Describing Secure Interfaces with Interface Automata

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FESCA Workshop

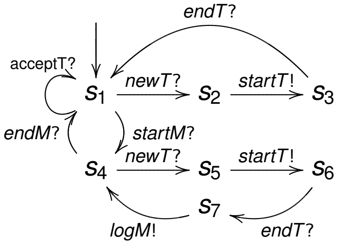
Outline

1. Interfaces Structure for Security
   - Interfaces Automata and Interface Structure For Security
   - Composition
   - Bisimulation-based (Strong) Non-deterministic Non-interference
2. Deriving secure ISS
   - Checking BSNNI
   - Synthesizing Secure ISS
   - The algorithm - Example
3. Preserving BSNNI after Composition
   - Preserving BSNNI after Composition
4. Contribution and future works

Outline

Interface Automata (IA):

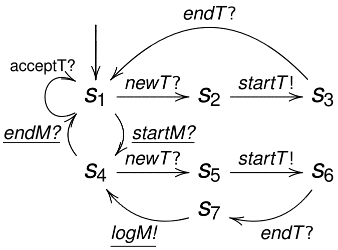
We use Interface Automata [De Alfaro, Hezinger 2001,2005] to represent interfaces. E.g.:



IA has three different sorts of actions: *input, output* and *hidden*. As usual, input are suffixed by ? and output by !. We indicate hidden actions by suffixing ;.

Interface Structure for Security (ISS)

- Extends IA to cope with security.
- Visible actions are separated in two classes:
  - public or low: can be observed/manipulated by any user
  - private or high: only for users with appropiate clearance.



High actions are underlined

Why IA and ISS?

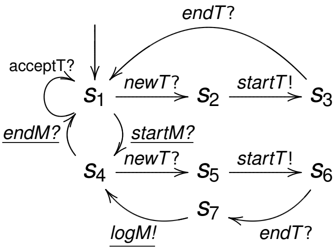
- Component Based Development and Design has become main approach for software development. Example: *web services*.
- We need good interface description that allows us to analyze interaction between components. In this way, we can predict if the composed system can satisfy our requirements.
- IA captures temporal aspects of the component interface. This framework requires that the communication is properly carried out by the interfaces.
- ISS inherits the properties of IA and also allows us to study properties related with secure data flow.

Example:

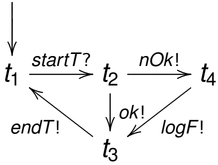
A distributed transaction processing system (DTPS):

- a main server (*Transaction Service*) that provides a service
- a remote transaction process unit (*Trans. Processing Unit*)
- a supervisor module (*Supervisor*).

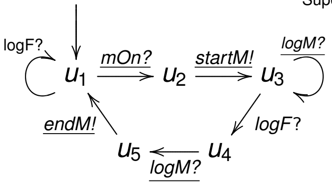
Transaction Service



Trans. Processing Unit



Supervisor



We are interested in studying
how the components work together.

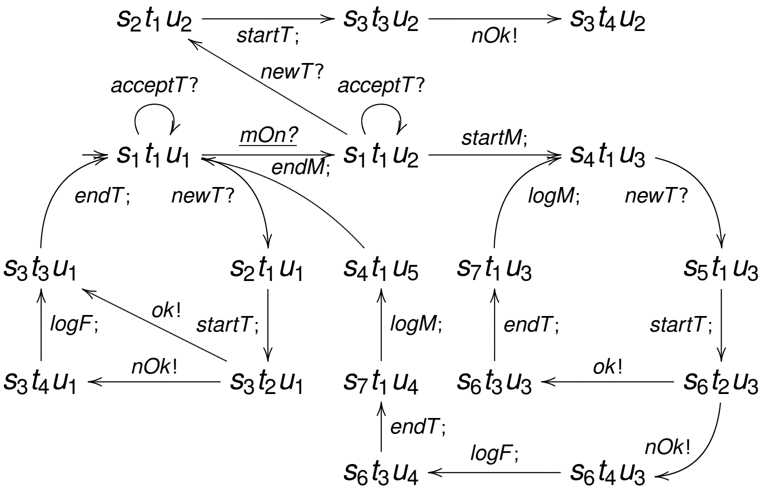
Therefore, we need a concept of composition.

