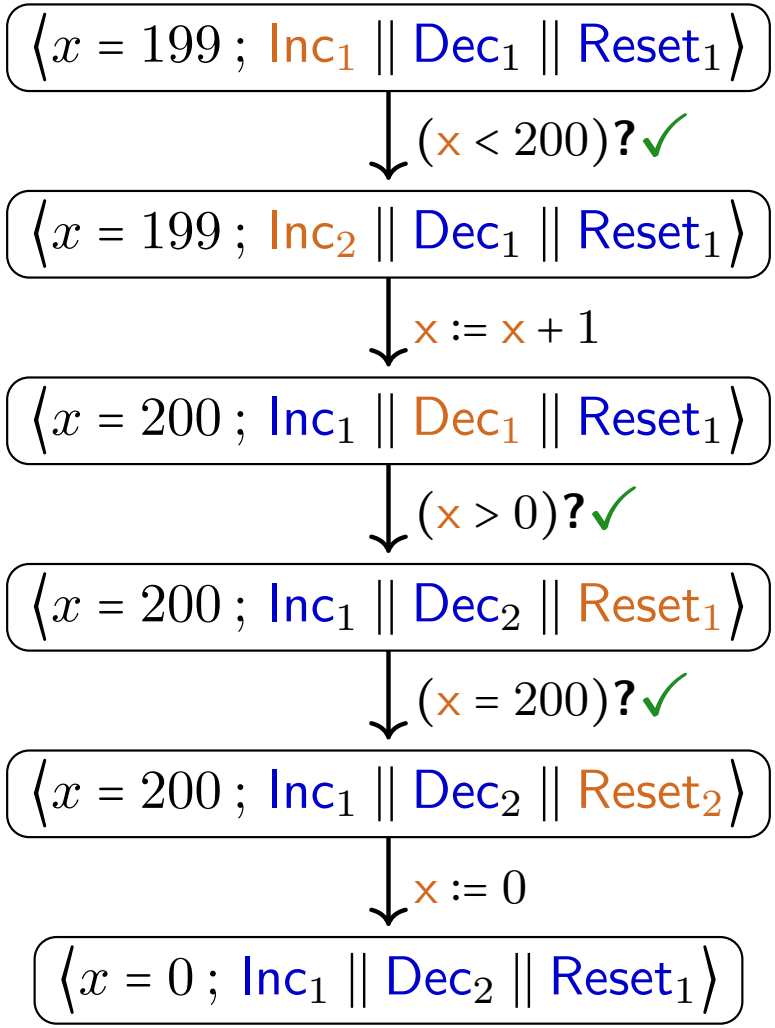

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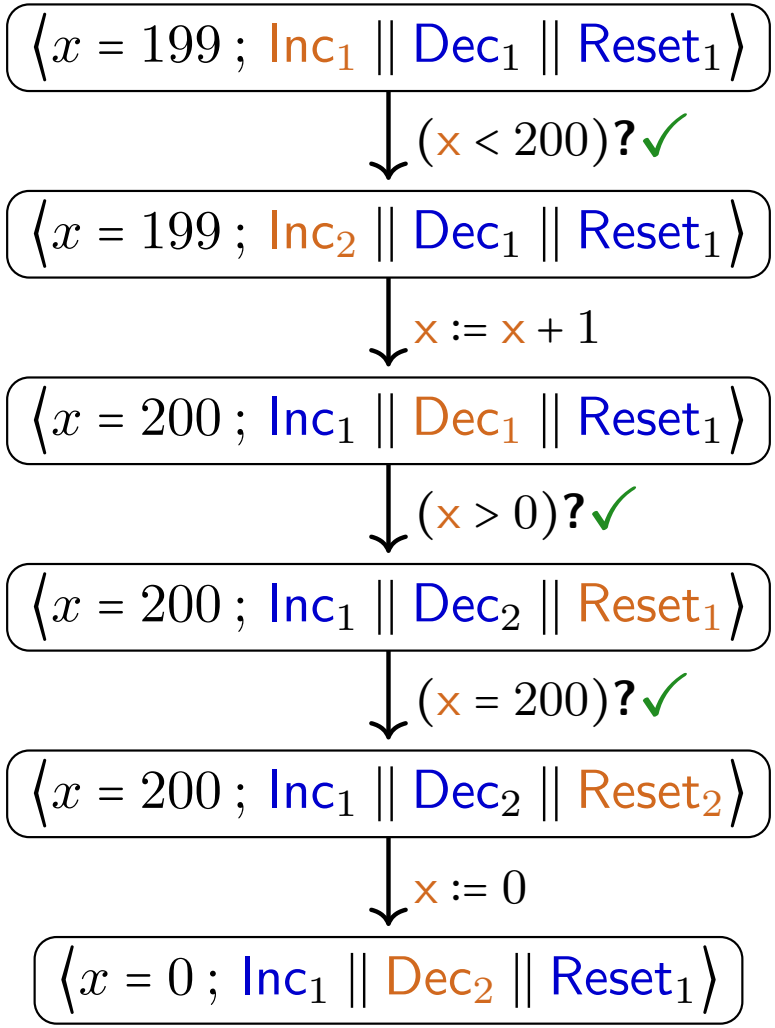

