On Choice in Protocol Specification

Generalizing Projection in Asynchronous Multiparty Session Types
CONCUR 21, with Rupak Majumdar, Madhavan Mukund, and Felix Stutz

On Channel Use in Protocols and General Point-to-Point Communication
under submission, with Felix Stutz

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MPI-SWS
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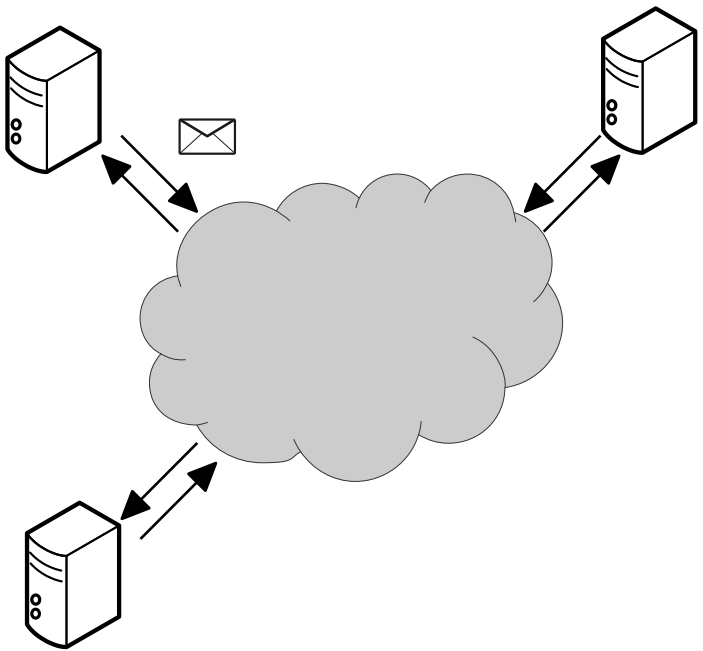
Overview

- Detour: why it is hard to reason about CSM?
- Binary session types and half-duplex channels
- Binary to multiparty session types
- Directed to generalized choice
- Future work

What is this about ?

Distributed systems
(message-passing)



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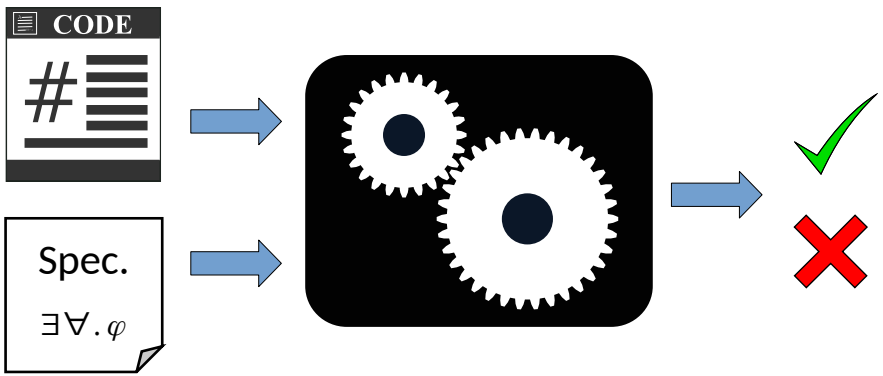
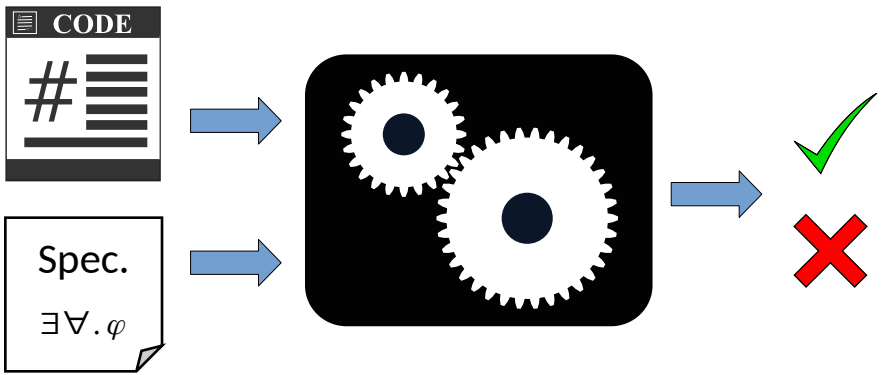
Verification



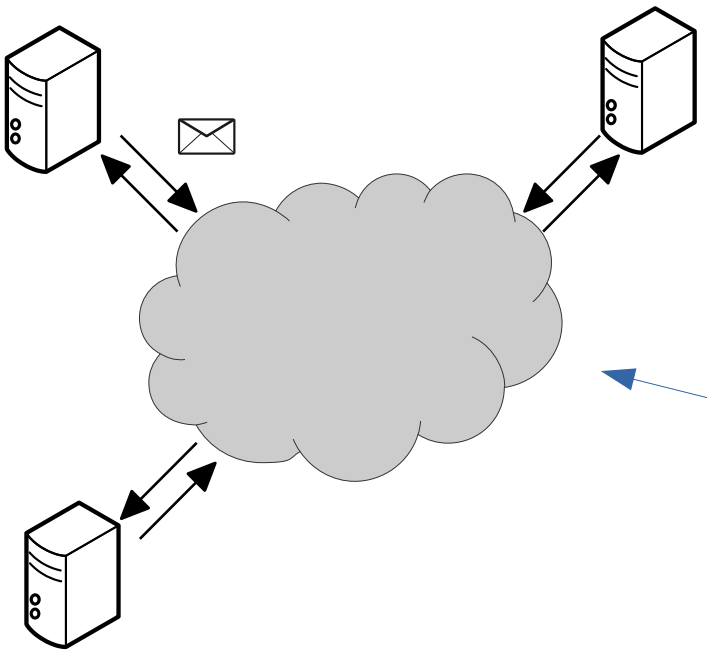
What to Verify?



A communication protocol is correctly implemented:

- messages follow a prescribed order
- deadlock-free
- no dangling messages

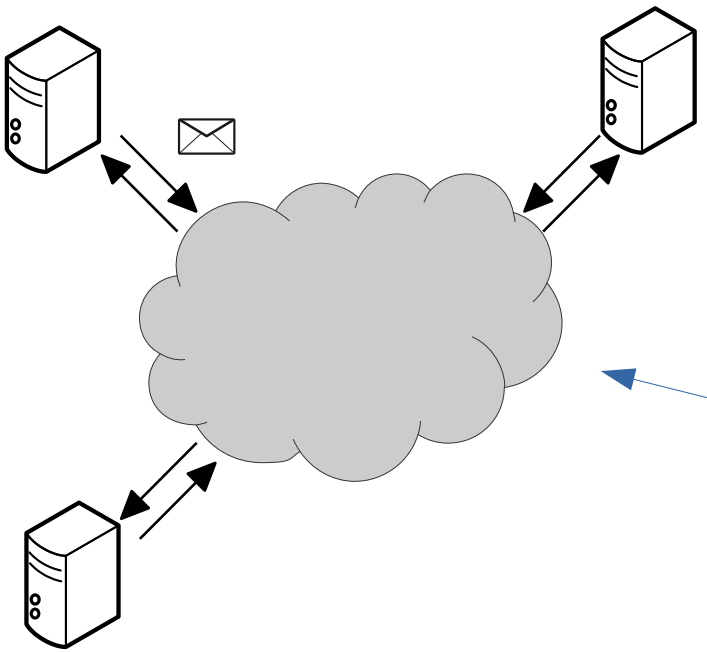
Model for the Software



Programs:
- Finite state machines
- Pushdown automata
- Turing machines

Communication channels:
- routing: point-to-point, broadcast, ...
- capacity: unbounded, bounded
- reliability: reliable, lossy, fair, ...
- ordering: FIFO, bag

Communicating State Machines (CSM)



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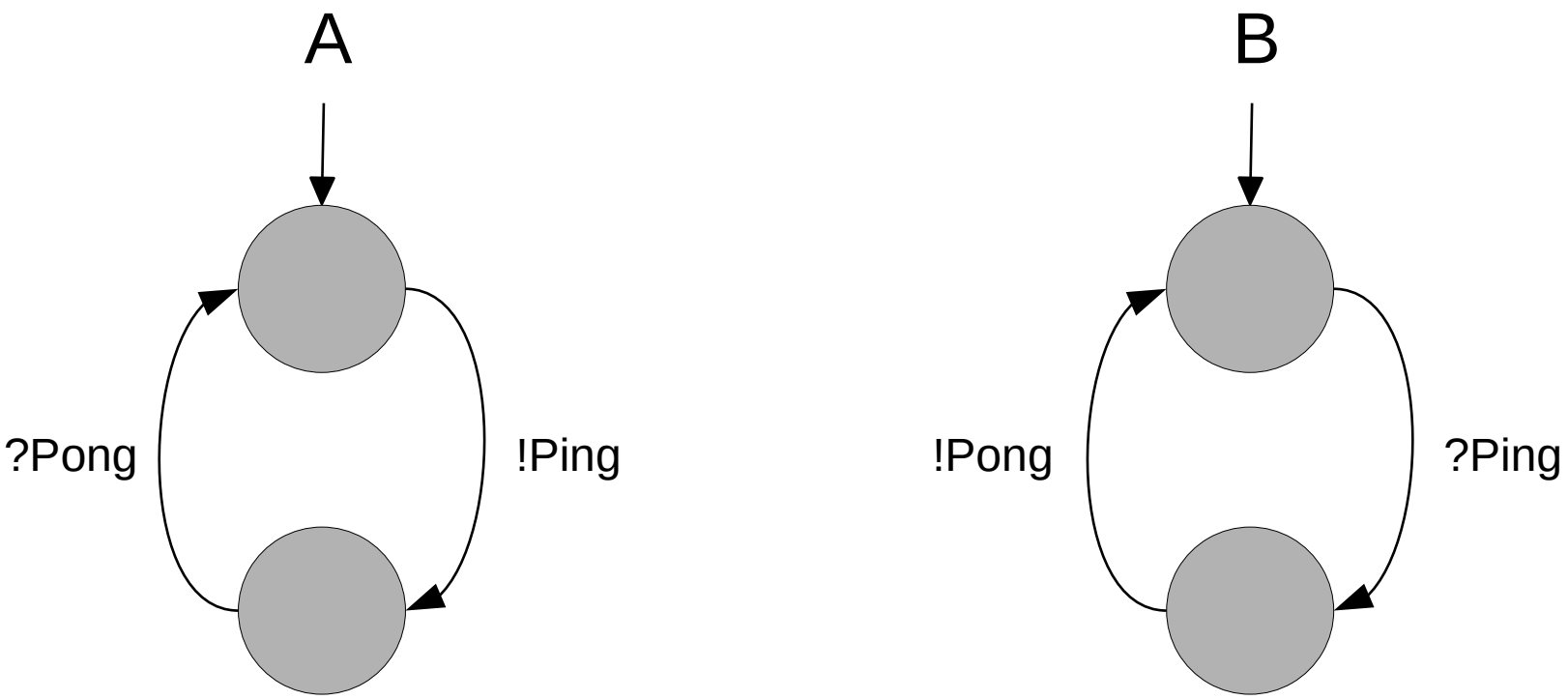
“Hello World” of Message-Passing



CSP notation: ‘!’ is send, ‘?’ is receive

CSM: Expressive Power

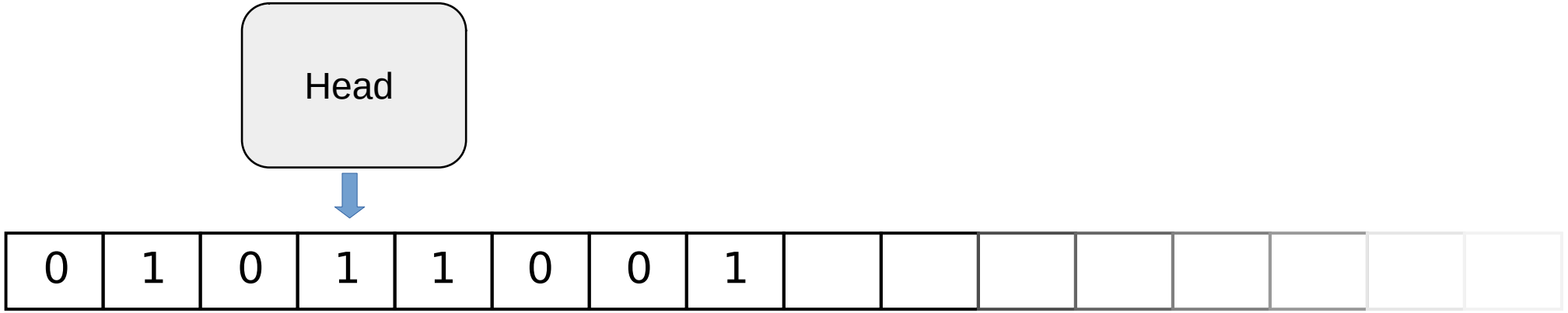
- Knowing the expressive power tells us what method can or cannot be applied.

