Safe Composition of CFSM Systems via Partial Gateways

Franco Barbanera

University of Catania

ICE'26 - June 12, 2026, Urbino

OVERVIEW

- Introduction: the need for system composability
- The "participants-as-interfaces" (PaI) approach to **binary** system composition [Barbanera-Hennicker-de'Liguoro]
- From binary PaI to: - multicomposition [Barbanera-Hennicker];
  - orchestrated multicomposition [Barbanera-Hennicker];
  - composition via partial gateways **ICE'26**;
- Exploiting the PaI approach in the asynchronous framework of **C**ommunicating **F**inite **S**tate **M**achines: Safety of the approach.
- The essential of PaI: (binary) partial-fusion composition **ICE'26**.

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The need of systems composability

- Concurrent/Distributed systems are

  not STAND-ALONE ENTITIES

- (expecially nowadays) they are parts of

  JIGSAWS NEVER COMPLETELY TERMINATED

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Good composition methods

They should be

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They should be

- CONSERVATIVE

Altering as less as possible the single systems

Good composition methods

They should be

- CONSERVATIVE
- FLEXIBLE

i.e. "system independent": the composition mechanism
- should not be part of the systems
- allows to consider **any** system as potentially **open**

Good composition methods

They should be

- CONSERVATIVE
- FLEXIBLE
- SAFE

  Guaranteeing not to “break” relevant properties of the single systems we compose.

Good composition methods are **safe** when...

If one starts from systems like this....

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Good composition methods are **safe**

...one does not end up with something like that

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...one does not end up with something like that

The "participants-as-interfaces" (PaI) approach

For systems with message-passing interactions

Introduced (as far as we know) in

Franco Barbanera, Ugo de'Liguoro, Rolf Hennicker,
Connecting open systems of communicating finite state machines.
J. Log. Algebraic Methods in Program. (2019)

The "participants-as-interfaces" (PaI) approach

applicable when

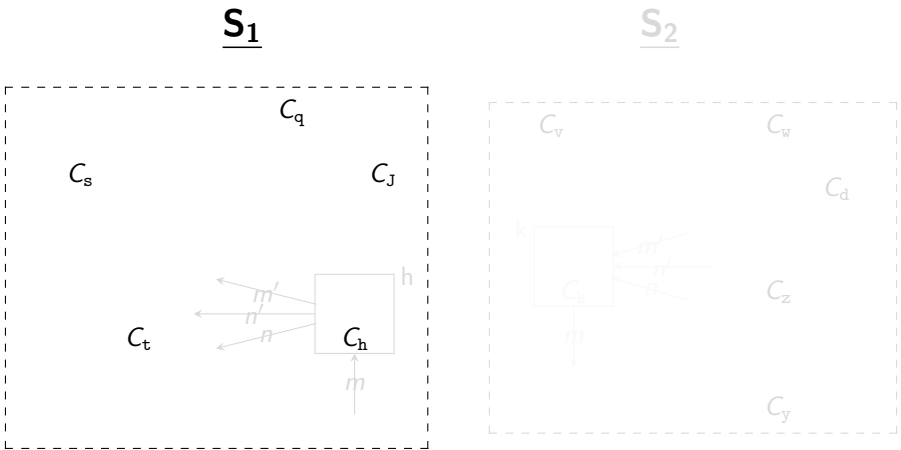
participant behaviour

system interface

where

interface = description of the possible interactions with the environment (tipically outer systems)

The "participants-as-interfaces" (PaI) approach



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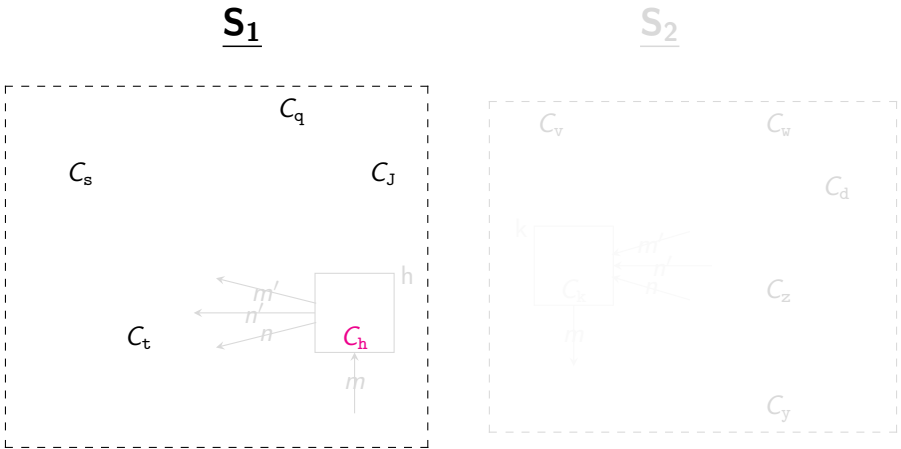

