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Synchronizing and Homing Experiments for Input/Output Automata

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Outline

- Motivation
- Introducing the class of Input/Output automata we are dealing with
- Defining homing and synchronizing sequences for Input/Output automata
- Deriving synchronizing sequences
- Deriving homing sequences
- Conclusions & future work

Motivation

Just now mostly theoretical interest ☺

o Finite State Machines and synchronizing/homing experiments with them are well studied and are widely used for test derivation

However…

o Not each reactive system produces an output immediately after applying an input

o Synchronizing/homing experiments with Input/Output Automata should be also considered

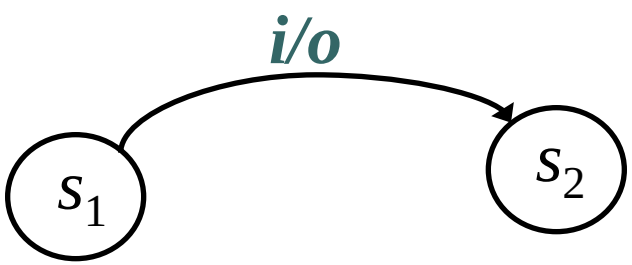
⇓

We define the synchronizing and homing sequences for Input/Output Automata and propose how to derive them

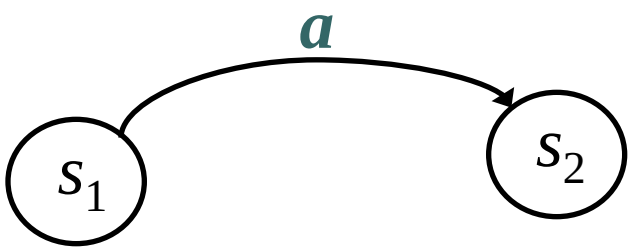
Finite State Machines and Automata

- *Finite state machines* (*FSMs*) and *Automata* describe the behavior of discrete event systems
- FSMs work in request/response mode

- FSM transitions are labeled with input/output pairs



FSM transition



Automata transition

- Both models are widely used for test generation and verification of software and hardware systems

Finite State Machine

$\boldsymbol{S} = (S, I, O, T_S)$ is a FSM

- S is a finite nonempty set of states
- I and O are finite input and output alphabets
- $T_S \subseteq S \times (I \times O) \times S$ is transition relation

Input/Output Automaton

$S = (S, I, O, T_S)$ is an I/O automaton

- S is a finite nonempty set of states
- I and O are finite input and output alphabets, $I \cap O = \varnothing$
- $T_S \subseteq S \times I \times S \cup S \times O \times S$ is transition relation

- $S = S_1 \cup S_2$, $S_1 \cap S_2 = \varnothing$ and $T_S \subseteq S_1 \times I \times S \cup S_2 \times O \times S$
- NO loops labeled with outputs
- $\exists\, \delta \notin O\ \forall s \in S_1$ $(s, \delta, s) \in T_S$