  (Don’t try to solve undecidable problems)

- It can tell us what feature of the model is important.
- Unfortunately, CSM can simulate Turing machines.

Turing Machine (TM)

- TM = finite control + unbounded tape (RAM)
- Operations: read/write memory, move left/right



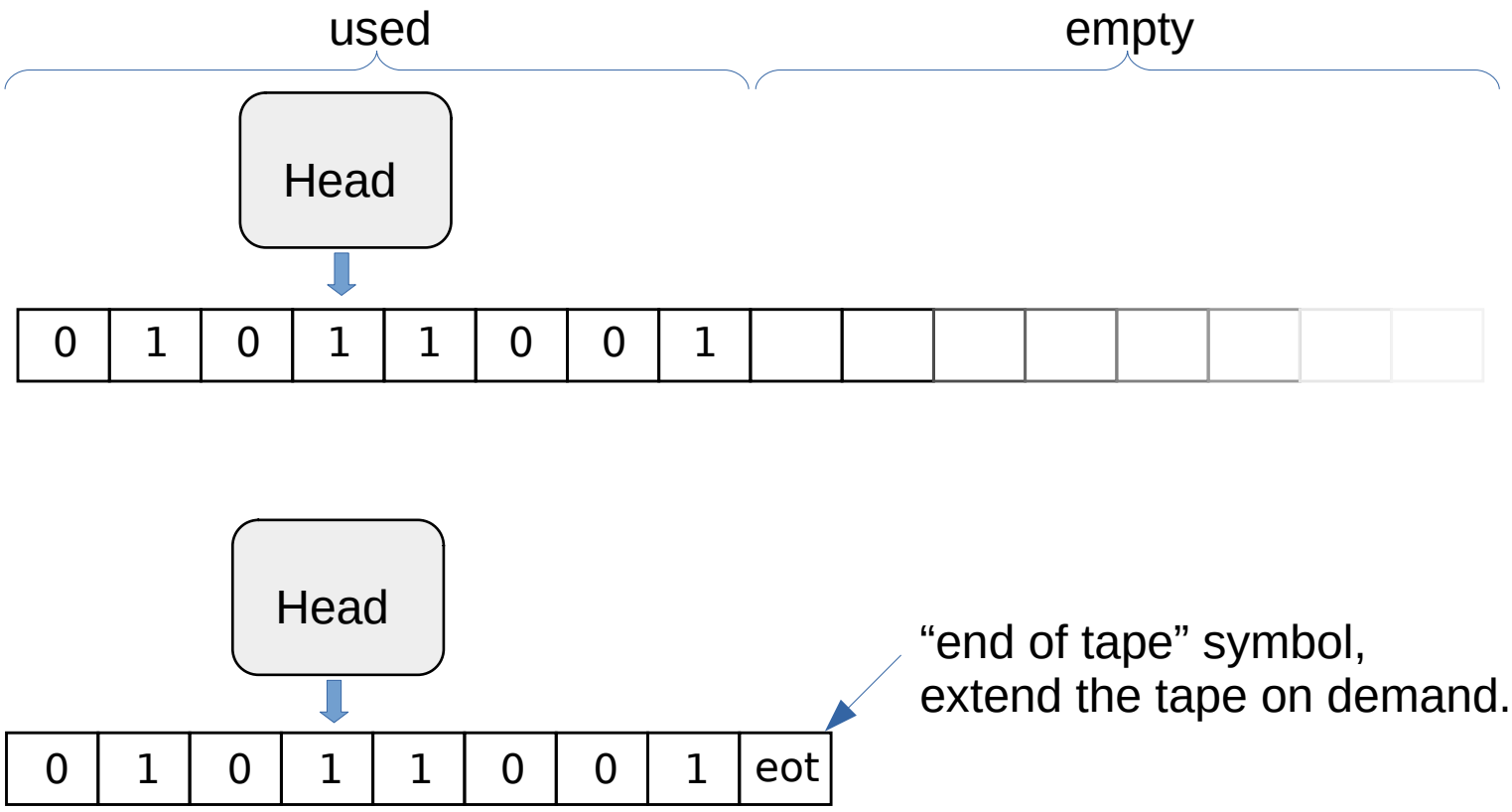
TM → CSM

Idea:

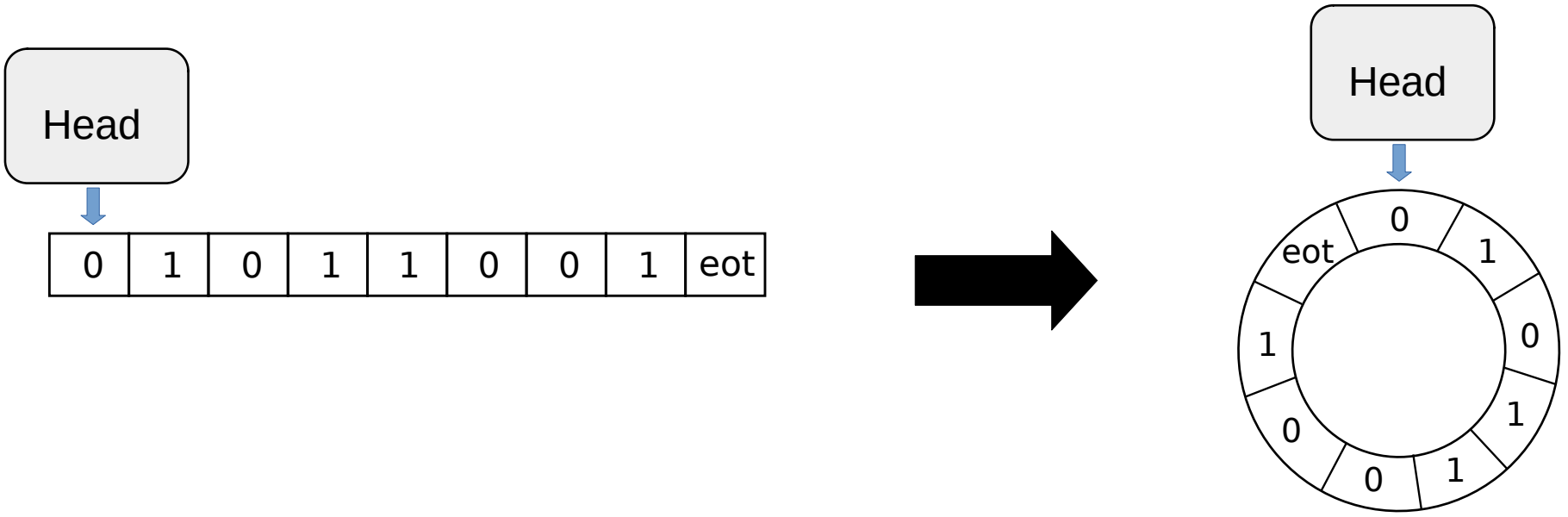
use the communication channels to store the content of the tape.

1) Store only the (finite) written part
2) Turn the tape into a loop
3) Extract the “Head part” of the tape
4) Split the loop in two parts (2 communication channels)

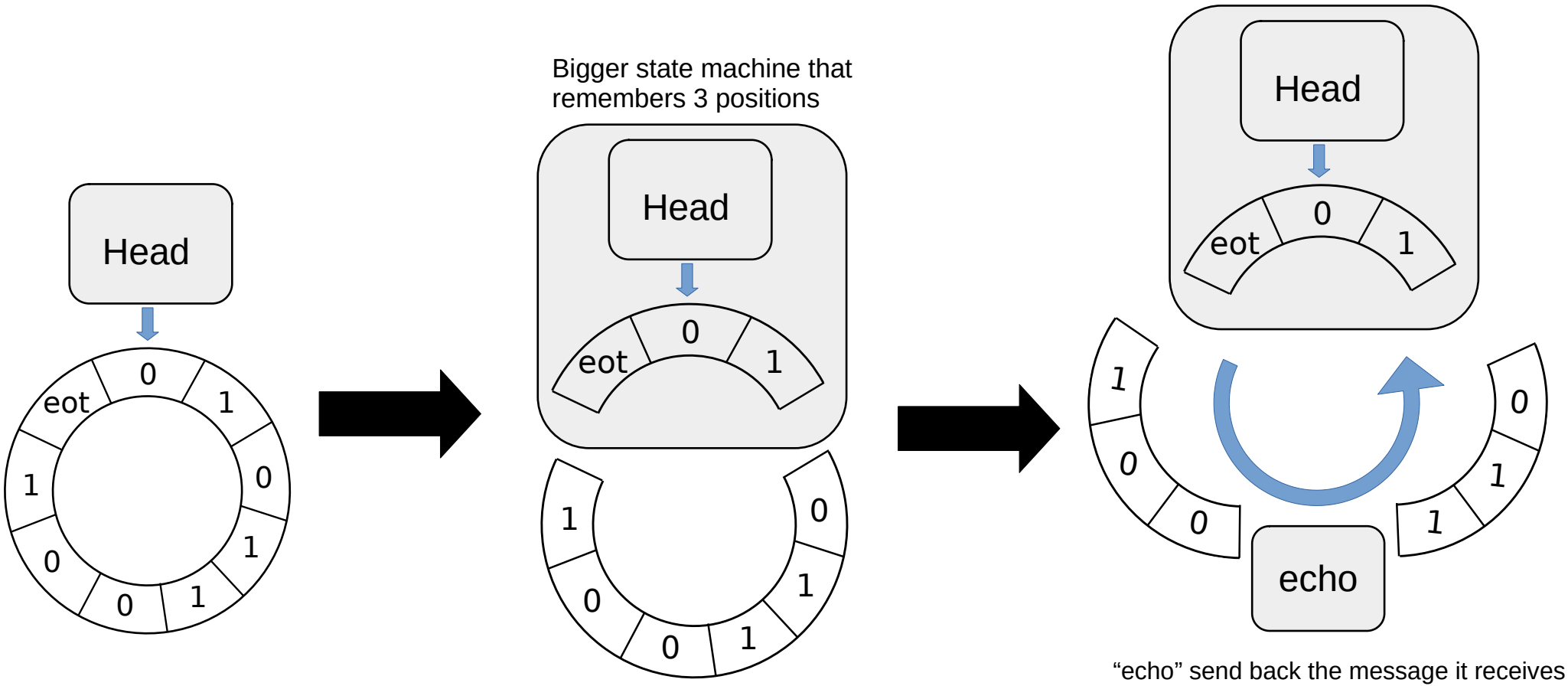
TM → CSM


used
empty
Head
0 1 0 1 1 0 0 1
Head
0 1 0 1 1 0 0 1 eot
“end of tape” symbol,
extend the tape on demand.