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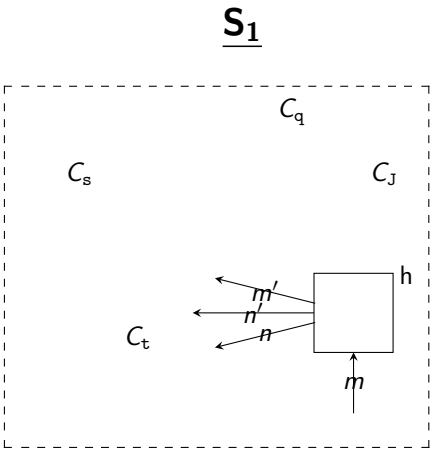

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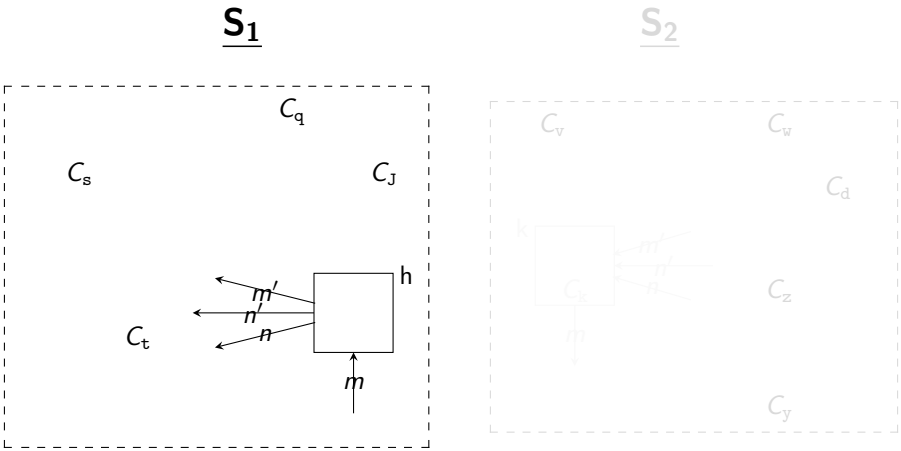

We abstract here from the way communications are performed and from the logical order of the exchanged messages.

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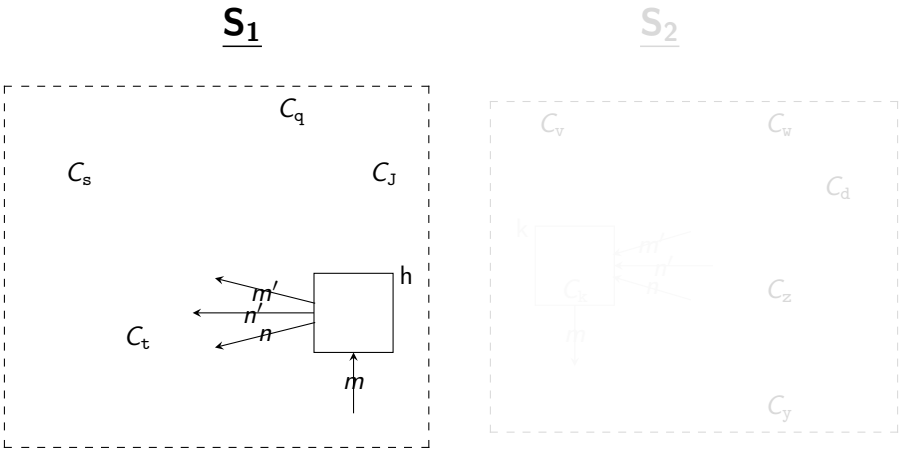

C_h's behaviour can be looked at as an interface (i.e. a description of what can be offered by an outer system)

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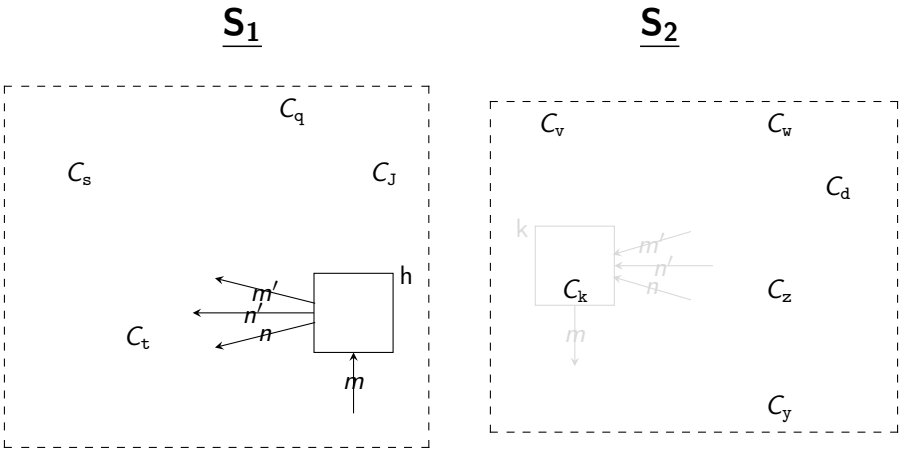

