On Composing Communicating Systems

Franco Barbanera[1], Ivan Lanese[2], Emilio Tuosto[3]

[1] University of Catania
[2] University of Bologna/INRIA
[3] GSSI (Gran Sasso Science Institute)

ICE - June 17, 2022

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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Composability is useful both

- at design phase (modular design);
- at deployment phase and beyond
  - modular deployment;
  - new functionalities needed;
  - system scalability
  - etc.

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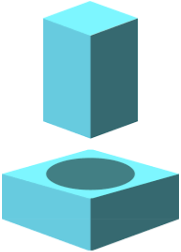
Good composition methods

They should be

- FLEXIBLE



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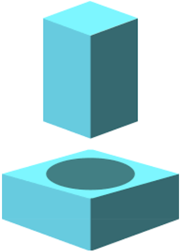

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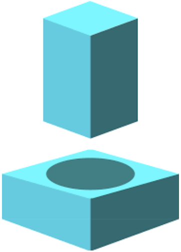

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Good composition methods are **safe**

If one starts from something like this....

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...should not end up with something like that

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Good composition methods are **safe**

Safe composition methods guarantee not to “break” any relevant property of the single systems we compose.

Good composition methods are **flexible**

A **flexible** composition method

- alters as less as possible the single systems
- is “system independent”, that is
  - the composition mechanism is not part of the system
  - it allows to consider any system as potentially open

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The “participants-as-interfaces” (PaI) approach

For systems with message-passing interactions

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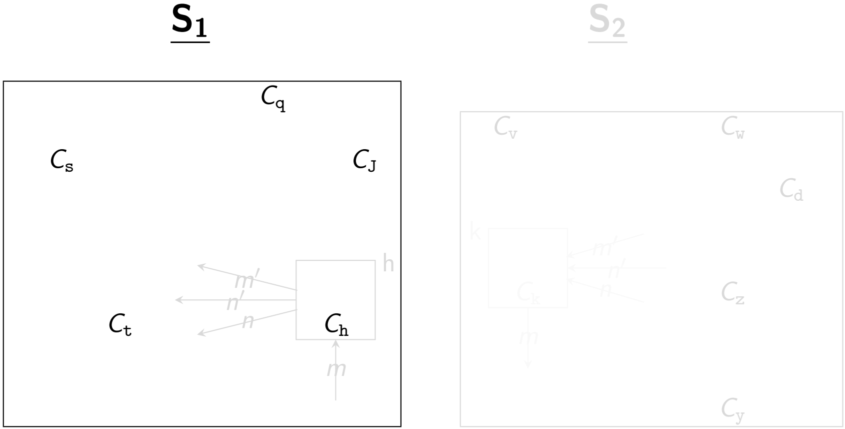

C_h’s behaviour can be looked at as what can be offered by an outer system

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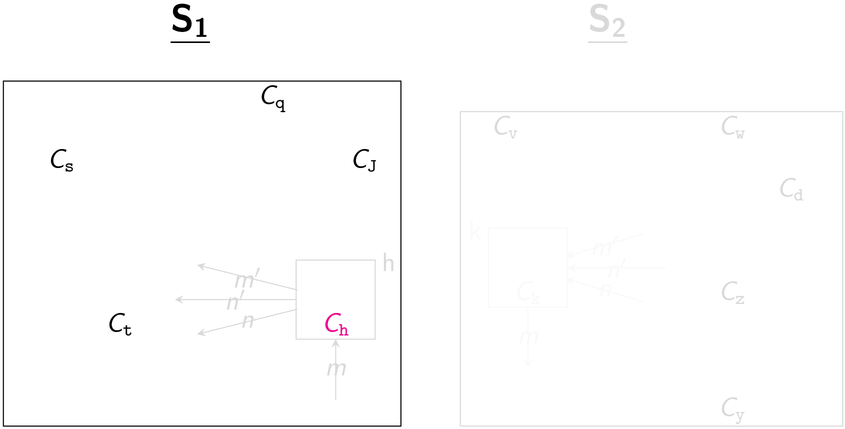

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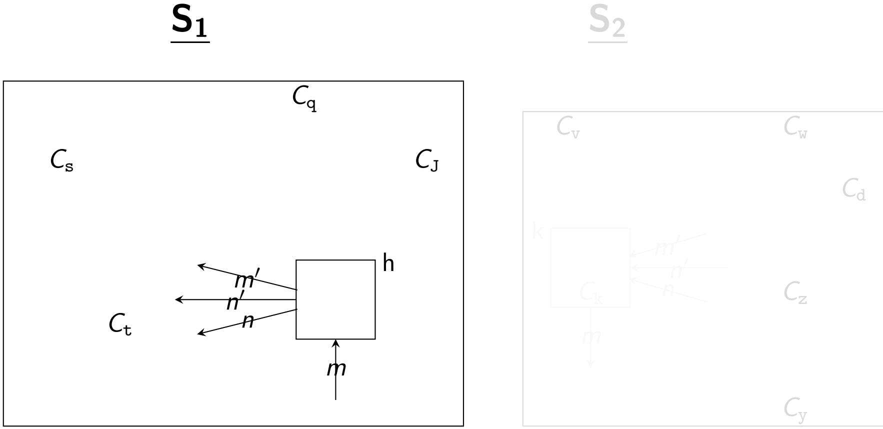

