Adaptive and Compositional Active Automata Learning

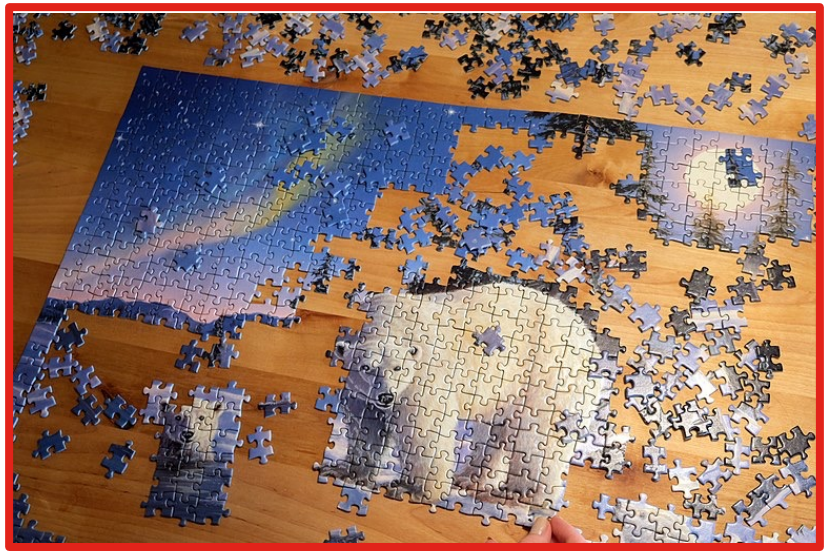
Mohammad Mousavi

mohammad.mousavi@kcl.ac.uk

26 June 2023

Active Automata Learning

Adaptive Learning



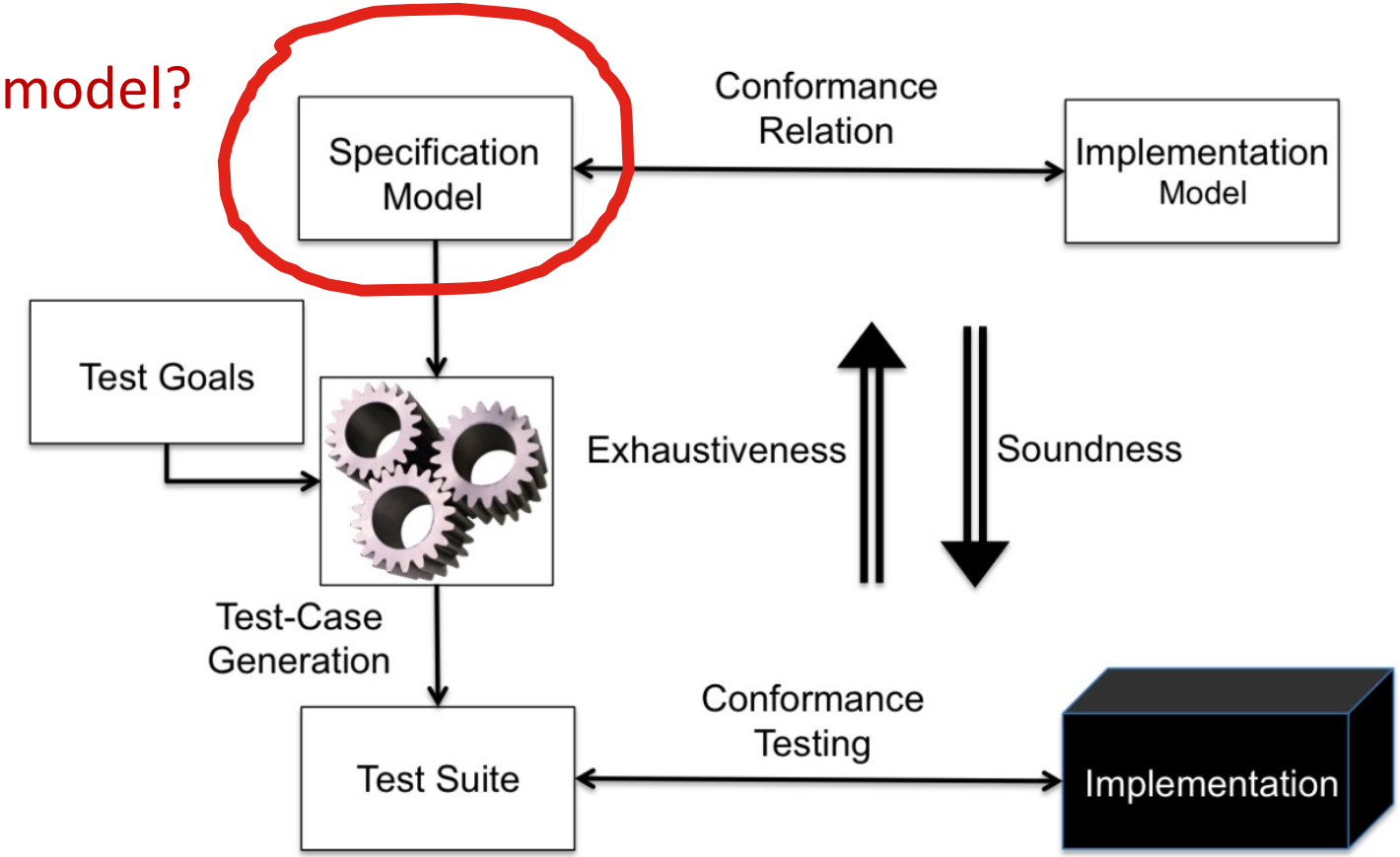
Compositional Learning

Open Problems

Active Automata Learning

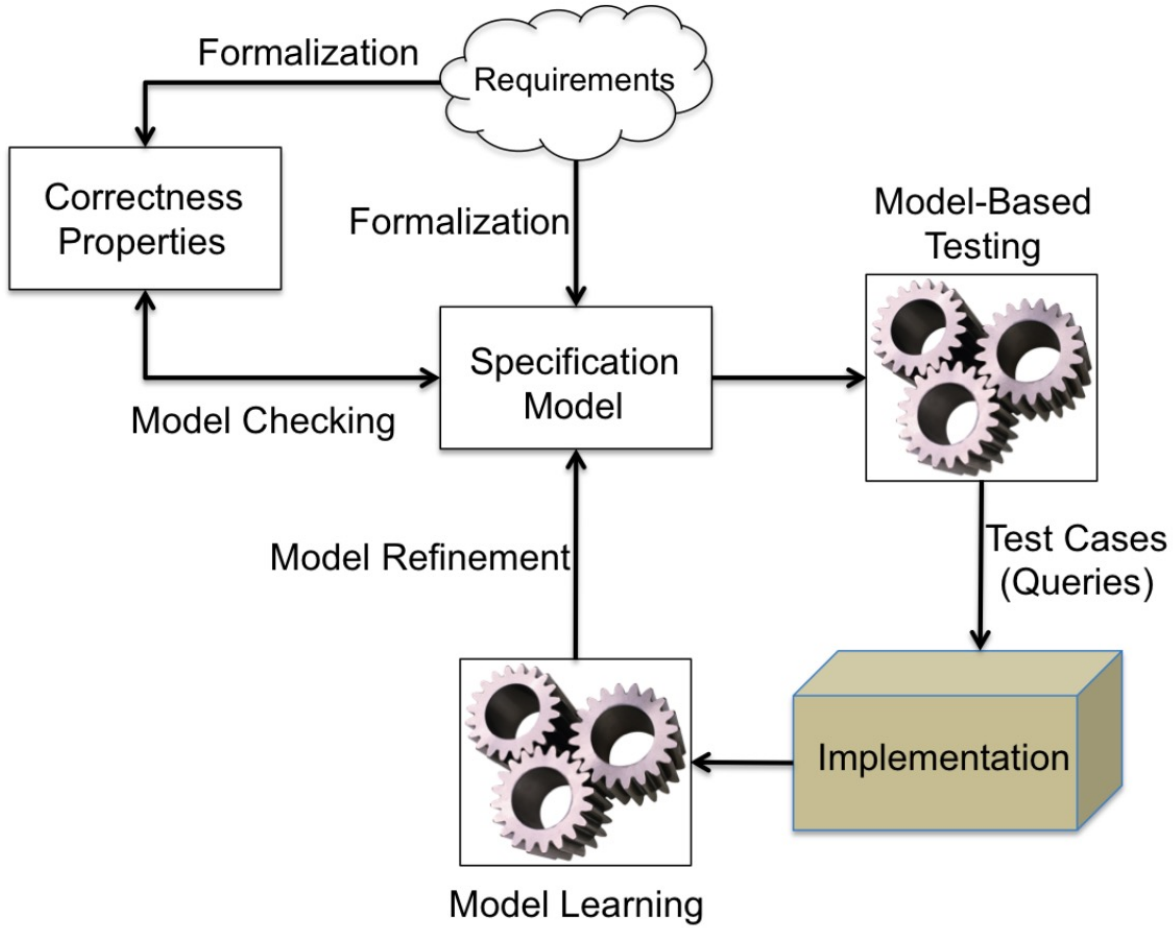
Active Learning: Why?

Model? What model?



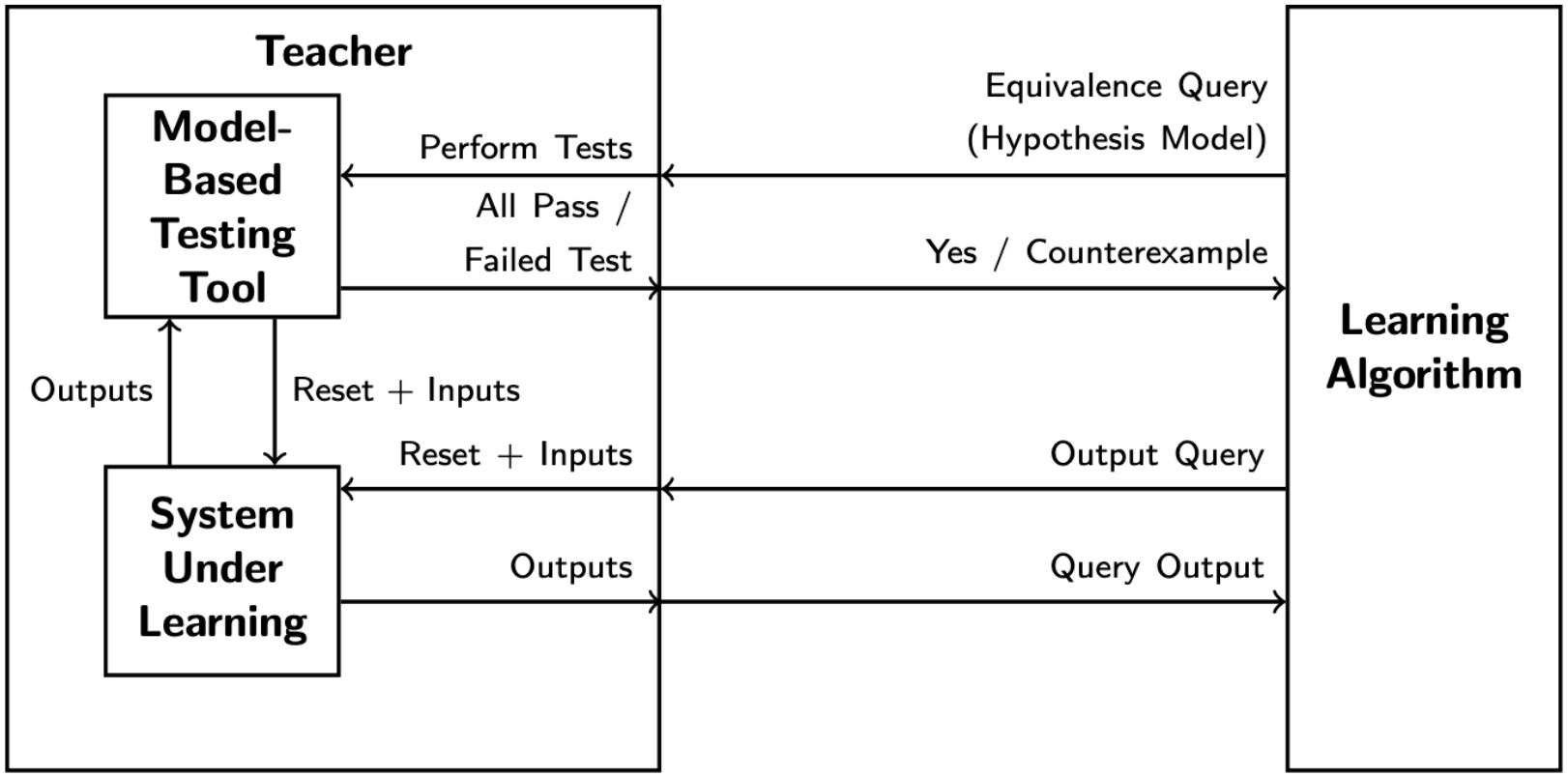
[Aichernig, Mostowski, Mousavi, Tappler and Taromirad. Model Learning and Model-Baed Testing]

Active Learning: Why?