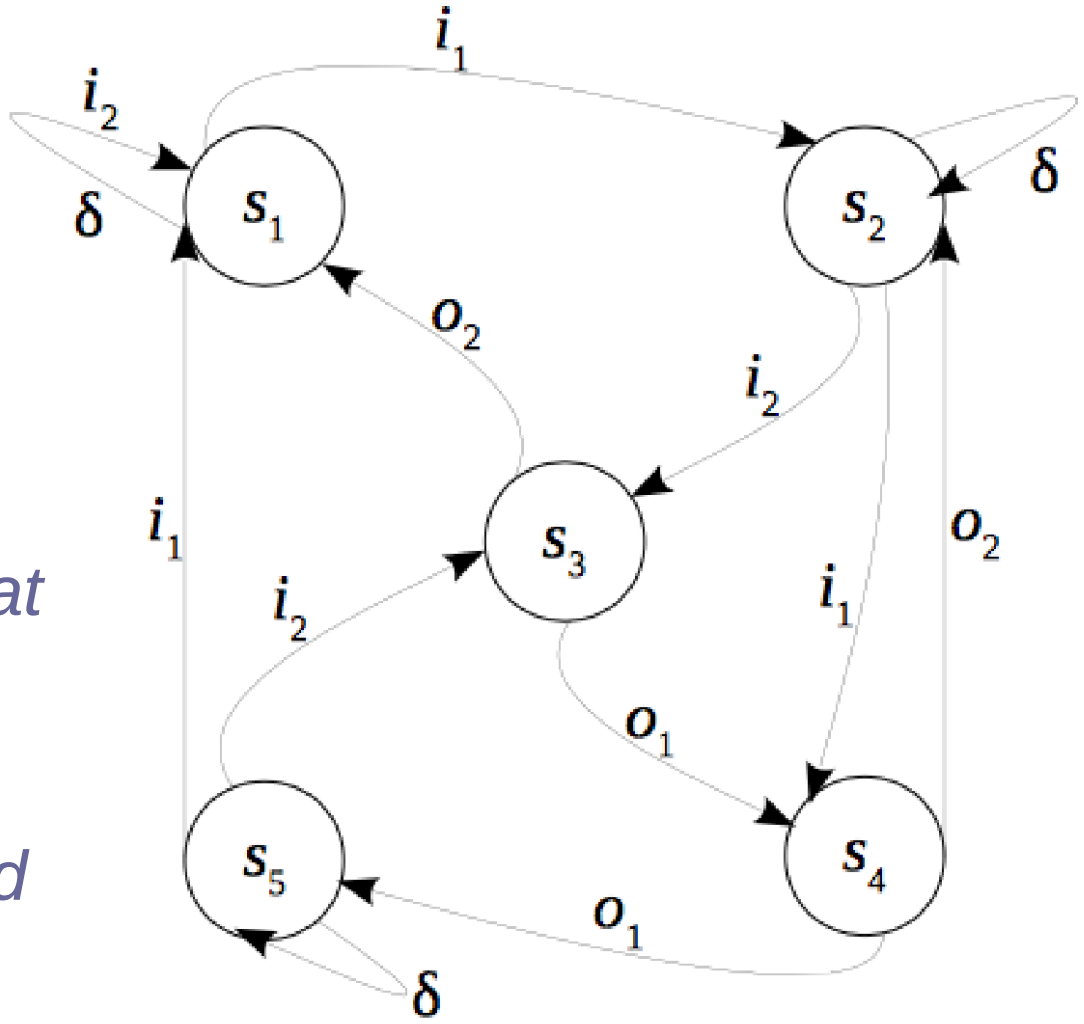
Some example...

- $S = \{s_1, \ldots, s_5\}$
- $S_1 = \{s_1, s_2, s_5\}$
- $S_2 = \{s_3, s_4\}$

$\Downarrow$

Inputs are accepted at s_1, s_2, s_5

Outputs are produced at s_3, s_4



When testing against FSMs…

1) Reaching each FSM state *s*

2) Traversing a transition to check the output and final state *s′*

3) Distinguishing the final state *s′* of the transition from any other FSM state

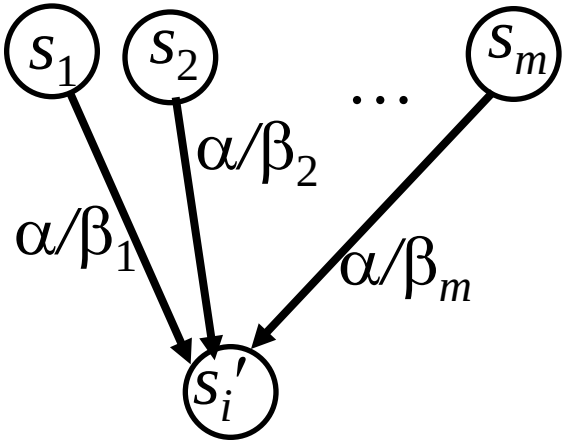
The reachability issue can be solved via an application of the homing or synchronizing sequence

FSM

Synchronizing sequence (SS)

- The sequence $\alpha = i_1 i_2 \ldots i_k$ allows to recognize the current state of the machine under experiment without observing the output response
- After applying α at any state s_i the final state s_i' becomes known

Synchronizing sequence α



Independently of $\beta_i = o_1 o_2 \ldots o_k$

FSM

Synchronizing sequence (SS)

γ-successor of the state $s \in S$ is the set of states that can be reached from state s through the trace γ

while the γ-successor of S is the set of states that can be reached from some state of S through the trace γ

FSM

Synchronizing sequence (SS)

