FalCAuN – CPS Testing with Automata Learning

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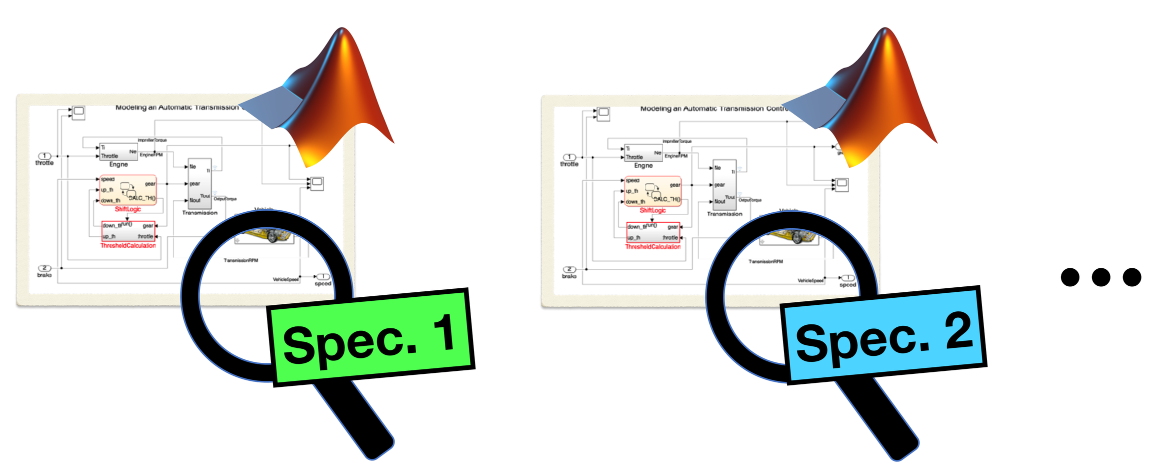
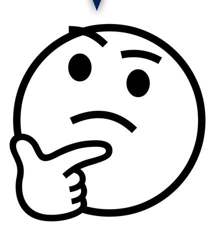
Q. How to enhance system testing?
e.g. Reusability, Explanation, Theoretical gurantee, …