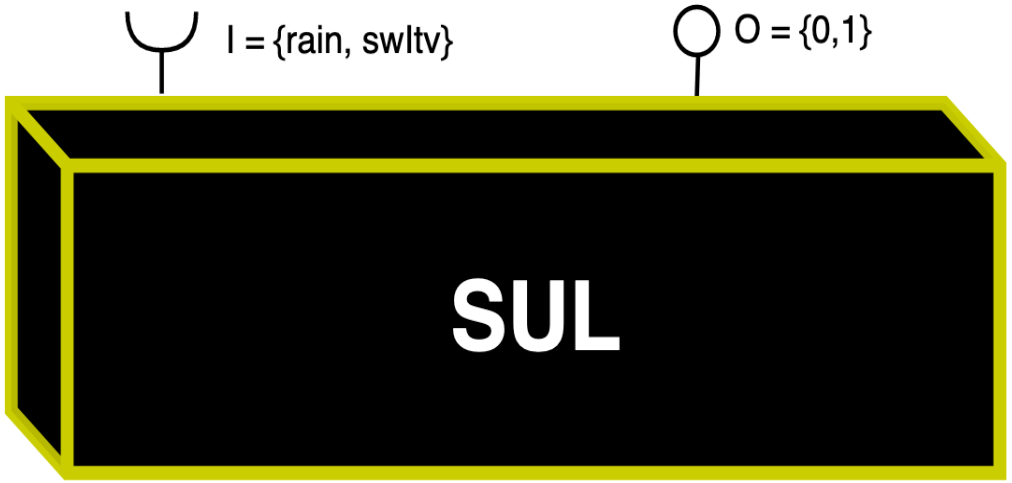
[Aichernig, Mostowski, Mousavi, Tappler and Taromirad. Model Learning and Model-Baed Testing]

Active Learning: What?

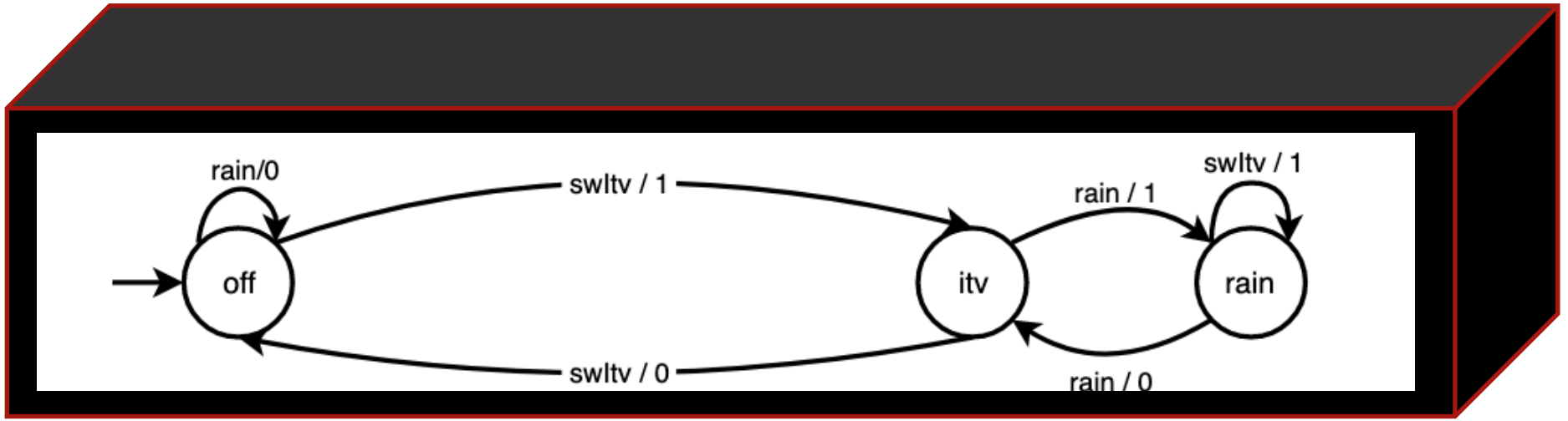


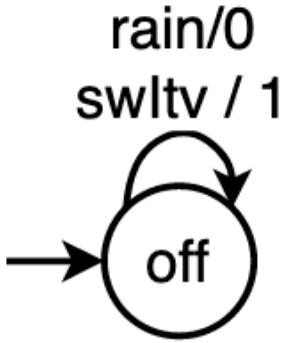
[Dana Angluin. Learning regular sets from queries and counterexamples.]

Active Learning: How?



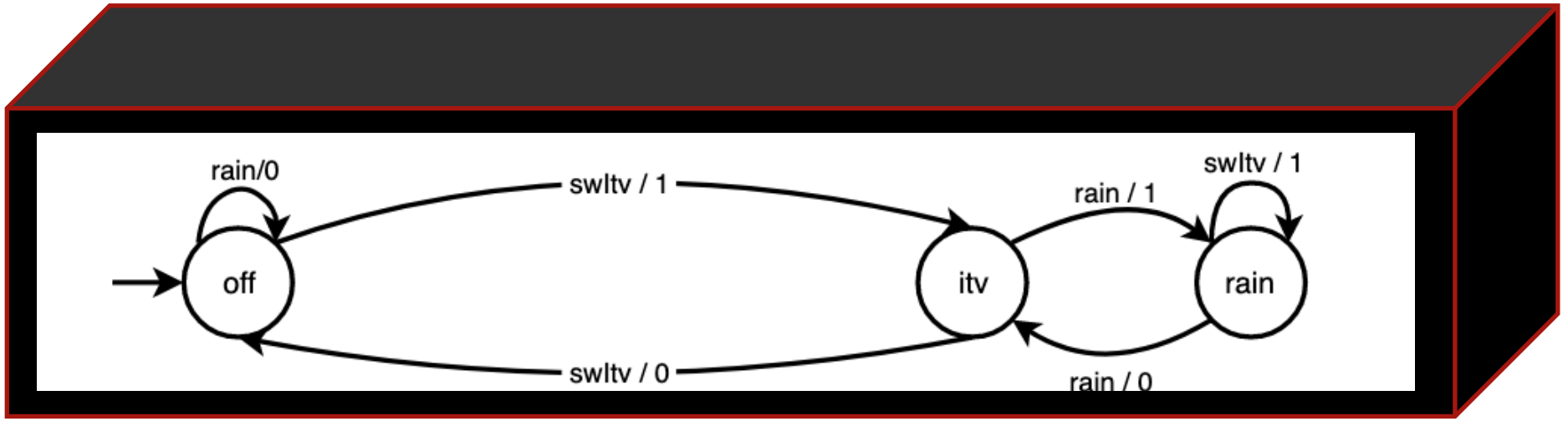
Active Learning: How?

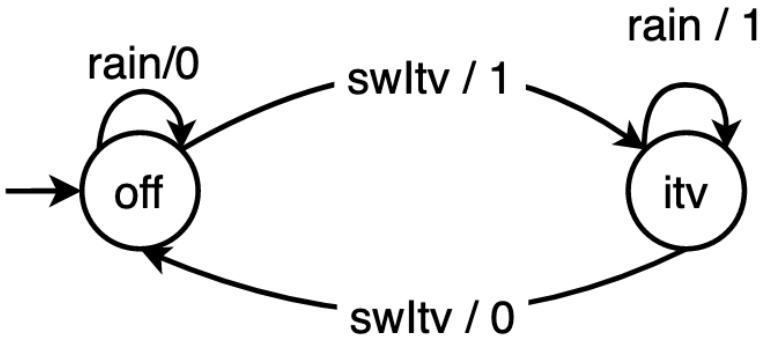




		rain	swItv
S	ϵ	0	1
$S \cdot I$	rain	0	1
	swItv	1	0

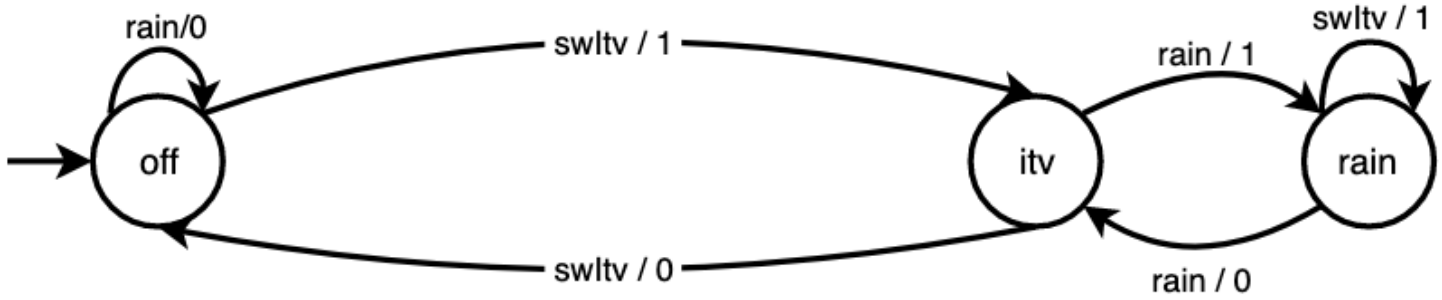
Active Learning: How?





		rain	swItv
S	ϵ	0	1
$S \cdot I$	rain	0	1
	swItv	1	0

Active Learning: How?



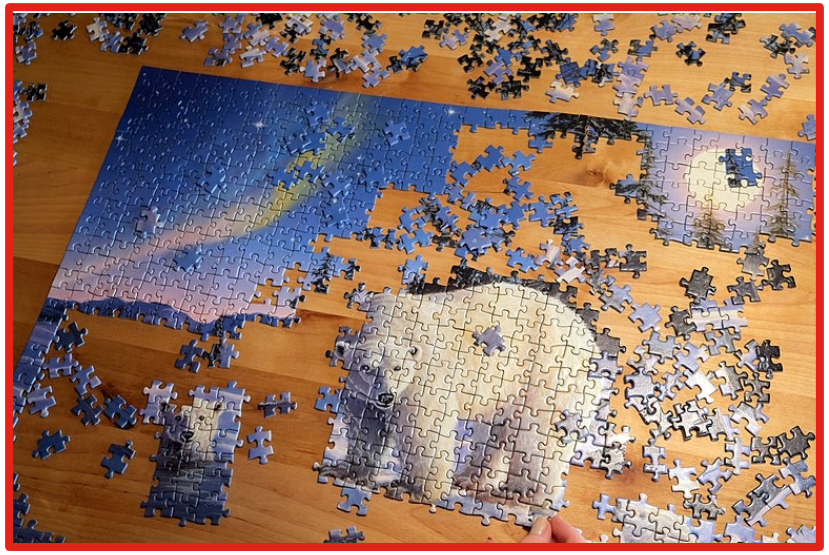
		$rain$	$swItv$	$rain \cdot rain$
S_r	ϵ	0	1	$0 \cdot 0$
	$swItv$	1	0	$1 \cdot 0$
	$swItv \cdot rain$	0	1	$0 \cdot 1$
$S_r \cdot I_r$	$rain$	0	1	$0 \cdot 0$
	$swItv \cdot swItv$	0	1	$0 \cdot 0$
	$swItv \cdot rain \cdot rain$	1	0	$1 \cdot 0$
	$swItv \cdot rain \cdot swItv$	0	1	$0 \cdot 1$

Consistent: $\forall p \in S_r \,.\, I_r \; \exists p' \in S_r \cdot p \cong p'$

Complete: $\forall p, p' \in S_r \cdot p \cong p' \Rightarrow \forall i \in I \; p.i \cong p'.i$

Active Automata Learning

Adaptive Learning



Compositional Learning

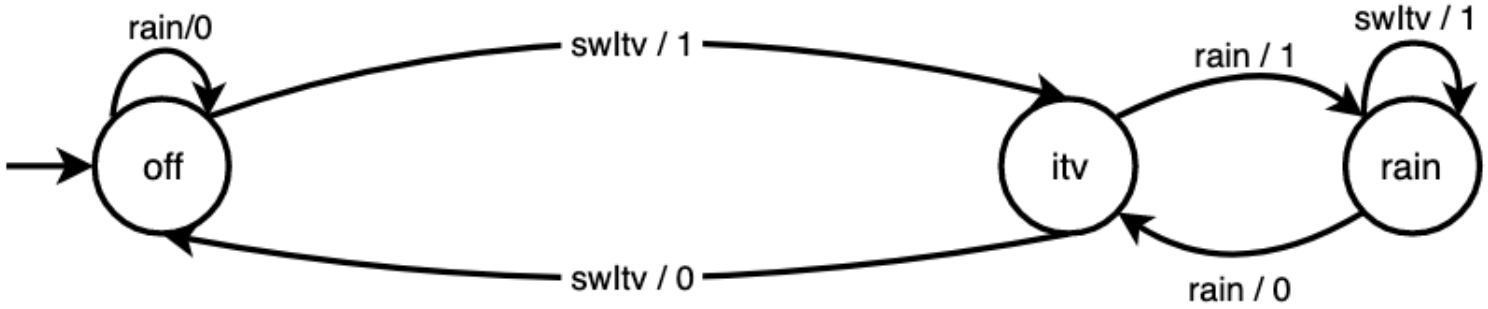
Open Problems

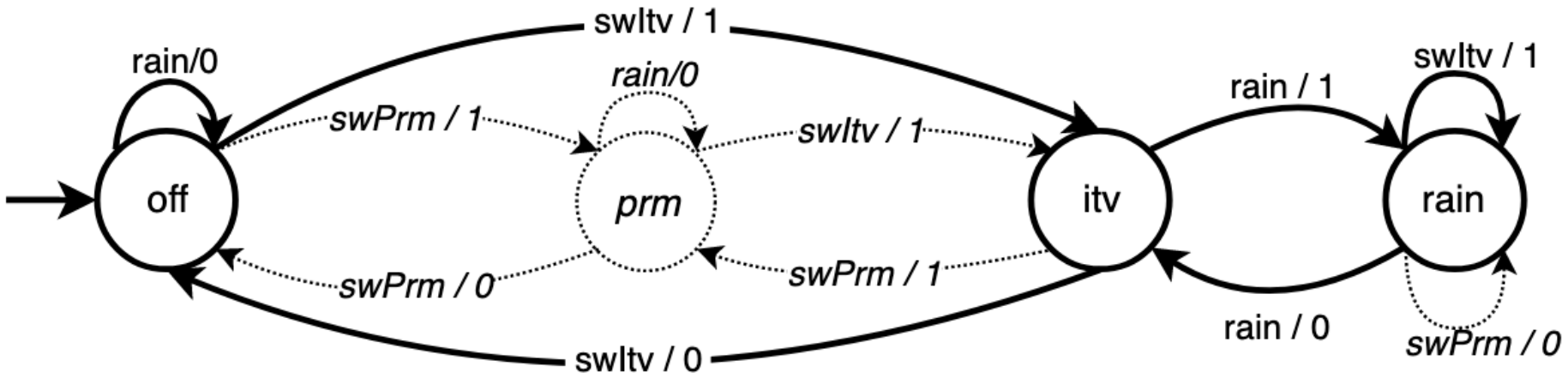
Adaptive Learning (in Time and Sapce)

Based on Joint Work with:

Diego Damasceno, Ramtin Khosravi, Adenilso Simao, and Shaghayegh Tavassoli

Why?