$\alpha = i_1 i_2 \ldots i_k$ is ***synchronizing***

if

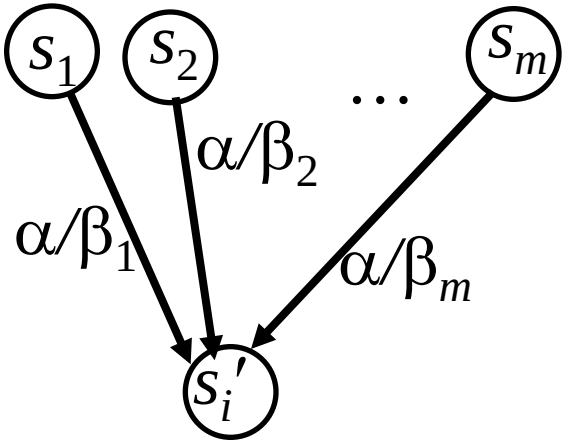
α **is defined at all states of** S

and $\exists\ s \in S$ **such that**

$\forall\ \gamma = i_1 o_1 i_2 o_2 \ldots i_k o_k$, **where**
$o_j \in O, j = 0, \ldots, k$

it holds that γ-state-after-S
is either empty
or is equal to $\{s\}$

Synchronizing sequence α



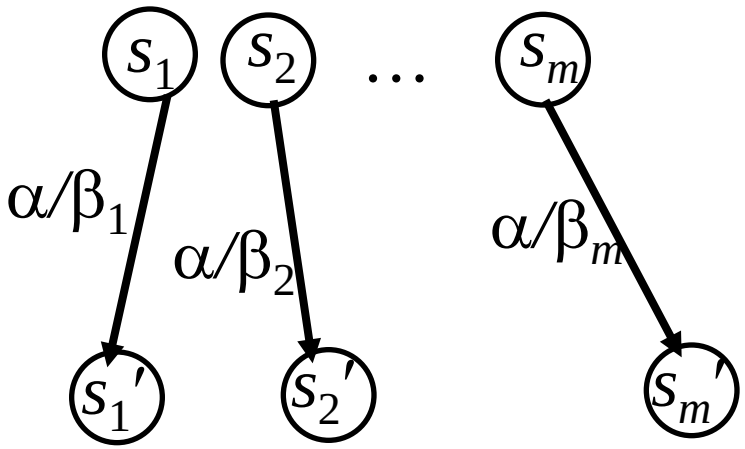
Independently of $\beta_i = o_1 o_2 \ldots o_k$

FSM

Homing sequence (HS)

- The sequence $\alpha = i_1 i_2 \ldots i_k$ allows to recognize the current state of the machine under experiment after observing the output response
- After applying α at any state s_i and observing an output response β_i the final state s_i' becomes known

Homing sequence α



$$\beta_1 \neq \beta_2 \neq \ldots \neq \beta_m$$

FSM

Homing sequence (HS)

$\alpha = i_1 i_2 \ldots i_k$ is ***homing***

if

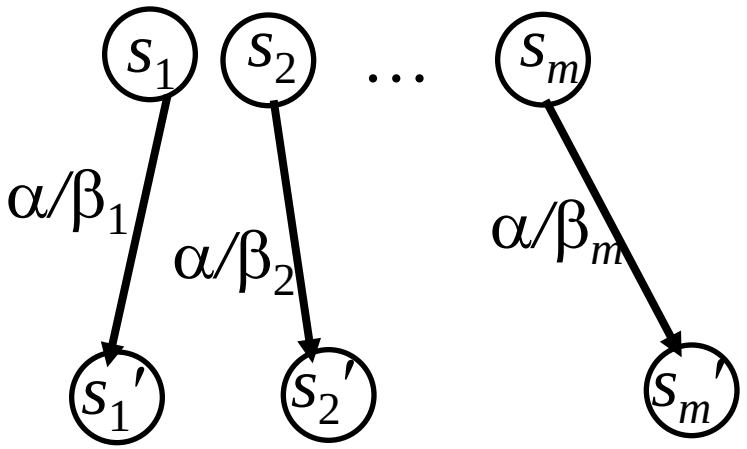
α **is defined at all states of** S

and $\exists\ s \in S$ **such that**

$\forall\ \gamma = i_1 o_1 i_2 o_2 \ldots i_k o_k$, **where**
$o_j \in O,\ j = 0, \ldots, k$