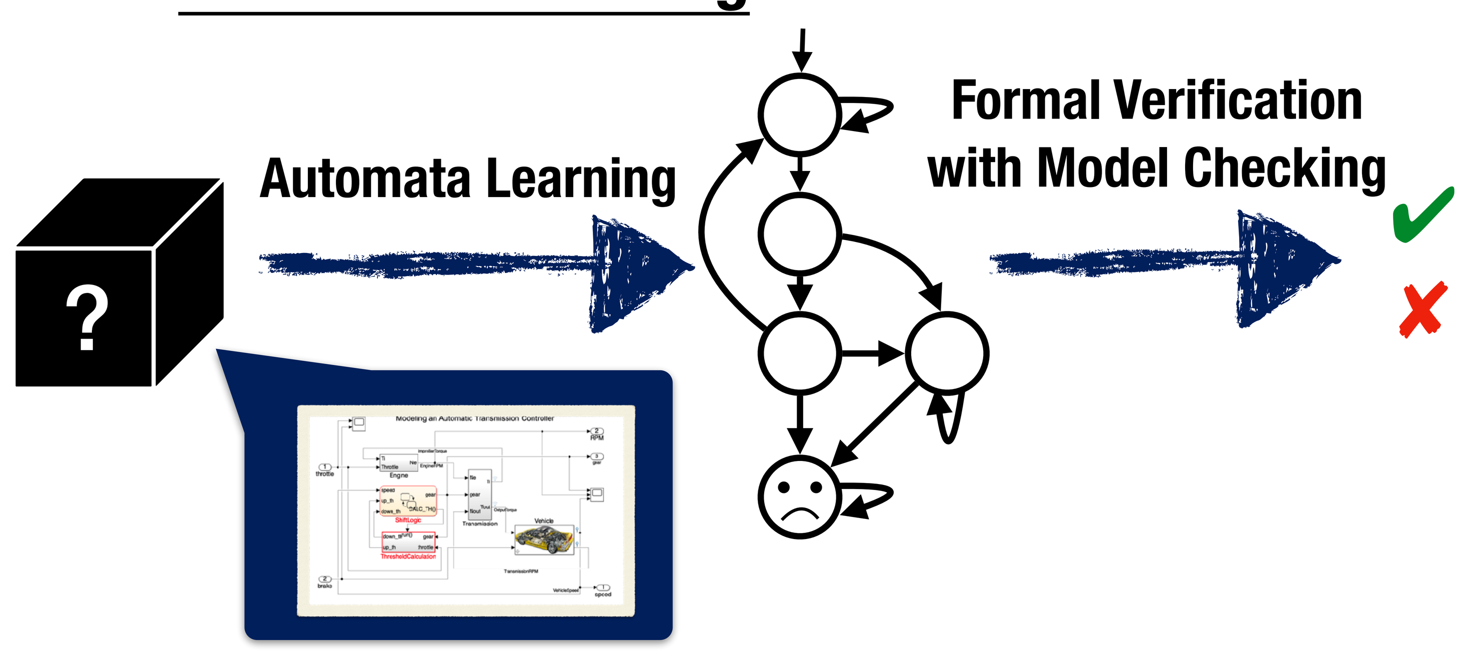


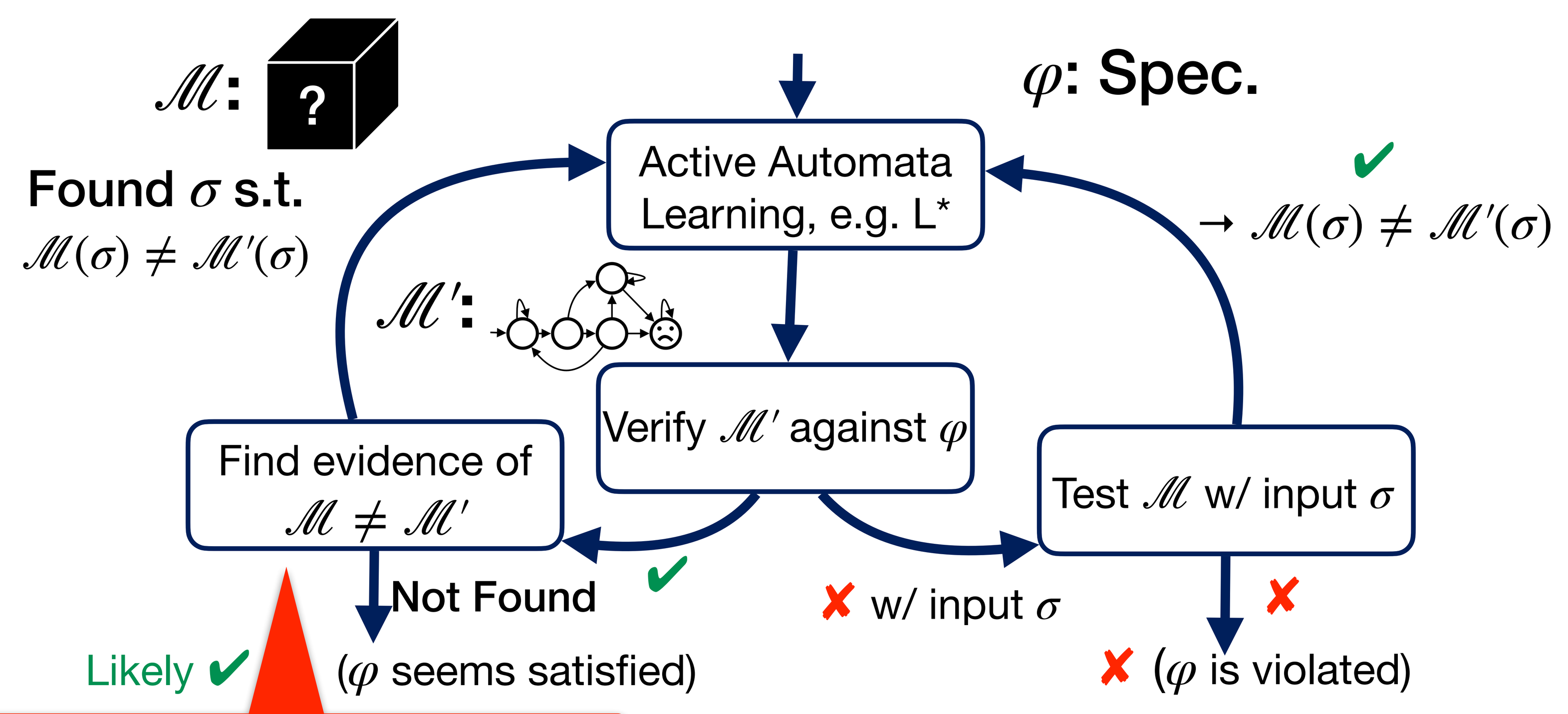
Can testing be faster?
Why tests passed?
Is it reliable?