Outline

Composition

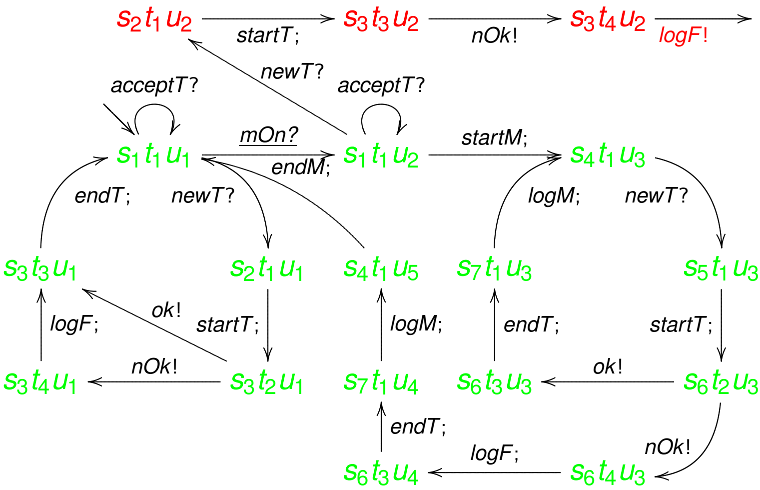
- CSP likes parallel composition in IA:
- the state space is the product of the set of states of the components,
- synchronization through shared action, i.e. both component should perform a transition with the same synchronizing label (one input, and the other output), and
- transitions with non-shared actions are interleaved.

Besides, shared actions are hidden in the product.


$s_2 t_1 u_2$
startT;
$s_3 t_3 u_2$
nOk!
$s_3 t_4 u_2$
newT?
acceptT?
acceptT?
$s_1 t_1 u_1$
mOn?
endM;
$s_1 t_1 u_2$
startM;
$s_4 t_1 u_3$
endT;
newT?
logM;
newT?
$s_3 t_3 u_1$
$s_2 t_1 u_1$
$s_4 t_1 u_5$
$s_7 t_1 u_3$
$s_5 t_1 u_3$
logF;
ok!
startT;
logM;
endT;
startT;
$s_3 t_4 u_1$
nOk!
$s_3 t_2 u_1$
$s_7 t_1 u_4$
$s_6 t_3 u_3$
ok!
$s_6 t_2 u_3$
endT;
logF;
nOk!
$s_6 t_3 u_4$
$s_6 t_4 u_3$

Error, Incompatible and Compatible states

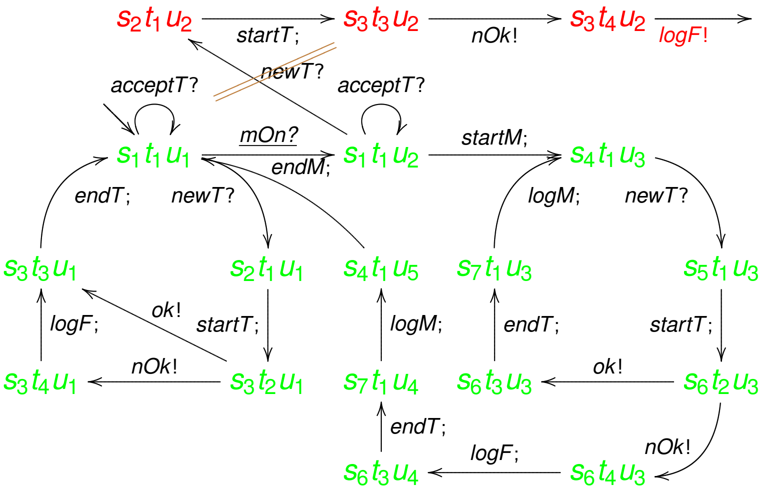
- In state $s_3 t_4 u_2$, the TP unit sends a message (LogF!) to the Supervisor, which is not ready to receive it. We call this *miscommunication*. The state $s_3 t_4 u_2$ is an error state.
- States $s_3 t_3 u_2$ and $s_2 t_1 u_2$ are incompatibles states because they reach an error/incompatible state autonomously (i.e. using only output and/or hidden actions).
- A state that is not incompatible is called compatible.
- For example, $s_1 t_1 u_2$ is compatible.
- If the initial state of the product is compatible, then the interfaces are compatible.