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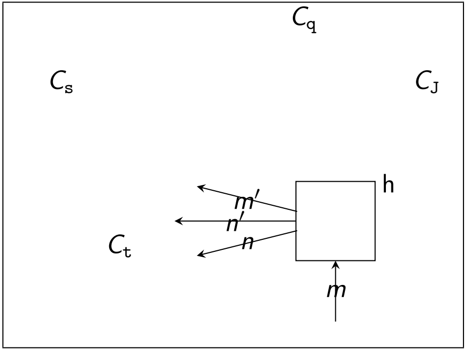
S₁



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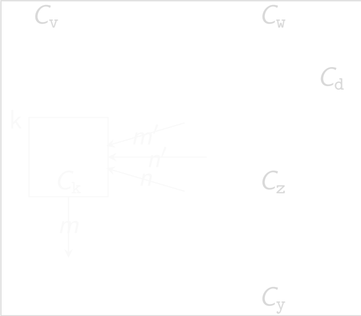

We abstract here from the way communications are performed and from the logical order of the exchanged messages. C_h's behaviour can be looked at as what can be offered by an outer system.

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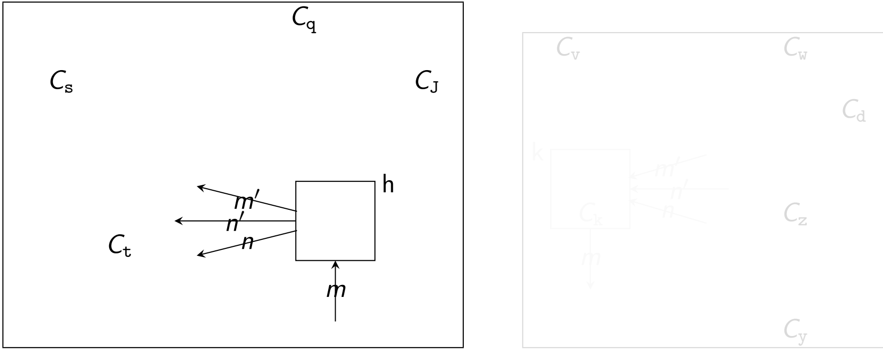
S$_1$ S$_2$



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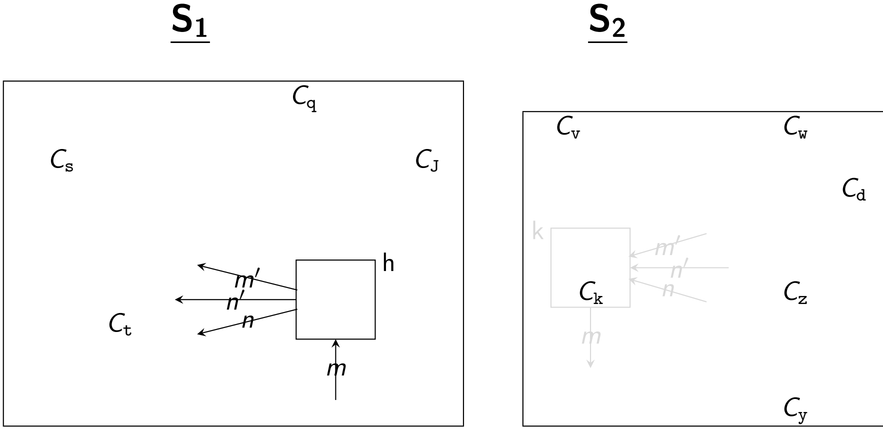

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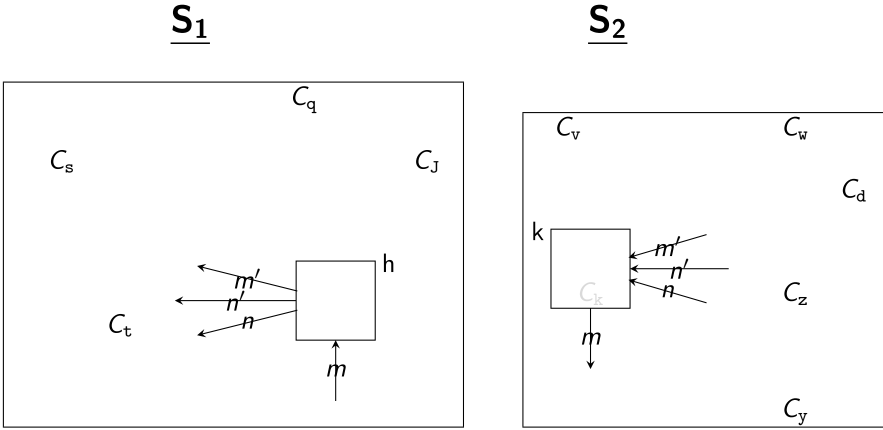