Black-Box Checking for CPS

Black-Box Checking [Peled et al., PSTV & FORTE'99]

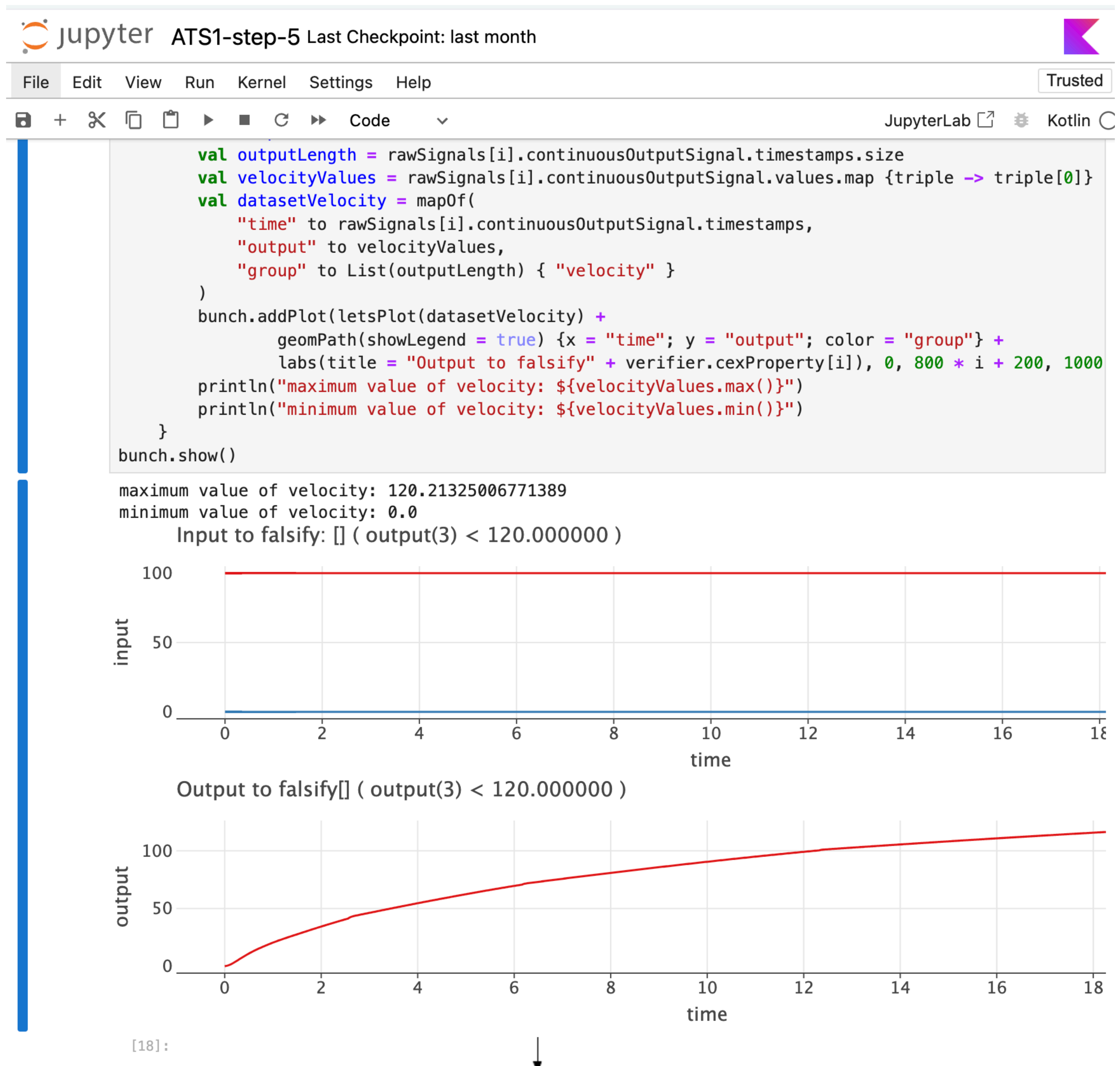


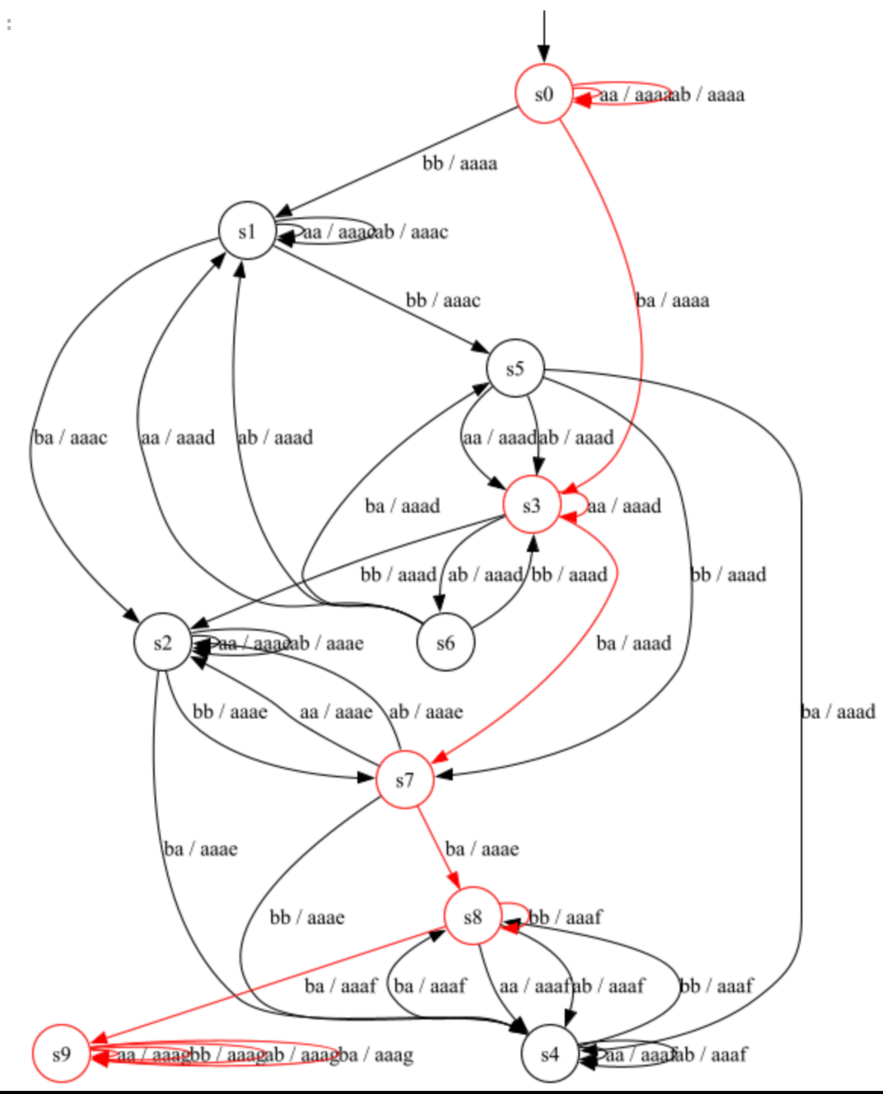


Difficult Part!!
- Typically by random test
- Hard to find corner cases or something useful to falsify φ

Our Approach Testing black-box CPS with Learning of formal model + Verification

Our Toolkit: FalCAuN (on Jupyter with Kotlin Kernel)