TM → CSM

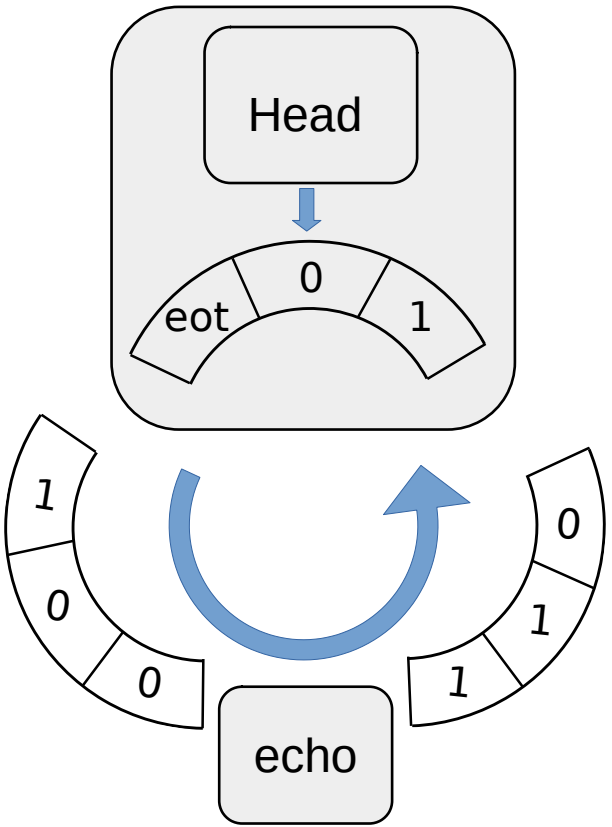


TM → CSM



“echo” send back the message it receives

TM → CSM



Emulating TM operations:

1) read/write: change local state of the head machine

2) move right: send to echo, receive from echo

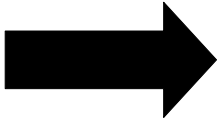
3) move left:
   - insert position marker before current position
   - loop around the tape (move right) until the marker

Other Channel Models

- capacity: unbounded, **bounded**
- reliability: reliable, lossy, ...
- ordering: FIFO, bag

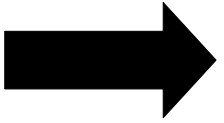
Finite state machine

- capacity: **unbounded**, bounded
- reliability: reliable, lossy, ...
- ordering: FIFO, **bag**



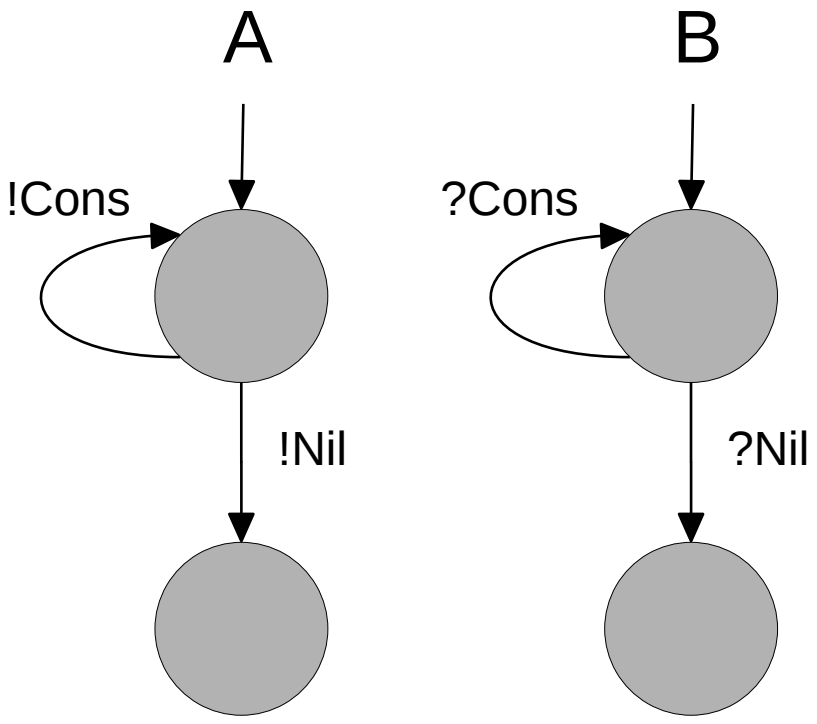
Petri net

- capacity: **unbounded**, bounded
- reliability: reliable, **lossy**, ...
- ordering: **FIFO**, bag



WSTS

Memory vs Communication Slack



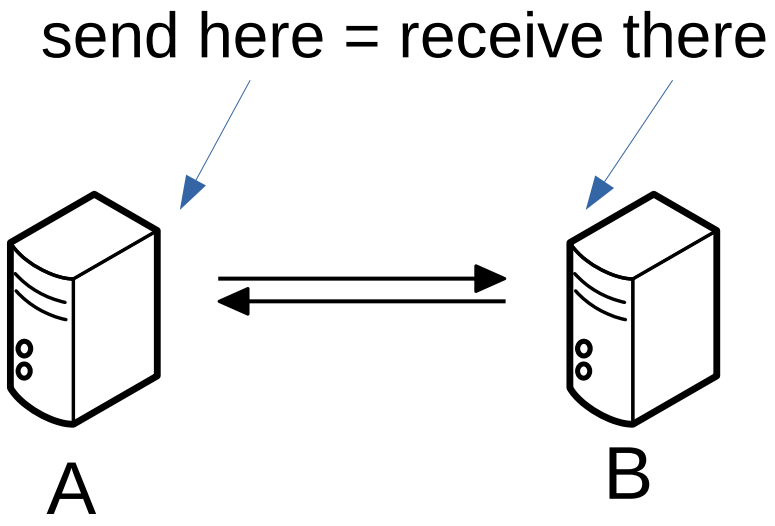
Some protocols using unbounded channels can be harmless.

What is the difference between

- channel as memory
  (store information for later)
- communication slack
  (delay in the propagation of information)

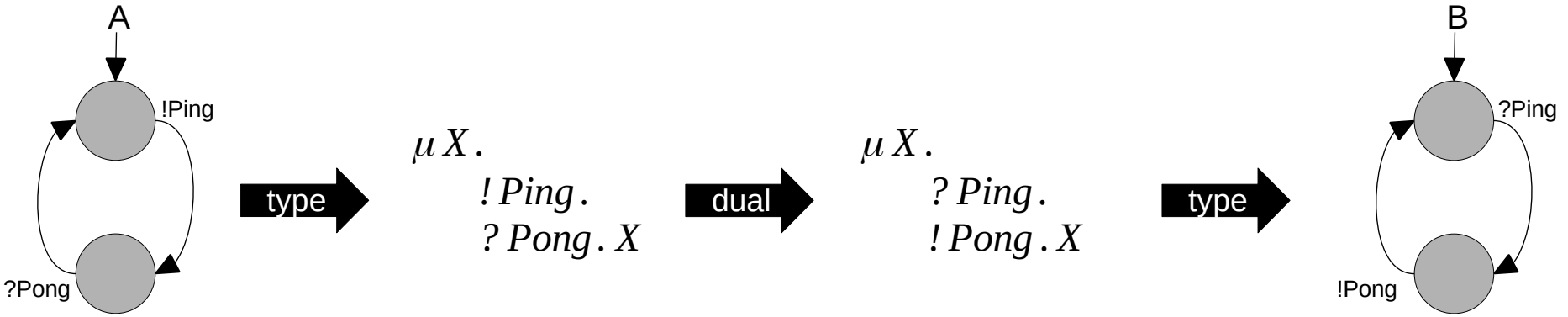
Looking at the Channels

Operations on channel endpoints are **dual**.

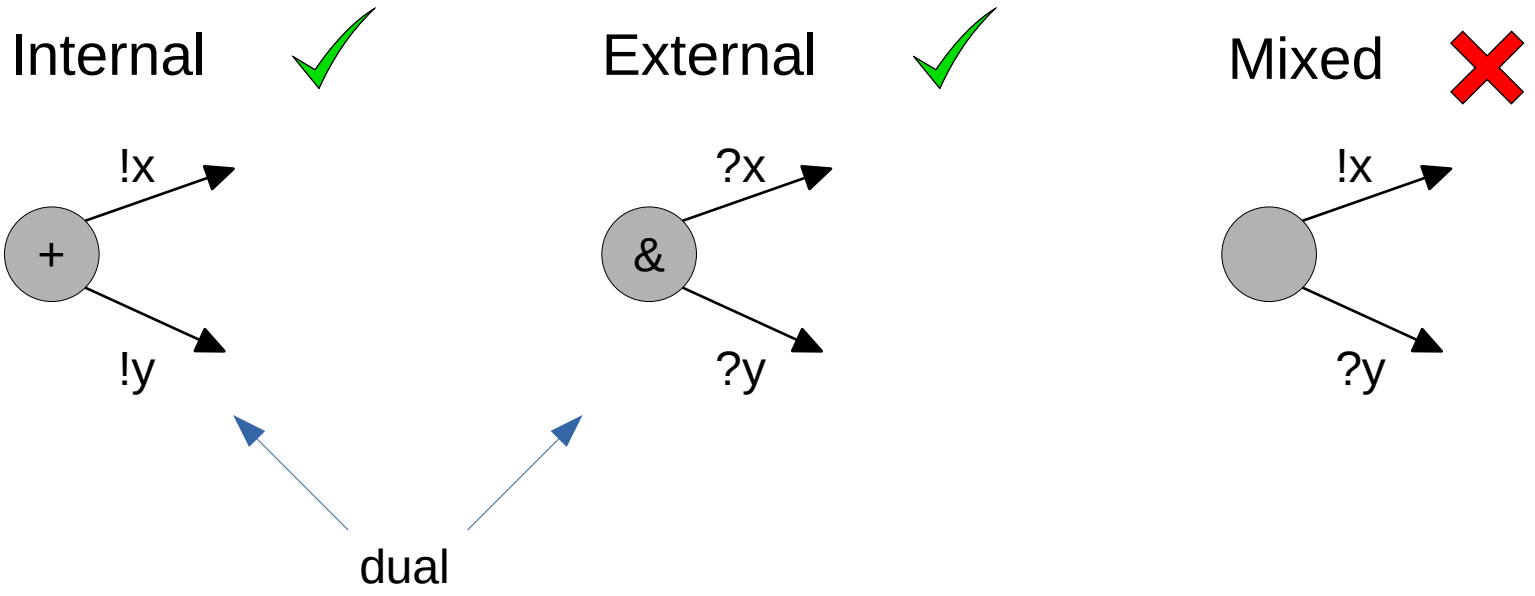


Binary Session Types (BST)

Idea: one side of the channel determines the operation on the other side.
1) get the operations for A
2) compute the operations for B using duality
3) check B executes the specified operations

