Towards Automatic Learning of Discrete-Event Models from Simulation

Ashfaq Farooqui, Petter Falkman, and Martin Fabian

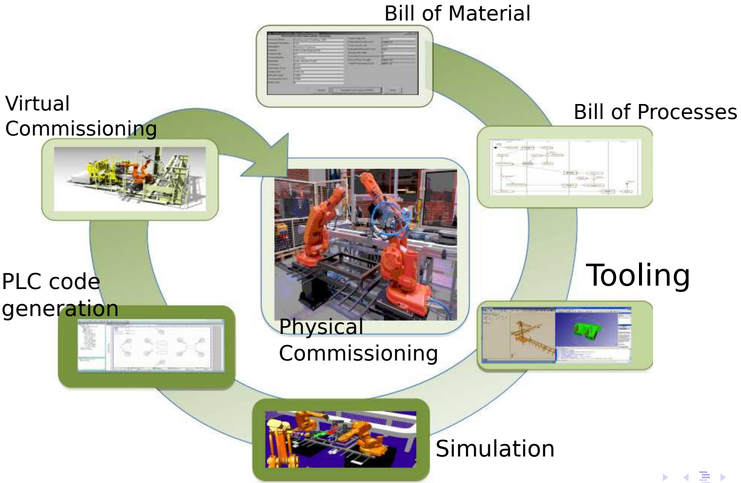
Department of Electrical Engineering,
Chalmers University of Technology,
Göteborg, Sweden

14th IEEE International Conference on Automation Science and Engineering, Munich, Germany
August 2018

Outline

Topic

Virtual Preparation and Commissioning in a nutshell



Formal Methods

- Mathematical techniques for specification, and verification of systems
- Formal Models: Less ambiguous way to define the behavior of the system
- Verification: Checks if the model satisfies the specifications
- Synthesis: Calculate a controller that satisfies the specifications
- Challenges: Hard to model physical systems – error prone process when done manually

Purpose

Proof of concept work to evaluate the possibility of automatically learning a formal model.

Topic

1 Motivation

2 Automata Learning

3 Automata Learning Applied to a Simulated Robotic arm

4 Outcome and Future work

Automata Learning

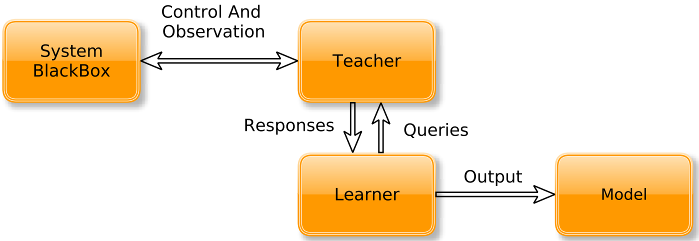
- Passive Learning
- Active Learning

Active Learning

Learning regular sets from queries and counterexamples. Dana Angluin. Information and Computation, 1987

- Famously called L^*
- L^* makes it possible to learn deterministic automata

Active Learning



L*

Learner Queries

- Membership queries $w \in \mathcal{L}_{\Updownarrow}$?
- Equivalence queries $\mathcal{L}(H) = \mathcal{L}$?

Observation Table

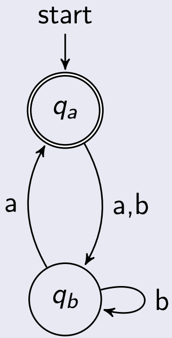
- $row : S \cup S.\Sigma \rightarrow \{1, 0\}$
- $row(s.e) = 1 \leftrightarrow se \in \mathcal{L}$

		E		
		ε	a	aa
S	ε	0	1	0
$S.\Sigma$	a	1	0	0
	b	0	0	0

Observation Table to Automata

Representing an Observation Table as an Automata

	ε
ε	1
a	0
b	0
aa	1
ab	0



Observation Table Properties

Closed

An observation table is said to be closed if for all $t \in S, a \in \Sigma$ there is an $s \in S$ such that the $row(s) = row(t.a)$.