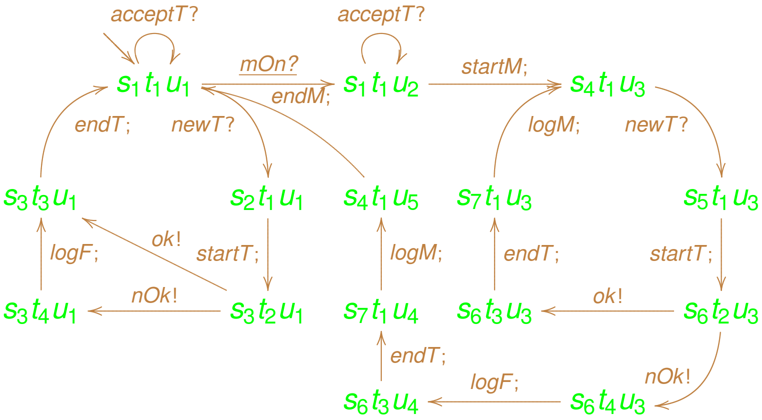

$s_2 t_1 u_2$
$startT;$
$s_3 t_3 u_2$
$nOk!$
$s_3 t_4 u_2$
$logF!$
$newT?$
$acceptT?$
$acceptT?$
$mOn?$
$startM;$
$s_1 t_1 u_1$
$endM;$
$s_1 t_1 u_2$
$s_4 t_1 u_3$
$endT;$
$newT?$
$logM;$
$newT?$
$s_3 t_3 u_1$
$s_2 t_1 u_1$
$s_4 t_1 u_5$
$s_7 t_1 u_3$
$s_5 t_1 u_3$
$logF;$
$ok!$
$startT;$
$logM;$
$endT;$
$startT;$
$nOk!$
$ok!$
$s_3 t_4 u_1$
$s_3 t_2 u_1$
$s_7 t_1 u_4$
$s_6 t_3 u_3$
$s_6 t_2 u_3$
$endT;$
$logF;$
$nOk!$
$s_6 t_3 u_4$
$s_6 t_4 u_3$

2nd Step: Avoid reaching incompatibles states

If a set of interfaces are compatible,
reaching incompatibles states in the composition
can be avoided by not allowing certain inputs.

In this way, we finally obtain the composition of the interface.


$s_2 t_1 u_2$
startT;
$s_3 t_3 u_2$
nOk!
$s_3 t_4 u_2$
logF!
newT?
acceptT?
acceptT?
$s_1 t_1 u_1$
mOn?
endM;
$s_1 t_1 u_2$
startM;
$s_4 t_1 u_3$
endT;
newT?
logM;
newT?
$s_3 t_3 u_1$
$s_2 t_1 u_1$
$s_4 t_1 u_5$
$s_7 t_1 u_3$
$s_5 t_1 u_3$
logF;
ok!
startT;
logM;
endT;
startT;
$s_3 t_4 u_1$
nOk!
$s_3 t_2 u_1$
$s_7 t_1 u_4$
$s_6 t_3 u_3$
ok!
$s_6 t_2 u_3$
endT;
logF;
nOk!
$s_6 t_3 u_4$
$s_6 t_4 u_3$


acceptT?
acceptT?
mOn?
startM;
endM;
$s_1 t_1 u_1$
$s_1 t_1 u_2$
$s_4 t_1 u_3$
endT;
newT?
logM;
newT?
$s_3 t_3 u_1$
$s_2 t_1 u_1$
$s_4 t_1 u_5$
$s_7 t_1 u_3$
$s_5 t_1 u_3$
logF;
ok!
startT;
logM;
endT;
startT;
$s_3 t_4 u_1$
nOk!
$s_3 t_2 u_1$
$s_7 t_1 u_4$
$s_6 t_3 u_3$
ok!
$s_6 t_2 u_3$
endT;
logF;
nOk!
$s_6 t_3 u_4$
$s_6 t_4 u_3$

Outline

Motivation

- In the previous example, low-level users should not be allowed to know whether they are under supervision
- I.e. they should not distinguish the occurrence of high actions.
- Therefore, for a low-level user, the system should behave in the same way regardless whether high actions are performed or not.

$\Rightarrow$ *non-interference*.

In our setting, the concept of non-interference is formalized by *bisimulation-based strong non-deterministic non-interference* (BSNNI) and *bisimulation-based non-deterministic non-interference* (BNNI).

BSNNI and BNNI (Focardi, Gorrieri 2001)

- $\mathcal{S} \approx \mathcal{S}'$ denotes weak bisimulation between $\mathcal{S}$ and $\mathcal{S}'$.
- $\mathcal{S}/X$ represents the hiding of actions X in $\mathcal{S}$
- $\mathcal{S}\backslash X$ represents the restriction of actions X in $\mathcal{S}$

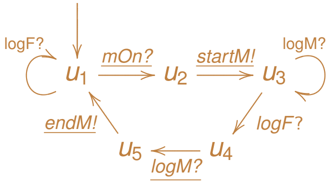
Definition

(i) $\mathcal{S}$ is *bisimulation-based strong non-deterministic non-interference (BSNNI)* if $\mathcal{S}\backslash A^h \approx \mathcal{S}/A^h$.