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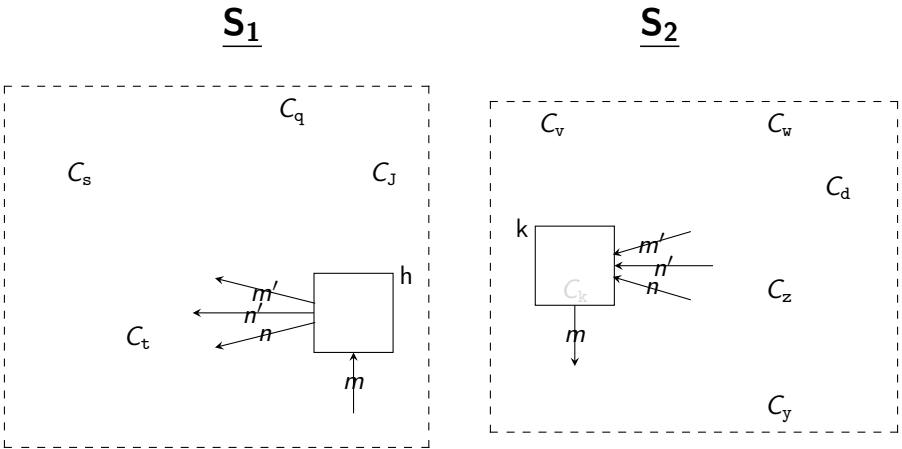

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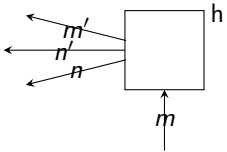
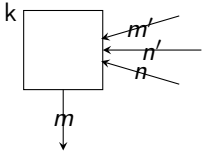
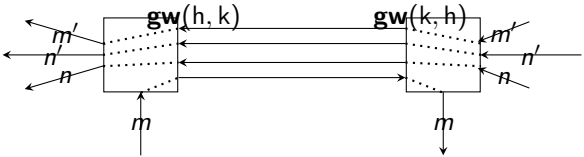




The "participants-as-interfaces" (PaI) approach

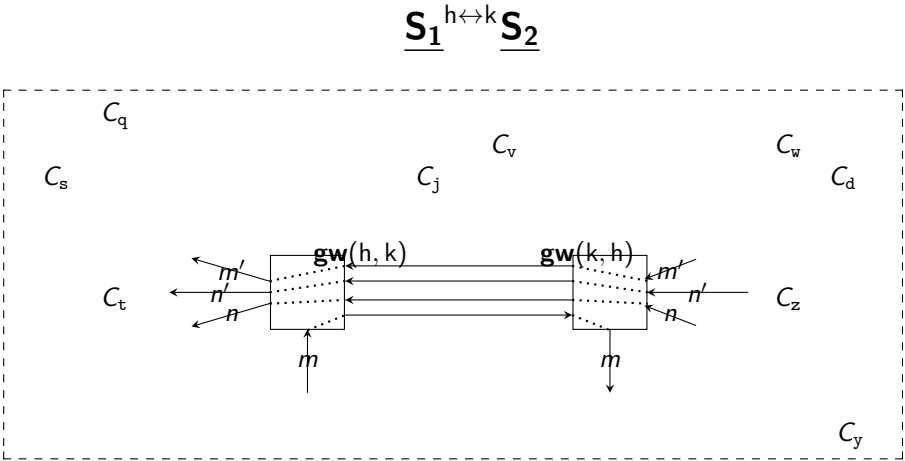
COMPATIBLE: an h's input is a k's output, and vice versa

The "participants-as-interfaces" (PaI) approach



Composition via gateways (forwarders)

The "participants-as-interfaces" (PaI) approach



The "participants-as-interfaces" (PaI) approach

Drawback of binary composition:

By connecting systems two-by-two we get only tree-topologies.

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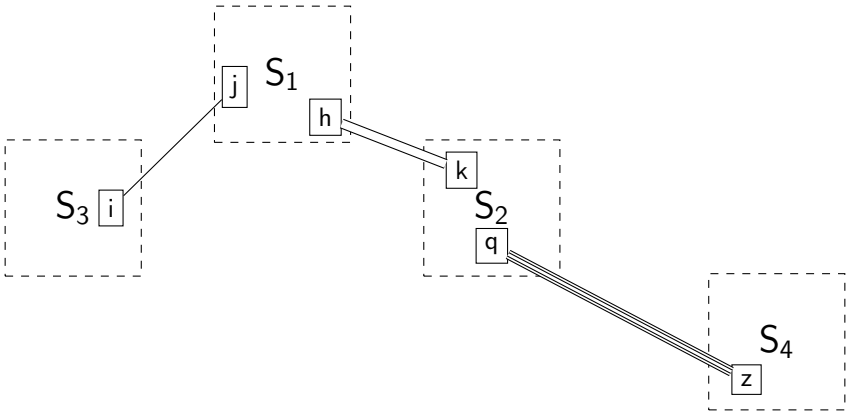

PaI Multicomposition

The composition via gateways trivially extends to simultaneous multiple system composition.