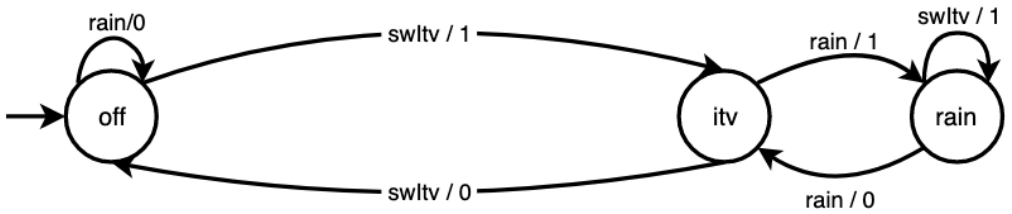

rain/0
swItv / 1
swItv / 1
rain / 1
off
itv
rain
swItv / 0
rain / 0

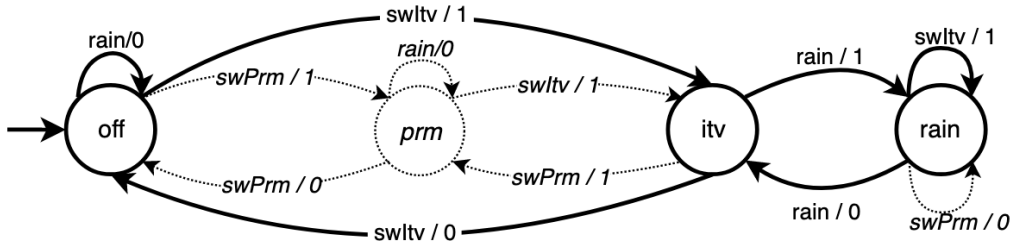

swItv / 1
rain/0
rain/0
swPrm / 1
swItv / 1
rain / 1
swItv / 1
off
prm
itv
rain
swPrm / 0
swPrm / 1
rain / 0
swPrm / 0
swItv / 0

What?

Given an evolving system that changed over time
how can we efficiently learn its evolved behavior?

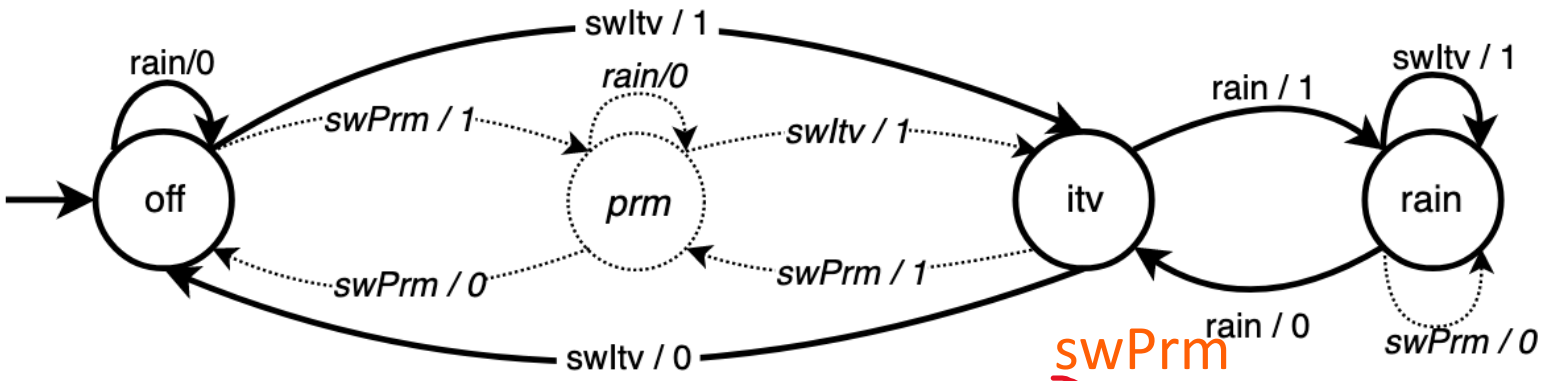
How sensitive is it to the amount of evolution?





[Groce, Peled, and Yannakakis. Adaptive model checking. 2002]
[Chaki, Clarke, Sharygina, Sinha.
Verification of evolving software via component substitutability analysis. 2008]

How?

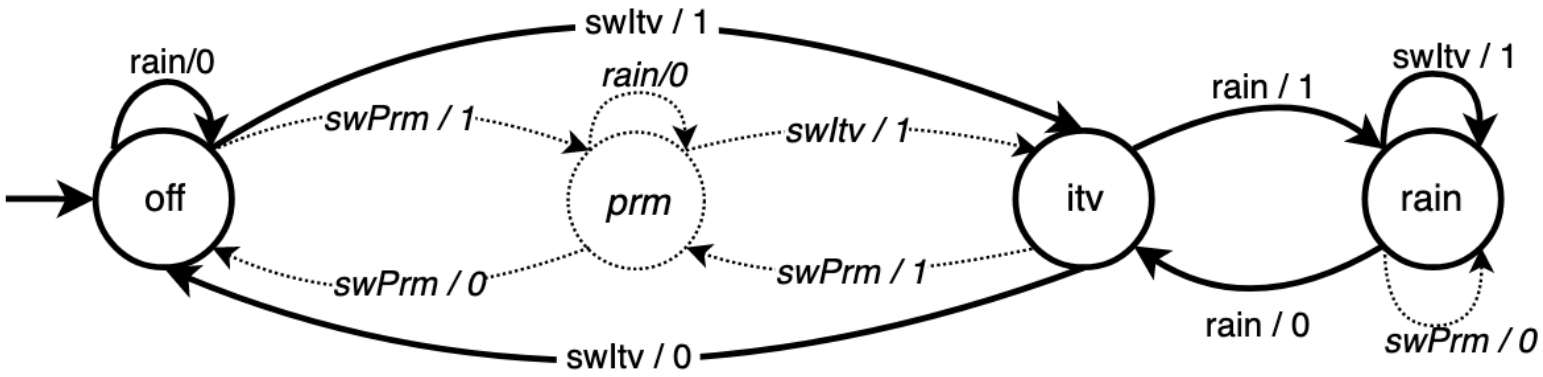


swPrm

Anything redundant?

		$rain$	$swItv$	$rain \cdot rain$
S_r	ϵ	0	1	$0 \cdot 0$
	$swItv$	1	0	$1 \cdot 0$
	$swItv \cdot rain$	0	1	$0 \cdot 1$
$S_r \cdot I_r$	$rain$	0	1	$0 \cdot 0$
	$swItv \cdot swItv$	0	1	$0 \cdot 0$
	$swItv \cdot rain \cdot rain$	1	0	$1 \cdot 0$
	$swItv \cdot rain \cdot swItv$	0	1	$0 \cdot 1$

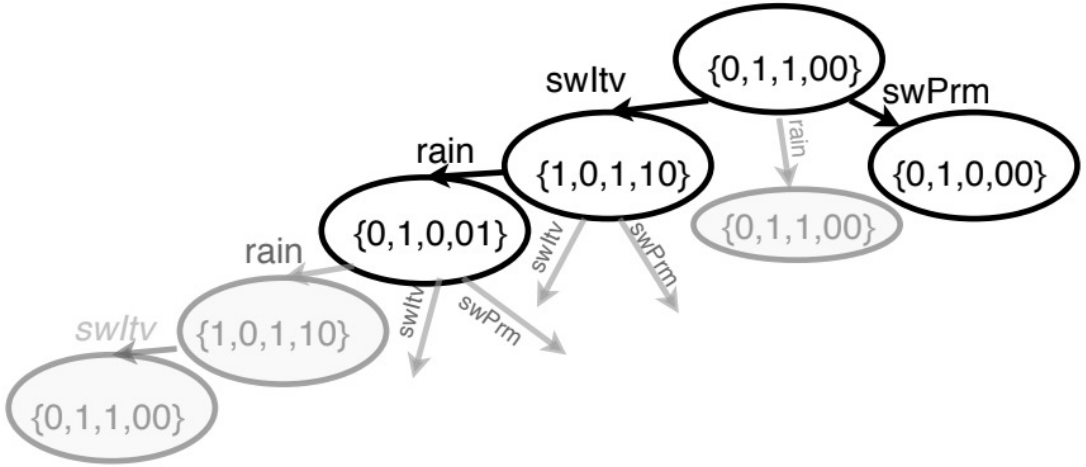
How?



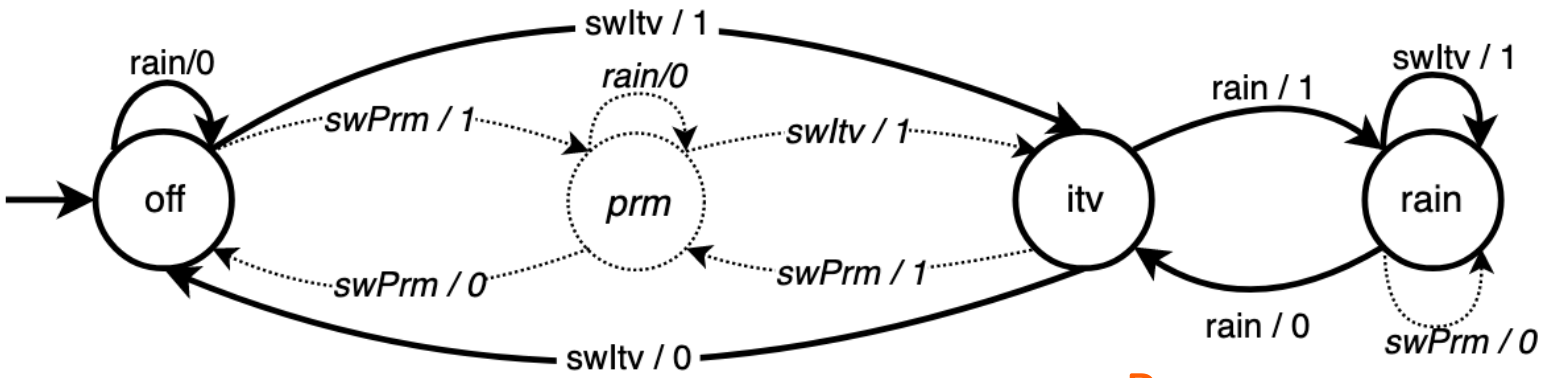
Anything redundant?

swPrm

		rain	*swItv*	*rain* · *rain*
S_r	ϵ	0	1	0 · 0
	swItv	1	0	1 · 0
	swItv · *rain*	0	1	0 · 1
$S_r \cdot I_r$	*rain*	0	1	0 · 0
	swItv · *swItv*	0	1	0 · 0
	swItv · *rain* · *rain*	1	0	1 · 0
	swItv · *rain* · *swItv*	0	1	0 · 1



How?