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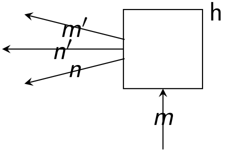

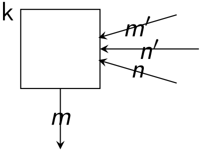

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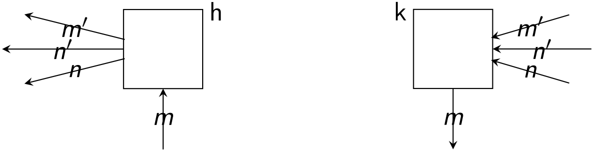

COMPATIBLE: an h's input is a k's output, and vice versa

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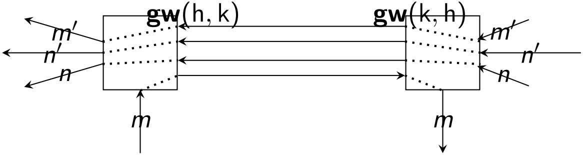

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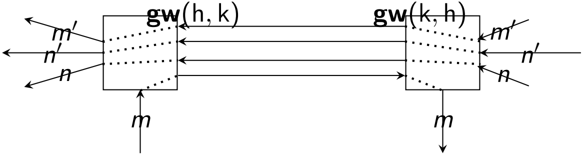
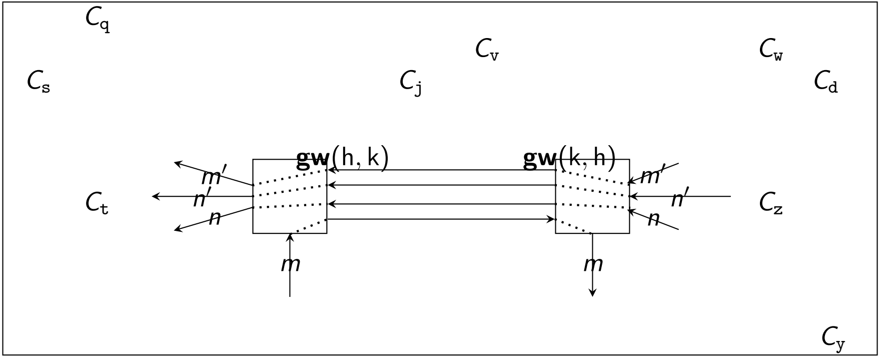


Composition via gateways (forwarders)

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

$$\underline{\mathbf{S_1}}\ {}^{\mathrm{J}\leftrightarrow\mathrm{K}}\ \underline{\mathbf{S_2}}$$



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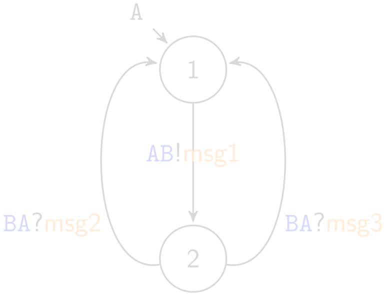
Investigating the PaI approach: **which formalism for participants' behaviours?**



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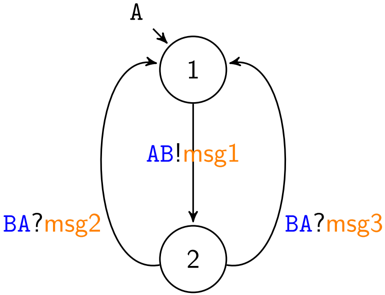
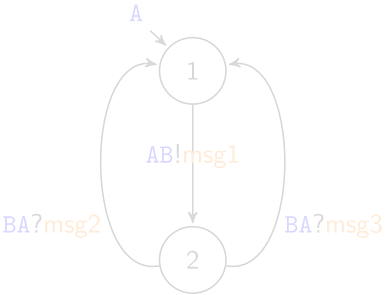


Communicating Finite State Machines (CFSMs)

An **automata-based** formalism for the description and the analysis of distributed systems. [BRAND AND ZAFIROPULO, 1983]

A machine $M_{\mathtt{A}}$



- $M_{\mathtt{A}}$ can send msg1 to machine $M_{\mathtt{B}}$;
- Then, either msg2 or msg3 can be received from $M_{\mathtt{B}}$;
- and so on....