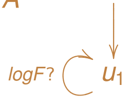
(ii) $\mathcal{S}$ is *bisimulation-based non-deterministic non-interference (BNNI)* if $\mathcal{S}\backslash A^{I,h}/A^{O,h} \approx \mathcal{S}/A^h$.

Example: $\mathcal{S}$ is BSNNI

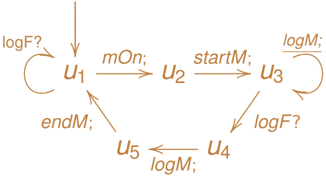
$\mathcal{S}$



$\mathcal{S} \backslash A^h$



$\mathcal{S} / A^h$



$$\mathcal{S} \backslash A^h \approx \mathcal{S} / A^h$$

BSNNI and Composition

Every single ISS component of our example is BSNNI but...

... the composed system is not! :'(

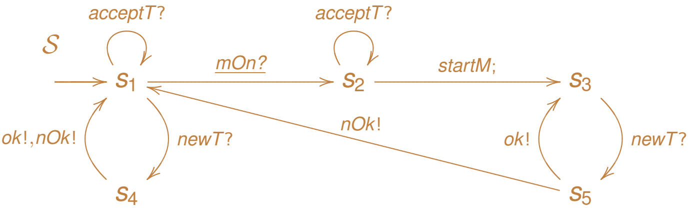
Outline

Algorithm for Checking Bisimulation

A variation of Fernandez and Mounier's algorithm to check bisimulation *on the fly*. Roughly, it works as follows:

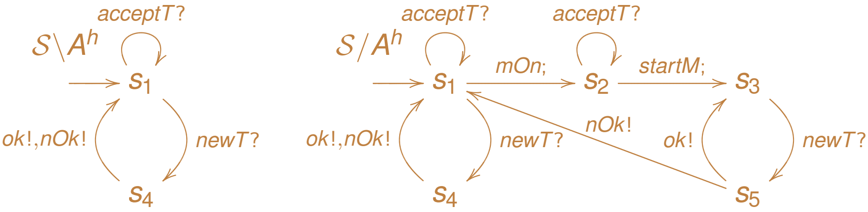
- the IA are saturated adding all weak transitions
- a full synchronous product is constructed where transitions synchronize whenever they have the same label;
- whenever there is a mismatching transition, a new transition is added on the product leading to a special *fail* state;
- if reaching a fail state is inevitable (we later define this properly) the IA are not bisimilar; if there is always a way to avoid reaching a fail state, the IA are bisimilar.

Consider a simplified version of the composed DTPS

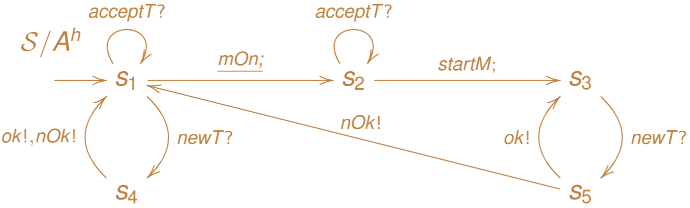


Checking the simplified DTPS

We first construct the restriction and hiding of the system



Saturation marking set B (with $B = \{\underline{mOn?}\}$)



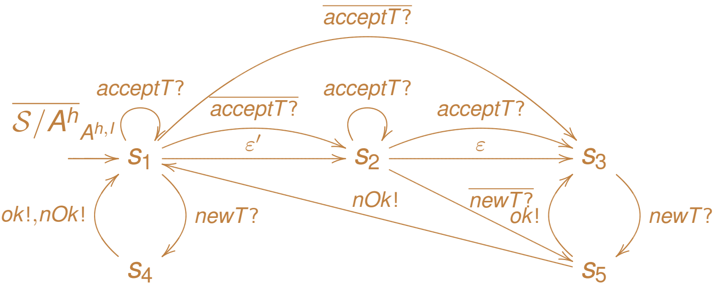
Actions in B will be replaced by ε', to record that these actions are high inputs actions that can be pruned. Other hidden actions are replaced by ε.

Saturation adds to all state a self loop with ε and ε' (not depicted)

Actions added by the saturation are overlined.

Saturation marking set B with $B = \{\underline{mOn?}\}$

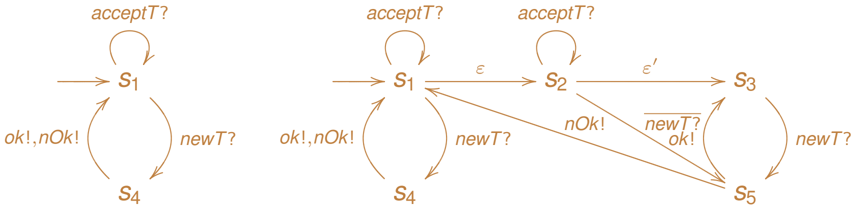
After the saturation we obtain this interface:



Note: In the next slides we will omit some actions added by the saturation process that are redundant.