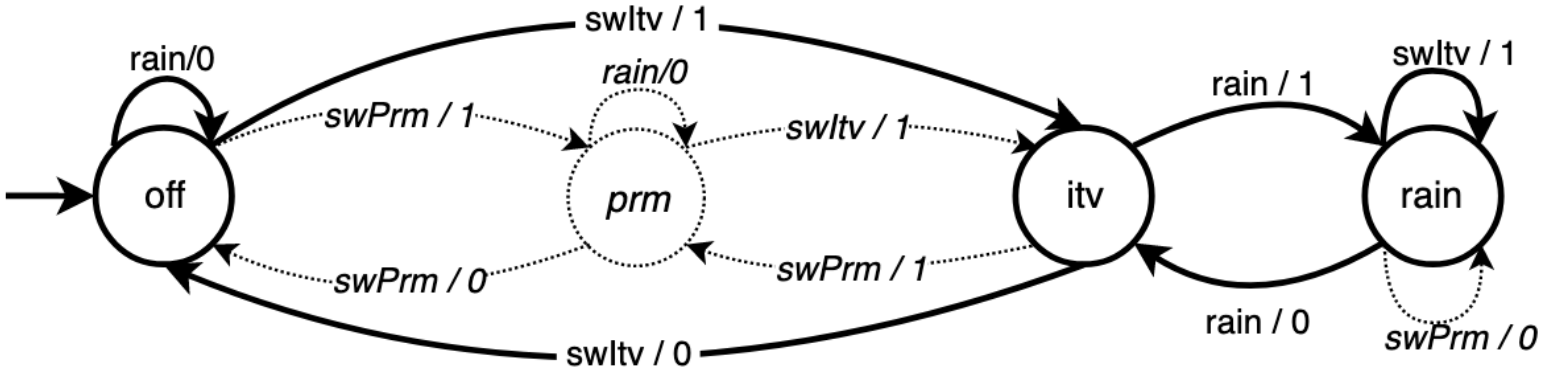


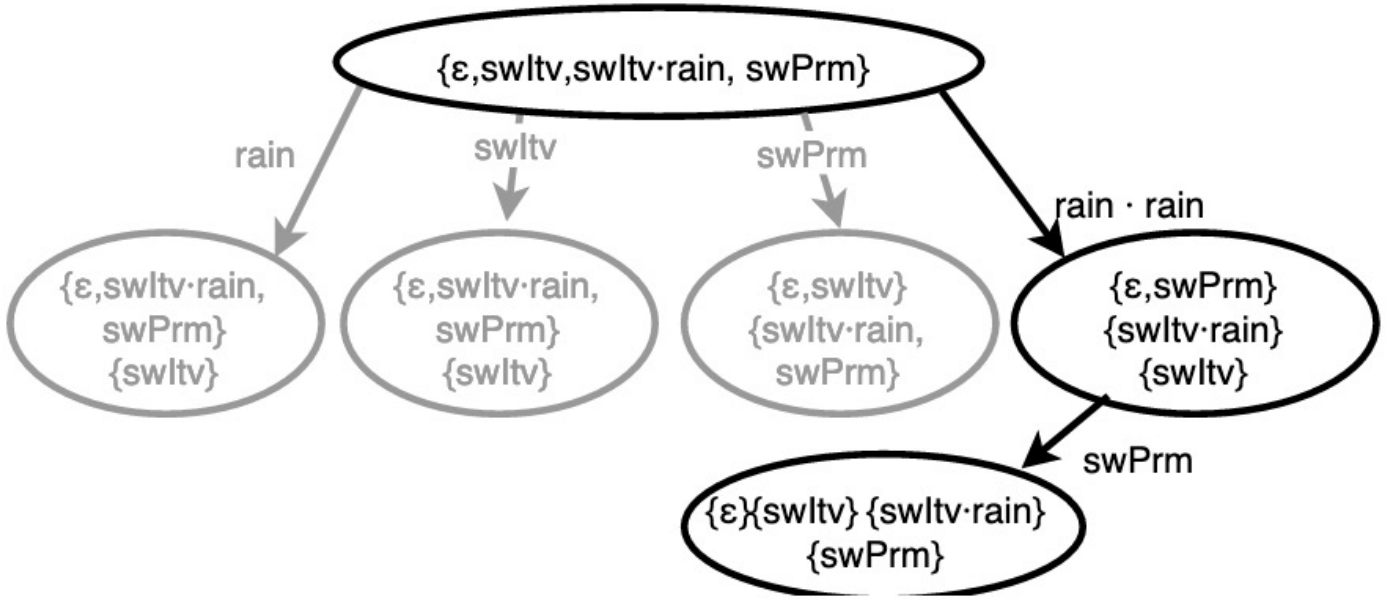
swPrm

New experiments?

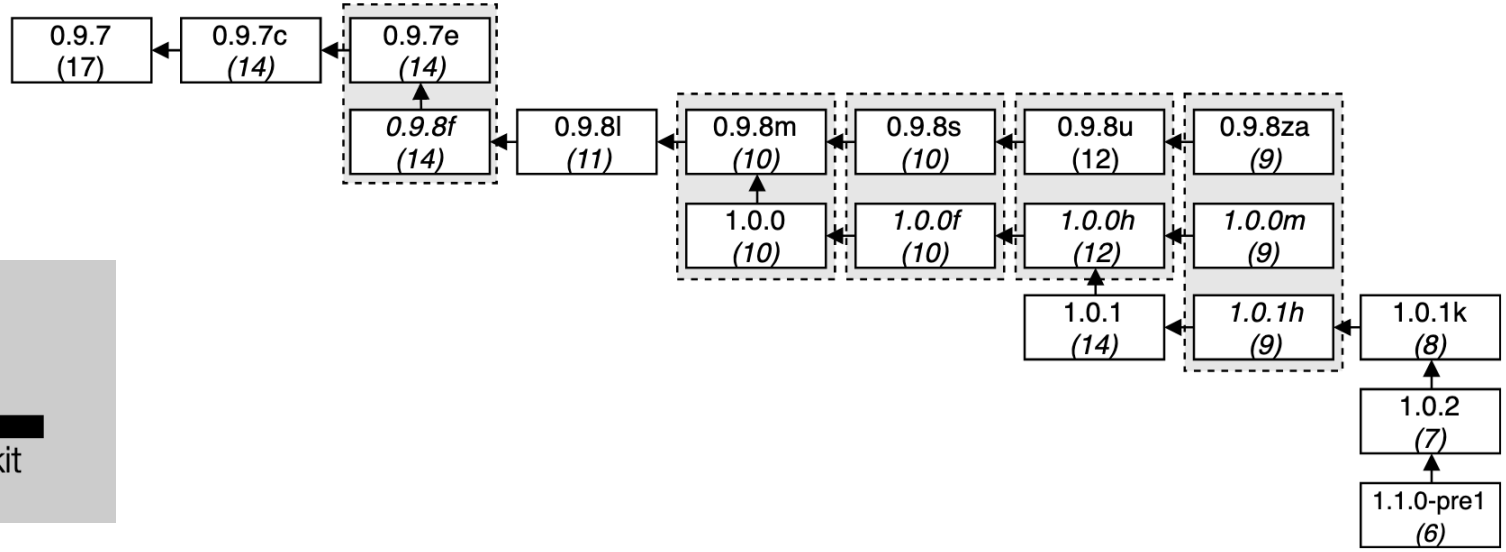
		$rain$	$swItv$	$rain \cdot rain$
S_r	ϵ	0	1	$0 \cdot 0$
	$swItv$	1	0	$1 \cdot 0$
	$swItv \cdot rain$	0	1	$0 \cdot 1$
$S_r \cdot I_r$	$rain$	0	1	$0 \cdot 0$
	$swItv \cdot swItv$	0	1	$0 \cdot 0$
	$swItv \cdot rain \cdot rain$	1	0	$1 \cdot 0$
	$swItv \cdot rain \cdot swItv$	0	1	$0 \cdot 1$

How?


swItv / 1
rain/0
rain/0
swPrm / 1
swItv / 1
rain / 1
swItv / 1
off
prm
itv
rain
swPrm / 0
swPrm / 1
rain / 0
swPrm / 0
swItv / 0


{ε,swItv,swItv·rain, swPrm}
rain
swItv
swPrm
rain · rain
{ε,swItv·rain, swPrm} {swItv}
{ε,swItv·rain, swPrm} {swItv}
{ε,swItv} {swItv·rain, swPrm}
{ε,swPrm} {swItv·rain} {swItv}
swPrm
{ε}{swItv} {swItv·rain} {swPrm}

Does it Really work?



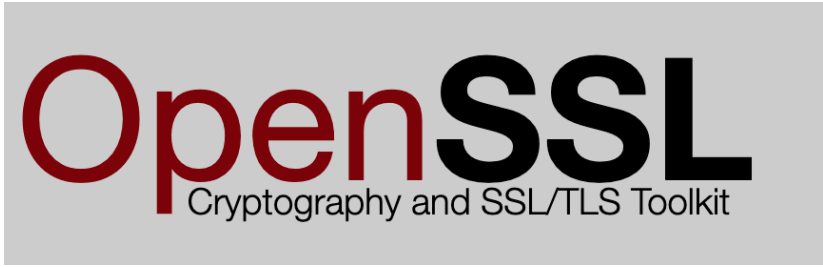
OpenSSL
Cryptography and SSL/TLS Toolkit

[https://www.openssl.org/]
[De Ruiter. A tale of the openssl state machine. 2016]

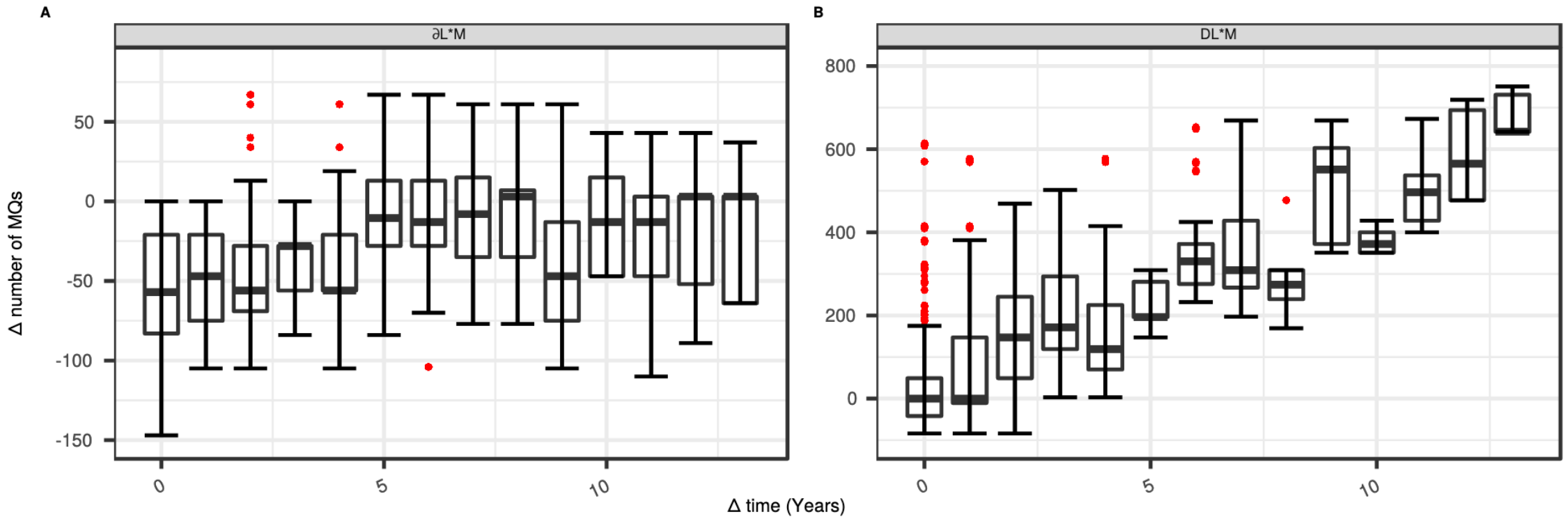
DOES IT REALLY WORK?

Given an evolving system that
changed over time
how can we efficiently
learn its evolved behavior?

How sensitive is it to
the amount of evolution?



Does it Really work?

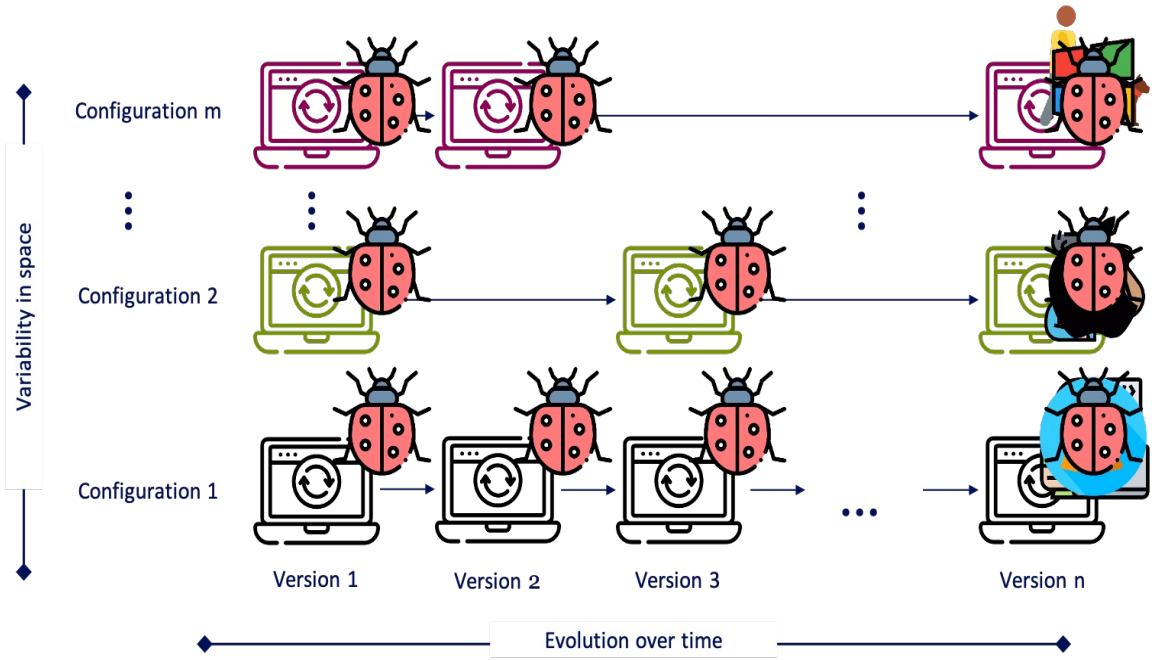


[Damasceno, M.R. Mousavi and A. Simao.
Learning to Reuse: Adaptive Model Learning for Evolving Systems. iFM'19]