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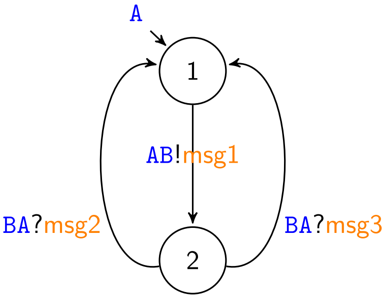

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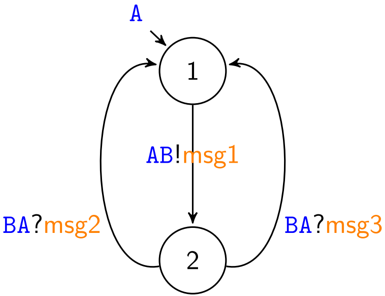

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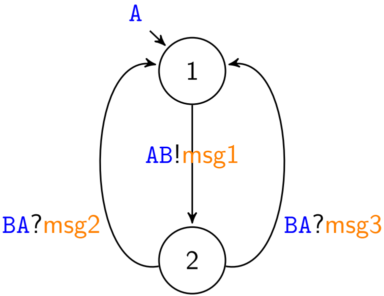

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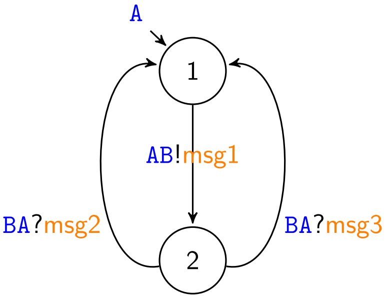

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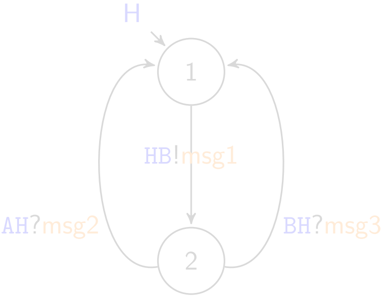
The PaI approach for systems of CFSMs

An “interface” participant like



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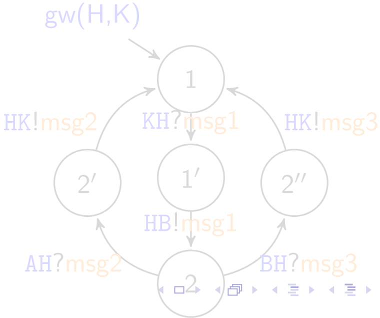

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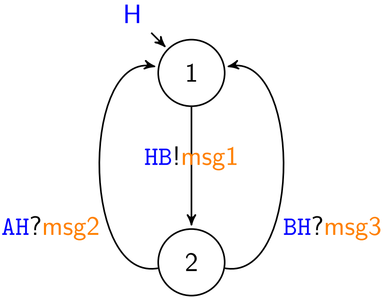

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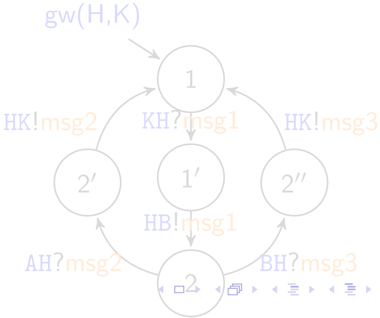

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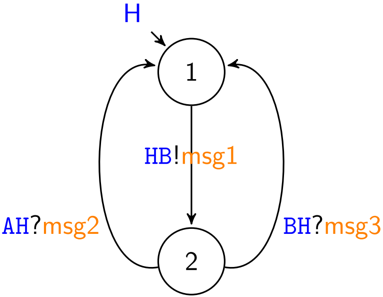

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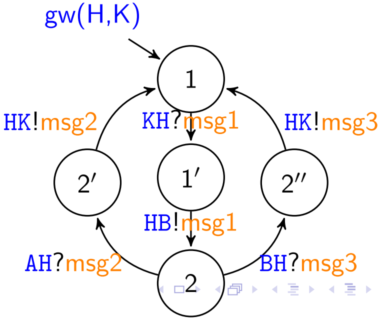

In the investigation of PaI for systems of CFSMs

Which underlying interaction model?

- **asynchronous**; *through the directed buffered FIFO channels (also other possibilities)*
- **synchronous**; *also for this, there is not just one formalization*

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PaI Composition of Systems of **asynchronous** CFSMs

Barbanera, de'Liguoro, Hennicker

> Connecting open systems of communicating finite state machines (JLAMP)

Several communication properties preserved by composition:

- deadlock freedom
- orphan message freedom
- unspecified reception
- progress

Required conditions on interfaces, besides **compatibility** (essentially bisimulation)

- **!(?)-determinism**: the message does uniquely determine the receiver(sender)
- **no-mixed-state**: from each state, either input or output actions, not both.

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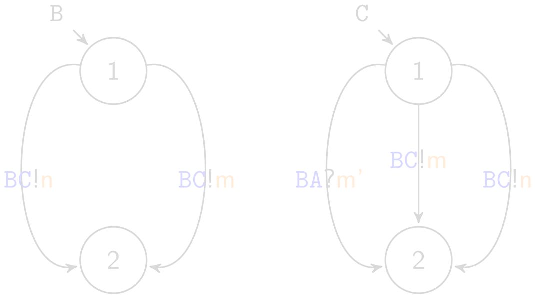
And for systems of **symmetric synchronous** CFSMs?