Synchronous Product: $\overline{\mathcal{S}\backslash A^h}_{\emptyset} \times \overline{\mathcal{S}/A^h}_{A^{h,l}}$

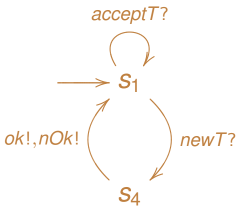
The saturated interfaces (with some transitions omitted):

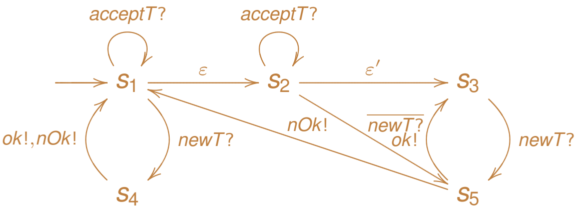


After saturating both interfaces, we can construct the synchronous product:

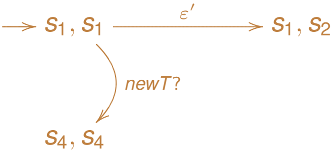
$$s_1, s_1$$

Synchronous Product: $\overline{\mathcal{S}\backslash A^h}_{\emptyset} \times \overline{\mathcal{S}/A^h}_{A^{h,l}}$

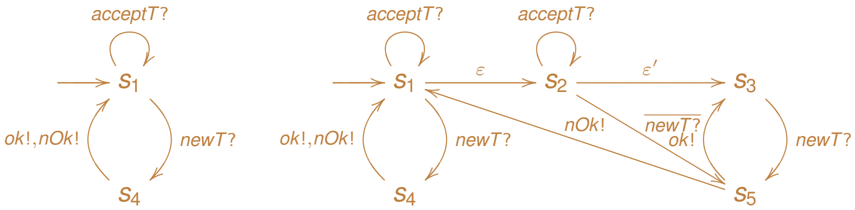




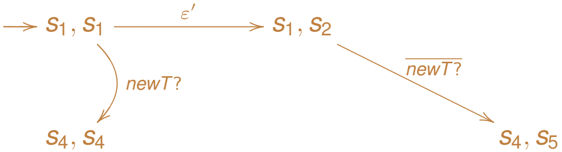
The product synchronizes using common actions:



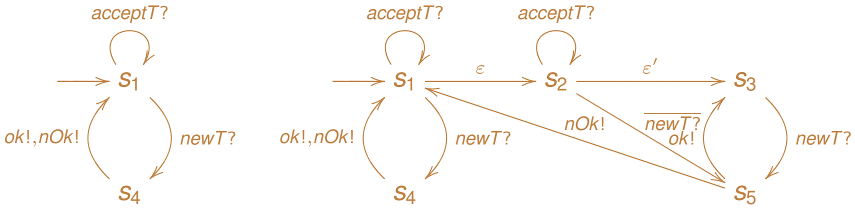
Synchronous Product: $\overline{\mathcal{S} \backslash A^h}_{\emptyset} \times \overline{\mathcal{S} / A^h}_{A^{h,l}}$



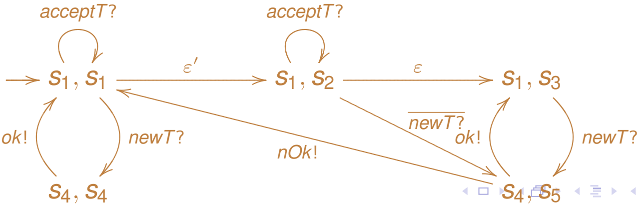
The process continue adding transitions and new states:



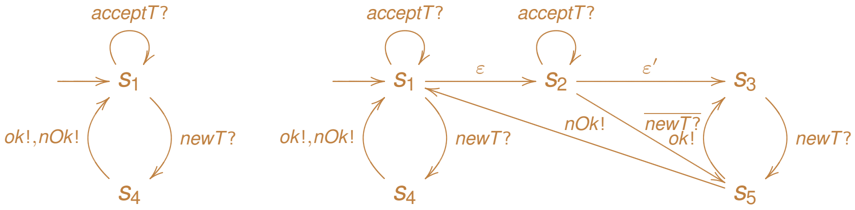
Synchronous Product: $\overline{\mathcal{S}\backslash A^h}_{\emptyset} \times \overline{\mathcal{S}/A^h}_{A^{h,l}}$