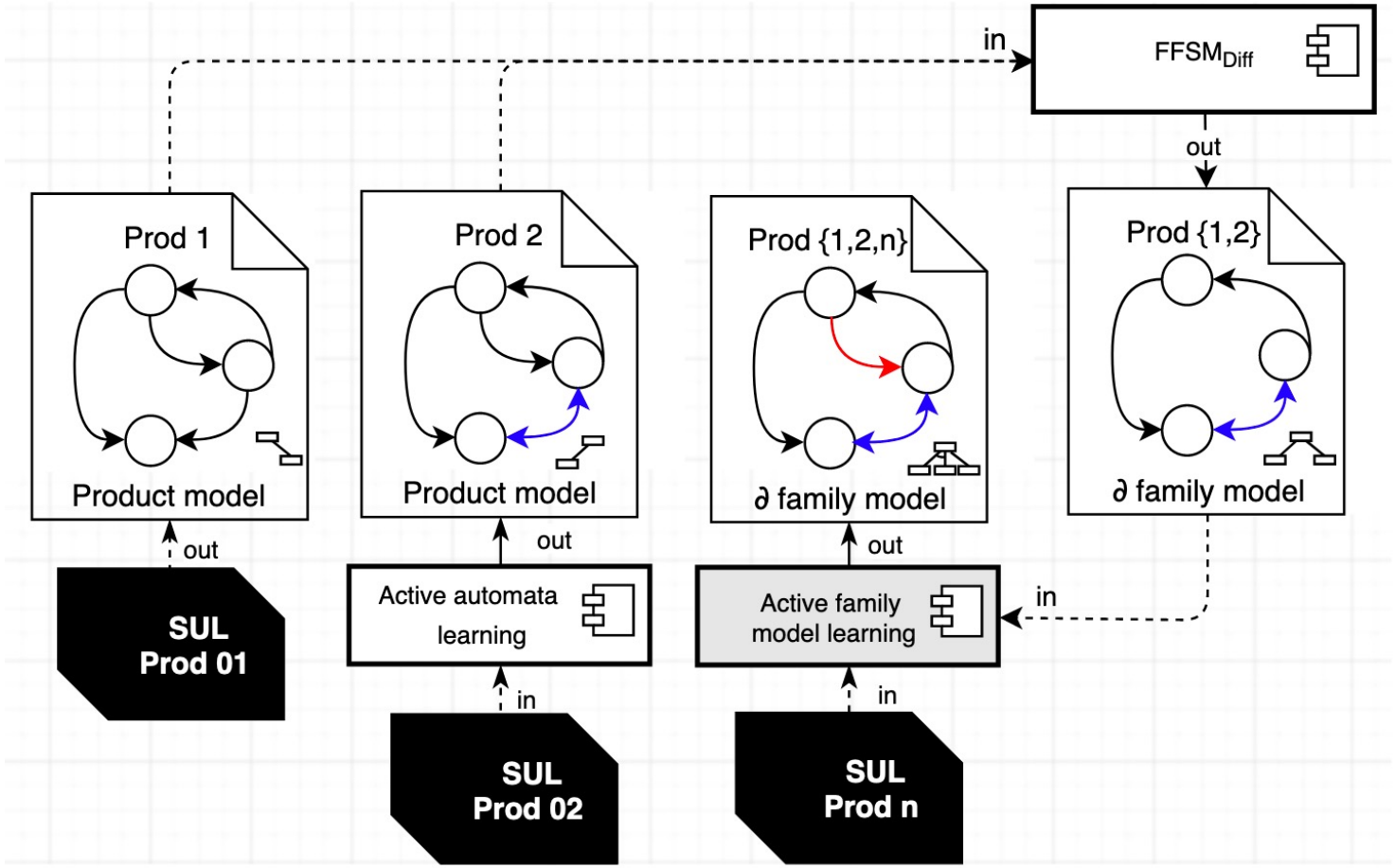
Adaptive Learning in Space

Given an evolving system that changed in space
how can we succintly summarise the variability?

How sensitive is it to the number of configuration samples?

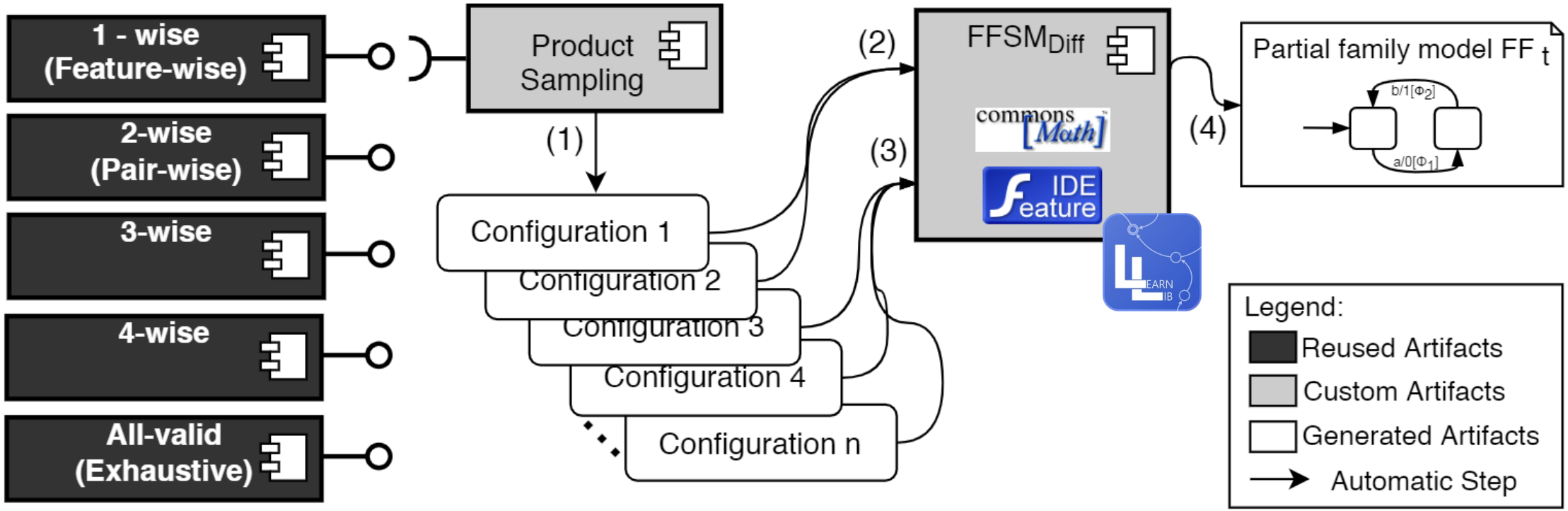


Adaptive Learning in Space

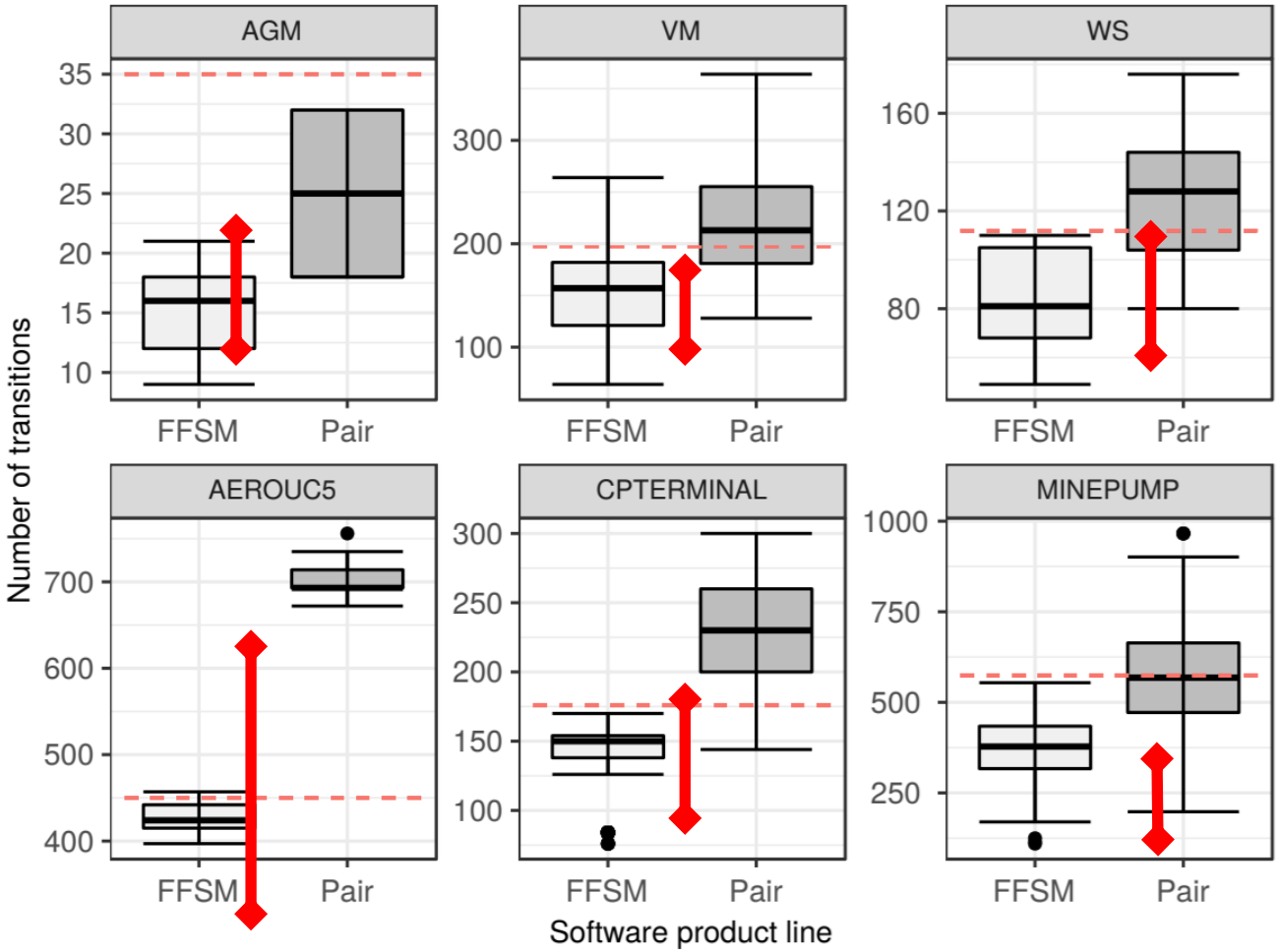


[Damasceno, Mousavi, Simao.
Learning by Sampling: Learning Behavioral Family Models from Software Product Lines. EMSE 21]

