Learning Nominal Automata

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POPL 2017
Paris

UCL ENGINEERING
Change the world

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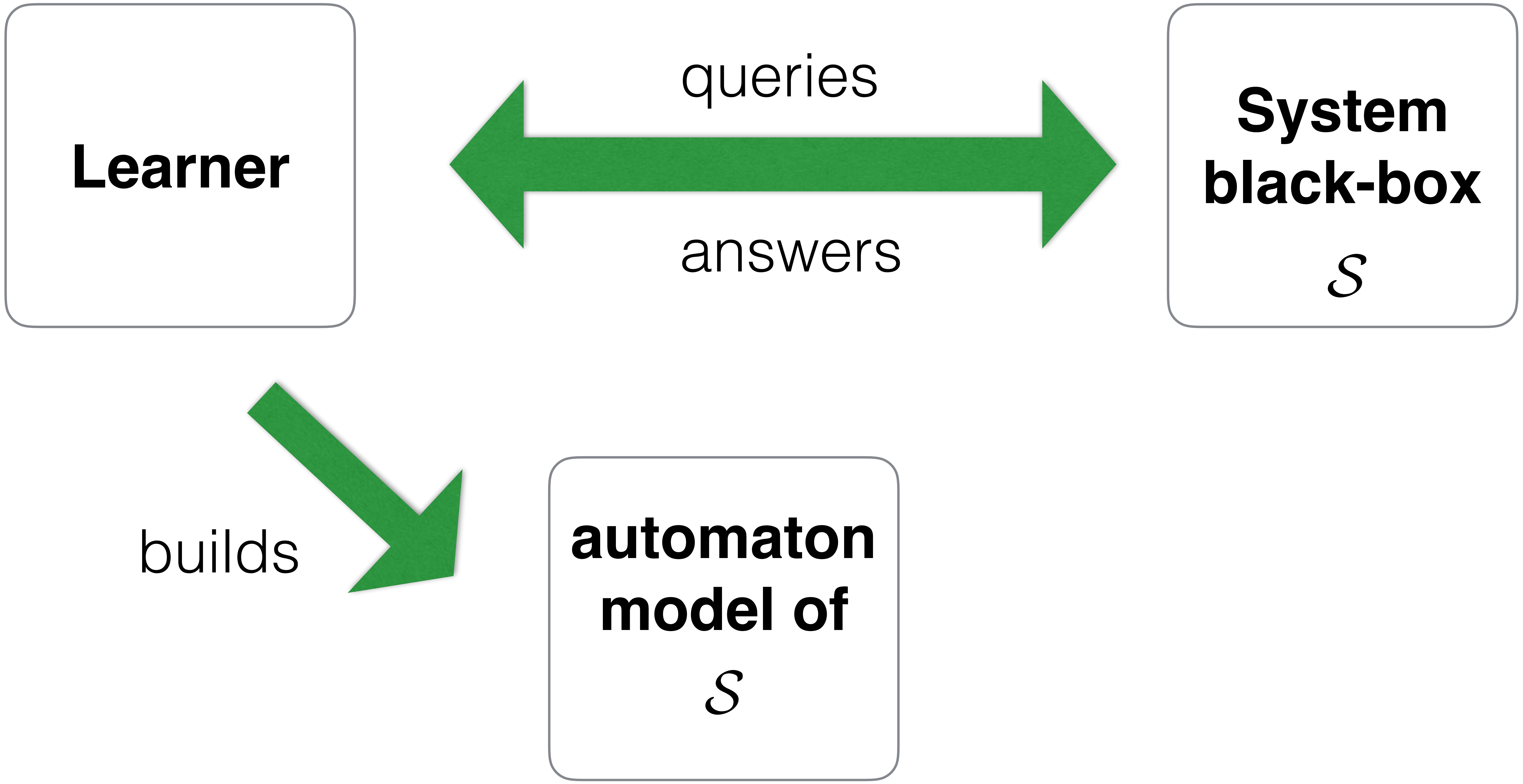
Active learning