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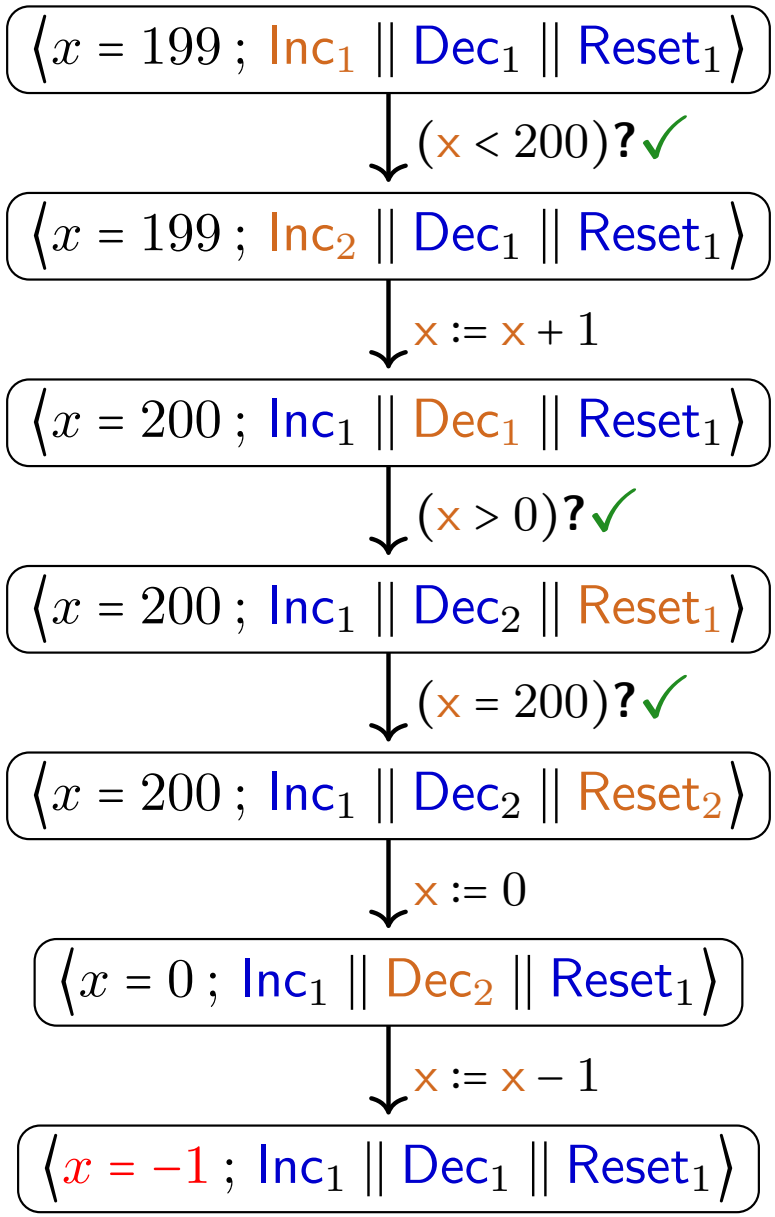
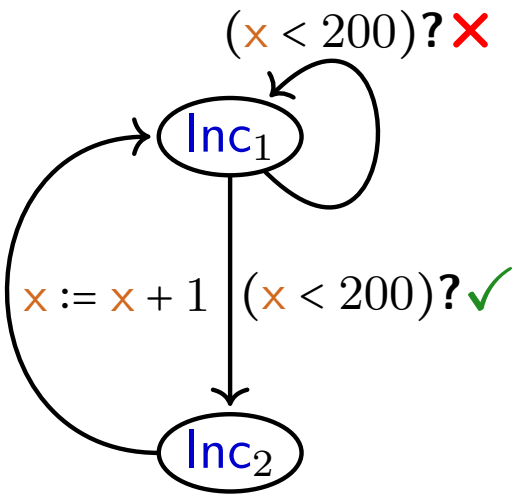
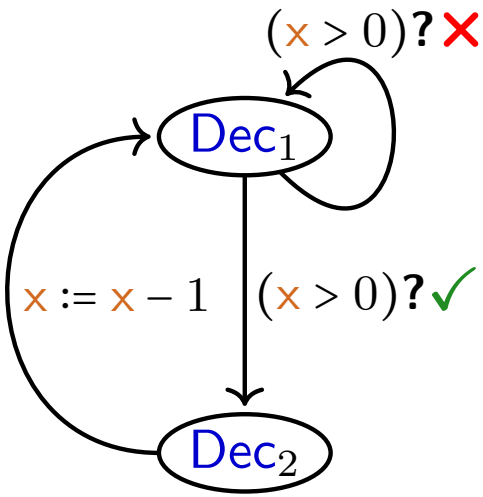