What is a synchronous communication (in the CFSM model)?
The **symmetric** approach:

> *sender and receiver play the same role in an interaction.*

Any choice is “external” (“agreed upon”).



In a sense, in CCS style

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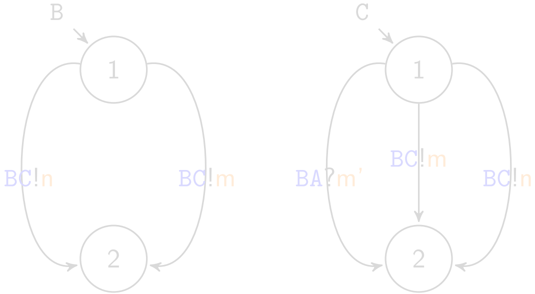

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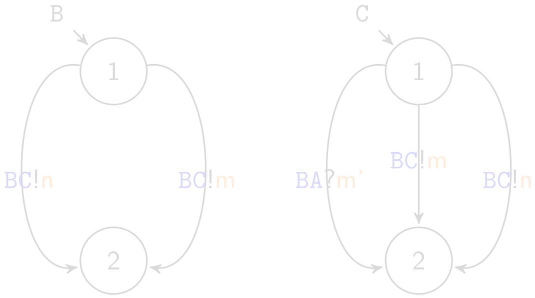

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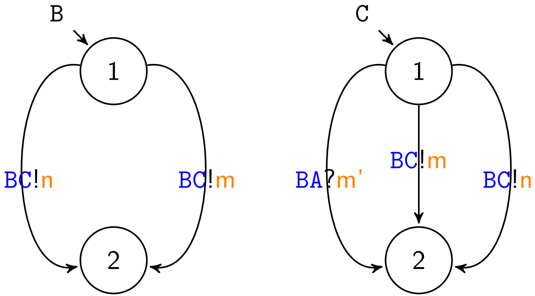

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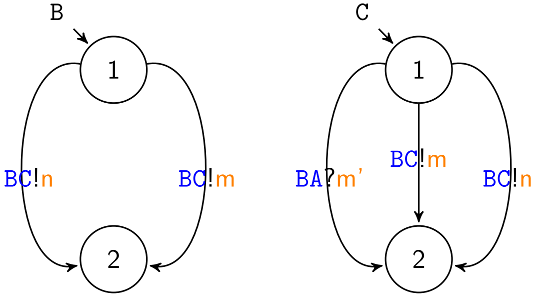

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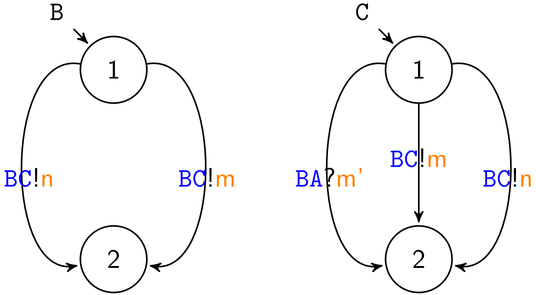

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Composing systems of **symmetric synchronous** CFSMs

Barbanera, Lanese, Tuosto

> COMPOSING COMMUNICATING SYSTEMS, SYNCHRONOUSLY. ISOLA (1) 2020

where

- Compatibility = Bisimulation (forgetting senders and receivers, and exchanging ‘!’ and ‘‘?’ on one side);
- **!?-determinism** and **no-mixed-state** still needed.

NOT enough!

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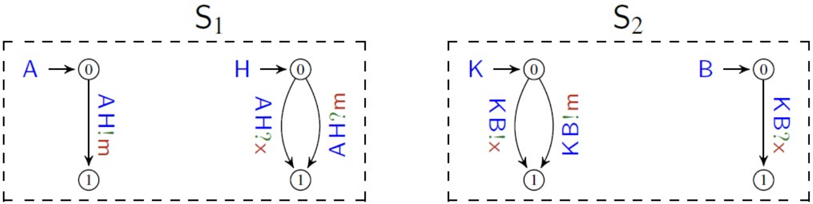

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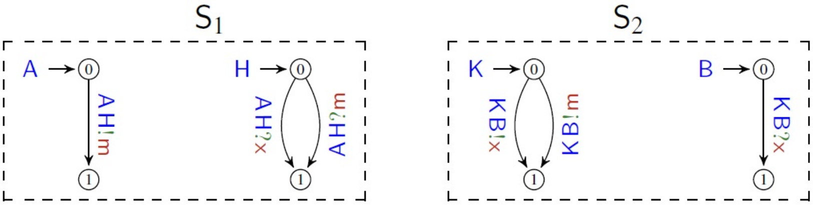
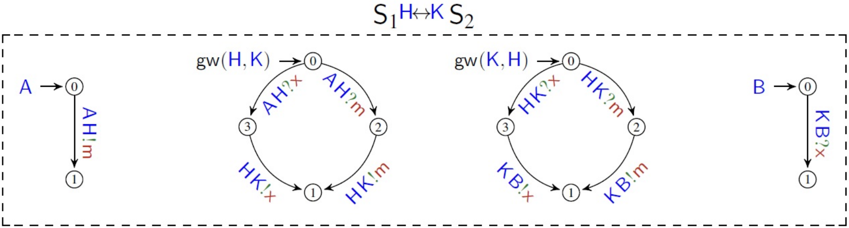