Experiment Design

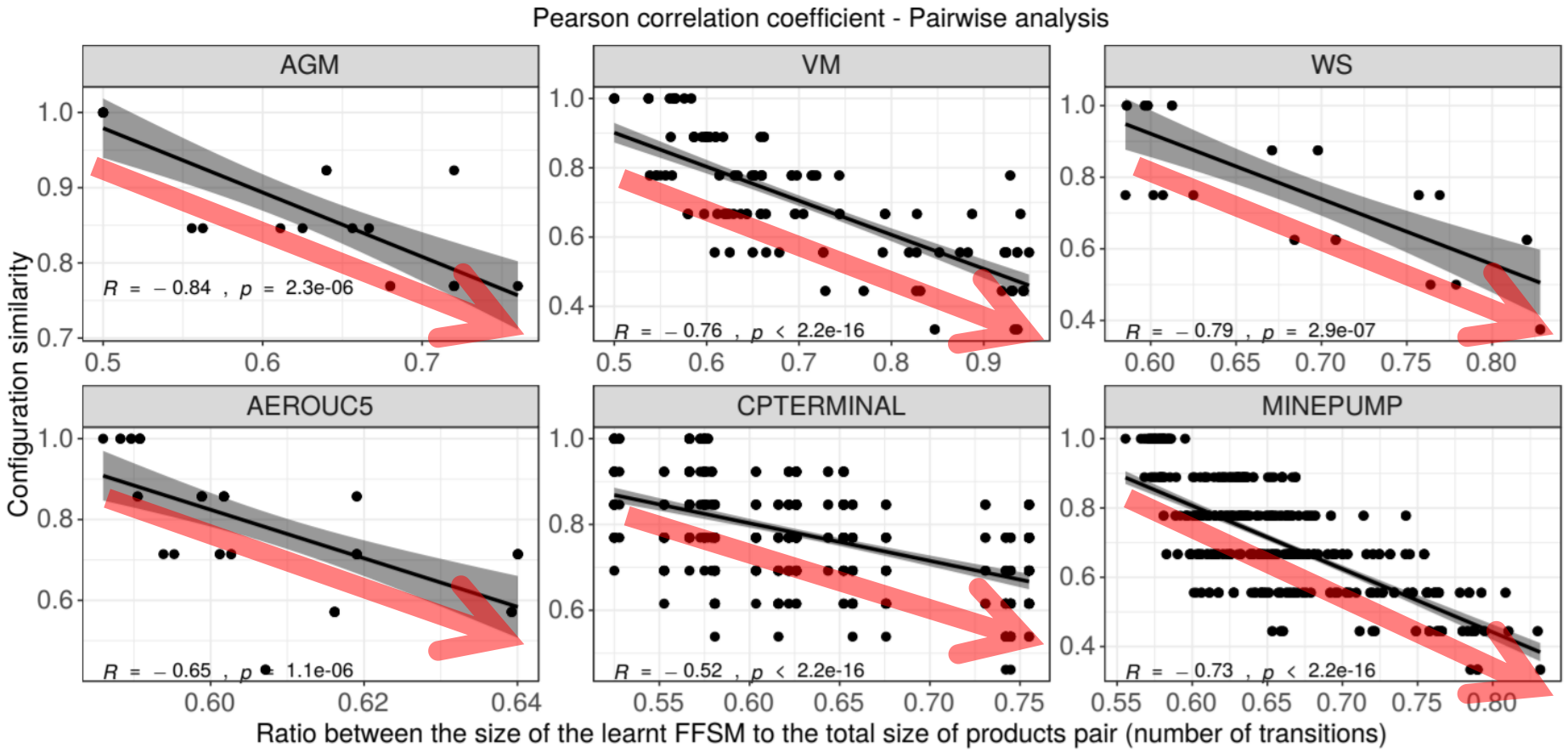


Analysis of Results: Size



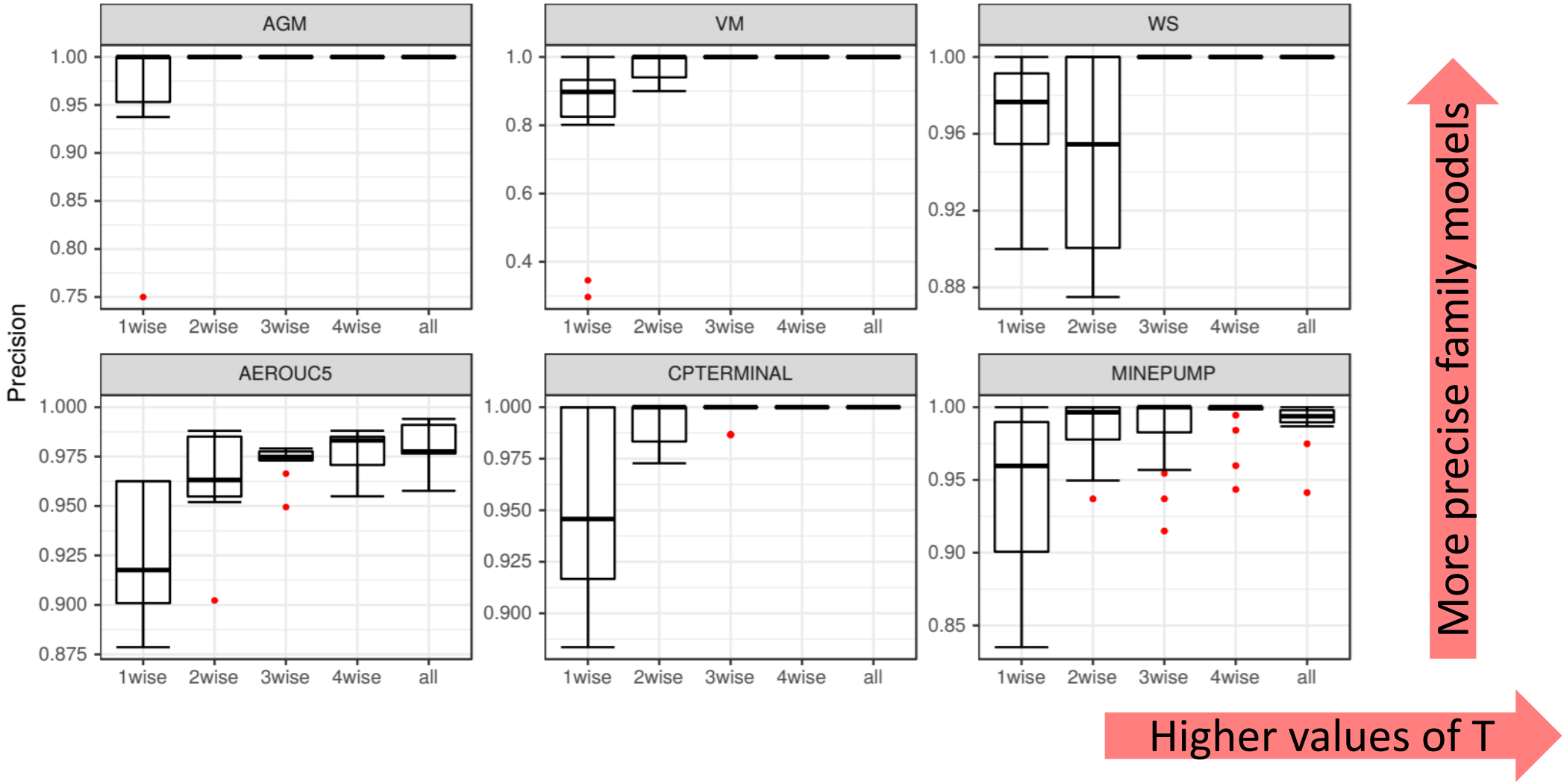
Mann-Whitney-Wilcoxon statistical test
Vargha-Delaney's Â effect size

Analysis of Results



Pearson correlation coefficient

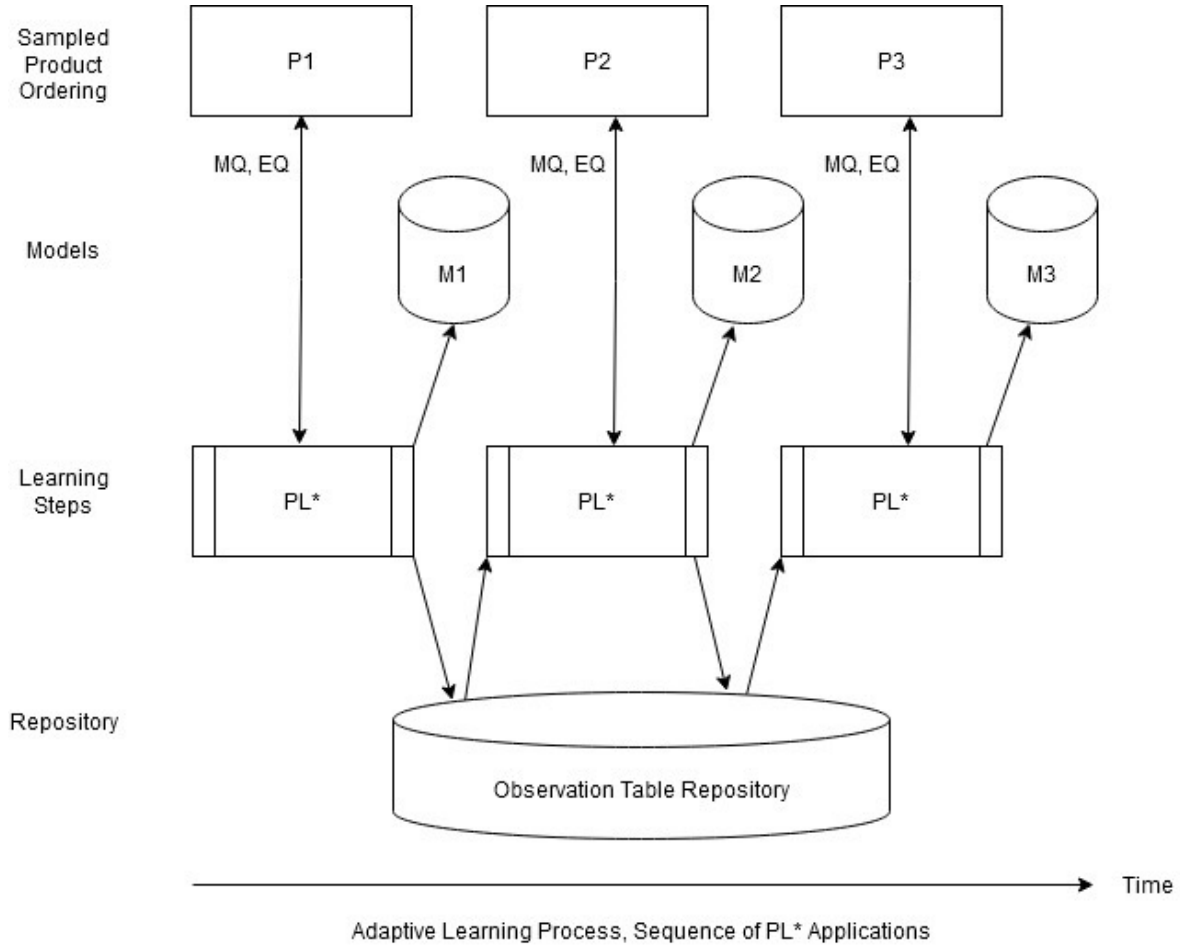
Analysis of Results: Sampling



Mann-Whitney-Wilcoxon statistical test
Vargha-Delaney's Â effect size

PL*

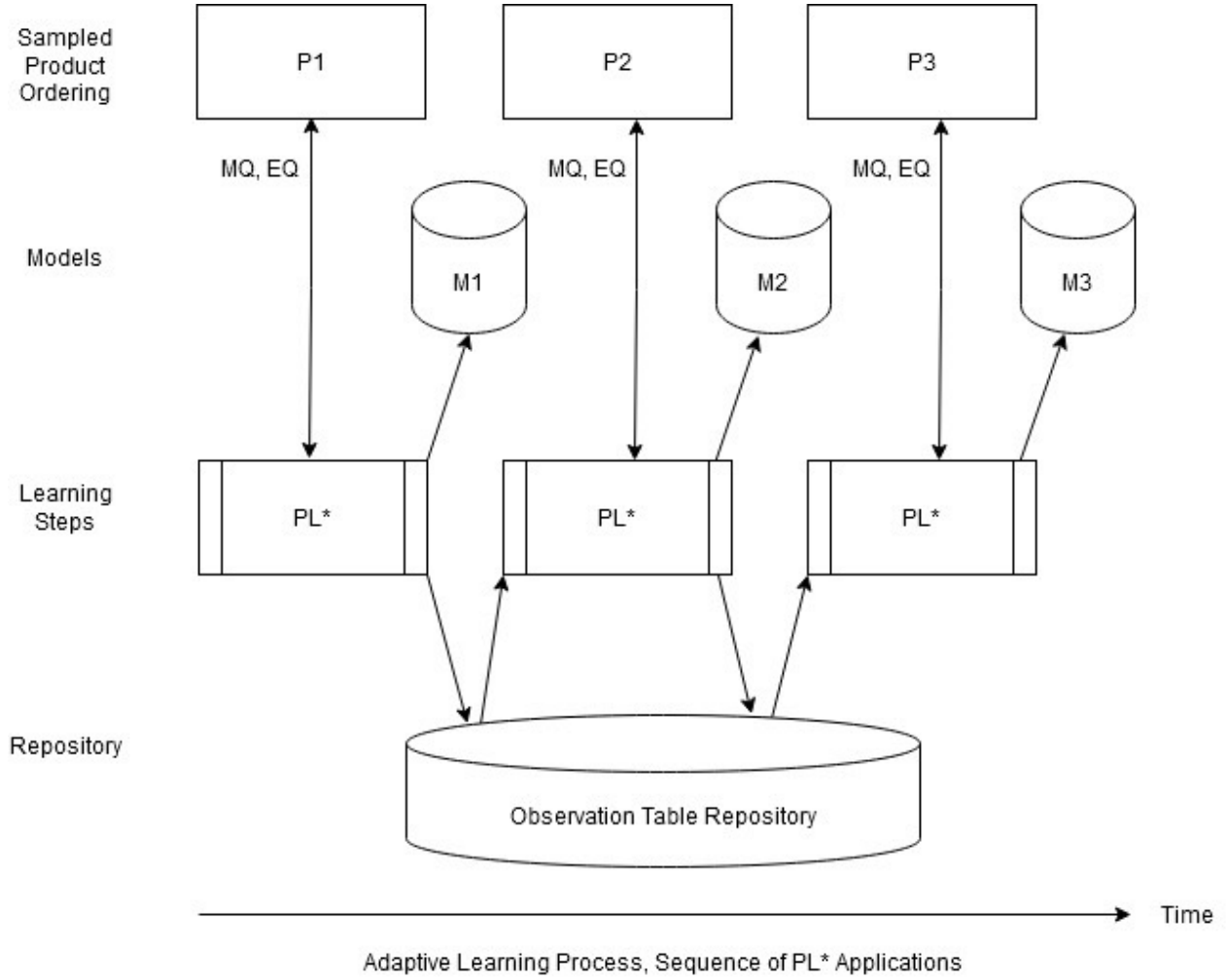
Building a repository of queries that
for changes in space



Adaptive Learning Process, Sequence of PL* Applications

PL*

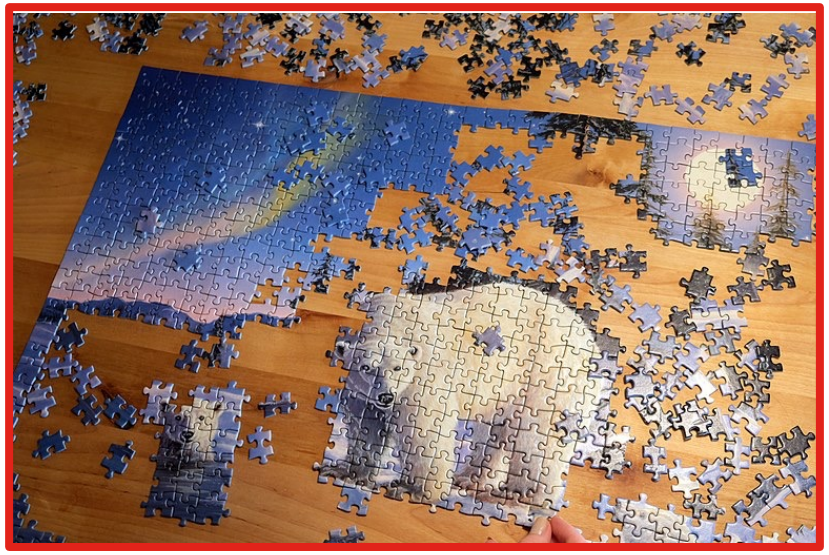
Building a repository of queries that for changes in space



[Tavassoli, Damasceno, Khosravi, Mousavi, SPLC 2022]