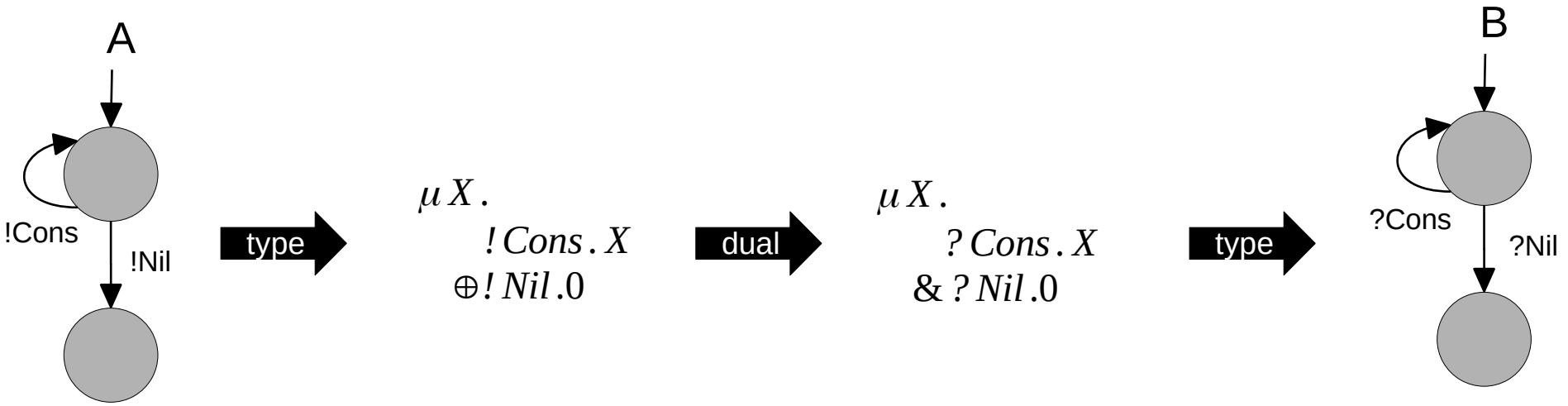


Duality in Choice



deterministic choice: all outgoing transitions have different labels

BST Example with Choice



BST and Model Checking

BST specifies only **half-duplex** protocols. [Cécé05]

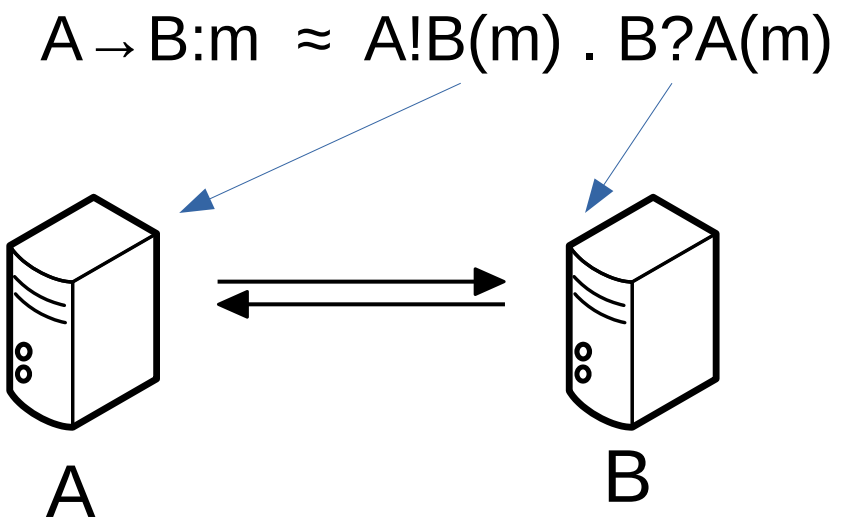
Half-duplex:
- Buffers are empty when communication switch direction
- With 2 processes: not Turing complete

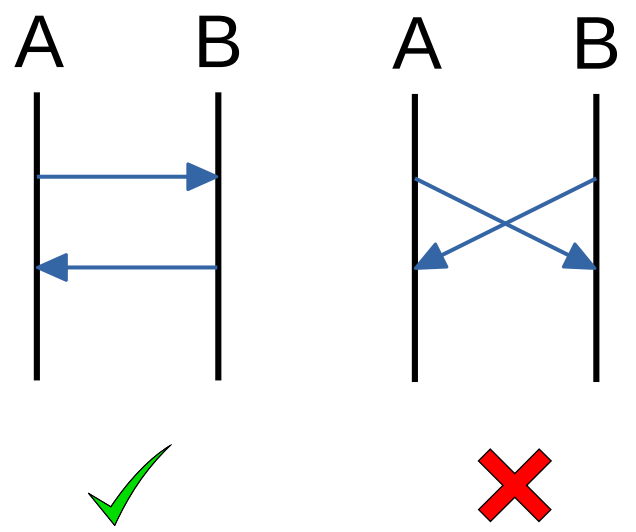
BST enforce this restriction on the protocol: runs the same on half- and full-duplex systems.

[Cécé05] Gérard Cécé and Alain Finkel. Verification of programs with half-duplex communication. Inf. Comput., 2005.

Duality and Message Spec.

Dual operations are easily **specified together**.





More than two Processes...

- 2 processes: well understood
- 3+ processes: badly understood
  - Projection of global description is lossy. It can introduce non-determinism.
  - Messages sent by different processes are independent.

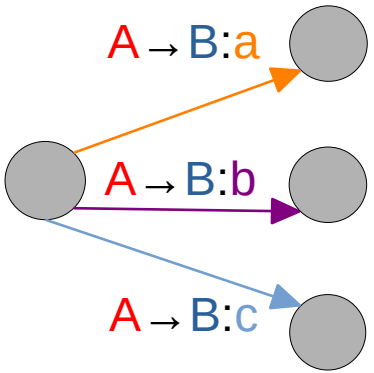
Binary to Multiparty

Find some restriction to keep protocol “well-behaved”.
Keep track of choices without getting confused.

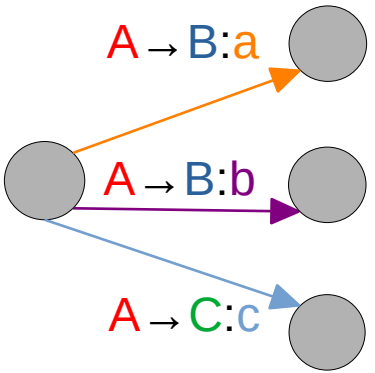
- First with directed choice (classical MST)
- Then with generalized choice (CONCUR paper)

Directed vs Generalized Choice

Globally



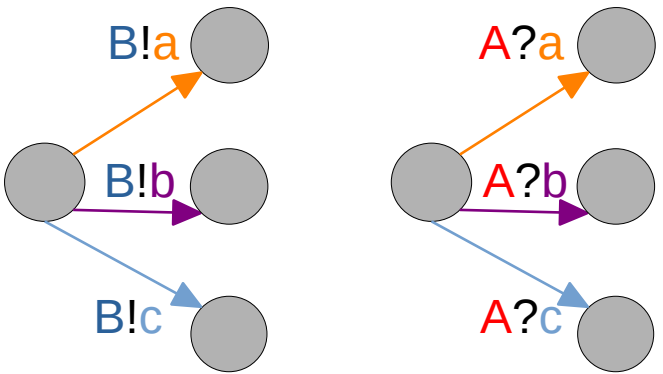
A,B are constant.
Only the messages (a,b,c) change



Sender A is constant.
The receivers (B,C) and messages changes

Directed vs Generalized Choice

Locally



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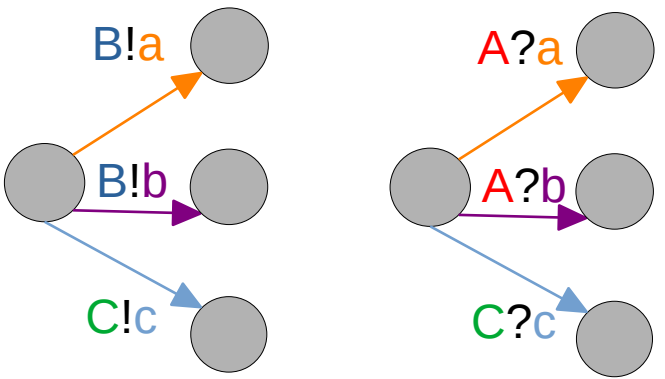
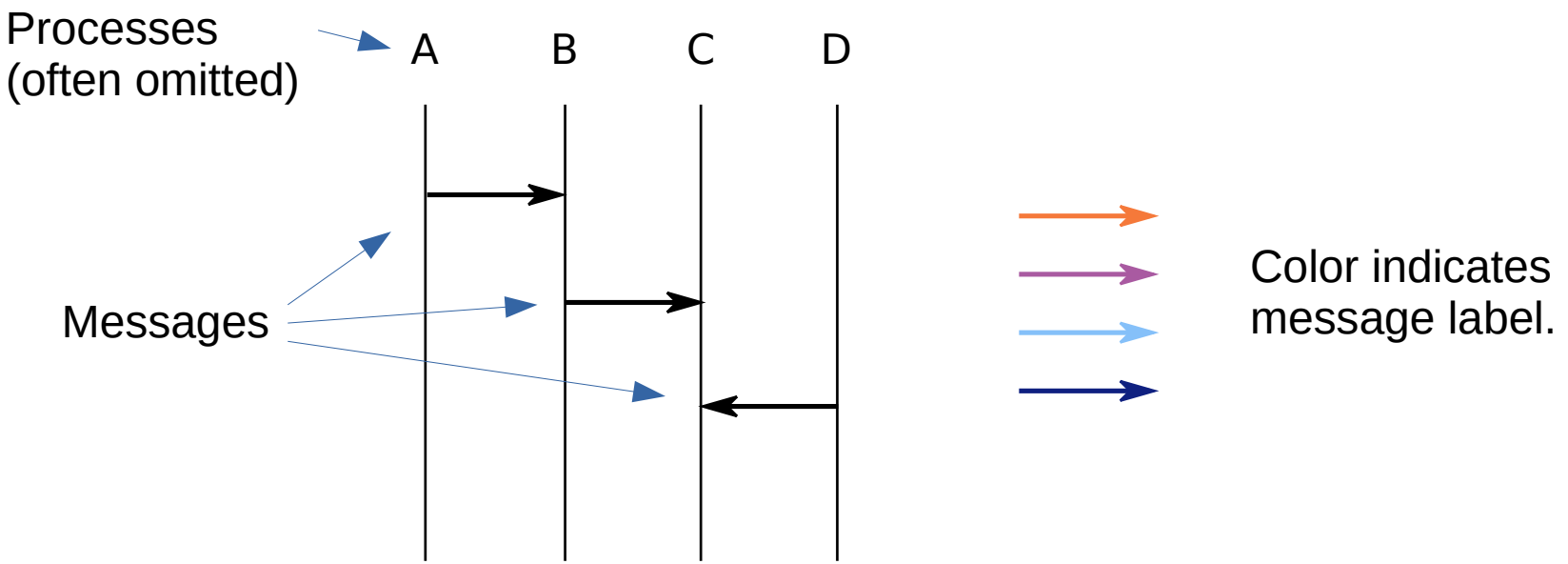
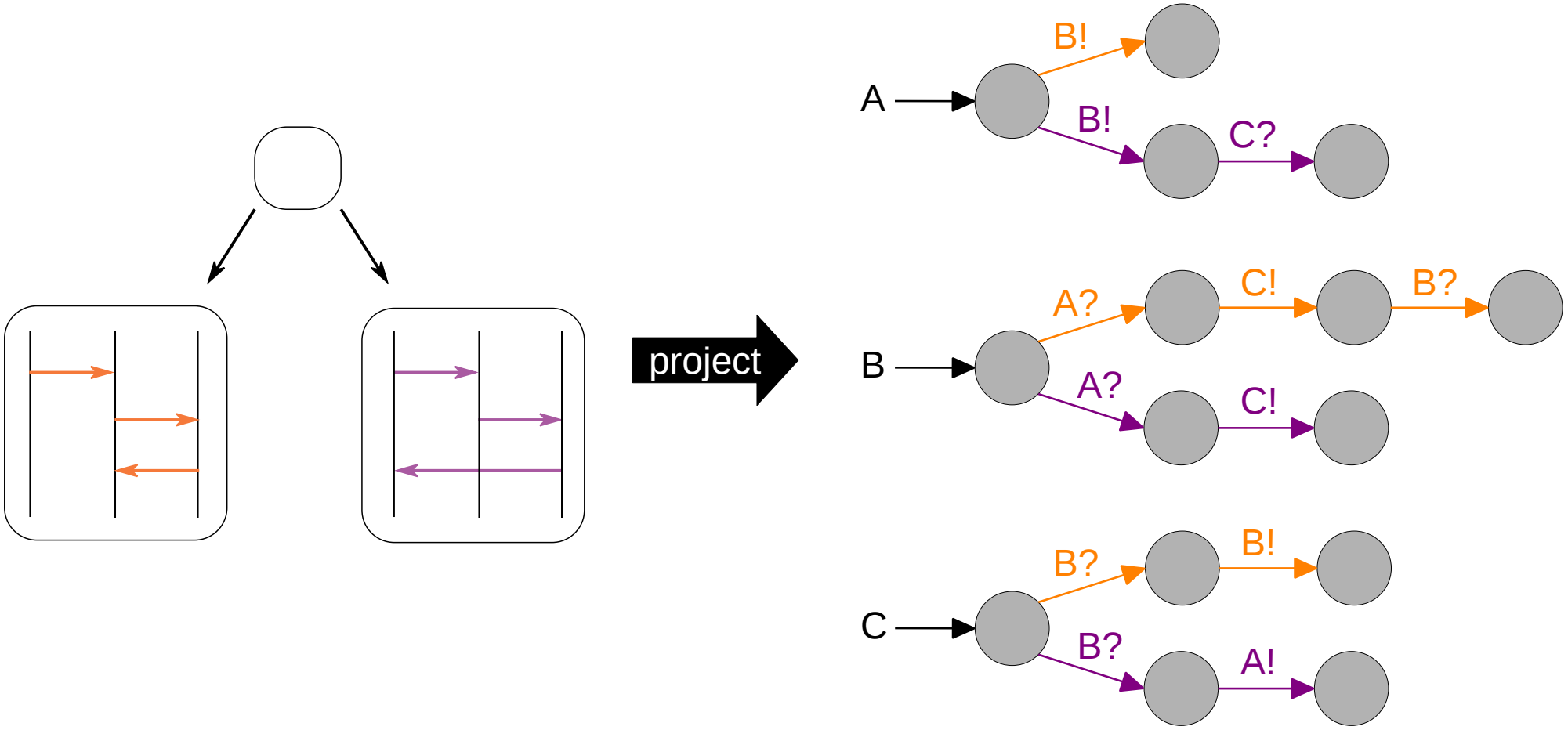