Both deadlock-free

Composing systems of **symmetric synchronous** CFSMs



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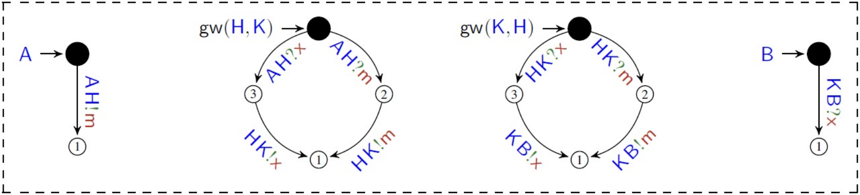

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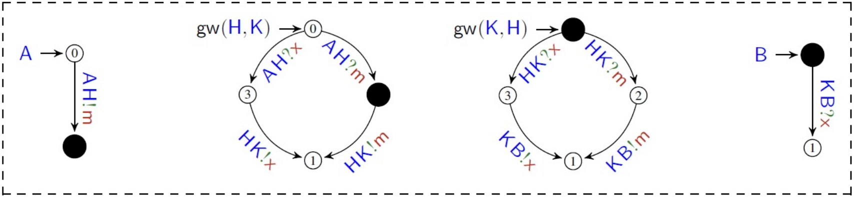

A→H: m

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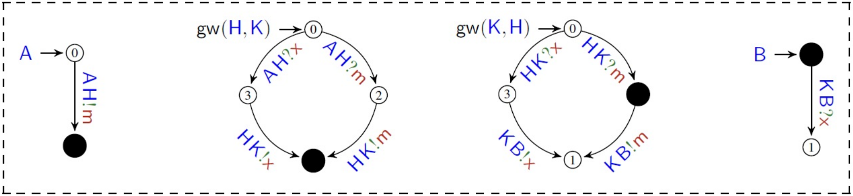

$\mathtt{gw(H,K)} \rightarrow \mathtt{gw(K,H)}$: m

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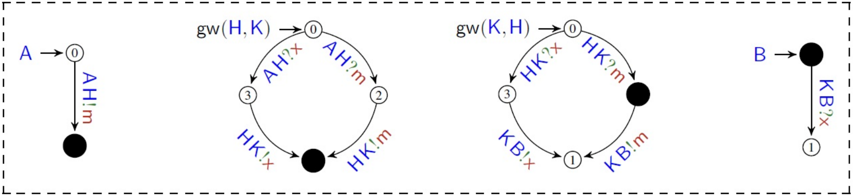

Deadlock!

Composing systems of **symmetric synchronous** CFSMs

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A CFSM A is

1. is **sequential** if each state has **at most** one outgoing transition.
2. is **!-live** if, for any reachable configuration s: any output action A can perform occurs in a continuation of the system. Formally

$$s(\mathsf{A}) \xrightarrow{\mathsf{A\,B!m}} \quad \textit{implies } s \to^* s' \xrightarrow{\mathsf{A \to B:\ m}} \quad \textit{for some } s'$$

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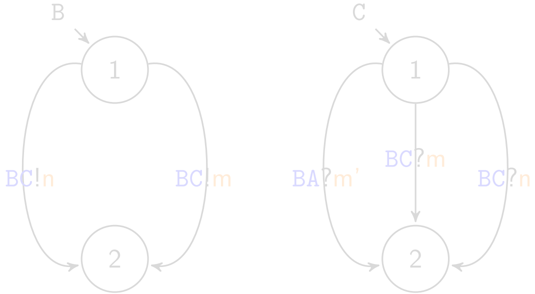
Sender and receiver play different roles in choice resolution while still relying on "handshakes"

In particular: Choices of outputs are "internal" ("sender chooses").