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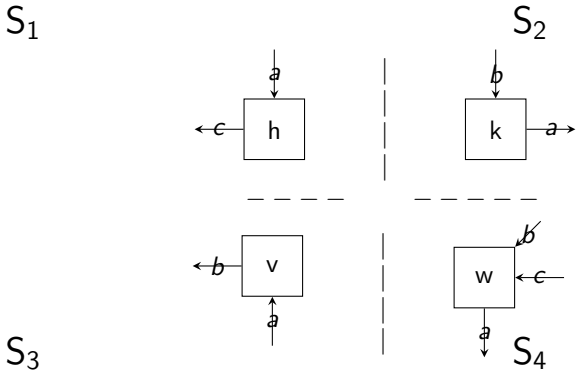

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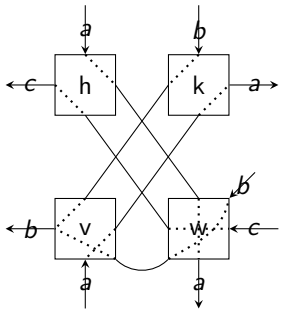

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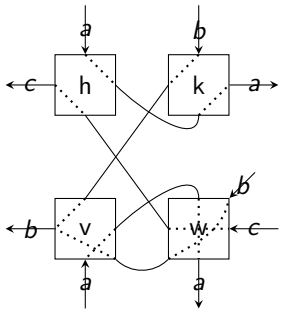

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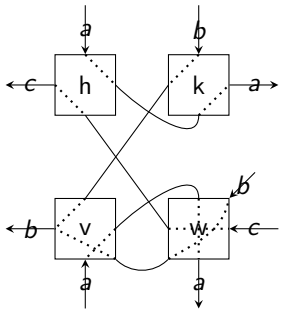
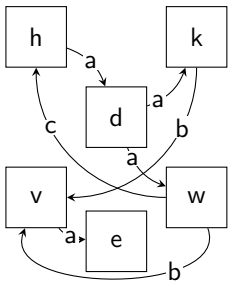


Issues: • Many different "connection policies" (all safe?).

Connection policies as systems

Gateways are built out of the interface participants and a choosen connection policy

Orchestrated connection policies



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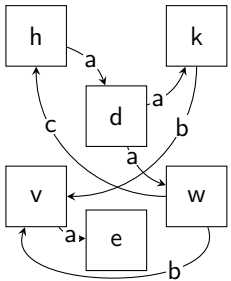
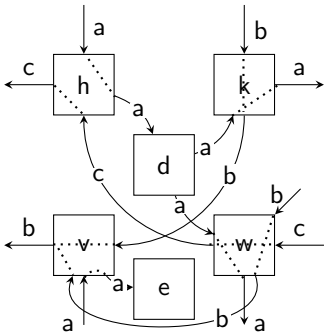
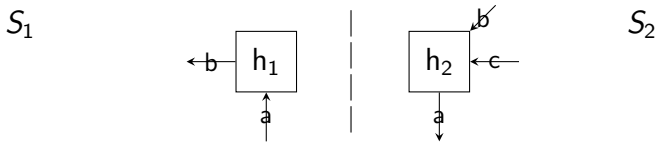




PaI is quite general - not relying on any "duality" on interfaces



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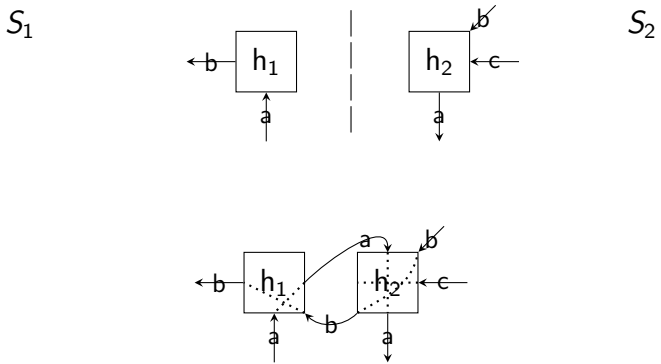

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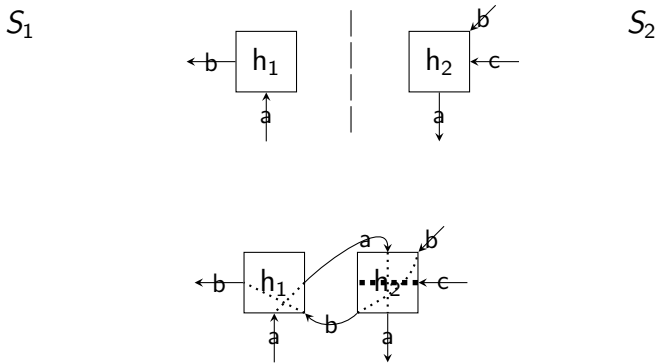