Everything can change.

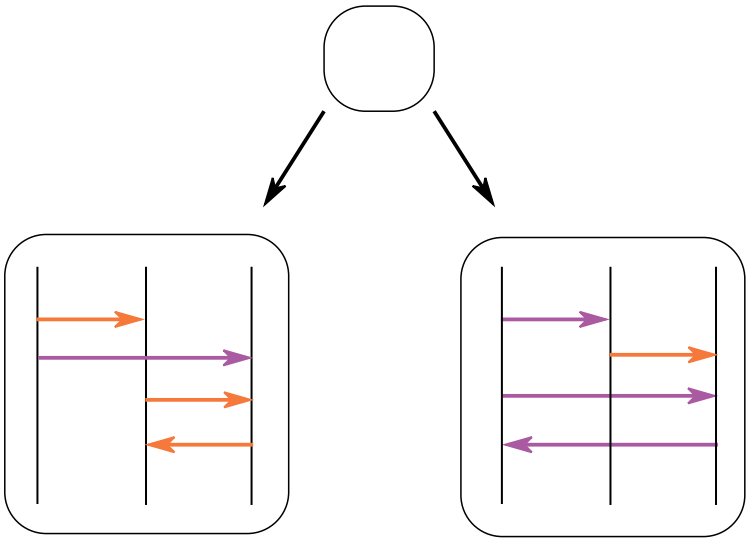
High Level Message Sequence Charts Notation