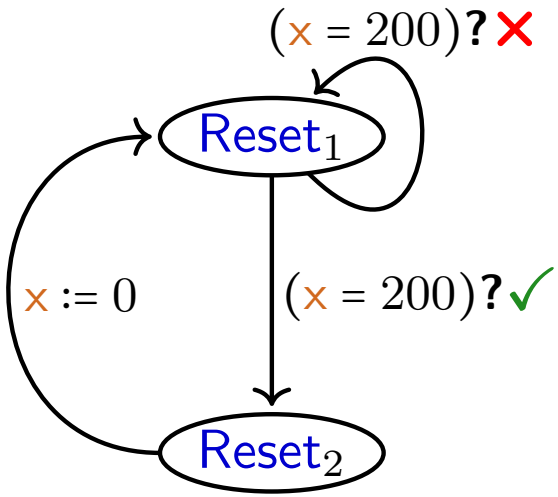


Formalizing properties (in temporal logic)







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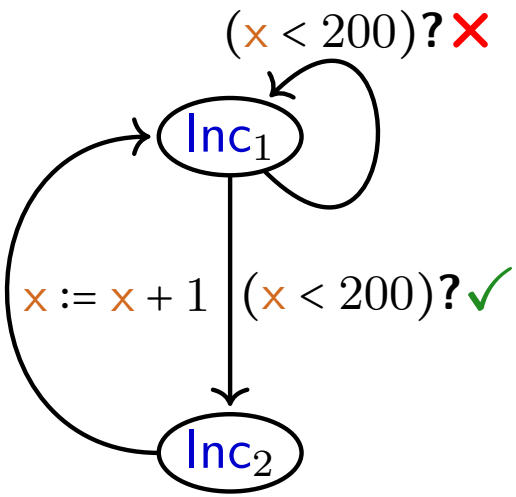