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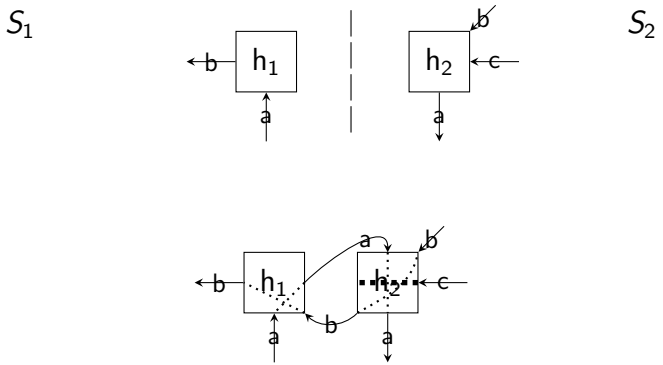

Some properties could be preserved by composition.

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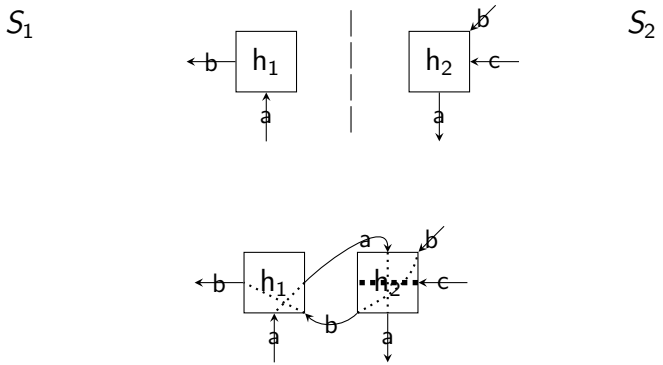

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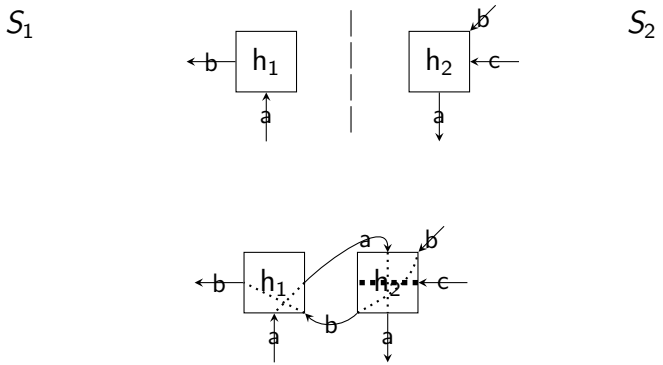

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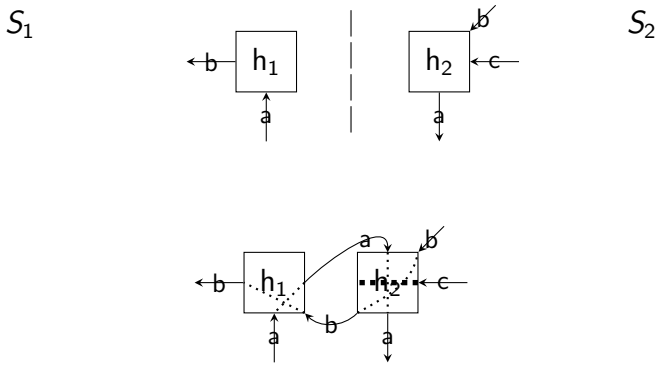

But the interface participants look nonetheless **badly chosen**. Really?

Perhaps the message c simply does not need to be forwarded.

SISTEMA DOMOTICO

Comfort, efficienza, benessere: tutto sotto controllo.

Illuminazione | Clima | Tapparelle | Sicurezza | Multimedia

DEVICE 2in1

Un unico dispositivo, due funzioni per il massimo comfort e benessere.

FUNZIONE 1

CONDIZIONATORE

Regola la temperatura e raffresca l'ambiente in modo intelligente ed efficiente.

FUNZIONE 2

UMIDIFICATORE

Mantiene il livello di umidità ideale per il benessere respiratorio e il comfort in ogni stagione.

SISTEMA DI UMIDIFICAZIONE DISTRIBUITO IN TUTTA LA CASA

Umidità ideale in ogni ambiente, in ogni stagione.

BENESSERE TOTALE
Mantiene il giusto livello di umidità per il comfort e la salute di tutta la famiglia.

PROTEZIONE DELLA CASA
Previene secchezza di legno, crepe nei muri e accumulo di elettricità statica.

EFFICIENZA E SILENZIOSITÀ
Tecnologia avanzata, consumi ridotti e funzionamento silenzioso.

COME FUNZIONA

1. Unità di produzione genera vapore umidificato.
2. Il vapore viene immesso nella rete di distribuzione.
3. Ugelli di erogazione in ogni ambiente rilasciano il giusto livello di umidità.
4. Sensori monitorano l'umidità e regolano automaticamente il sistema.

SOTTOTETTO
Umidità controllata anche negli ambienti più isolati.

SECONDO PIANO
Comfort costante in camere e bagni.