it holds that γ-state-after-S
is either empty
or is a singleton $\{ s_i' \}$

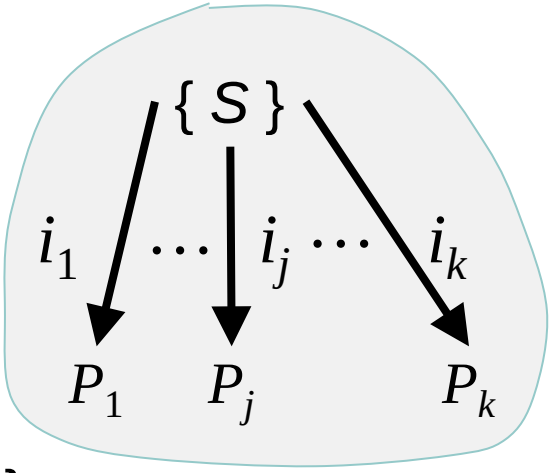
Homing sequence α



$\beta_1 \neq \beta_2 \neq \ldots \neq \beta_m$

FSM

‘Classical’ approach for SS/HS derivation for FSMs



Derive a successor tree (ST)

$s \in S$: *io*-successor $s =_{def} \{ s' \mid (s, i, o, s') \in T_S \}$

$R \subseteq S$: *io*-successor $R =_{def} \cup \{$ *io*-successor $s \mid s \in R \}$

$R \subseteq S$: *i*-successor $R =_{def} \{$ *io*-successor $R \neq \varnothing \mid o \in O \}$

$P \subseteq 2^S$: *i*-successor $P =_{def} \cup \{$ *i*-successor $R \mid R \in P \} =$

$= \{$ *io*-successor $R \neq \varnothing \mid R \in P \ \&\ o \in O \}$

$P \subseteq 2^S$, $P \xrightarrow{i}$ *i*-successor P **iff** $\forall R \in P$ *i*-successor $p \neq \varnothing$

FSM

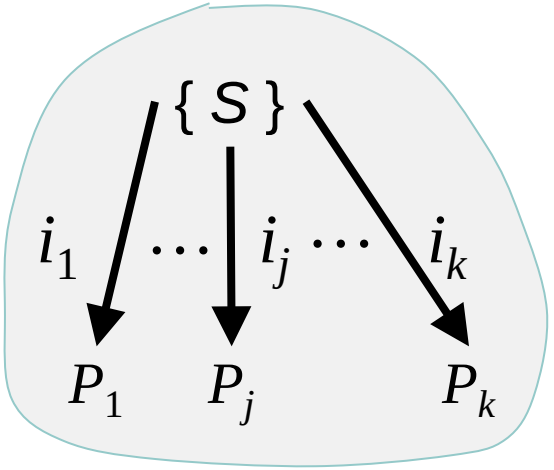
‘Classical’ approach for SS derivation for FSMs

Derive a truncated successor tree (ST)

$s \in S$: *io*-successor $s =_{\text{def}} \{ s' \mid (s, i, o, s') \in T_s \}$

$R \subseteq S$: *io*-successor $R =_{\text{def}} \cup \{$ *io*-successor $s \mid s \in R \}$

$P \subseteq 2^S$: *i*-successor $P =_{\text{def}} \cup \{$ *io*-successor $R \neq \varnothing \mid R \in P \ \& \ o \in O \}$



$P \subseteq 2^S$, $P \text{—}i\text{→}$ *i*-successor P **iff** $\forall R \in P$ *i*-successor $p \neq \varnothing$

Truncating rules:

Rule 1 P has only one singleton $\exists s \in S \quad P = \{ \{ s \} \}$

Rule 2 Set P coincides with the set P' that is met ‘upper’ in the tree

α is a synchronizing sequence iff it labels the path truncated by Rule 1

FSM

‘Classical’ approach for HS derivation for FSMs

Derive a truncated successor tree (ST)

$s \in S$: *io*-successor $s =_{\text{def}} \{ s' \mid (s, i, o, s') \in T_S \}$

$R \subseteq S$: *io*-successor $R =_{\text{def}} \cup \{$ *io*-successor $s \mid s \in R \}$