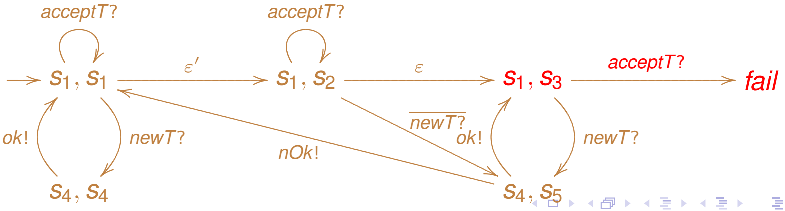
Notice that $s_1 \xrightarrow{accept?} s_1$ but $s_3 \overset{accept?}{\not\longrightarrow}$.



Synchronous Product: $\overline{\mathcal{S} \backslash A^h}_{\emptyset} \times \overline{\mathcal{S} / A^h}_{A^{h,l}}$



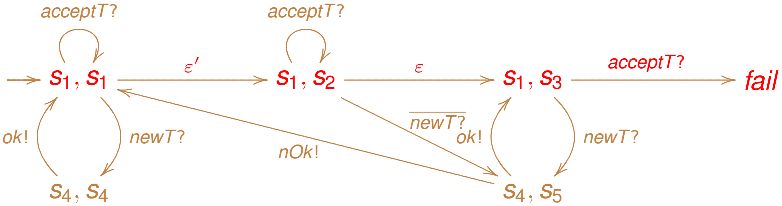
Therefore, we add a transition to a special state *fail*



Synchronous Product: $\overline{\mathcal{S}\backslash A^h}_{\emptyset} \times \overline{\mathcal{S}/A^h}_{A^{h,l}}$

- $s_1 s_3$ contains a pair of state that are not bisimilar.
- In this case, we say the state $s_1 s_3$ *does not pass the bisimulation test*
- We let *NoPass* be the set of pair of states not passing the bisimulation test.
- The definition of *NoPass* is inductive. Under some restrictions, it propagates the condition *"does not pass the bisimulation test"* to predecessor states in the synchronous product.

Synchronous Product: $\overline{\mathcal{S}\backslash A^h}_{\emptyset} \times \overline{\mathcal{S}/A^h}_{A^{h,l}}$



- If the initial state does not pass the bisimulation test, the interfaces are not bisimilar.
- Otherwise, the interfaces are bisimilar, and then, the system is secure.
- In the example, the interfaces are not bisimilar and hence the system is not secure.

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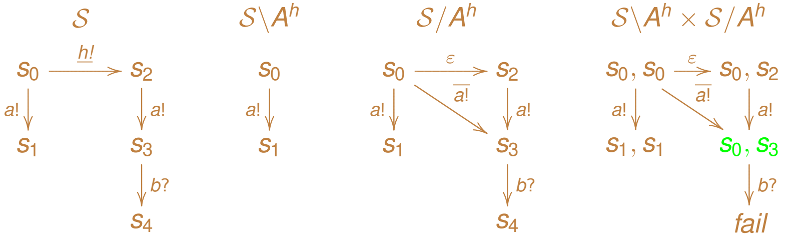
Synthesizing Secure ISS

If the system does not pass a the bisimulation test, we divide all the pairs of states of the synchronous product that does not pass the bisimulation test in 3 disjoint sets:

- May State: contains all pairs that may become bisimilar if some particular low input transition is not executed.
- Fail State: contains all pairs that cannot be turned into bisimilar by avoiding input transitions.
- Undetermined state: Contains all undetermined pairs. This is consequence that they may become bisimilar if a high input transitions is not executed.

May State Example:

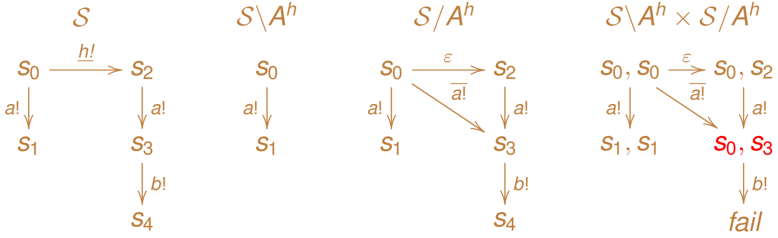


The interface is not secure as a consequence of transition $s_3 \xrightarrow{b?} s_4$.

If this transition is forbidden/pruned (i.e., the interface provides fewer services), the resulting ISS is secure.

This is the same approach used to avoid miscommunication.