PRIMO PIANO
Ogni stanza riceve la giusta umidità.

PIANO TERRA
Benessere in tutta la zona giorno.

PIANO INTERRATO
Unità di produzione vapore e controllo centrale del sistema.

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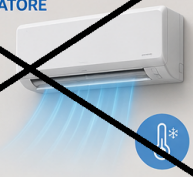

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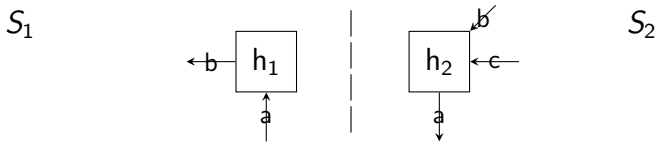

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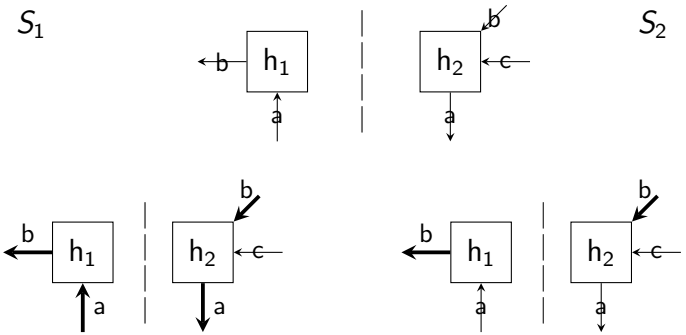
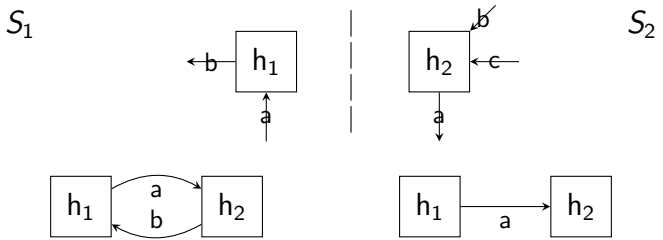


Pal Composition via **partial** gateways - **ICE'26**



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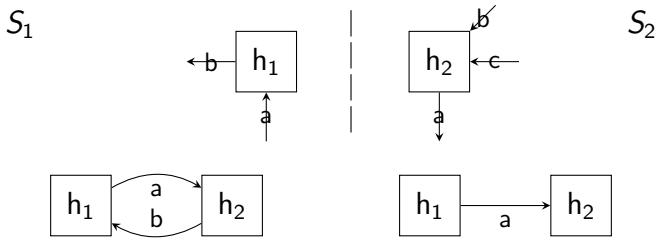
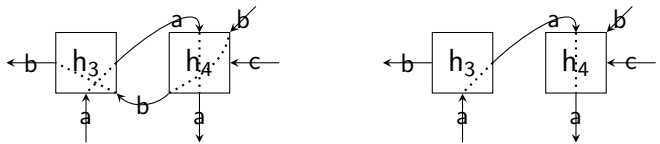


The above connection policies lead to the following **partial gateways**



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It depends!

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- On the concurrent-system description formalism

- SAFE

It depends!

- On the concurrent-system description formalism
- On the communication model

Safety in Synchronous formalisms

Rather severe restrictions in both

- **M**ulti**P**arty **S**ession **T**ypes
  - F. Barbanera, M. Dezani-Ciancaglini, I. Lanese, E. Tuosto: Composition and decomposition of multiparty sessions. JLAMP (2021)
  - F. Barbanera, M. Dezani-Ciancaglini, L. Gheri, N. Yoshida: Multicompatibility for Multiparty-Session Composition. PPDP 2023
- **synchronous** version of **CFSM**
  - F. Barbanera, Ivan Lanese, Emilio Tuosto: Composition of synchronous communicating systems. JLAMP (2023)

Exploiting the PaI approach

in

(**asynchronous**)
Communicating **F**inite **S**tate **M**achines

Communicating Finite State Machines (CFSMs)

A formalism for the description and the analysis of distributed systems.

A machine M_A

- M_A can send msg1 to machine M_B;
  asynchronously; *through the directed buffered FIFO channel* AB
- Then, either msg2 or msg3 can be received from M_B or M_C;
  through channels BA or CA;
- and so on....

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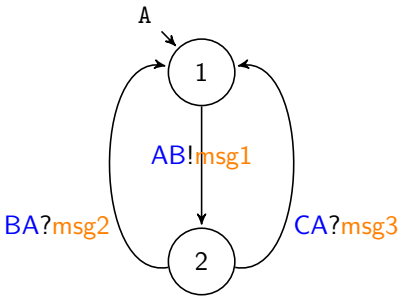

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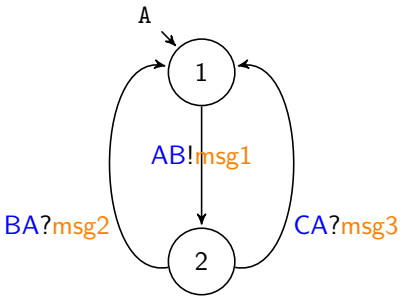
Communicating Finite State Machines (CFSMs)

A formalism for the description and the analysis of distributed systems.