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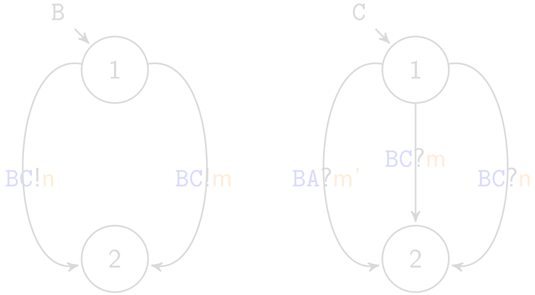

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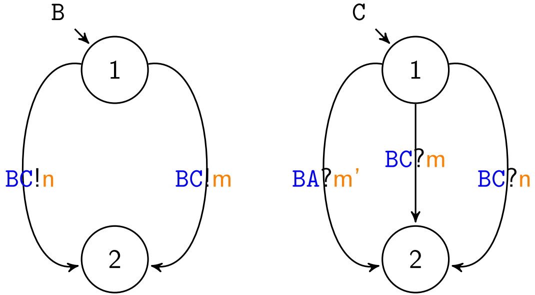

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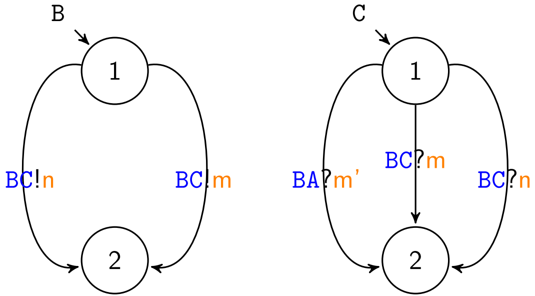

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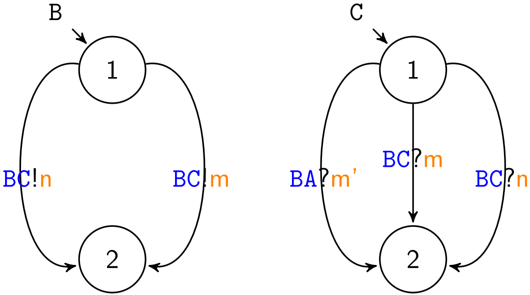

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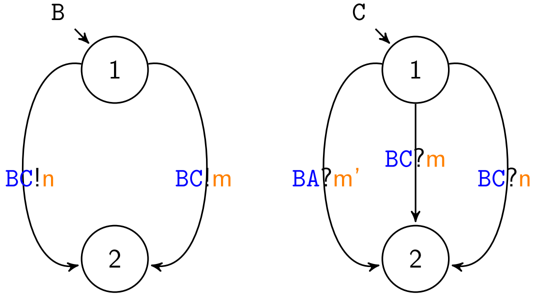

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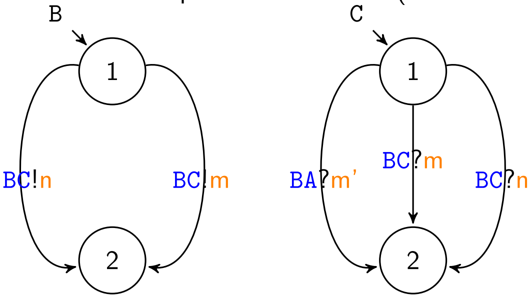

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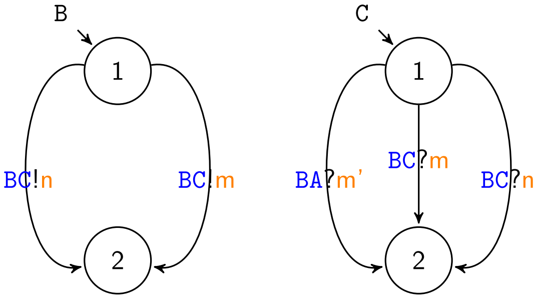

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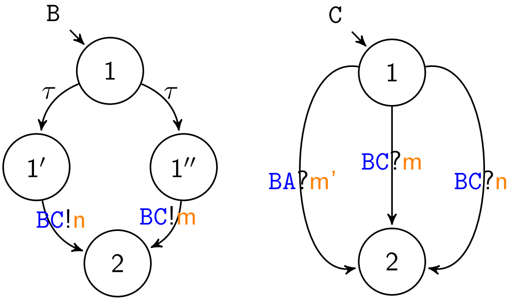

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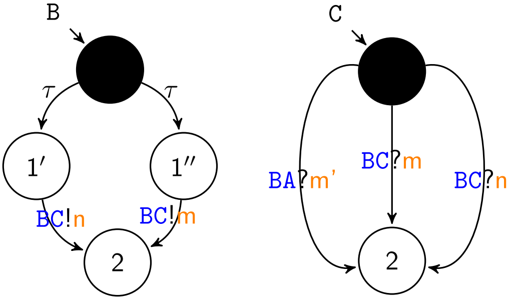

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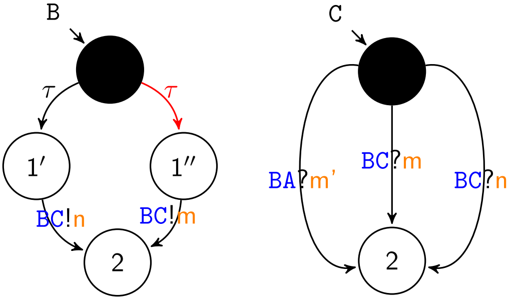