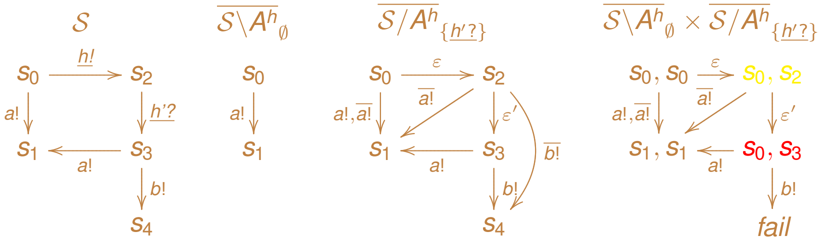
Fail state Example:



A similar example to the previous one, but now transition b is an output action.

Then, the transition cannot be pruned (since it is not controllable), and hence the interface is not *"recoverable"*.

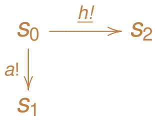
Undetermined states (example 1):



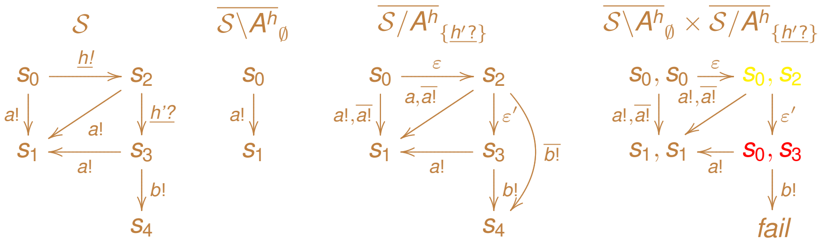
$\mathcal{S}$ is not secure.

The only option to recover is the elimination of transition $s_2 \xrightarrow{h'?} s_3$.

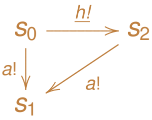
Then, we obtain the next interface, which is not secure:



Undetermined states (example 2):



If transition $s_2 \xrightarrow{h'?} s_3$ is eliminated, the resulting interface is secure.
Notice: this example is the previous one with the new transition: $s_2 \xrightarrow{a!} s_1$.

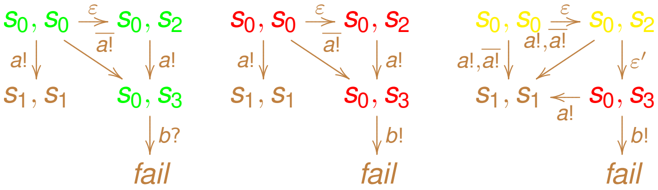


May/Fail/Undetermined ISS

The definitions of May/Fail/Undetermined state are inductive.

Under some restrictions the property propagates to predecessor states in the synchronous product.

If the initial state of the sync. product is a may (fail, undetermined) state, we say that interface may pass (fail, is undetermined w.r.t.) the bisimulation test.



Main result:

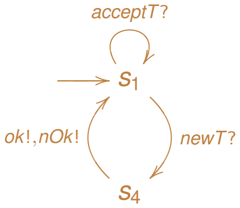
Theorem

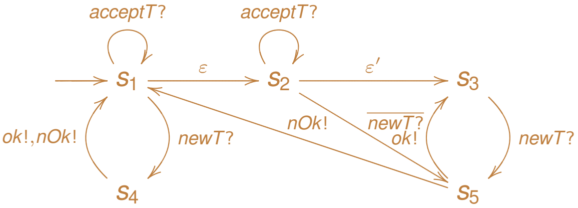
If $\overline{\mathcal{S}\backslash A^h}_{\emptyset} \times \overline{\mathcal{S}/A^h}_{A^{h,l}}$ may pass the bisimulation test, then there is a set $\rightarrow_\chi$ of low input transitions s.t. the ISS obtained from $\mathcal{S}$ by removing all transitions in $\rightarrow_\chi$ is BSNNI.

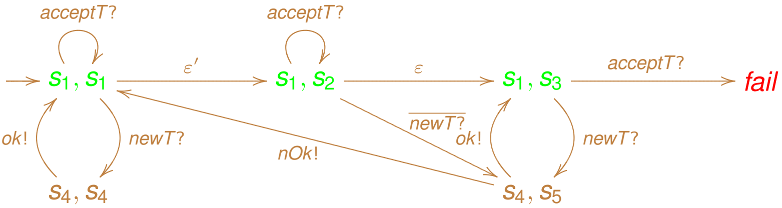
- The set $\rightarrow_\chi$ is obtained by calculating a succession sets $EC(\mathcal{S})$ of *eliminable candidates*
- $EC(\mathcal{S})$ contains all (low input) transitions that go from May states to Fail or Undetermined states.
- The proof is constructive and it defines the algorithm.