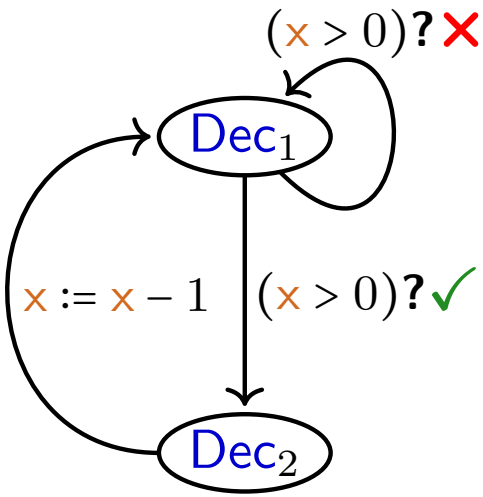

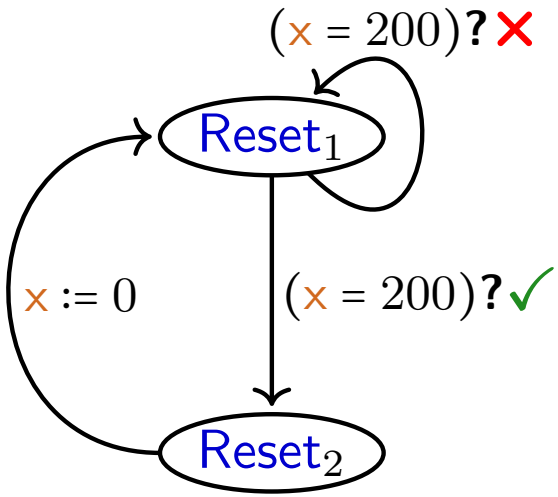

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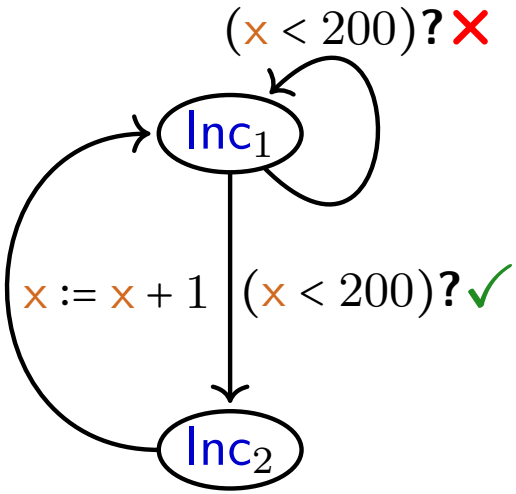

