



Composing Communicating Systems, Synchronously

Ivan Lanese
Computer Science Department
University of Bologna/INRIA
Italy

Joint work with Franco Barbanera
and Emilio Tuosto

Map of the talk

- Preservation of deadlock freedom under composition
- Composition via gateways
- Semi-direct composition
- Conclusion



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Analyzing large systems

- Today's systems (the Internet, the Cloud, sensor networks, ...) are large, yet we want to ensure they behave well
- Compositionality of analysis techniques is a need
- Aim of this paper: understand whether properties of systems are preserved under composition
- We select:
 - One specific property: deadlock freedom
 - Two forms of composition
 - Synchronous semantics for communication
- We work on systems described as sets of Communicating Finite State Machines (CFSMs)

Systems of CFSMs

- A CFSM is a finite state automaton whose transitions are labelled with communication actions:
 - $AB!m$: A sends a message m to B
 - $AB?m$: B receives message m from A
- A system is composed by one CFSM per participant
- Synchronous semantics: A and B can move iff A can perform $AB!m$ and B can perform $AB?m$ (for some m)



Deadlock freedom

- A system is in a deadlock state iff
 - there are no enabled communications
 - at least one participant is willing to perform a communication action
- A system is deadlock free if no reachable state is a deadlock

Map of the talk

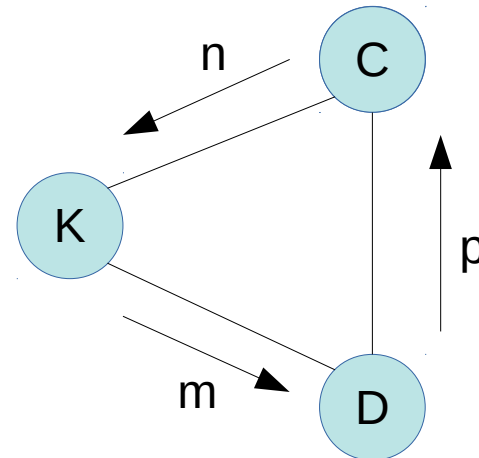
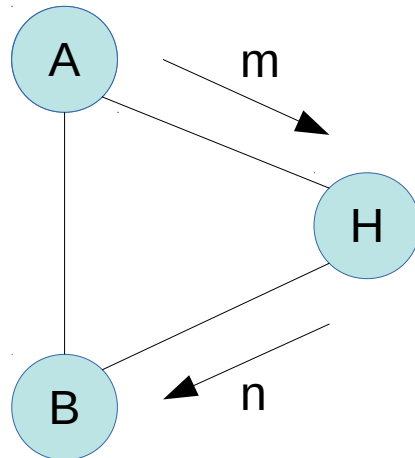
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Opening systems of CFSMs

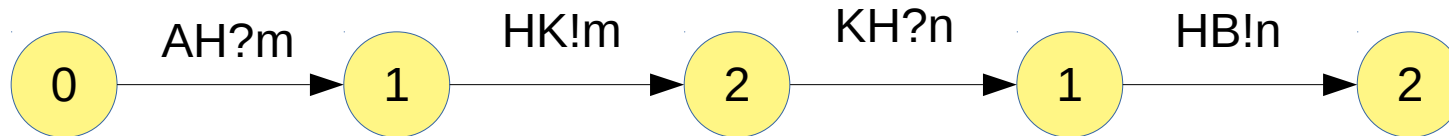
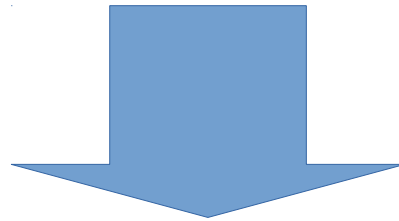
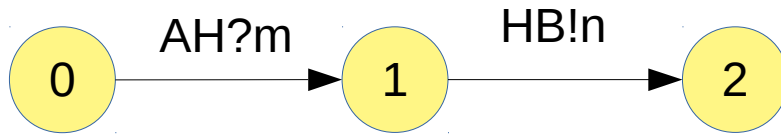