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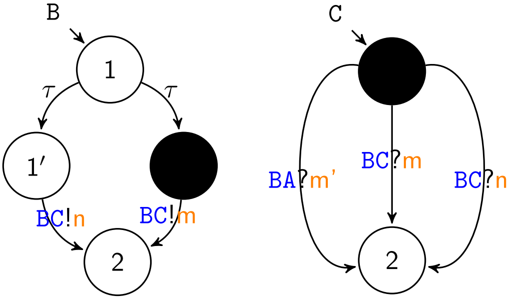

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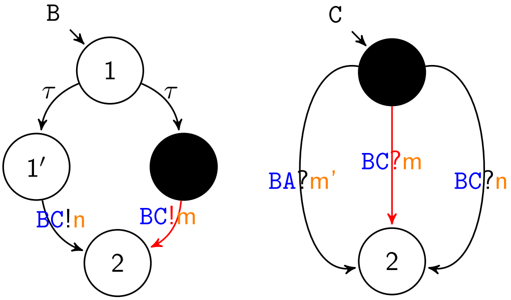

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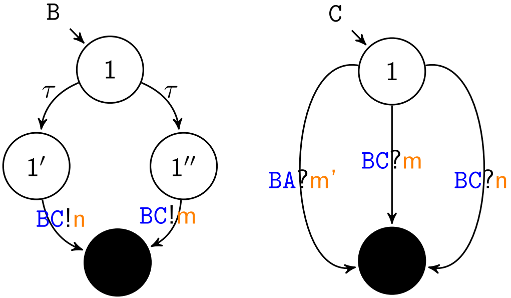


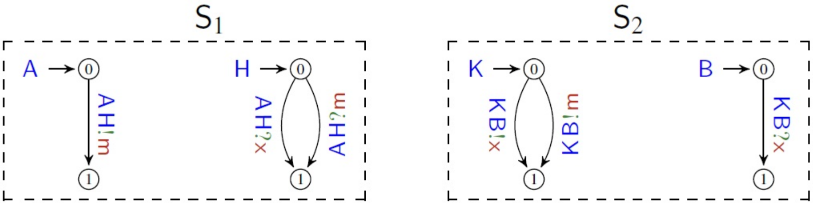
PaI with **Asymmetric synchronous** interactions

Barbanera, Lanese, Tuosto

ICE 2022

Composition with **Asymmetric synchronous** interactions

Counterexample for symmetric synchronous interactions does not apply



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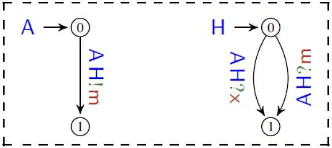
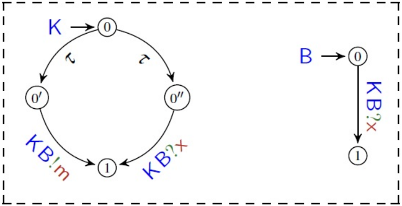


S_2



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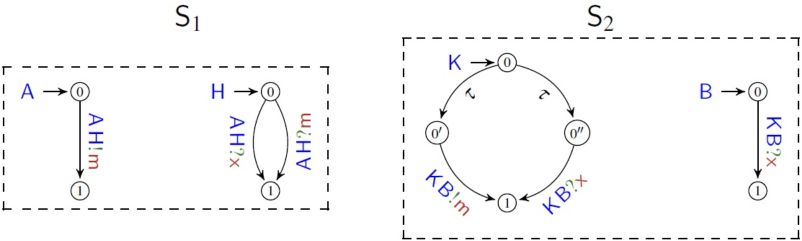

S_2 is not deadlock-free

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Deadlock-freedom: when the system cannot proceed, no participant is willing to proceed;
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Strong lock-freedom: when a participant is willing to proceed, the system allows that in any of its continuations.

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For !?-deterministic, no mixed states and compatible interfaces, composition preserves

- *deadlock-freedom (in a sense it implies !-liveness);*
- *strong lock-freedom;*
- *lock-freedom (***sequentiality required!***).*

Proof Essentially, a deadlock/lock/strong-lock in the composed system "corresponds" to a deadlock/lock/strong-lock in one of the two systems we started with. Unfortunately cannot be shown trivially as it sounds...

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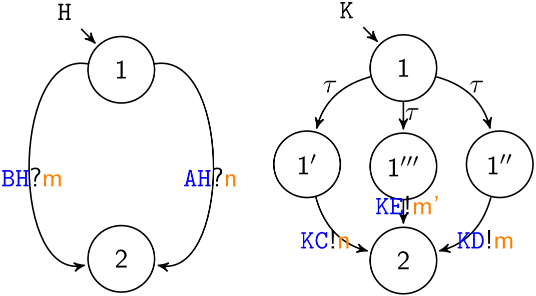

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The need of systems composability

Composability is useful both

- at design phase (modular design);
  Application of PaI for Multi-Party Session Types

- at deployment phase and beyond OUR SETTING

Thank you for your attention.