A machine M_A



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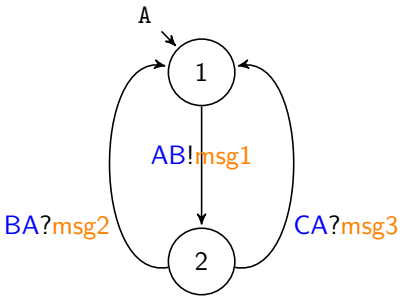

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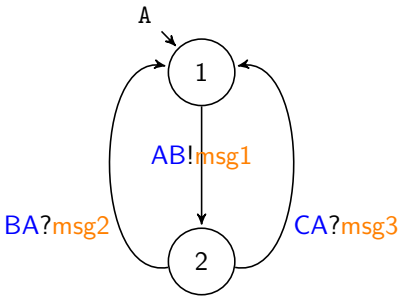

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Let
- $\{S_i\}_{i \in I}$ be a set of CFSM systems
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Safeness for PaI Orchestrated Multicomposition [Barbanera-Hennicker]

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Safeness for PaI composition via partial gateways - **ICE'26**

Let • $\{S_i\}_{i \in I}$ be a set of CFSM systems
- $\mathbb{K}$ an orchestrated comm. policy for choosen interfaces and choosen interface transitions.
- $\mathcal{P}$ be a communication property

IF all S_i's and $\mathbb{K}$ enjoy $\mathcal{P}$ (and *no-mixed-state* holds, **even indirect**)

THEN **PartGWcomp**$(\{S_i\}_{i \in I}, \mathbb{K})$ enjoys $\mathcal{P}$.

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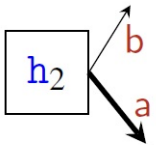
A requirement needed on interfaces for PaI composition with partial gateways



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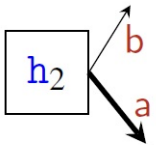

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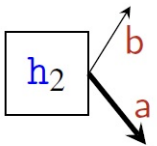

The resulting partial gateways either send b or expect a to forward it.

A mixed choice: harmful in CFSM. Property-preservation is disrupted.

All proofs by contradiction

Based on
the notion of **projection**: configurations of original systems and of connection policy obtainable from a configuration of the composed system;

and on the fact that projection preserves (roughly) reachability

All preserved properties are safety properties.
So - roughly - problematic reachable configurations of original systems and of connection policy obtaineble from a problematic reachable configuration of the composed system

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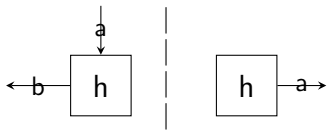
The basis of all:
Partial Fusion Composition - **ICE'26**

S_1



S_2

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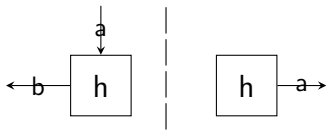

S_2

If some transitions of h in S_1 perfectly complement the transitions of h in S_2...

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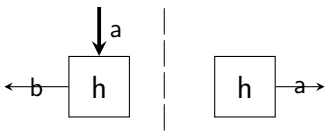

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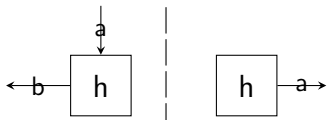

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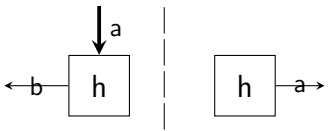
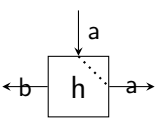


... then FUSE the two h's

$S_1 \overset{\text{h}}{\texttt{fuse}} S_2$



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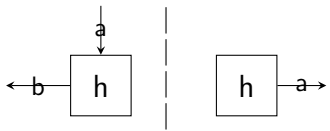

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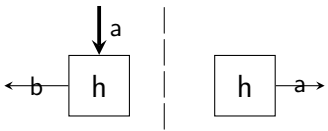

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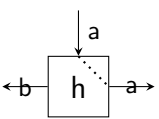

Partial Fusion is **SAFE**

An example of PaI composition via partial gateways

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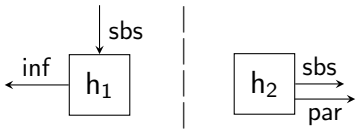

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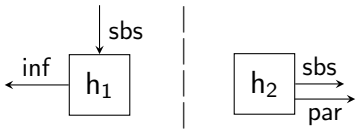
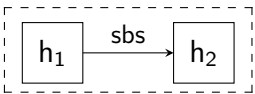