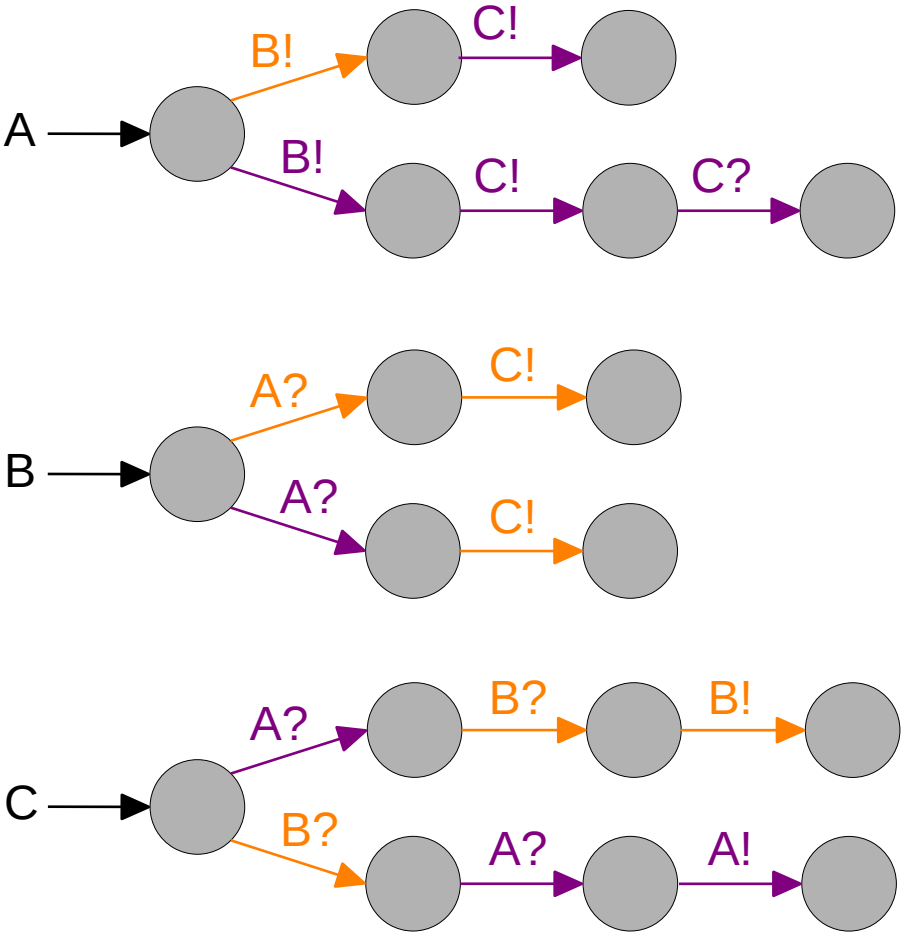
From Duality to Projection



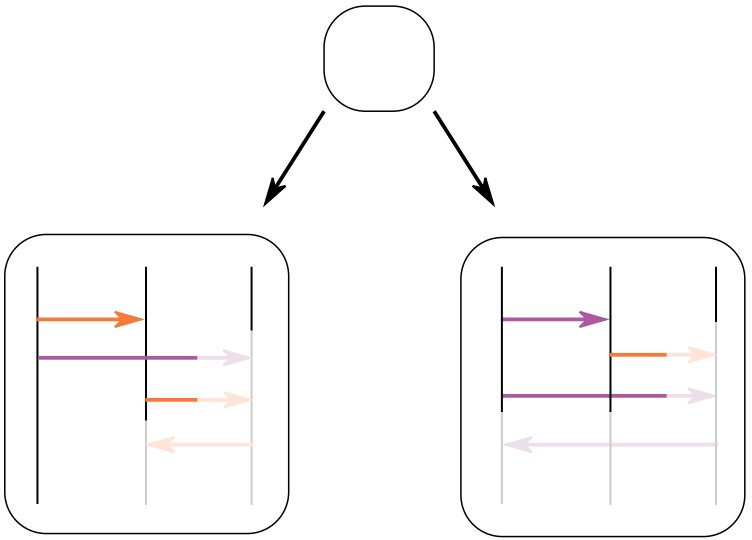
Another Example



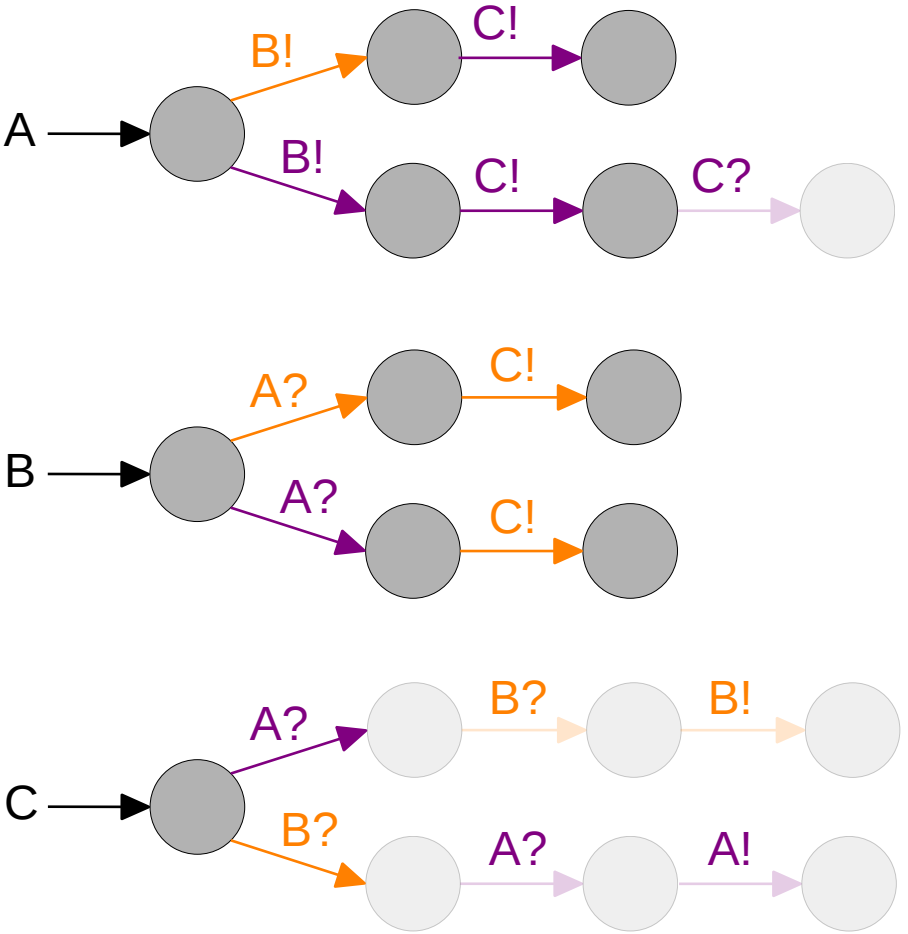
project



Which is Wrong



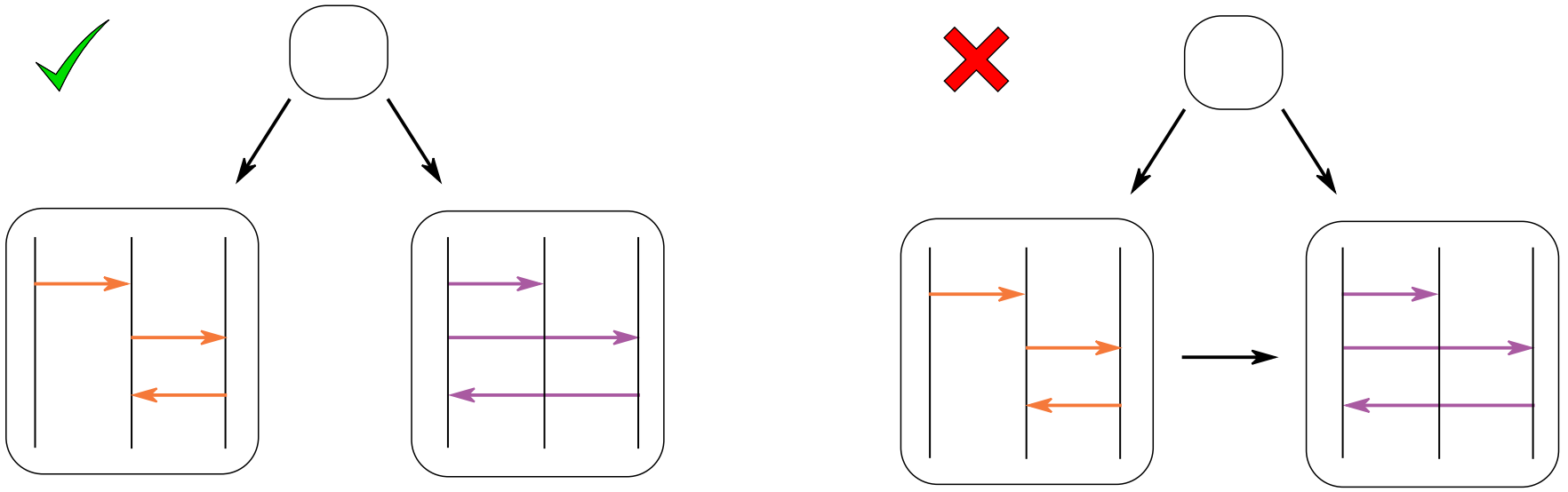
project



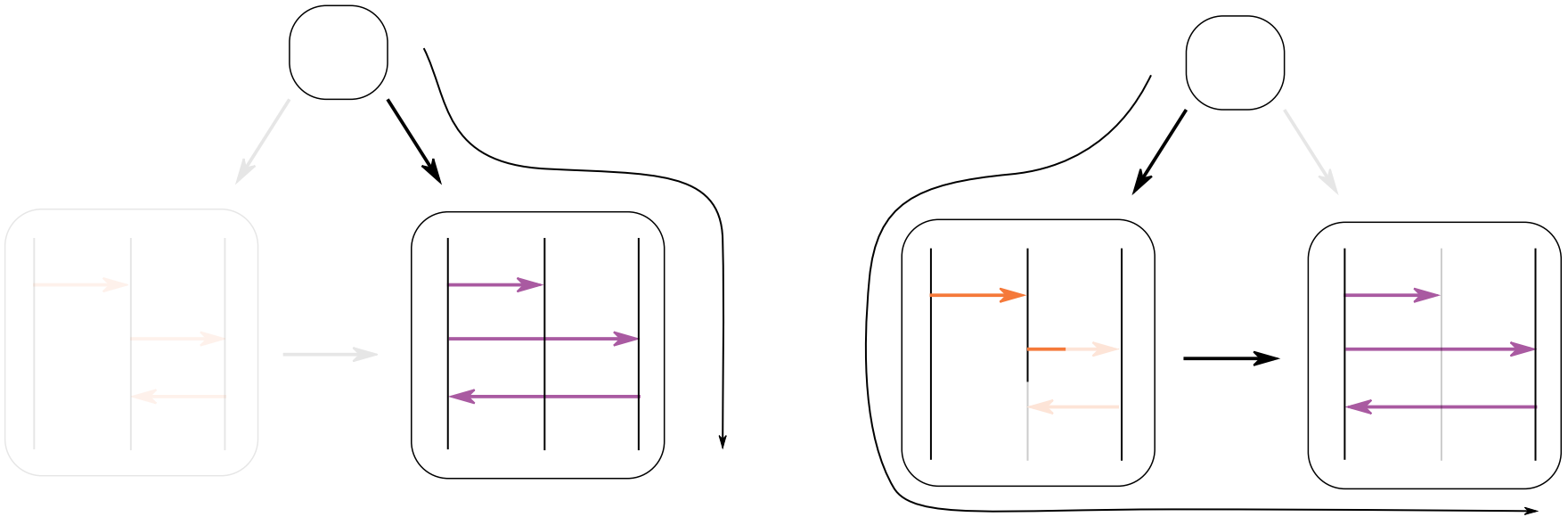
The messages from A,B are independent.
C cannot rely on their ordering.

No Compositionality

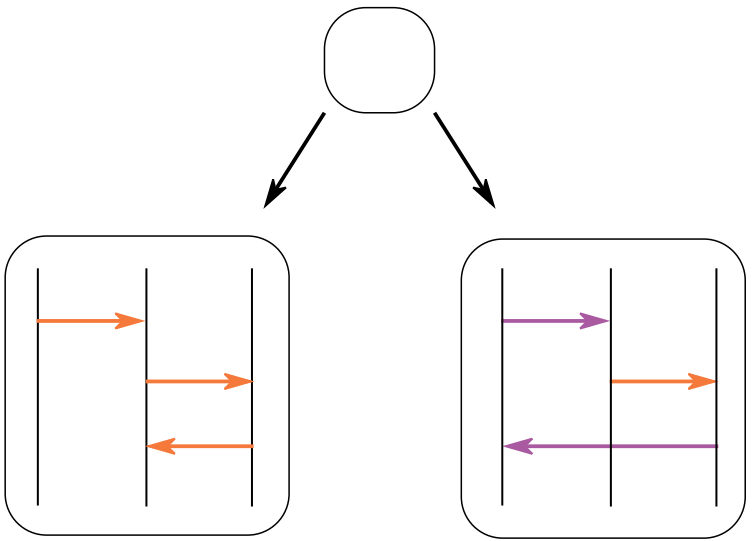
Composing two correct subprotocols can result in an incorrect one...



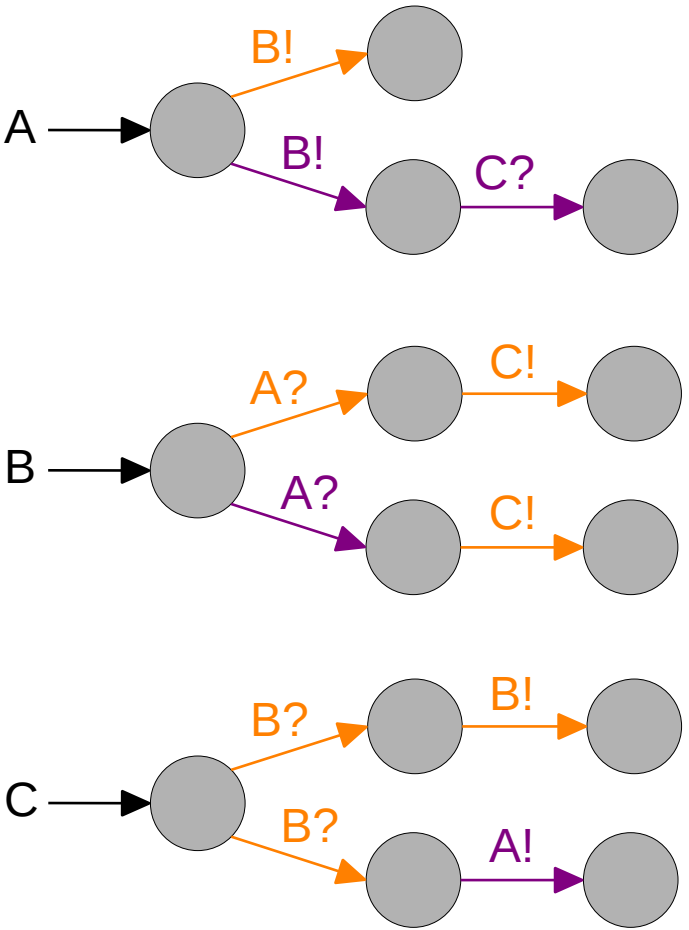
Counterexample



Determinism does not carry over



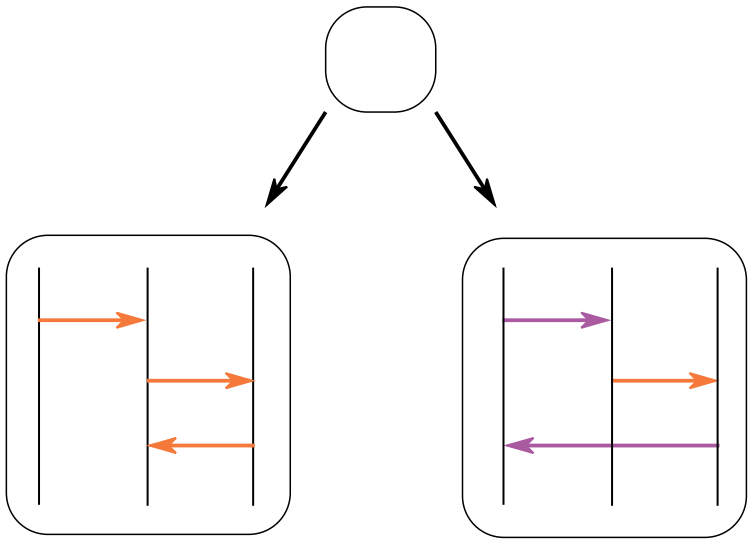
project



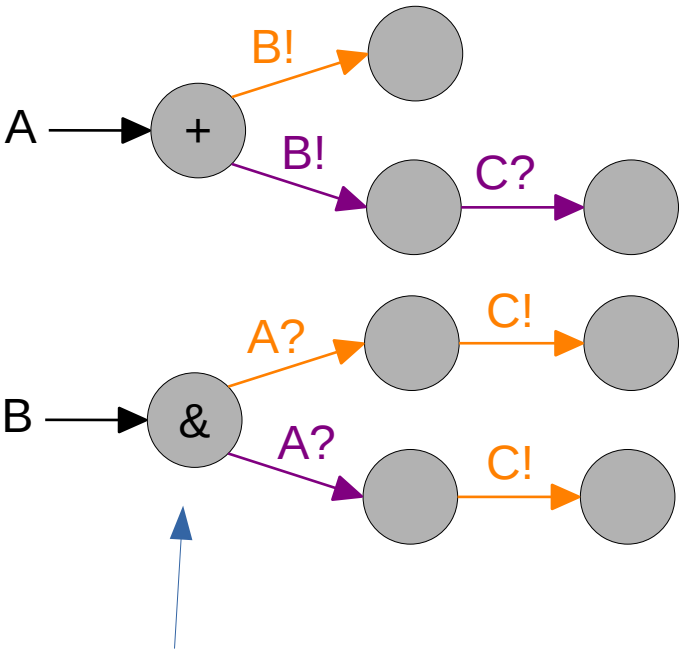
A makes the choice,
B is deterministic,
but C is not...