Outline

Iteration 1

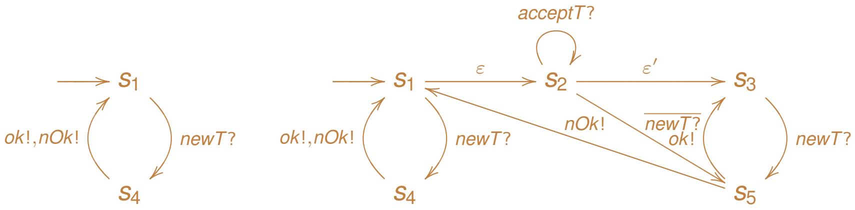


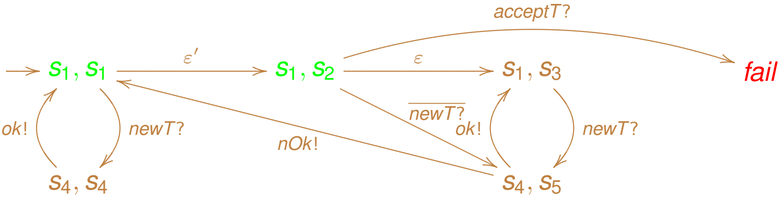




$$EC(\mathcal{S}) = \{ s_1 \xrightarrow{acceptT?} s_1 \}$$

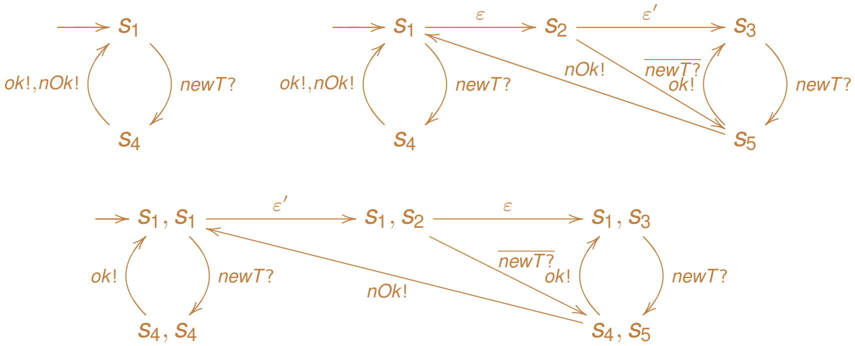
Iteration 2





$$EC(\mathcal{S}) = \{s_2 \xrightarrow{acceptT?} s_2\}$$

Iteration 3



We obtain a secure interface!

and $\rightarrow_\chi = \{s_1 \xrightarrow{acceptT?} s_1, s_2 \xrightarrow{acceptT?} s_2\}$

Outline

1. Interfaces Structure for Security
   - Interfaces Automata and Interface Structure For Security
   - Composition
   - Bisimulation-based (Strong) Non-deterministic Non-interference
2. Deriving secure ISS
   - Checking BSNNI
   - Synthesizing Secure ISS
   - The algorithm - Example
3. Preserving BSNNI after Composition
   - Preserving BSNNI after Composition
4. Contribution and future works

The following lemma give sufficient conditions to ensure that composition leads to secure systems.

Lemma

Let $\mathcal{S} = \langle S, A^h_S, A^l_S \rangle$ and $\mathcal{T} = \langle T, A^h_T, A^l_T \rangle$ be two composable ISS. Define

- $\mathcal{S}' = \langle S, A^h_S - shared(S,T), A^l_S \cup shared(S,T) \rangle$
- $\mathcal{T}' = \langle T, A^h_T - shared(S,T), A^l_T \cup shared(S,T) \rangle$

If $\mathcal{S}'$ and $\mathcal{T}'$ are BSNNI/BNNI and $\mathcal{S} \otimes \mathcal{T}$ has not error states, then $\mathcal{S} \parallel \mathcal{T}$ is BSNNI/BNNI.

Contributions

- We extended Interface Automata to cope with security and adapted the definition of no interference to this context.
- We design an algorithm to synthesis a secure interface from a non-secure one whenever possible.
- The algorithm proceeds by controlling the permitted low input transitions.
- We give sufficient conditions to ensure that the composition of ISS results in a non-interferent ISS.

Future Work

- Relax the necessary conditions to preserve no interference under composition.
- Adapt the concept of refinement of IA to ISS and studying its relation to BSNNI and BNNI.
- Define new concepts of “security” to ISS and adapt the results of this work to the new definitions.