Active Automata Learning

Adaptive Learning



Compositional Learning

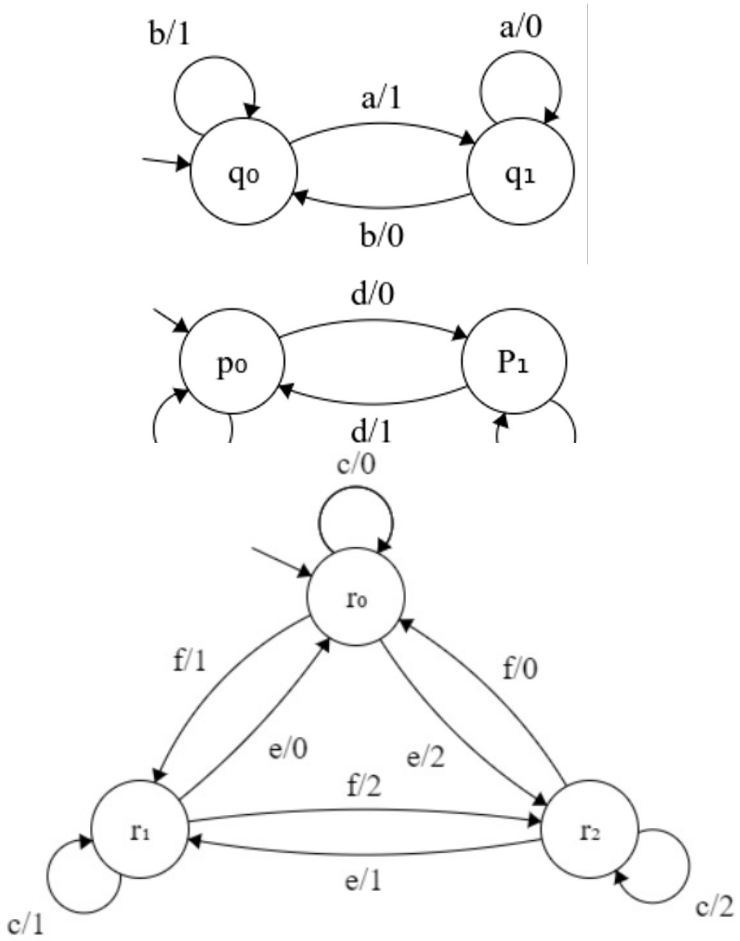
Open Problems

Compositional Learning

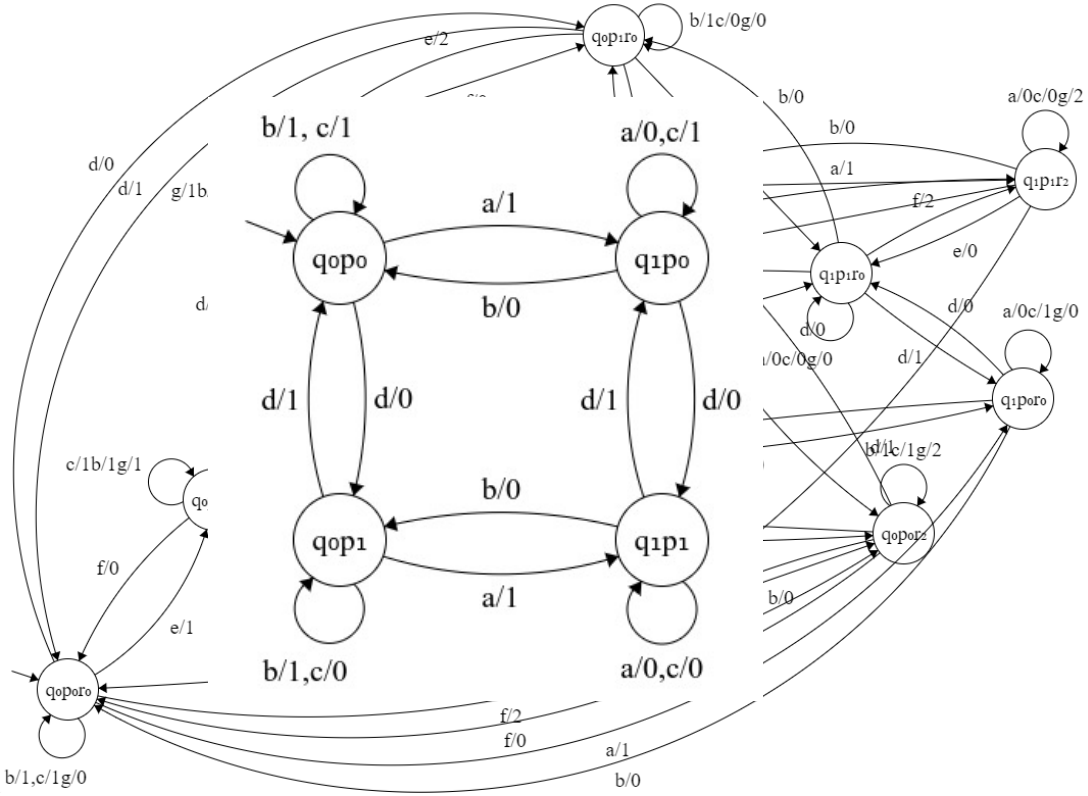
Based on Joint Work with:

Faezeh Labbaf, Jan Friso Groote, and Hossein Hojjat

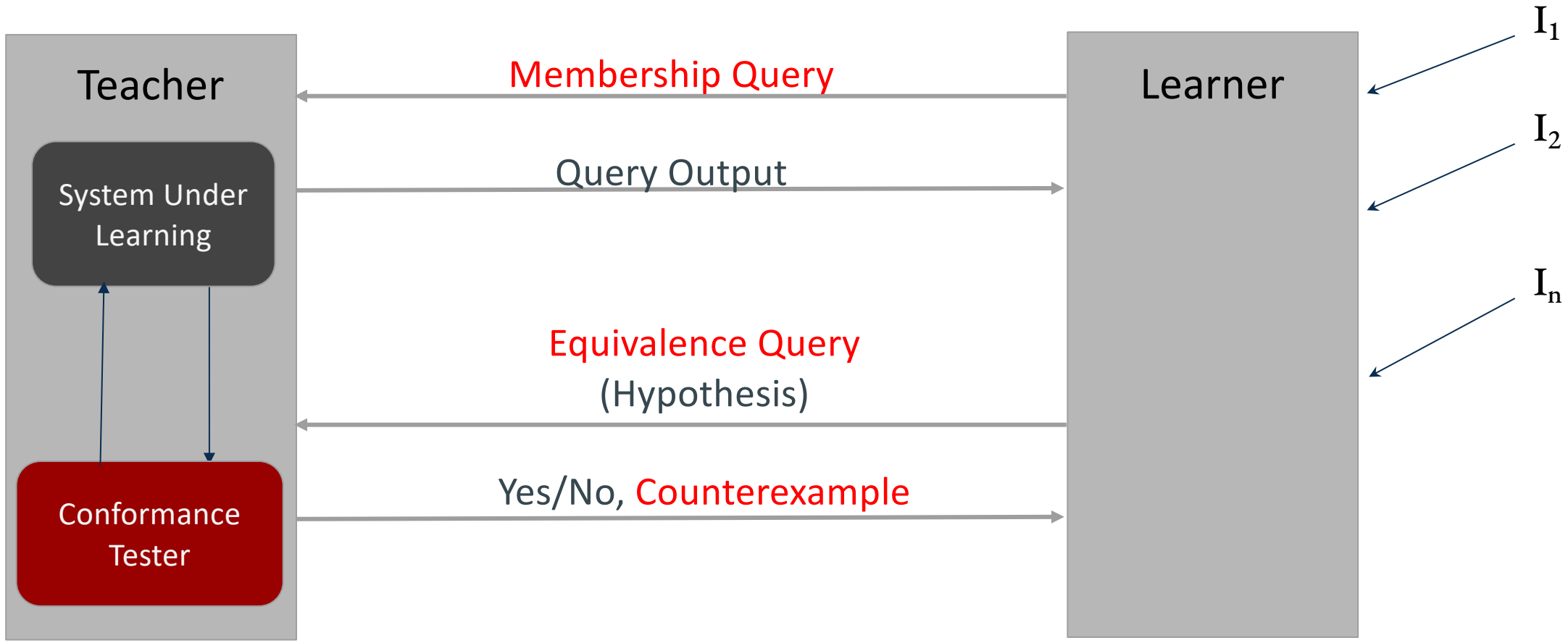
Interleaving Parallel Systems



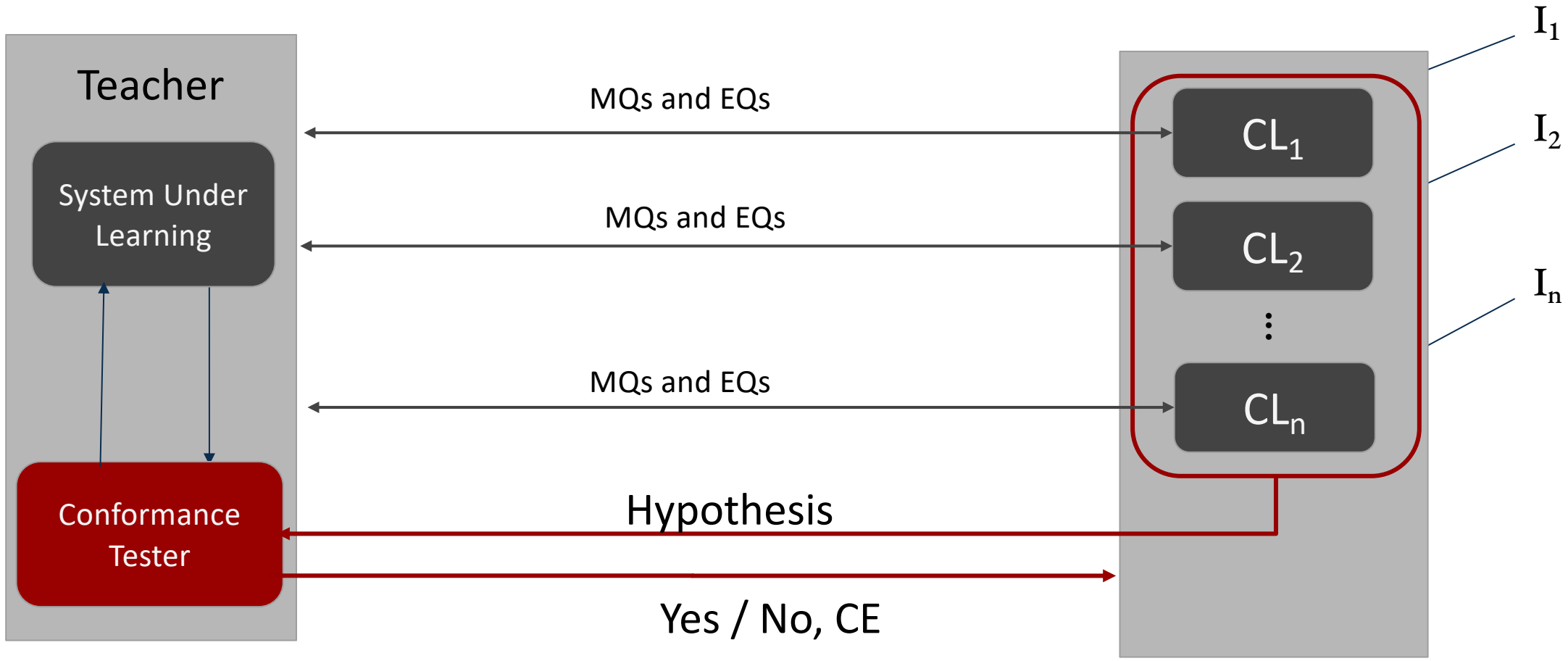
Interleaving Parallel Composition



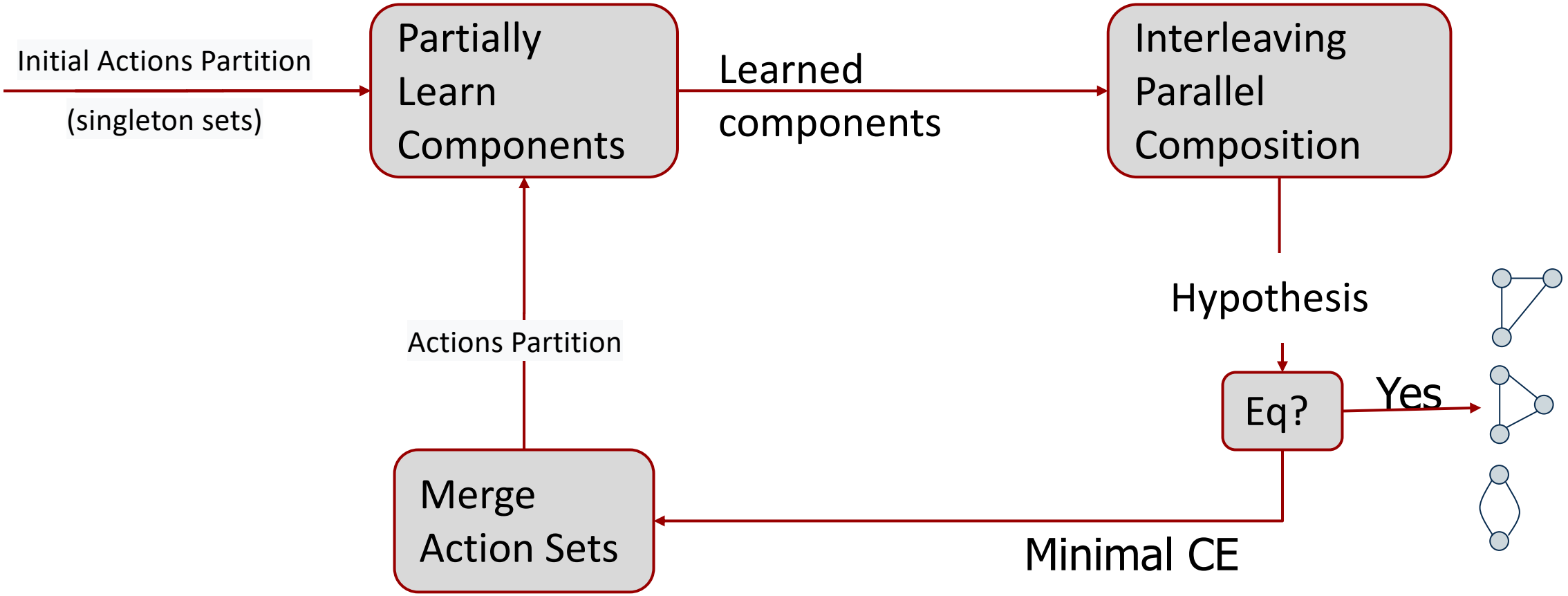
L*


Teacher
System Under Learning
Conformance Tester
Membership Query
Query Output
Equivalence Query
(Hypothesis)
Yes/No, Counterexample
Learner
I_1
I_2
I_n