- Such systems are close: communications target other participants of the same system
- Composition technique from [Barbanera, de'Liguoro, Hennicker: JLAMP 2019]
- Open systems by selecting a participant as interface and transforming it into a gateway towards another system



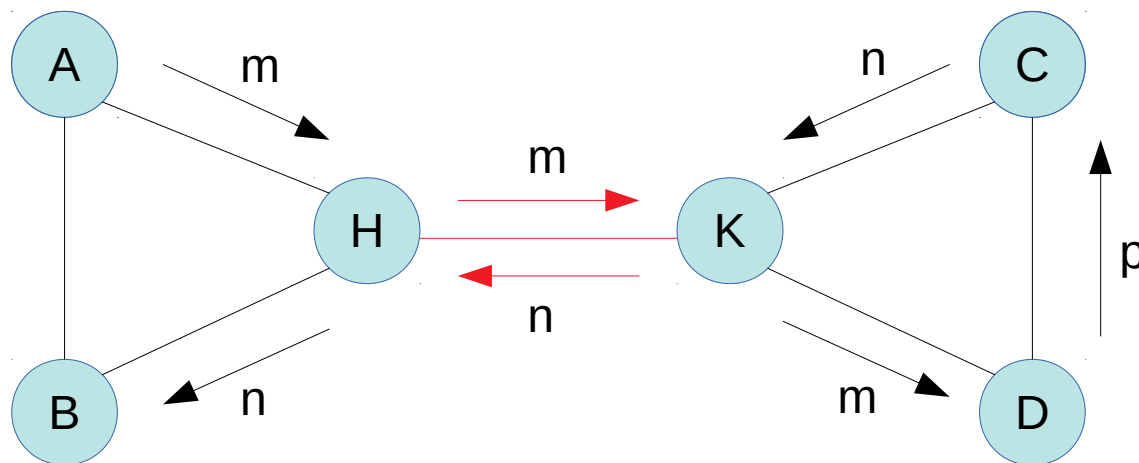
Transformation into gateway

H:



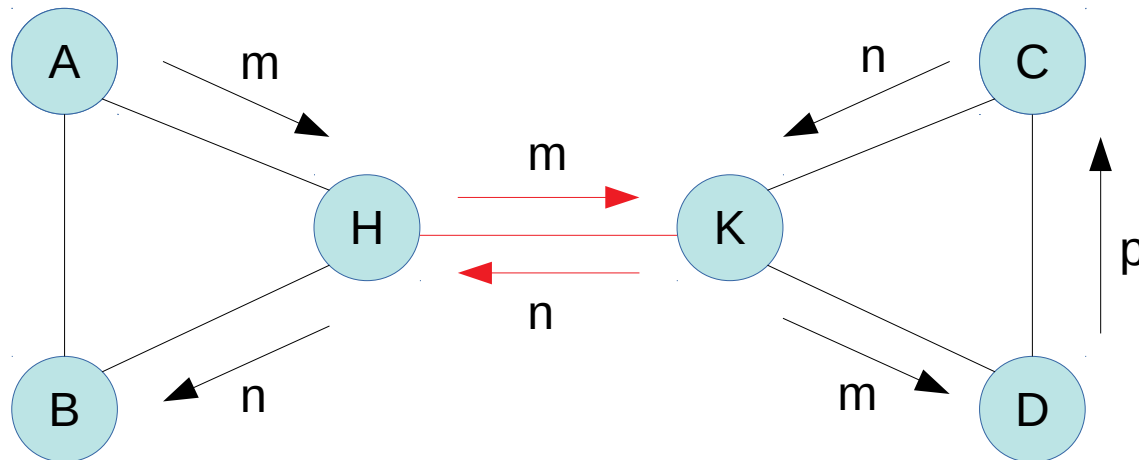
Composing systems of CFSMs via gateways

- Systems can now be composed via gateways
- Any participant can be chosen as interface
- For successful interaction, the pair of chosen interface participants need to be compatible