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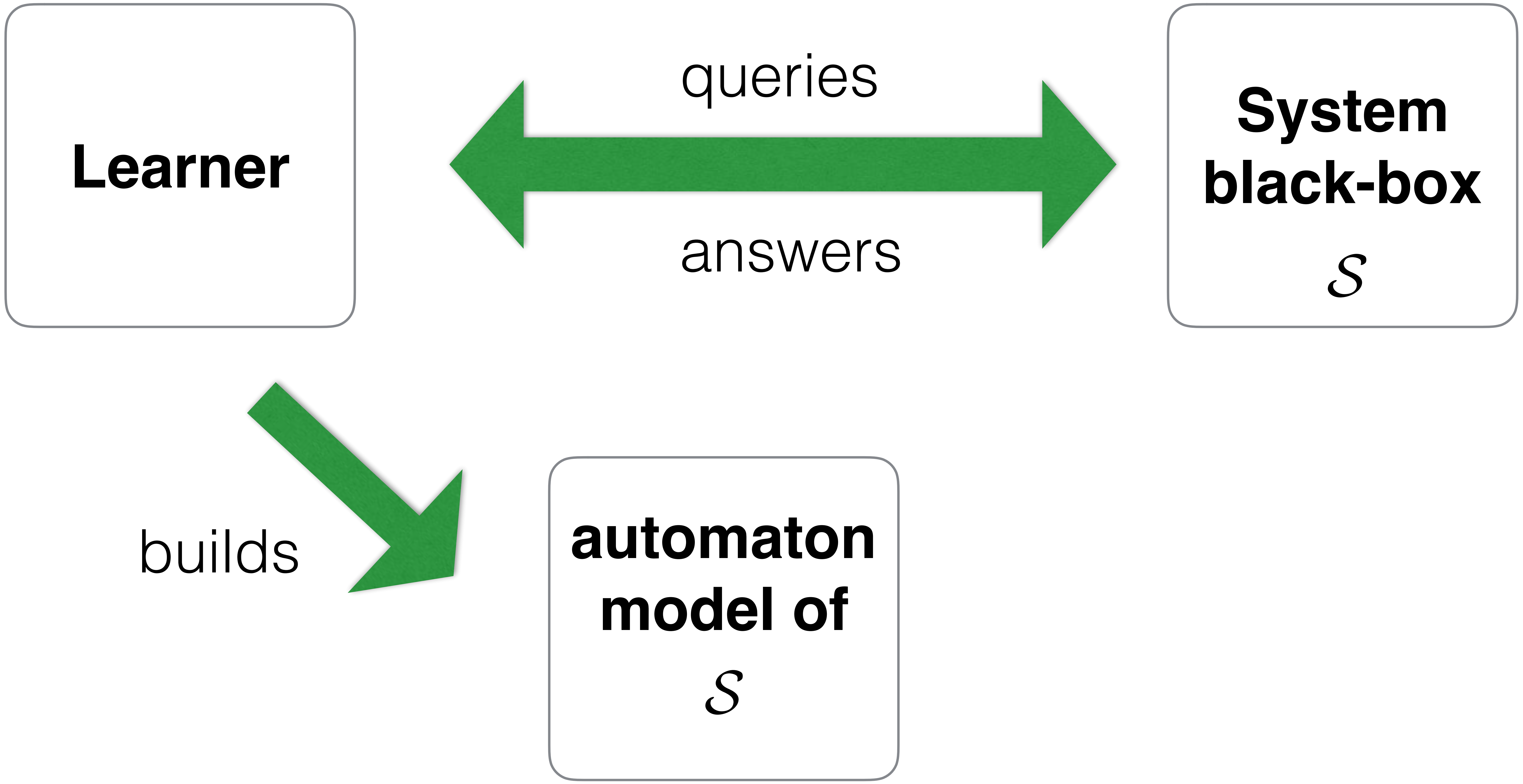

No formal specification available? **Learn it!**

L* algorithm (D.Angluin ’87)

Finite alphabet of system’s actions A

set of system behaviors is a **regular language** $\mathcal{L} \subseteq A^\star$