MST in a Nutshell (1)

Projects the protocol and checks the projection does not introduce unwanted nondeterminism.



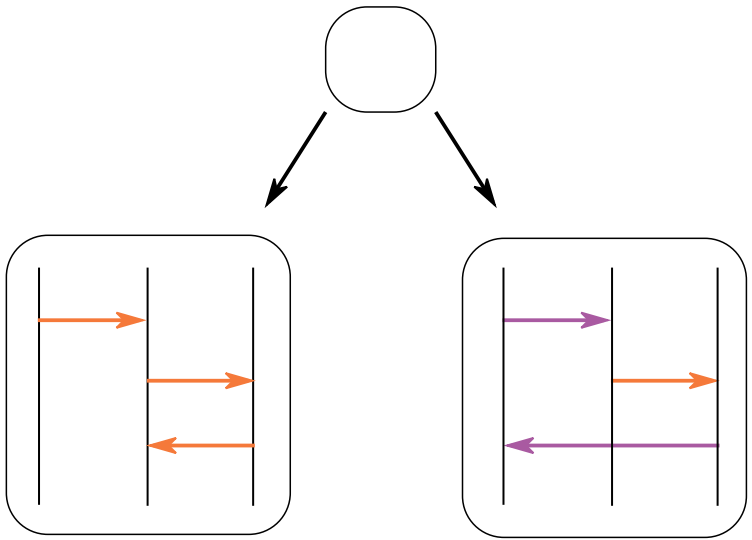
project



Keep track of internal/external choice

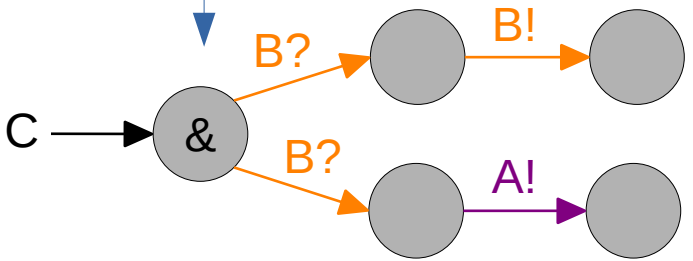
MST in a Nutshell (2)

Projects the protocol and checks the projection does not introduce unwanted nondeterminism.



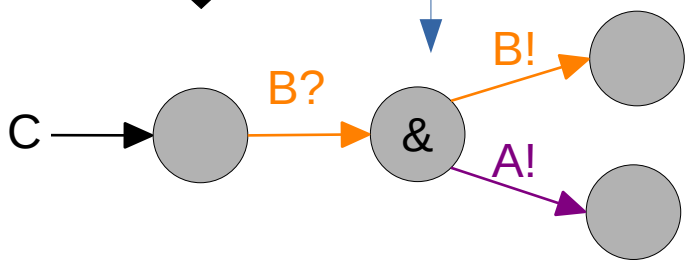
project

Same message on both side
Postpone choice resolution

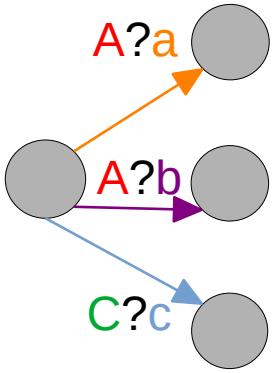


merge

External choice + send = error

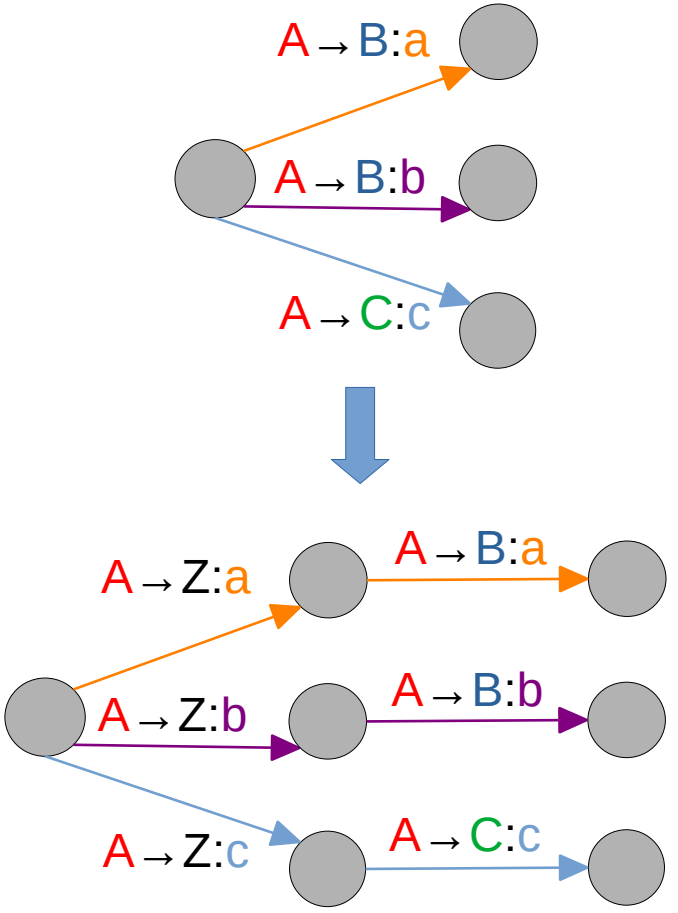


Generalized Choice

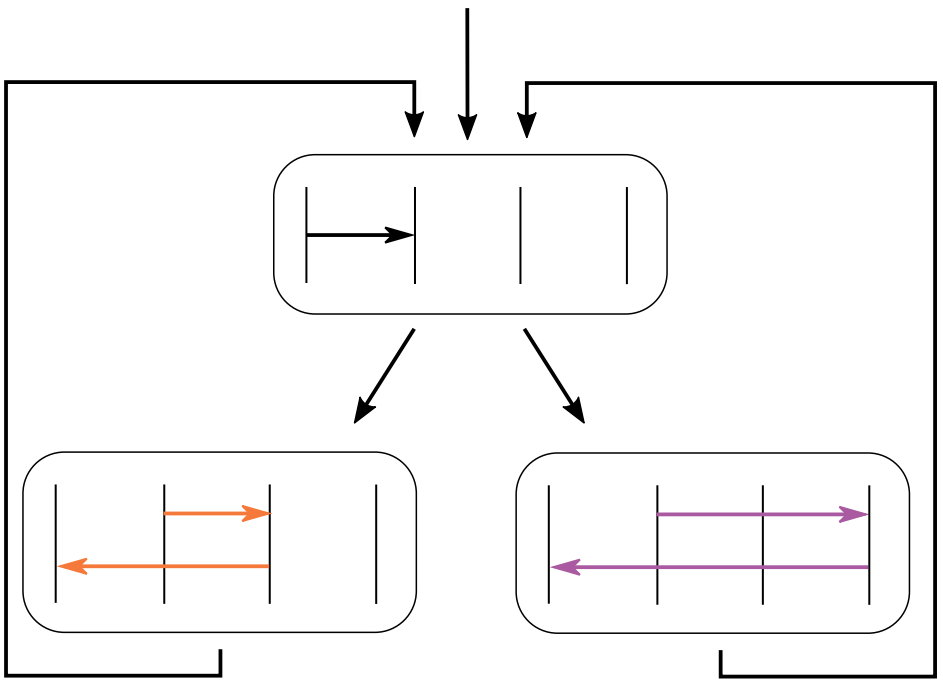


Local generalize receive that matters.

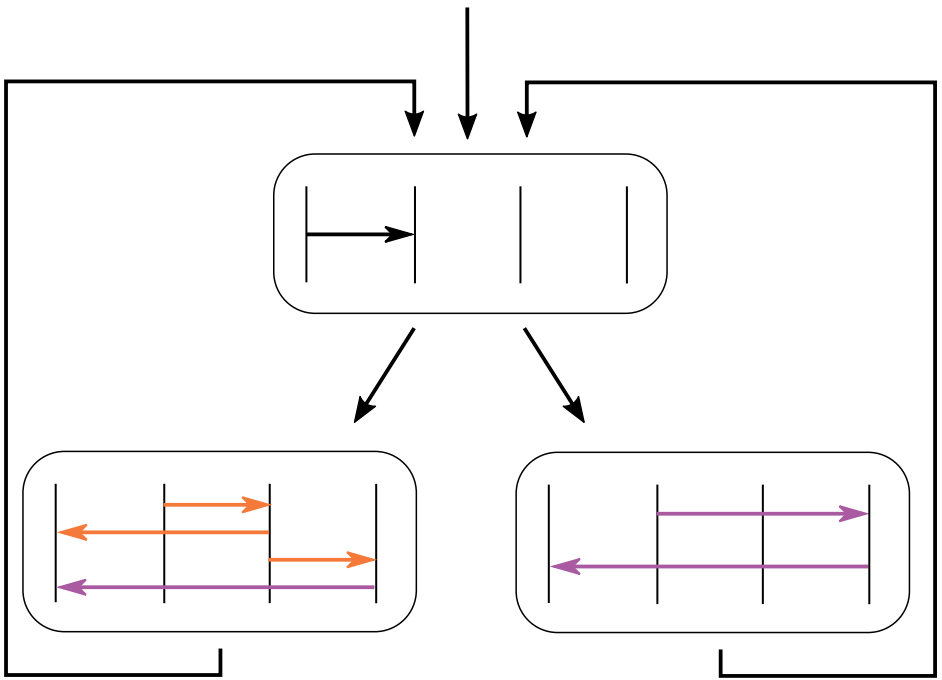
Global and sending can be simulated with an extra process.