Compatibility

- Two actions are compatible iff they have opposite directions and the same message (regardless of participants)
- Two CFSMs are compatible iff they can play the bisimulation game answering challenges with a compatible communication action

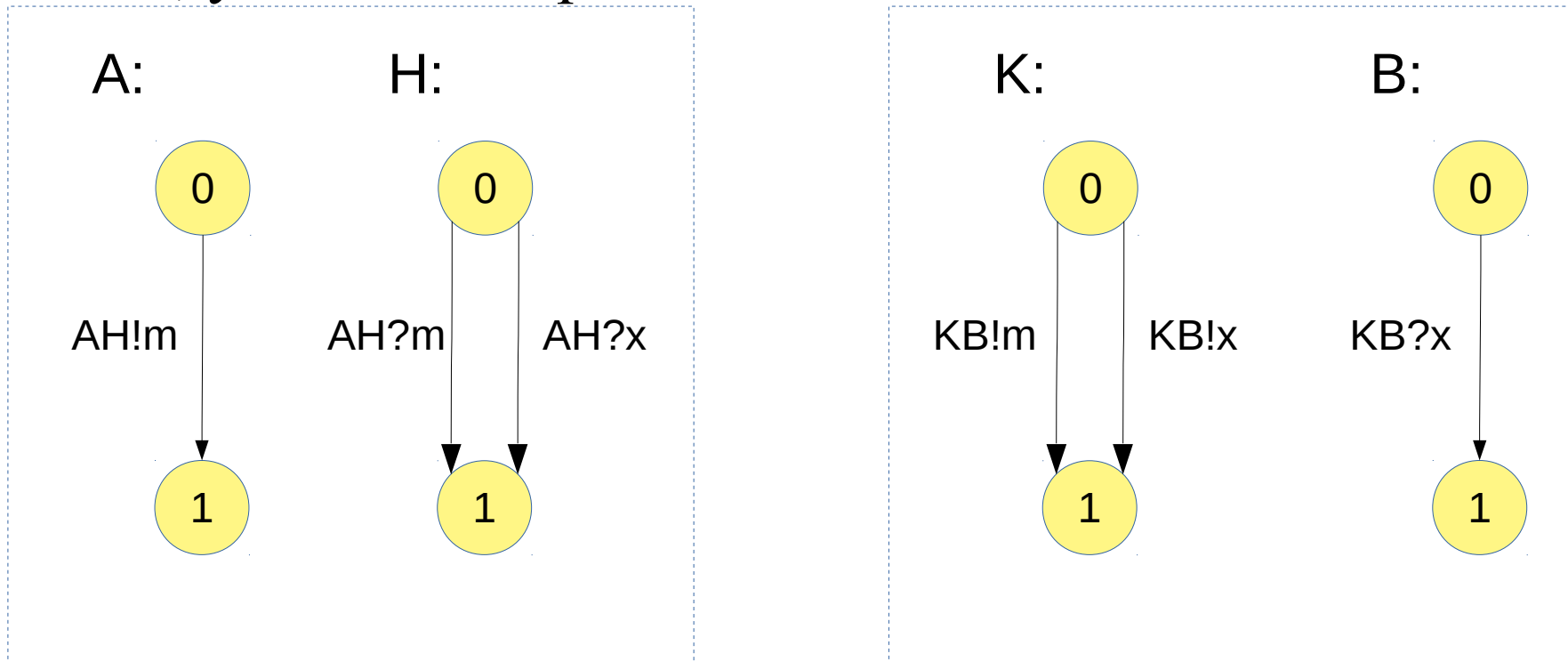


(H,K)-composability

- Under which conditions the composition of two deadlock free systems is deadlock free?
- **Under the FIFO asynchronous semantics** if they are (H,K)-composable [Barbanera, de'Liguoro, Hennicker: JLAMP 2019]
- Two systems are (H,K)-composable iff:
 - H and K are compatible, ?!-deterministic and have no mixed states
 - ?!-deterministic: coinitial transitions with the same direction and message should lead to the same state
- Does the same hold **under the synchronous semantics**?