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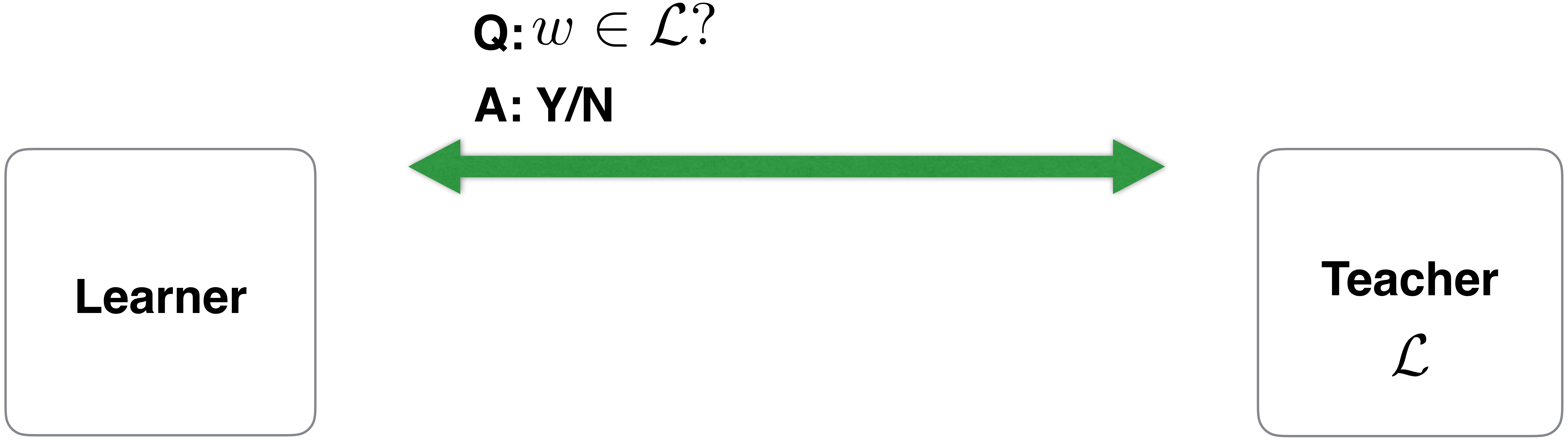

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set of system behaviors is a **regular language** $\mathcal{L} \subseteq A^\star$

Q: $w \in \mathcal{L}?$

A: Y/N

Learner

Q: $\mathcal{L}(H) = \mathcal{L}?$

A: Y / N + counterexample

Teacher

$\mathcal{L}$

H = hypothesis automaton

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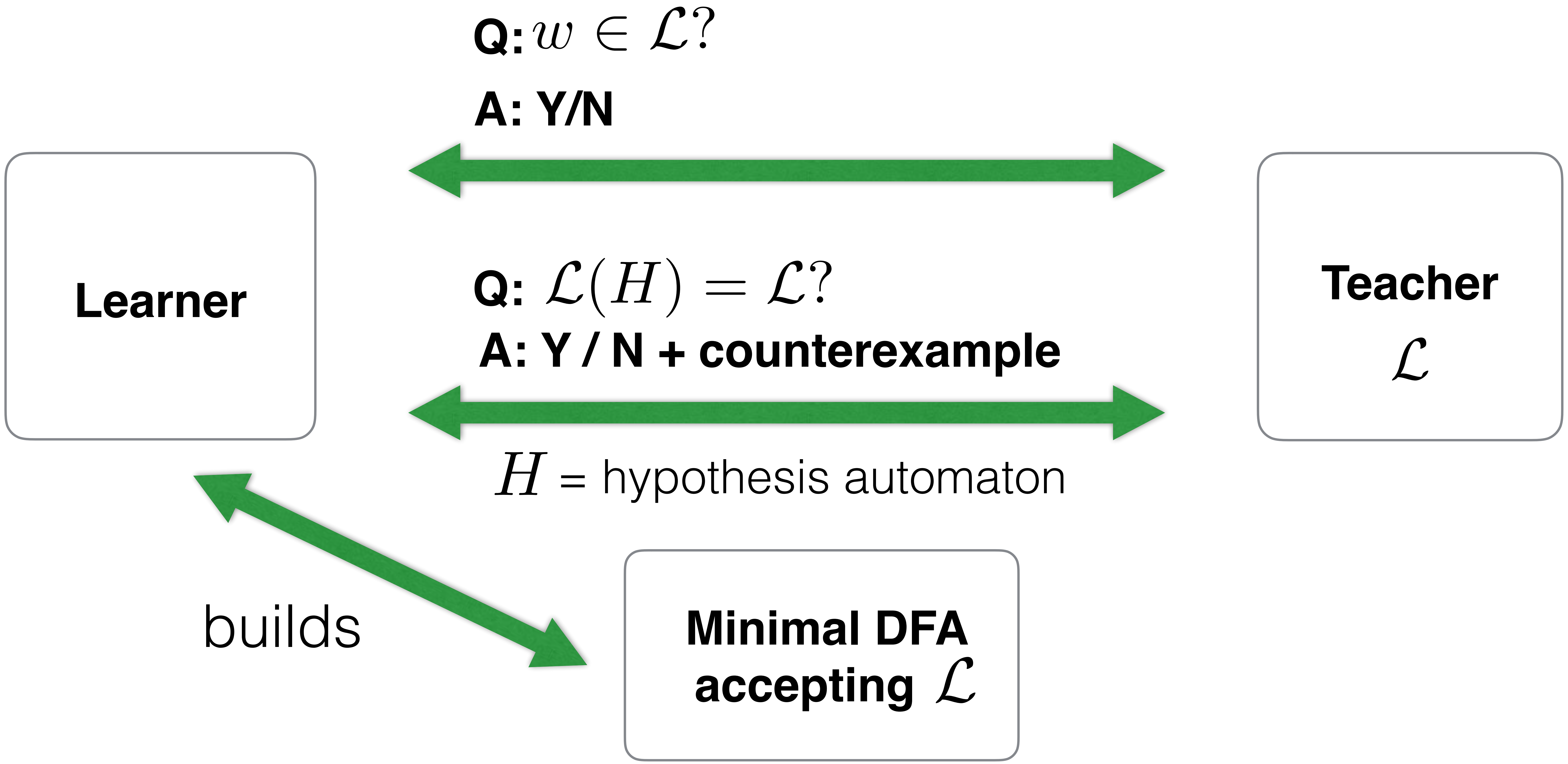