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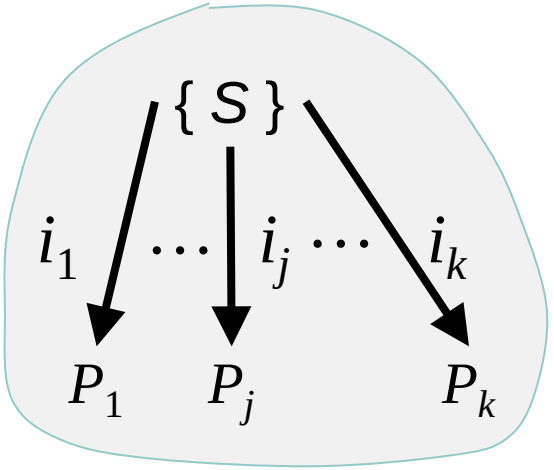


$P \subseteq 2^S$, $P \text{—}i\rightarrow$ *i*-successor P **iff** $\forall R \in P$ *i*-successor $p \neq \varnothing$

Truncating rules:

Rule 1 P has only singletons $\forall p \in P \quad \exists s \in S \quad p = \{ s \}$

Rule 2 Set P coincides with the set P' that is met ‘upper’ in the tree

α is a homing sequence iff it labels the path truncated by Rule 1

Adapting FSM based techniques to I/O Automata

The problem statement

o How to define HS and SS for Input/Output Automata?

o How to use the FSM ‘classics’ for their derivation?

⇓

Hypothesis : before applying any input, a tester waits for a given maximal output timeout t

If no output is produced by the system in *t* time units

Then the tester applies the next input (if any) and resets the timer

FSM

Synchronizing sequence (SS)

$\alpha = i_1 i_2 \ldots i_k$ is ***synchronizing***

if $\exists\ s \in S$ **such that**

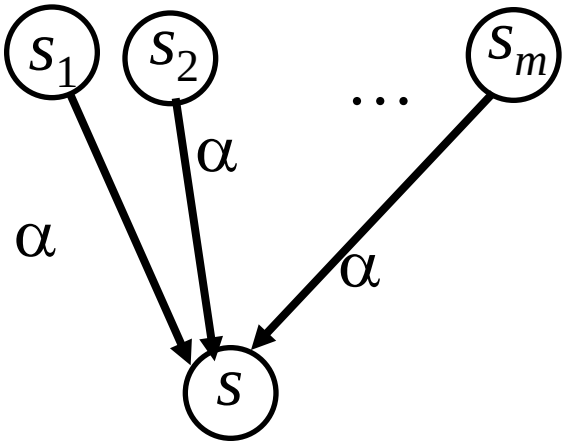
$\forall\ \gamma = i_1 o_1 i_2 o_2 \ldots i_k o_k$, **where**

$o_j \in O$, $j = 0, \ldots, k$

it holds that

γ-state-after-S is equal to $\{s\}$

Synchronizing sequence α



Synchronizing sequence (SS)

I/O Automaton

$\alpha = i_1 i_2 \ldots i_k$ is ***synchronizing***

if $\exists\ s \in S$ **such that**

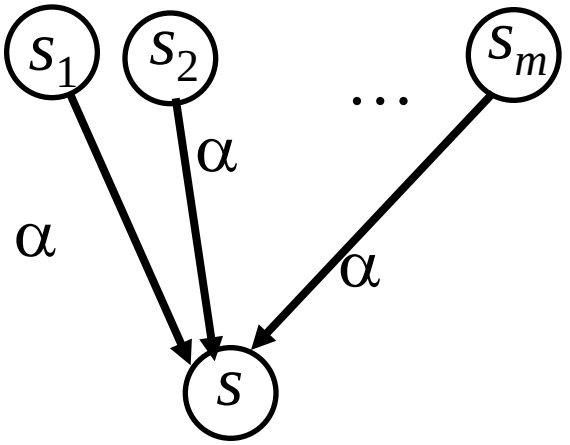
$\forall\ \gamma = \beta_0 i_1 \beta_1 i_2 \beta_2 \ldots i_k \beta_k$, **where**

$\beta_j \in (O \cup \{\delta\})^p$, $j = 0, \ldots, k$

it holds that

γ-state-after-S is equal to $\{s\}$

Synchronizing sequence α



p is the length of a longest sequence of consecutive outputs

FSM

Homing sequence (HS)