S_2

$\mathbb{K}$



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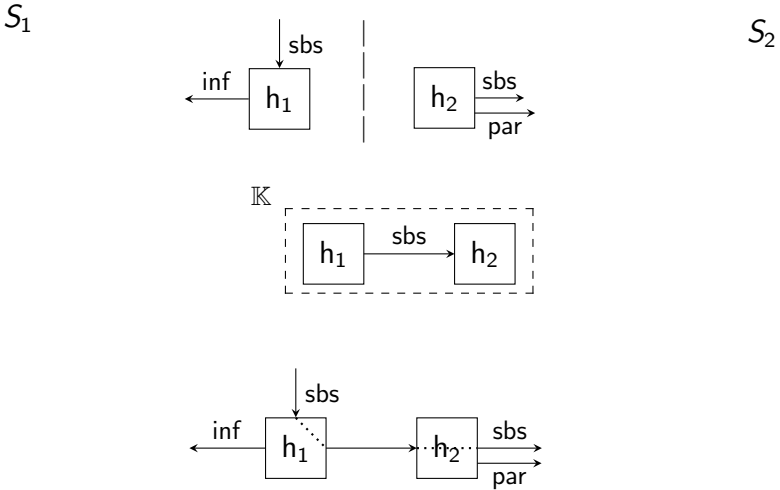

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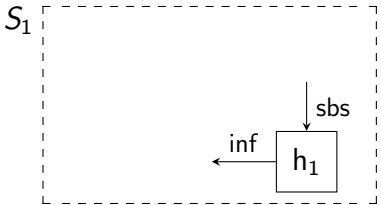

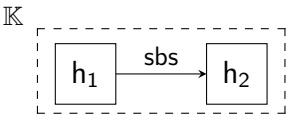

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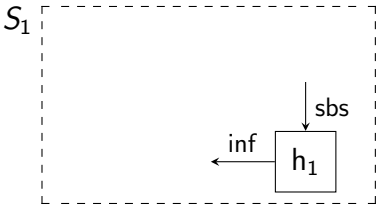

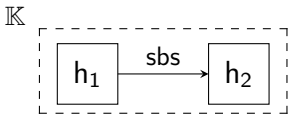

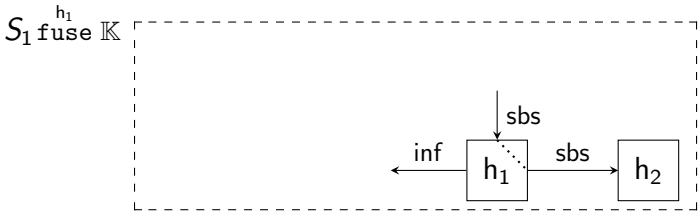

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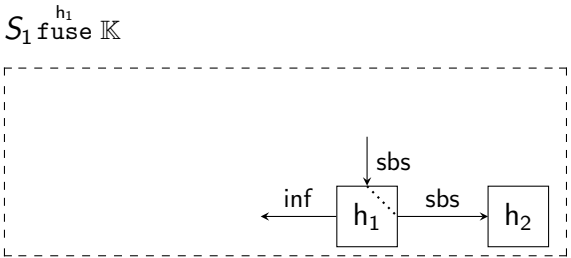

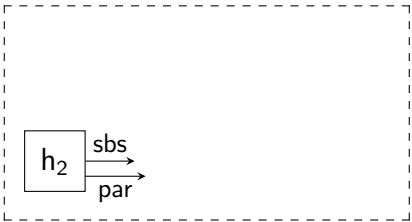

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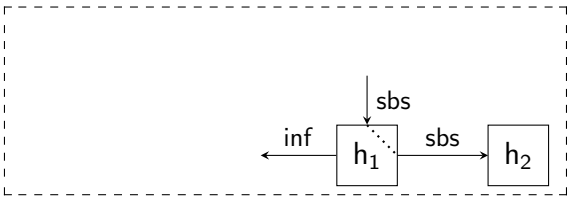
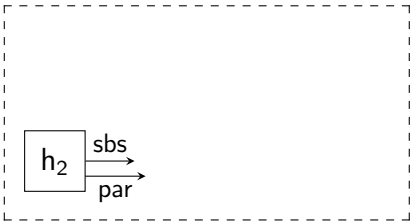
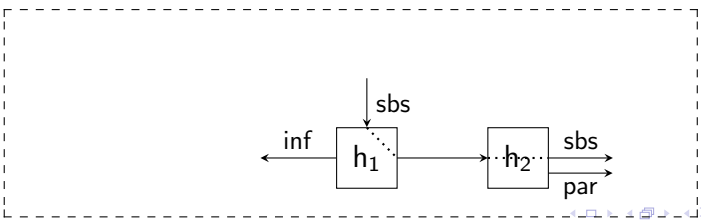


S_2



$(S_1 \overset{h_1}{\texttt{fuse}}) \overset{h_2}{\texttt{fuse}} S_2$



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he/she can always be helpful and inspiring

In the future

- formally show that all the partial PaI multicompositions are obtainable from fusion composition:
- some (liveness?) conditions to get Lock-freedom preservation for partial fusion composition (and hence lock-freedom for all the partial versions of multicomposition.
- investigating PaI in frameworks other than CFSM.

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