Observation table

E

	ϵ	**a**	**aa**
ϵ	0	0	1
a	0	1	0
b	0	0	0

S

$S{\cdot}A$

$S, E \subseteq A^{\star} \quad A = \{a, b\}$

$$row\colon S \cup S{\cdot}A \to 2^{E}$$

$$row(s)(e) = 1 \iff se \in \mathcal{L}$$

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S: ϵ; $S{\cdot}A$: ***a***, ***b***

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$$row(s)(e) = 1 \iff se \in \mathcal{L}$$

Hypothesis automaton

states = $\{row(s) \mid s \in S\}$

final states = $\{row(s) \mid s \in S, row(s)(\epsilon) = 1\}$

initial state = $row(\epsilon)$

transition function $\quad row(s) \xrightarrow{a} row(sa)$

Observation table

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$S{\cdot}A$	*a*	0	1	0
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Hypothesis automaton

states = $\{row(s) \mid s \in S\}$

final states ... $)(\epsilon) = 1\}$

initial state

Why is this correct?

transition function $row(s) \xrightarrow{a} row(sa)$

Table properties

Closed

$$\forall t \in S \cdot A \quad \exists s \in S \qquad row(t) = row(s).$$

next state exists

Consistent

$$\forall s_1, s_2 \in S \quad row(s_1) = row(s_2) \implies \forall a \in A \;\; row(s_1 a) = row(s_2 a)$$

next state is unique

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Fixed by extending the table

$$\forall s_1, s_2 \in S \quad row(s_1) = row(s_2) \implies \forall a \in A \;\; row(s_1 a) = row(s_2 a)$$