Unfortunately not

- The systems below are (H,K)-composable and deadlock free, yet their composition deadlocks



- Under the asynchronous semantics the second system in isolation would deadlock as well

Ensuring deadlock-freedom preservation

- Other counterexamples [see paper] suggest that strong conditions are needed
- Theorem: deadlock freedom is preserved if interface participants are **sequential**
 - Sequential: each state has at most one outgoing transition
- Theorem: deadlock freedom is preserved if interface participants are **!live** in their system
 - !live: if the participant wants to do a send sooner or later it will be able to do it
 - This is a property of the system, not of the interface participant alone

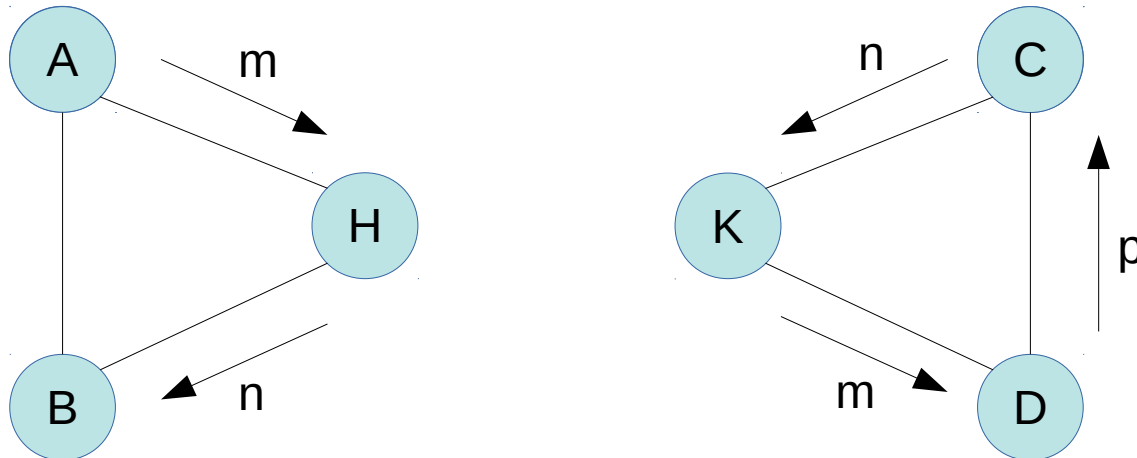
Map of the talk

- Preservation of deadlock freedom under composition
- Composition via gateways
- **Semi-direct composition**
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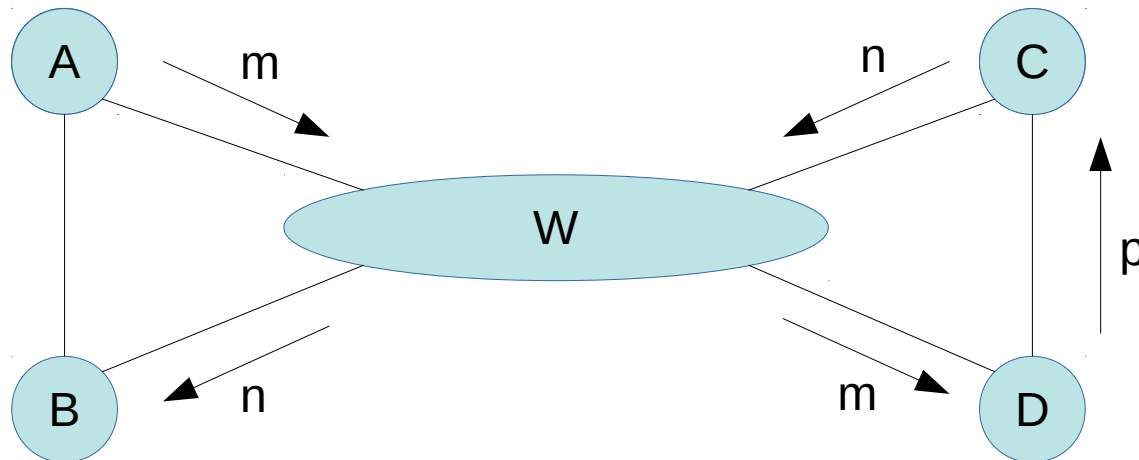
Semi-direct composition