CL*


Teacher
System Under Learning
Conformance Tester
MQs and EQs
MQs and EQs
MQs and EQs
Hypothesis
Yes / No, CE
CL1
CL2
CLn
I1
I2
In

CL* Algorithm



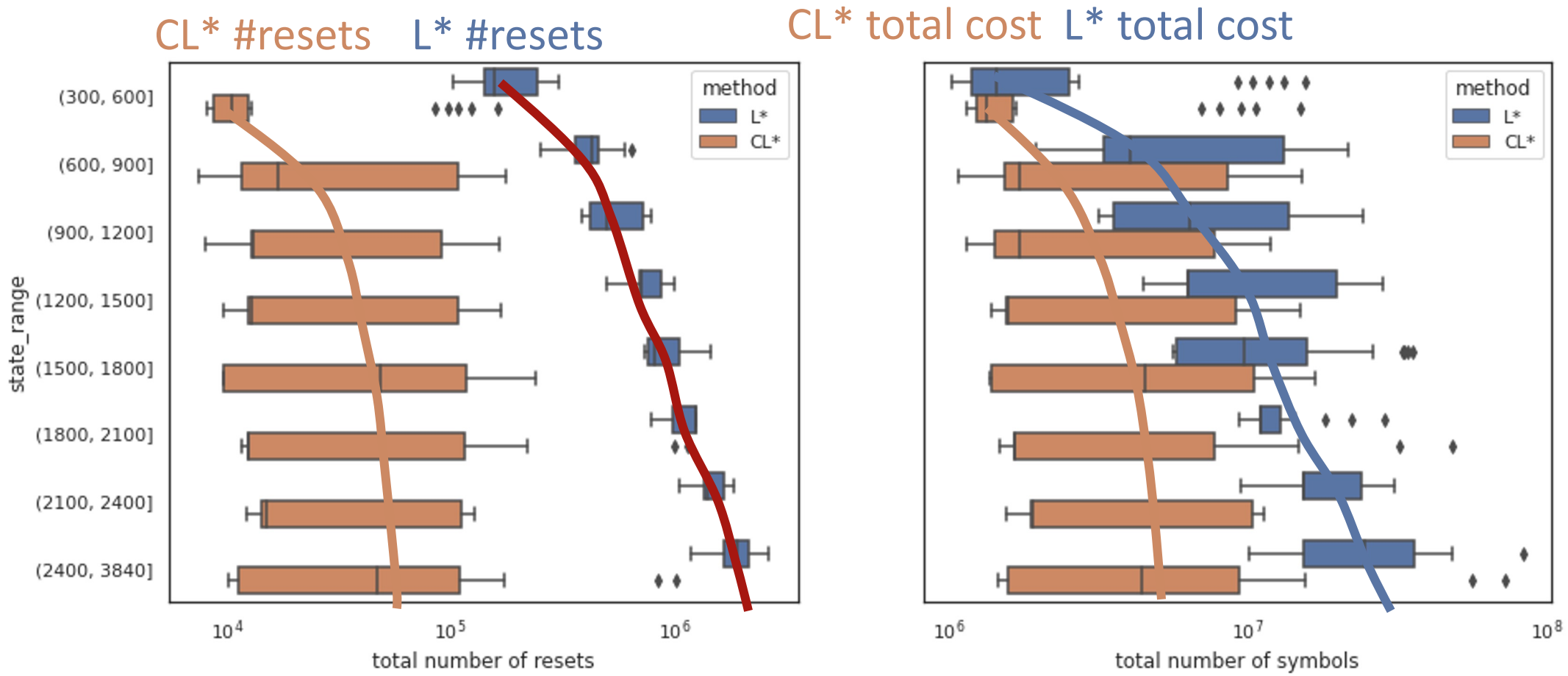
Experiments: Subject Systems

- Body Comfort System
  - An automotive software product line of Volkswagen Golf model.
  - Contains 27 components

- Benchmarks
  - 100 FSMs
  - 2 to 9 components
  - 0 to 3840 states, average: 1278

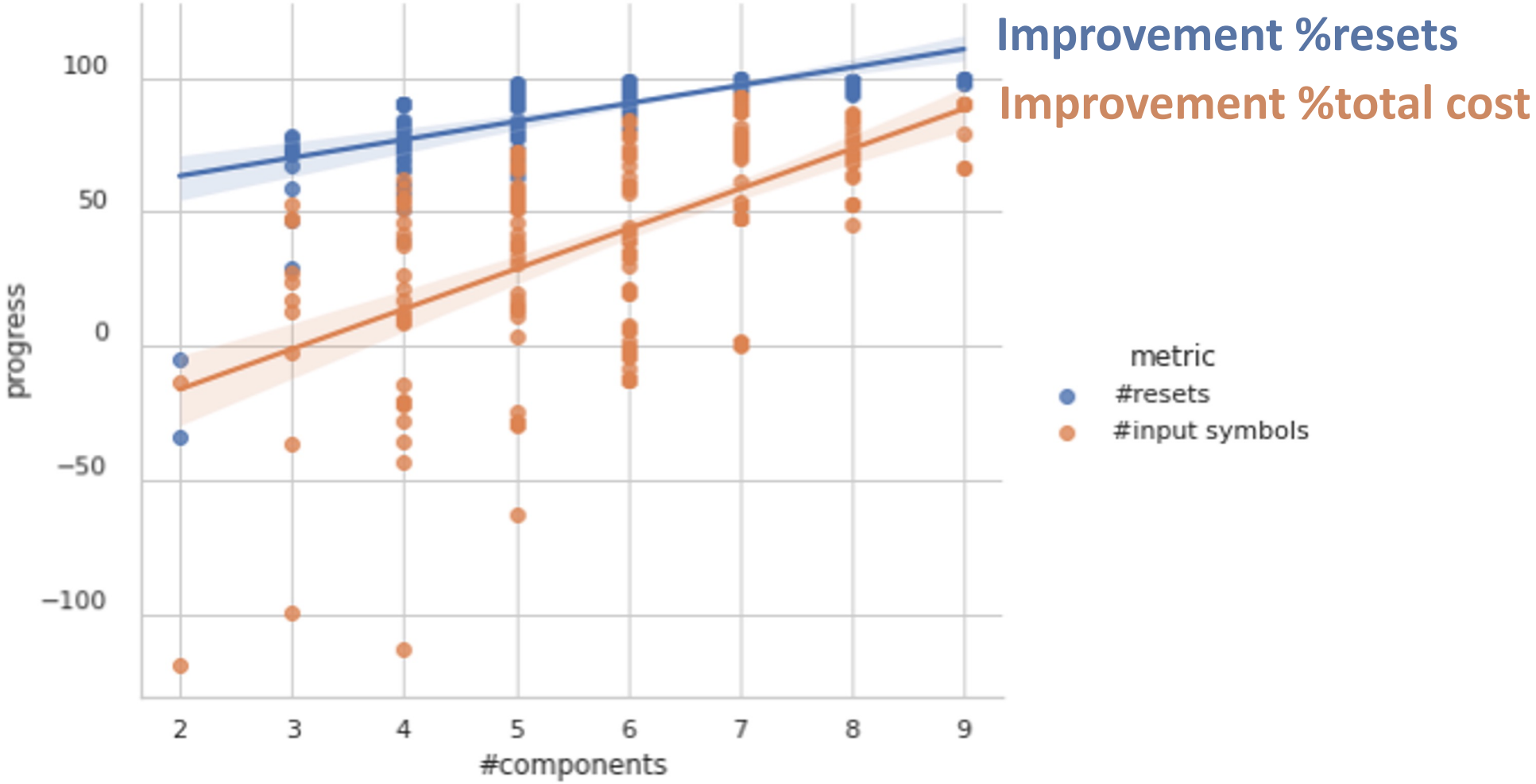
[Lity, Lachmann, Lochau, and Schaefer.
Delta-oriented Software Product Line Test Models – The Body Comfort System Case Study]

Experiments: Performance



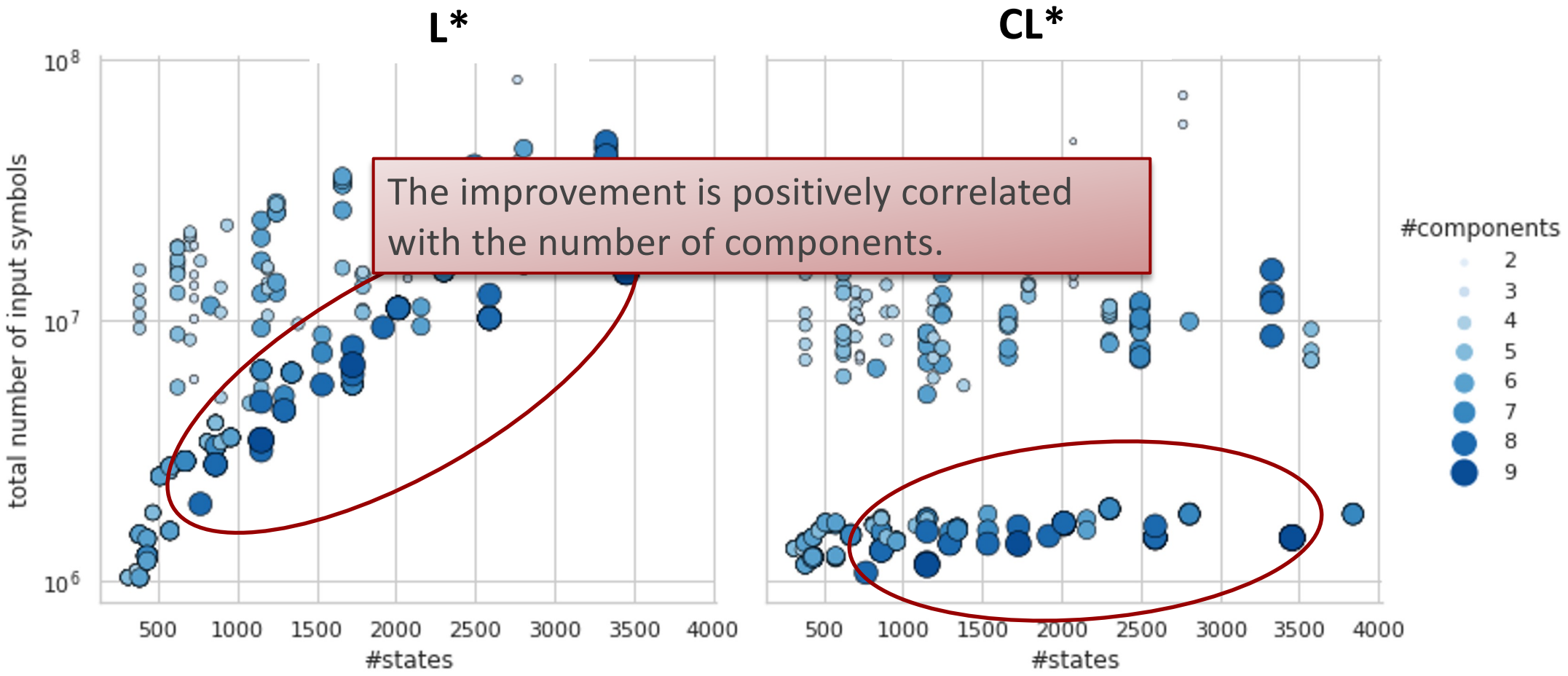
[Labbaf, Groote, Hojjat, MRM, FOSSACS 2023]

Experiments: Improvement



[Labbaf, Groote, Hojjat, MRM, FOSSACS 2023]

Experiments: Effect of Parallelism



[Labbaf, Groote, Hojjat, MRM, FOSSACS 2023]

Active Automata Learning

Adaptive Learning

Compositional Learning

Open Problems

Open Problems

Open Problems

- Compositional and Adaptive **Equivalence Queries**

- Compositional Learning of **Synchronising Automata**
  Cf. [Niele and Sammartino, FASE 2023],
  many challenges in **identifying dependencies**

- Compositional and Adaptive **Tree-Based Learning** : TTT and $L^{\#}$
  Cf. [Ferreira, van Heerdt, Silva, Frits Fest 2022]

Active Automata Learning

Adaptive Learning

Compositional Learning

Open Problems

Thank You!

Thank you very much!

Mohammad Mousavi
mohammad.mousavi@kcl.ac.uk