next state is unique

Pros of L* …

simple is beautiful

&

POWERFUL

Applications : Hardware verification, security/network protocols…

Generalizations : Mealy machines, I/O automata, …

… and shortcomings

L* learns **control-flow**

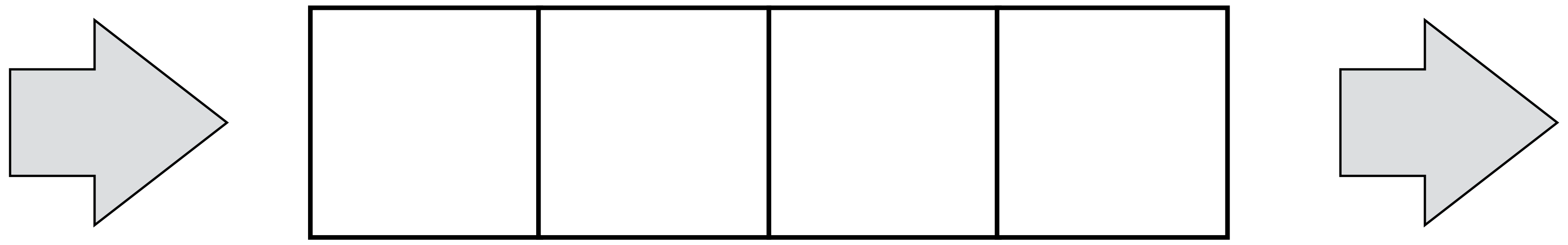
What if program model needs to express **data-flow?**

operations on **data values**

comparisons between data values

FIFO

push(x)



pop(y)

y = front element

Automata over infinite alphabets
(nominal automata)

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$$\mathcal{L} = \{aa, bb, cc, dd, \dots\}$$

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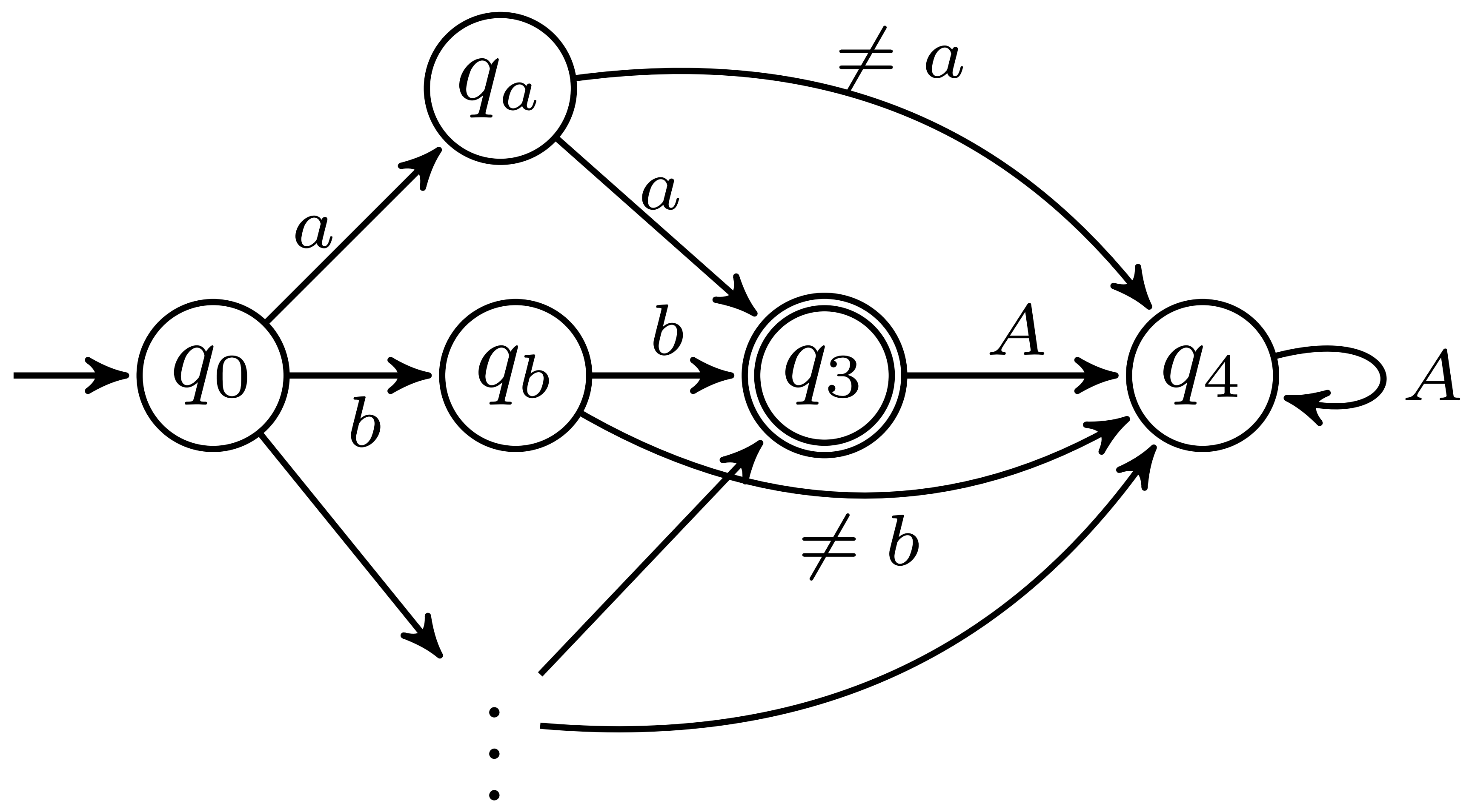