$\alpha = i_1 i_2 \ldots i_k$ is ***homing***

if $\exists\, s \in S$ **such that**

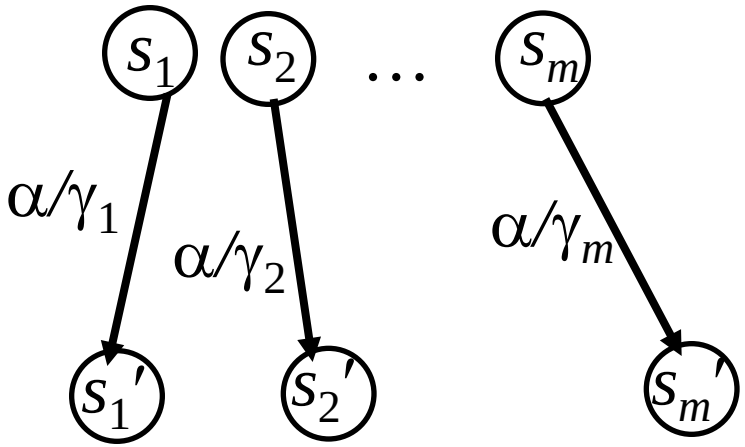
$\forall\, \gamma = i_1 o_1 i_2 o_2 \ldots i_k o_k$, **where**

$o_j \in O$, $j = 0, \ldots, k$

it holds that

γ-state-after-S is a singleton $\{ s_i' \}$

Homing sequence α



Homing sequence (HS)

I/O Automaton

$\alpha = i_1 i_2 \ldots i_k$ is ***homing***

if $\exists\ s \in S$ **such that**

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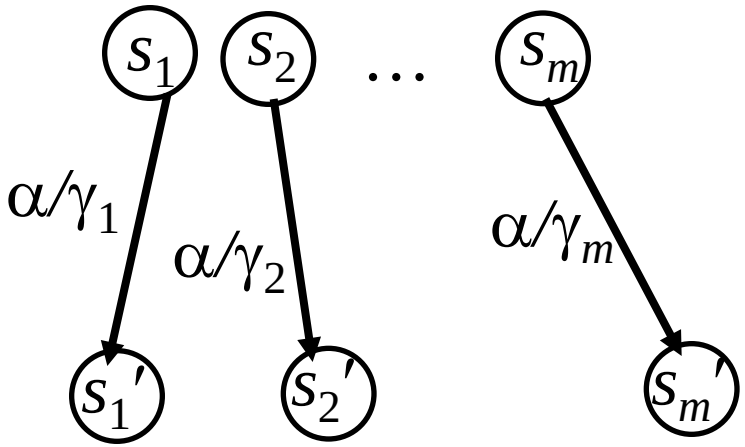
it holds that

γ-state-after-S is a singleton

$\{ s_i' \}$

Homing sequence α



p is the length of a longest sequence of consecutive outputs

Converting an input-output automaton to an FSM

Input: Input/Output automaton $\boldsymbol{S} = (S, I, O, T_{\boldsymbol{S}})$, $S = S_1 \cup S_2$

Output: FSM $\boldsymbol{M} = (S_1, I, O \cup O^2 \cup \ldots \cup O^p \cup \{\delta\}, T_{\boldsymbol{M}})$

p - length of a longest output trace of $\boldsymbol{S}$

Step 1 $T_{\boldsymbol{M}} := \varnothing$.

Step 2

For each state $s \in S_1$, such that $(s, i, s') \in T_{\boldsymbol{S}}$, $s' \in S_1$,
add to the $T_{\boldsymbol{M}}$ the transition (s, i, δ, s')

For each state $s \in S_1$, such that $(s, i, s'') \in T_{\boldsymbol{S}}$, $s'' \in S_2$,
add to the $T_{\boldsymbol{M}}$ the transition $(s, i, o_1\, o_2 \ldots o_k, s''')$, where
$k \leq p$, $s''' \in S_1$ is the $o_1\, o_2 \ldots o_k$-successor of state s''

Deriving a synchronizing sequence for an I/O automaton ***S***

Input: Input/Output automaton ***S*** = (S, I, O, T_S)

Output: SS α or a message “The automaton ***S*** is not synchronizing”

Step 1 Converting an input-output automaton ***S*** to an FSM ***M***

Step 2

Check the existence and derive a synchronizing sequence α for ***M***:

If the sequence α is derived then **Return** α

Else Return the message “The automaton ***S*** is not synchronizing”

Deriving a homing sequence for an I/O automaton ***S***

Input: Input/Output automaton ***S*** = (S, I, O, T_S)

Output: HS α or a message “The automaton ***S*** is not homing”