Consistent

A table is consistent if for $s_1 \in S$ and $s_2 \in S$ and $row(s_1) = row(s_2)$ then for all $a \in \Sigma, row(s_1.a) = row(s_2.a)$.

L^*, an example

- Let $\Sigma = \{a, b\}$
- Let $\mathcal{L} = \{w \in \Sigma^* \mid w$ contains even number of a's and b's$\}$

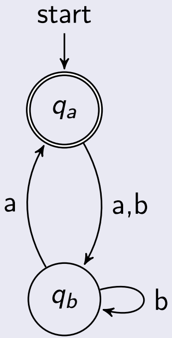
Initial Table

	ε
ε	1
a	0
b	0

L*, an example

First Hypothesis

	ε
ε	1
a	0
b	0
aa	1
ab	0

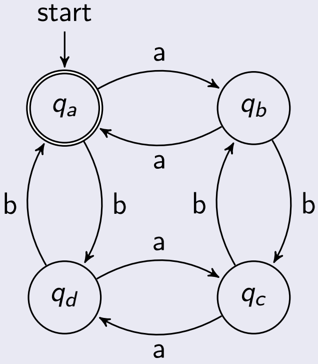


- Counter example $\langle aba \rangle$

L^*, an example

Final Hypothesis

	ε	a	b
ε	1	0	0
a	0	1	0
ab	0	0	0
aba	0	0	1
$abab$	1	0	0
b	0	0	1
aa	1	0	0
abb	0	1	0
$abaa$	0	0	0
$ababa$	0	1	0
$ababb$	0	0	1



Topic

Robotic arm configuration

Operations:

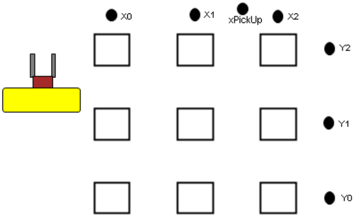
$O\langle \text{PreGuard}, \text{PreActions}, \text{PostGuard}, \text{PostActions} \rangle$

Goal

A predicate over the sensor values to define the marked states

Operation Grip Example

PreGuard : (extended== true && gripping == false)
PreAction : gripper := true
PostGuard : gripping == true
PostAction: -



The Interface

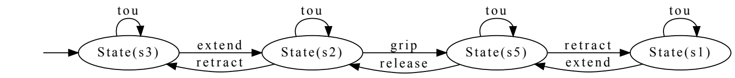
- Membership queries (Mq) were obtained by running sequences in the simulator
- Equivalence queries (Eq) were obtained using random walks on the hypothesis

Results

Some observations

Grid	States	Eq	Mq
3x3	37	8	17600
4x4	65	9	55230
5x5	101	10	102780

Graph showing the gripping operation



Topic

Outcomes

- It was possible to learn a model of the simulated target system.
- The algorithm works well on small systems, but could not easily scale for larger systems
- Bottlenecks:
  - Finding counter examples using random walks is not always effective in large systems
  - Checking if the Observation Table is consistent is time consuming, and this needs to be done at every iteration

Future Work

- Improve performance using more advanced data structures
- Further study on finding counterexamples
- Extending the current work to real world manufacturing systems
- Learn richer formalism's (Extended finite automata)

Thank You!

L* Algorithm

Result: A Hypothesis DFA $\mathcal{H}$
initialization $S, E \leftarrow \varepsilon$;
repeat
  while *the table is not closed or not consistent* **do**
    if *table is not closed* **then**
      find $u \in S, a \in A$ such that $row(ua) \neq row(s) \forall s \in S$;
      $S \leftarrow S \cup \{ua\}$;
    end
    if *table is not consistent* **then**
      find $s_1, s_2 \in S$, $a \in A$ and $e \in E$ such that $row(s_1) = row(s_2)$ and $row(s_1ae) \neq row(s_2ae)$;
      $E \leftarrow E \cup \{ae\}$;
    end
  end
  Construct the hypothesis $\mathcal{H}$ to the teacher **if** *the teacher replies* no *with a counterexample* c **then**
    $S \leftarrow S \cup prefixes(c)$
  end
until *the teacher replies* yes;
return $\mathcal{H}$