infinite automaton

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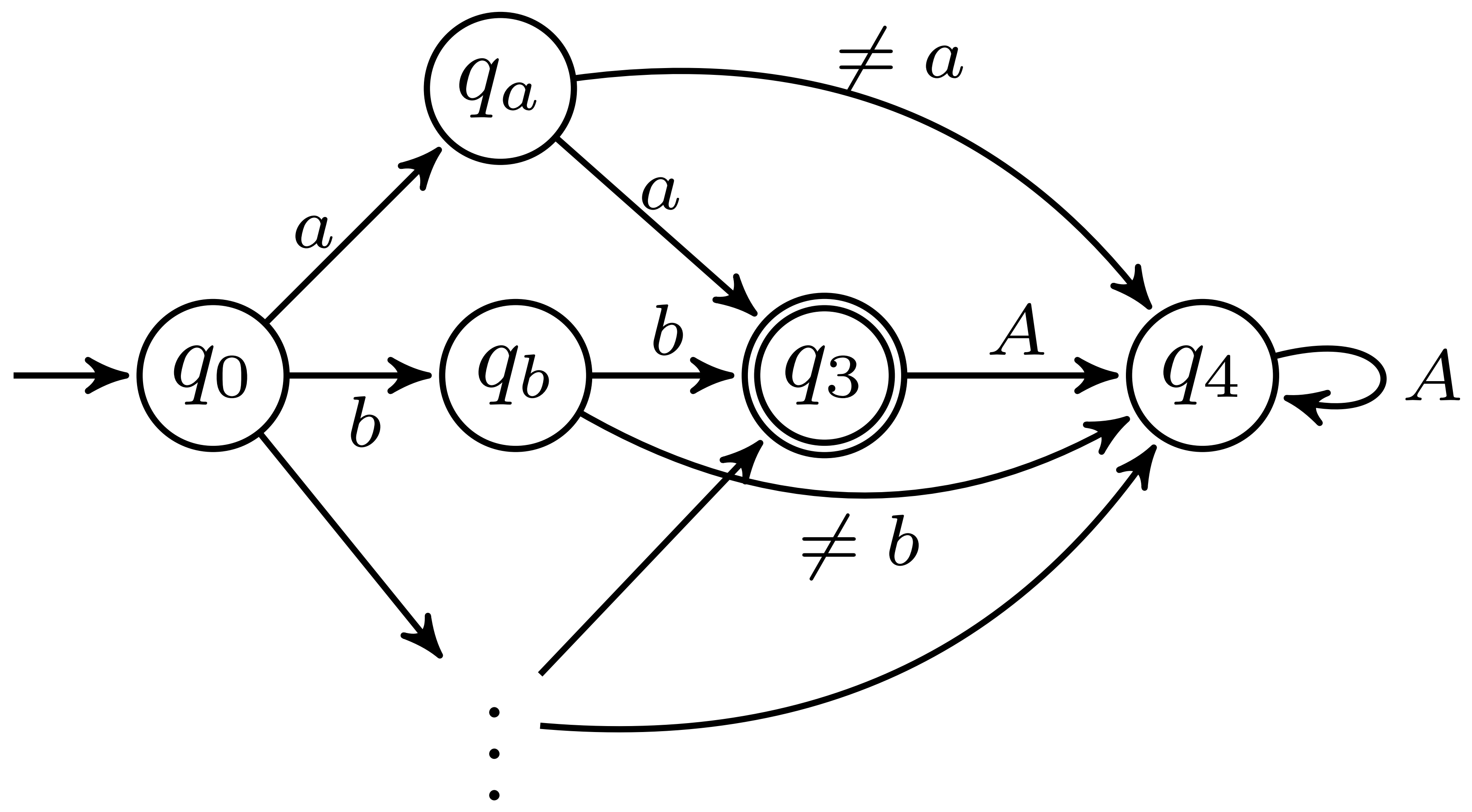
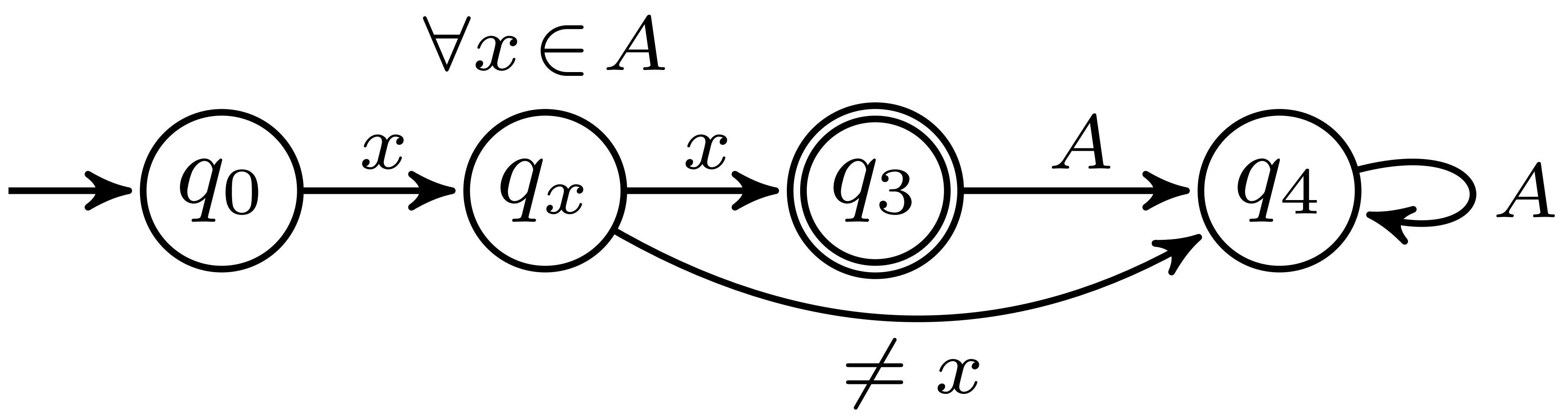