Step 1 Converting an input-output automaton ***S*** to an FSM ***M***

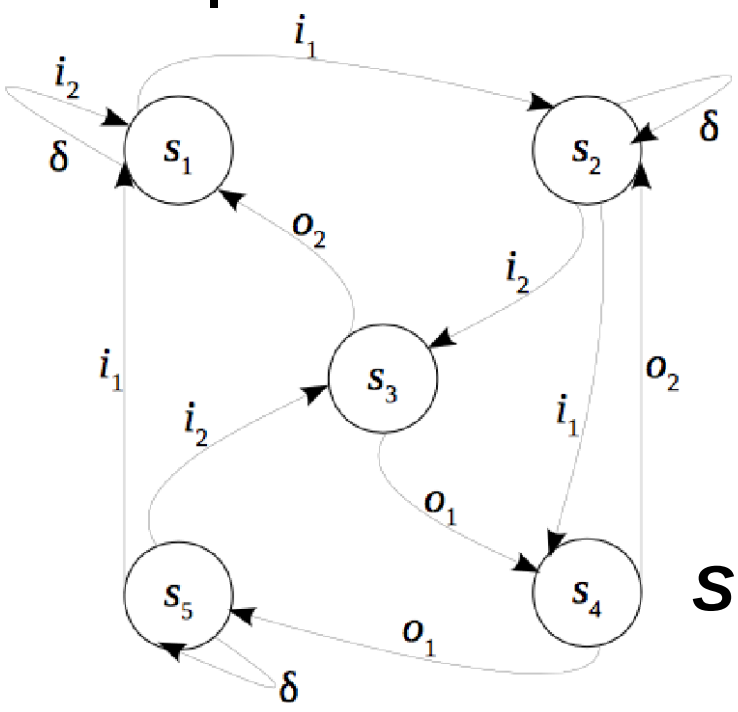
Step 2

Check the existence and derive an HS α for ***M***:

If the sequence α is derived then **Return** α

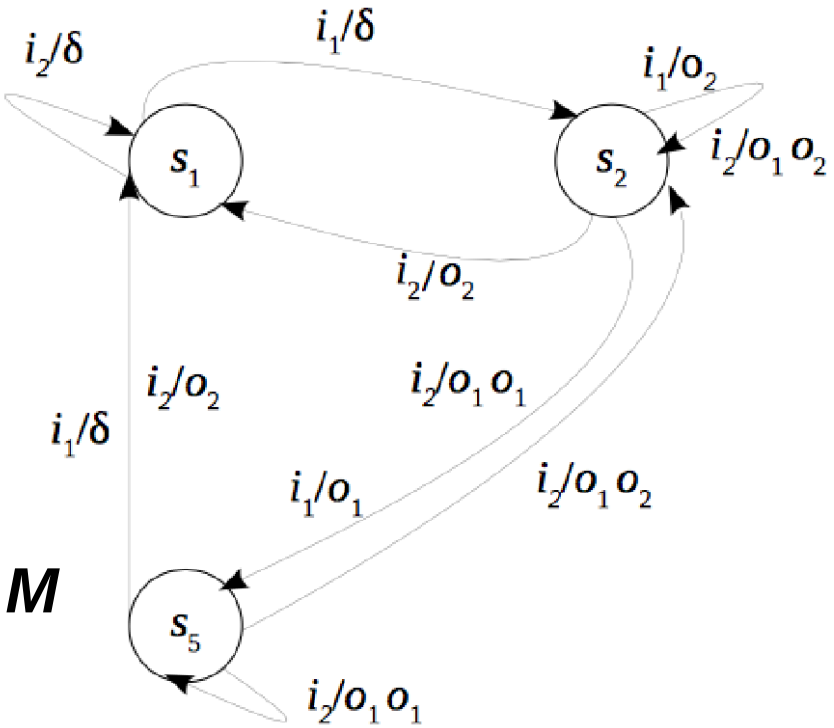
Else Return the message “The automaton ***S*** is not homing”

Back to the example...



S

M



An automaton ***S***
Withoit SS
HS $\alpha = i_1 i_1$

An FSM ***M***
Not synchronizing
HS $\alpha = i_1 i_1$

Conclusions and future work

- New problems are raised!
- Synchronizing and Homing Sequences for Input/Output Automata are introduced!

It is of course interesting…

- To extend the class of the machines, *i.e. delete so many restrictions*
- To define distinguishing sequences/experiments
- To consider adaptive experiments instead of preset
- …

Thank you!