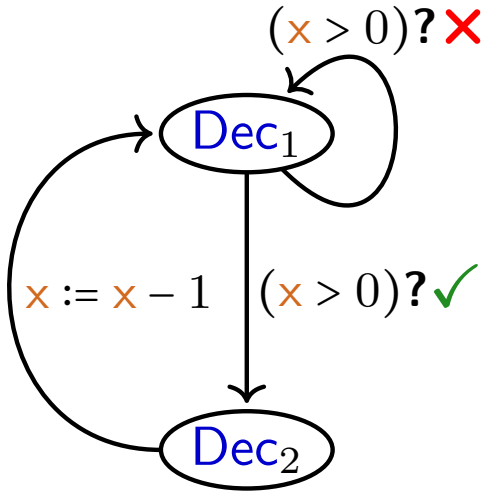

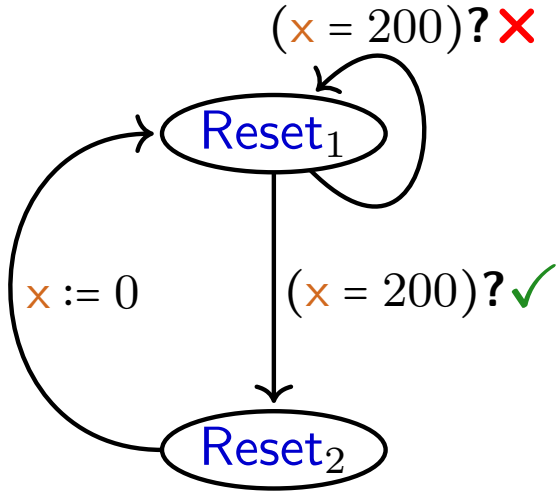

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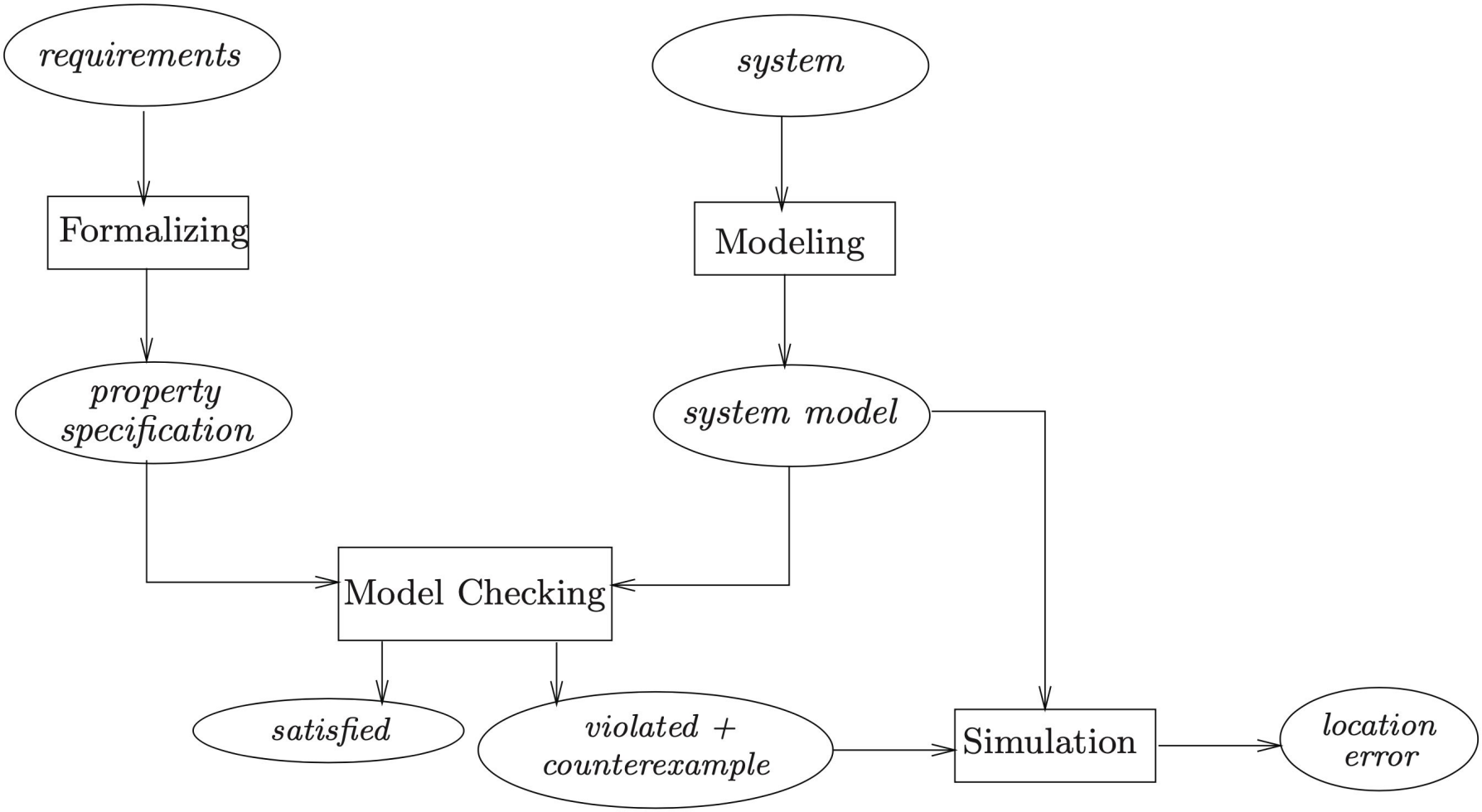
$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \not\models \forall\Box(0 \leq x \wedge x \leq 200)$ (Computation-Tree-L formula)