infinite automaton



but with a finite representation

How to learn them?

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Ad-hoc algorithm? **NO!**

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Challenges:

- table needs to be **infinite**
- code operates on **infinite sets**

$$\forall t \in S \cdot A \quad \exists s \in S \qquad row(t) = row(s).$$

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- table needs to be **infinite**
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$$\forall t \in S \cdot A \quad \exists s \in S \qquad row(t) = row(s).$$

Everything is "finitely representable"

$$\forall s_1, s_2 \in S \quad row(s_1) = row(s_2) \implies \forall a \in A \;\; row(s_1 a) = row(s_2 a)$$

A paradigm shift

(finite) sets ➡ (orbit-finite) nominal sets

functions ➡ equivariant functions

(change category from **Set** to **Nom**)

Nominal automata theory

Nominal Programming languages

Mikolaj Bojanczyk, Bartek Klin, Slawomir Lasota:
Automata with Group Actions. LICS 2011

Bartek Klin, Michal Szynwelski:
SMT Solving for Functional Programming over Infinite Structures. MSFP 2016

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First non-trivial application of a new programming paradigm (**NLambda**)

Mikolaj Bojanczyk, Bartek Klin, Slawomir Lasota: **Automata with Group Actions**. LICS 2011

Bartek [illegible]
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Eryk Kopczynski, Szymon Torunczyk: **LOIS: syntax and semantics.** POPL 2017

Correctness and termination

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NLambda guarantees that **each line of code terminates**

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Algorithm correctness and termination **from scratch**?

Correctness and termination

NLambda guarantees that **each line of code terminates**

Algorithm correctness and termination **from scratch**?