- Composition via gateways introduces some amount of forwarding that may seem redundant
- Semi-direct composition merges the two interface participants into one gateway, reducing the forwarding



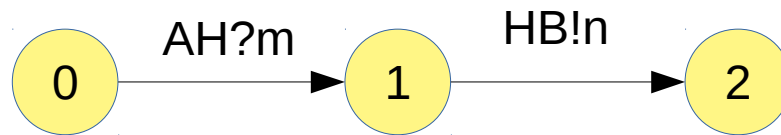
Semi-direct composition

- States of W include:
 - pairs of states of H and K that are matched by the bisimulation
 - triples with states of H and K , plus a message received and not yet forwarded

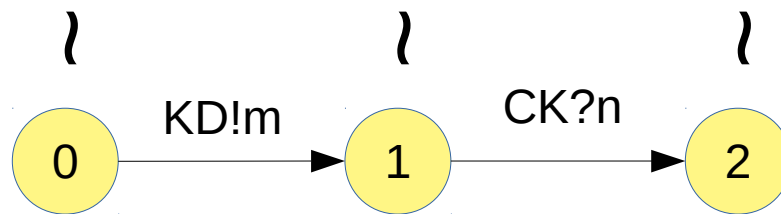


Definition of W

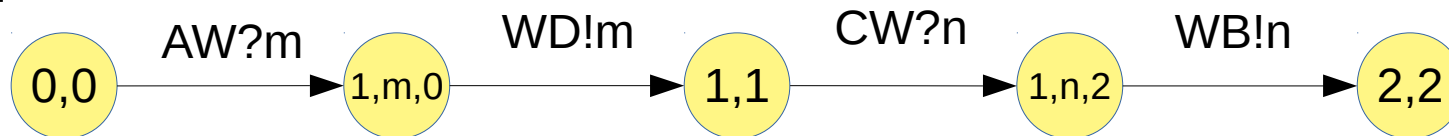
H:



K:



W:



What about deadlock preservation?

- Essentially as for composition via gateways
- Composability can be slightly relaxed by allowing mixed states provided that actions with different direction have different messages
- Deadlock-freedom preservation proved for interface participants sequential or !live in their systems

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Comparing different forms of composition

	Via gateways	Semi-direct	Direct*
Interface participants become	Two gateways	One gateway	Are dropped
Amount of forwarding	High	Medium	None
Restructuring on participants	None	Renaming	Complex
Conditions to define the composition	None	Bisimulation	Behavioural types

* From [Barbanera, Dezani-Ciancaglini, Lanese, Tuosto, JLAMP 2021]

Summary

- We studied deadlock-freedom preservation under two forms of composition
 - Composition via gateways
 - Semi-direct composition
- Surprisingly, conditions needed for the synchronous case are much stronger than for the asynchronous one

Future work



- Prove similar results for other properties as well (e.g., lock freedom)
- Extend the results in [Barbanera, Dezani-Ciancaglini, Lanese, Tuosto, JLAMP 2021] to a setting with no behavioural types
 - Direct composition
 - Decomposition

End of talk

Thanks!

Questions?