$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \models \exists\Box(0 \leq x \wedge x \leq 200)$ (CTL formula)

$\mathsf{Inc}_1 \parallel \mathsf{Dec}_1 \parallel \mathsf{Reset}_1 \models \forall\Box\exists\Diamond(x < 0)$ (CTL formula)

Model checking

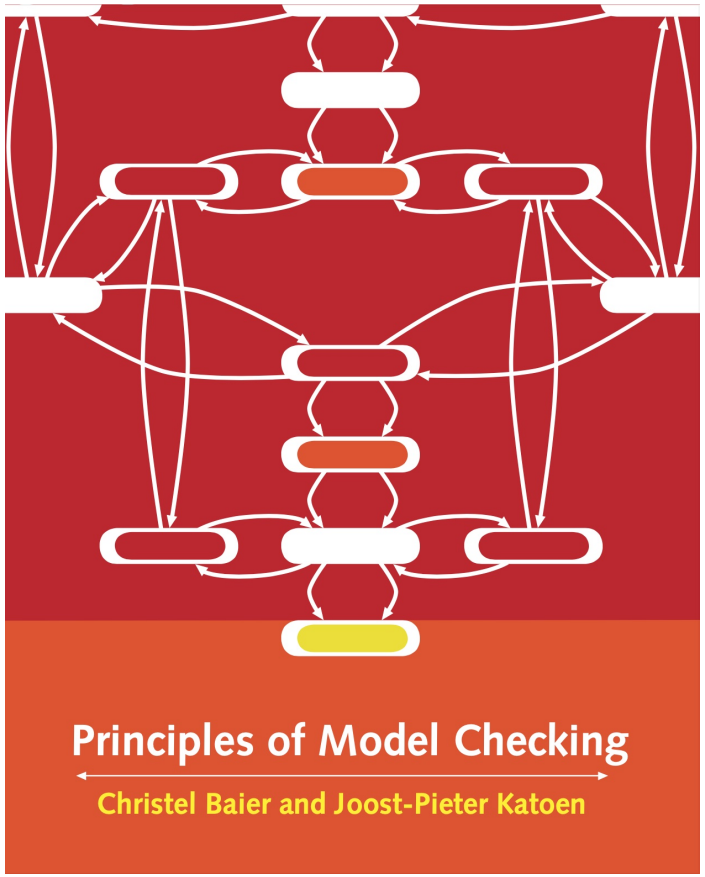


Any [such] verification is only as good as the model of the system.

Topics of the module

- modeling systems by labeled transition systems (LTSs)
- fairness
- Linear Temporal Logic (LTL)
  - model checking formulas
    - express properties by Büchi automata
    - model check LTSs and properties via product automata
- Computation Tree Logic (CTL)
- partial model checking
  - partially known systems (state properties/states/transitions)
- analysing system behavior with the SPIN model-checker

Book



- pdf available:
  https://is.ifmo.ru/books/_principles_of_model_checking.pdf

Organization

Lectures (Emilio 2/Clemens 5)

- presentations on blackboard
- notes after the lecture (notes 2025/26 available)
- January 19 – January 28 (7 lectures)

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- options:
  - small verification project (of an algorithm, e.g. in SPIN)
  - presentation about a paper
  - written exam?

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