Not really

Set-based proofs as **guidelines**

L* enjoys a nice **category-theoretic** generalization

Bart Jacobs, Alexandra Silva
Automata Learning: A Categorical Perspective, Horizons of the Minds 2014

What we've done

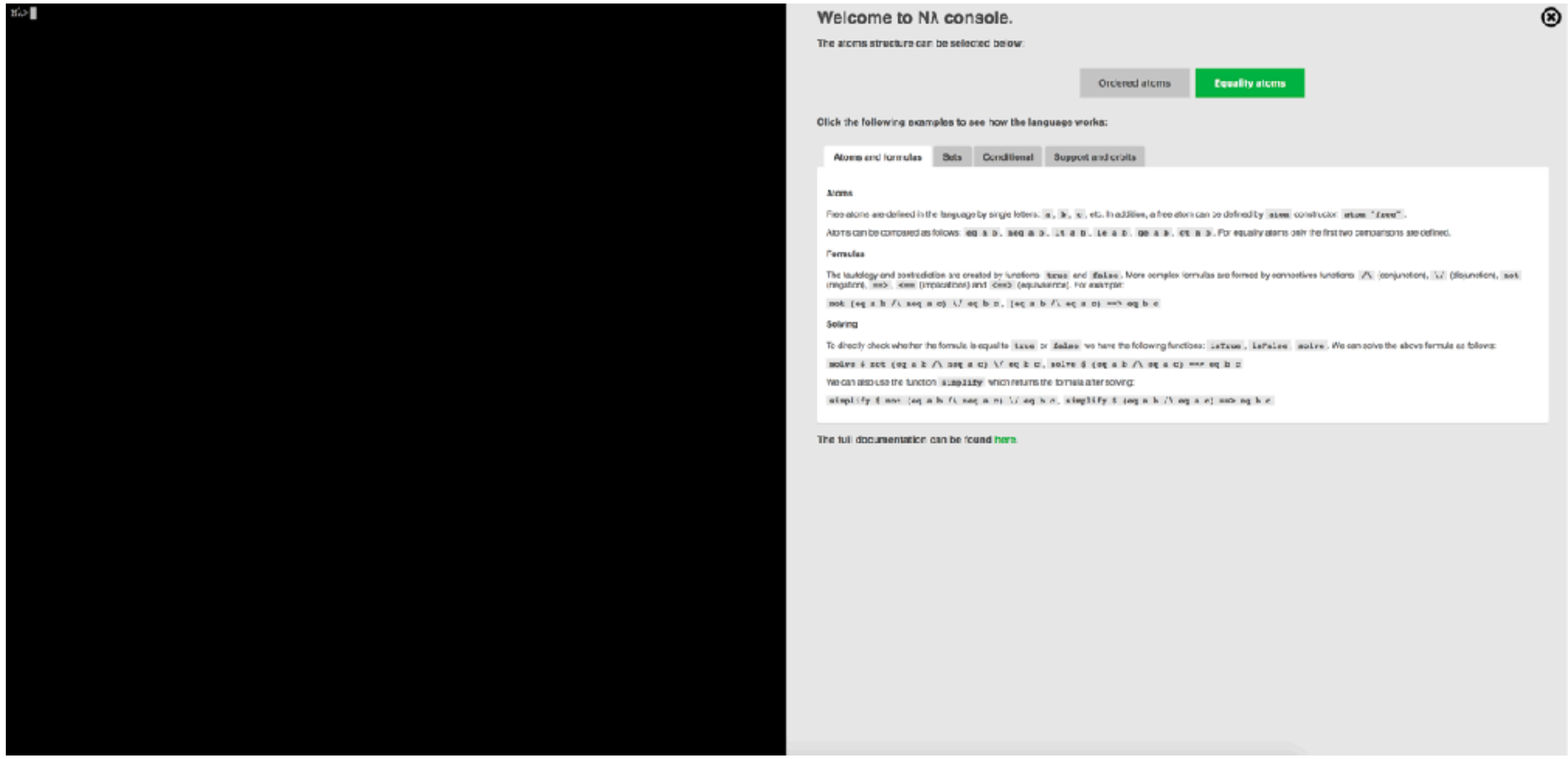
- Nominal L*
- **More in the paper**: variations, Nominal NL*
- NLambda (Haskell) Implementation
- Experimental results

What's next…

- Improve NLambda
- Other active learning algorithms
- Other optimizations
- Applications: large-scale software, crypto protocols…

Try it yourself

https://www.mimuw.edu.pl/~szynwelski/nlambda/



https://github.com/Jaxan/nominal-lstar