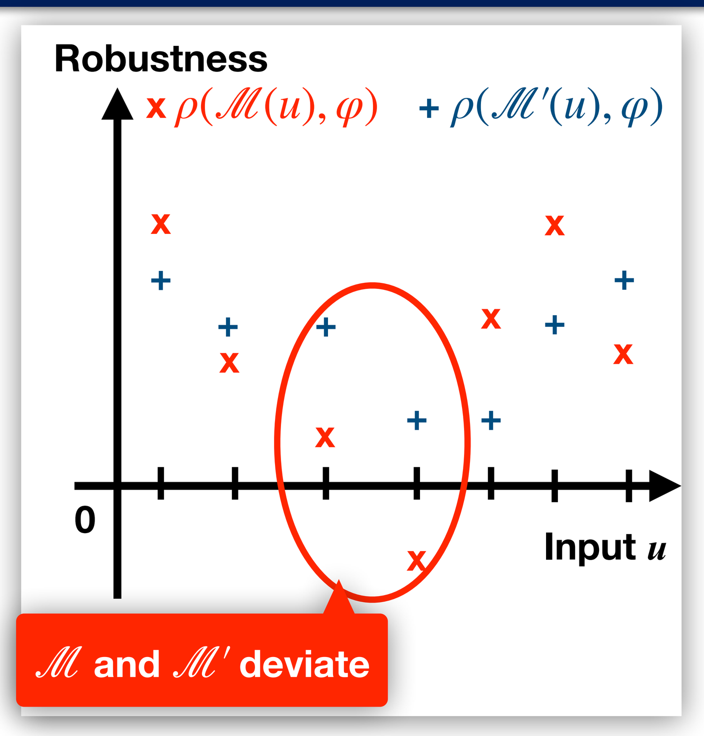
Robustness-guided equivalence test [Waga, HSCC'20]

Idea: Find evidence of $\mathcal{M} \neq \mathcal{M}'$ using inputs w/ low robustness i.e. use inputs leading "near dangerous" status

Assumption: $\mathcal{M} \nvDash \varphi$
Robustness of $\mathcal{M}$ can get negative for some inputs

Fact: $\mathcal{M}' \vDash \varphi$
Robustness of $\mathcal{M}'$ is always positive (Guaranteed by model checking)

Heuristic: Find u s.t. $\mathcal{M}(u) \neq \mathcal{M}(u)$ focusing on u making $\mathcal{M}$ less robust



Counterexample synthesis via Model Checking of strengthened formulas [Shijubo, Waga, Suenaga, RV'21]

Idea: Model checking of "related" specification can find useful evidence of $\mathcal{M} \neq \mathcal{M}'$

Fact: Counterexample σ of model checking progresses learning if $\mathcal{M}$ does not violate φ with σ

Observations:
- Model checking is typically faster than equivalence testing
- σ obtained by model checking is often useful for learning since it is related to φ
- Also the case for the formulas "related" to φ

Approach: Syntactically strengthen LTL formulas and conduct model checking with it

Eventually μ → … → Always μ

1. *For any $\mu, \nu \in$ **LTL**, we have $(\mu \vee \nu) \rightarrowtail (\mu \wedge \nu)$.*
2. *For any $\mu \in$ **LTL**, we have $\Diamond\mu \rightarrowtail \Box\Diamond\mu$.*
3. *For any $\mu \in$ **LTL**, we have $\Box\Diamond\mu \rightarrowtail \Diamond\Box\mu$.*
4. *For any $\mu \in$ **LTL**, we have $\Diamond\Box\mu \rightarrowtail \Box\mu$.*
5. *For any $\mu \in$ **LTL** and for any indices $i, j \in \mathbb{N} \cup$ have $\Diamond_{[i,j)}\mu \rightarrowtail \Box_{[i,j)}\mu$.*
6. *For any $\mu, \nu \in$ **LTL**, we have $(\mu\, \mathcal{U}\, \nu) \rightarrowtail (\Box\mu \wedge \Box$*

⋮

Notes on formal guarantee

Assumption: Target system can be modeled with a Mealy machine $\mathcal{M}$

- If ∀ input, eq. test eventually try it, then we can find any counterexample in the limit
- If we know the number of states of $\mathcal{M}$, we can stop eq. test with correctness guarantee (based on conformance testing, such as W-method [Chow, TSE' 78])
  - Alternatively, we can stop with probably approximately correct (PAC) guarantee [Angluin, '87]

Future directions

- Testing of Python classes, particularly (R)NNs
- Better illustration of falsifying executions
- Support of hyperproperties, e.g., to test robustness and fairness
- Support numeric inputs (w/ symbolic automata)
- Extension for stochastic systems

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