Partial Order Across Channels

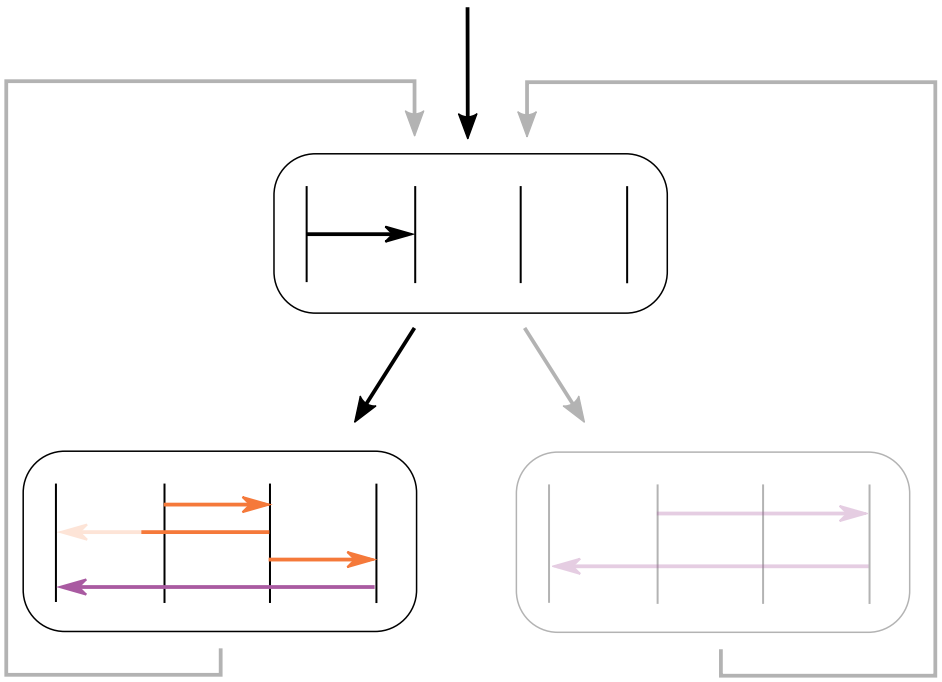


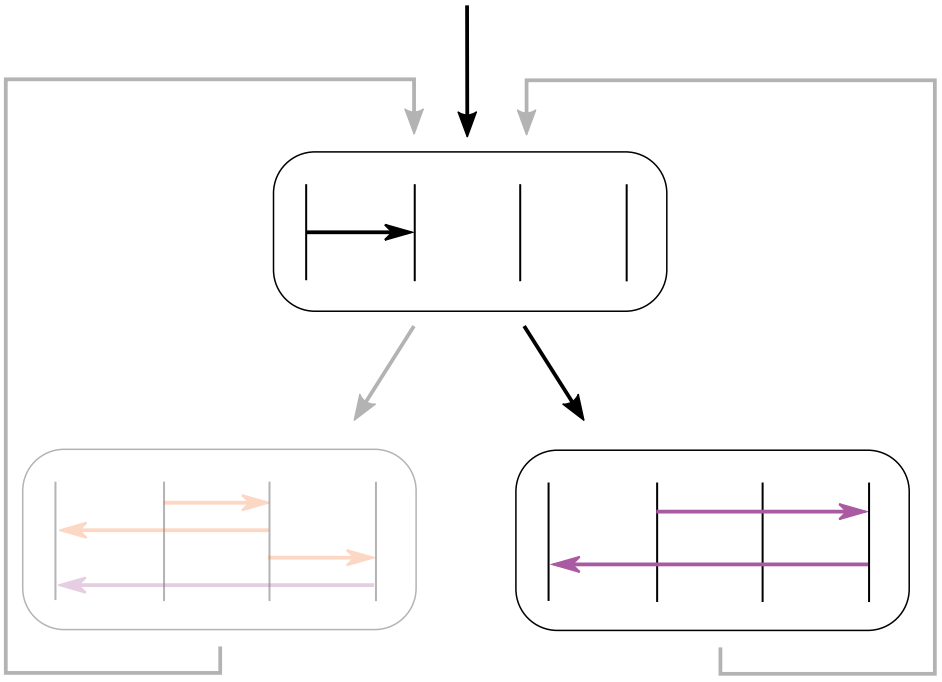
Well-formed



Wrong

Wrong Example





Projection and Merge

- Projection is similar to MST
- Merge checks for potential confusion

Available messages

$$\langle\, \&_{i\in I}\, \mathtt{q}_i?m_i.AL_{1,i}\ ,Msg_1\rangle \sqcap \langle\, \&_{i\in J}\, \mathtt{q}_i?m_i.AL_{2,i}\ ,Msg_2\rangle\ =$$

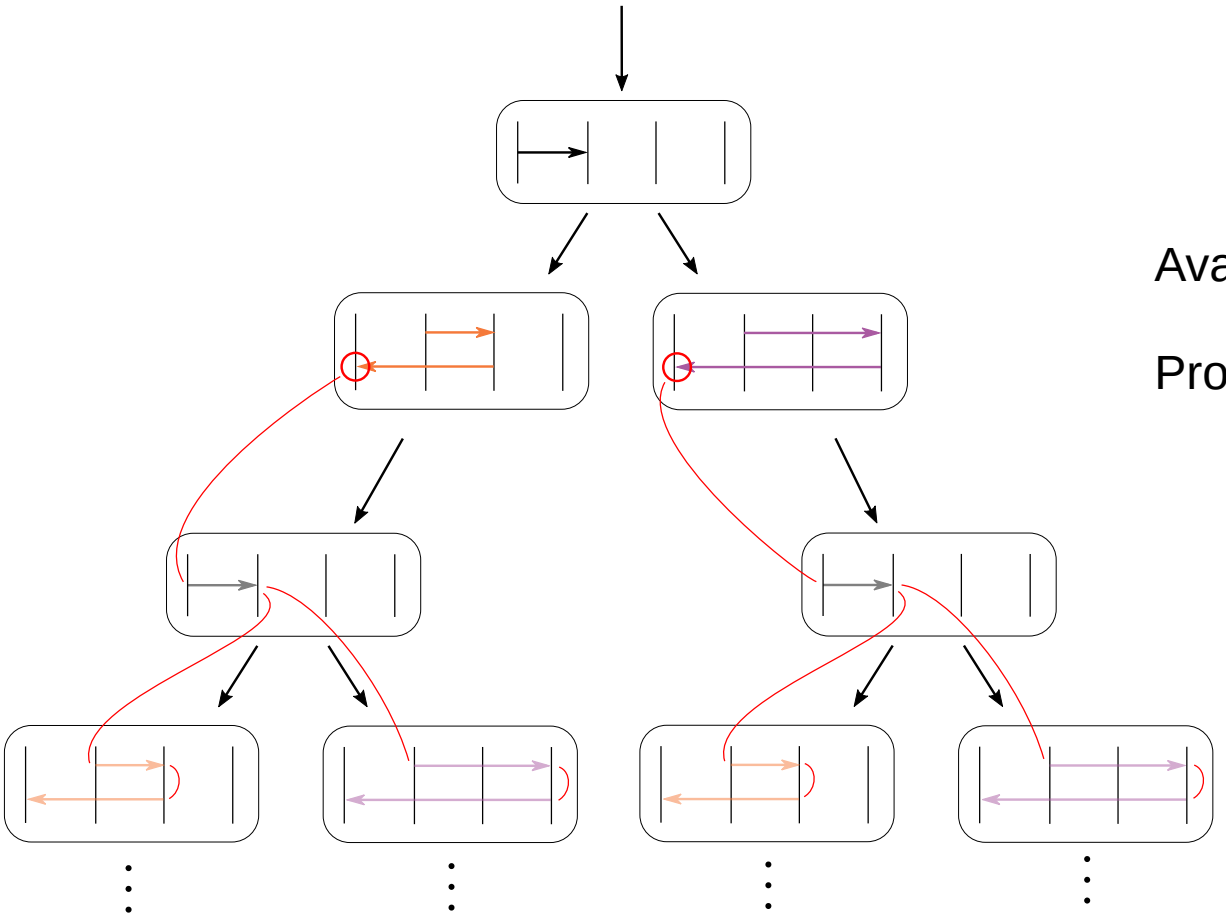
$$\&_{i\in I\setminus J}\, \mathtt{q}_i?m_i.AL_{1,i} \quad \&$$
$$\&_{i\in I\cap J}\, \mathtt{q}_i?m_i.(AL_{1,i}\sqcap AL_{2,i}) \quad \&$$
$$\&_{i\in J\setminus I}\, \mathtt{q}_i?m_i.AL_{2,i} \qquad if \begin{cases} \forall i\in I\setminus J.\, \mathtt{r}\triangleleft \mathtt{q}_i?m_i \notin Msg_2, \\ \forall i\in J\setminus I.\, \mathtt{r}\triangleleft \mathtt{q}_i?m_i \notin Msg_1 \end{cases}$$

No confusion

Available Messages

- 1st message in the channels (FIFO)
- Messages indep. from the receptions to merge
- Effectively computable (unfold recursion once)

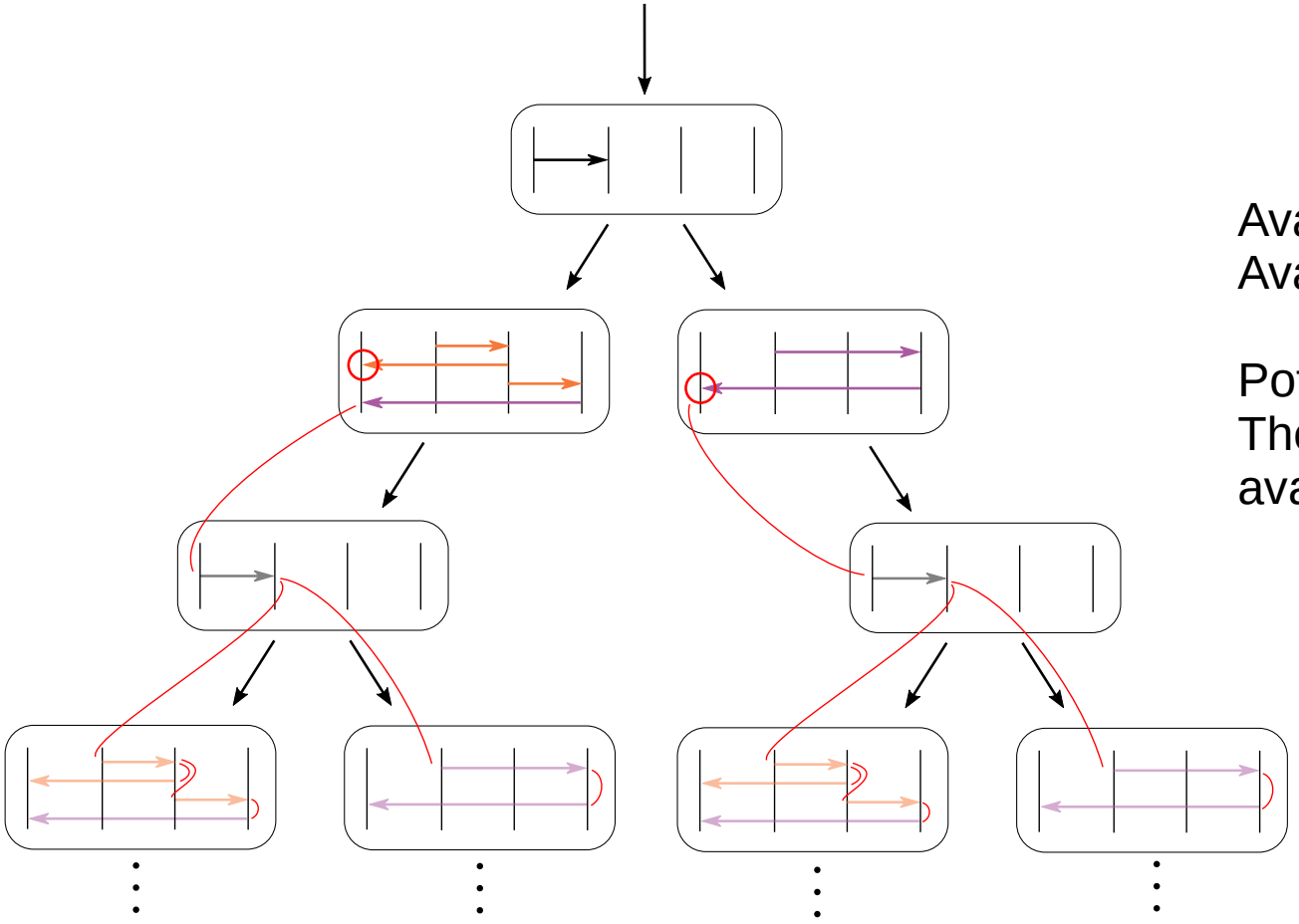
Computing Available Messages 1



Available messages are $\varnothing$.

Protocol is one long causal chain.

Computing Available Messages 2



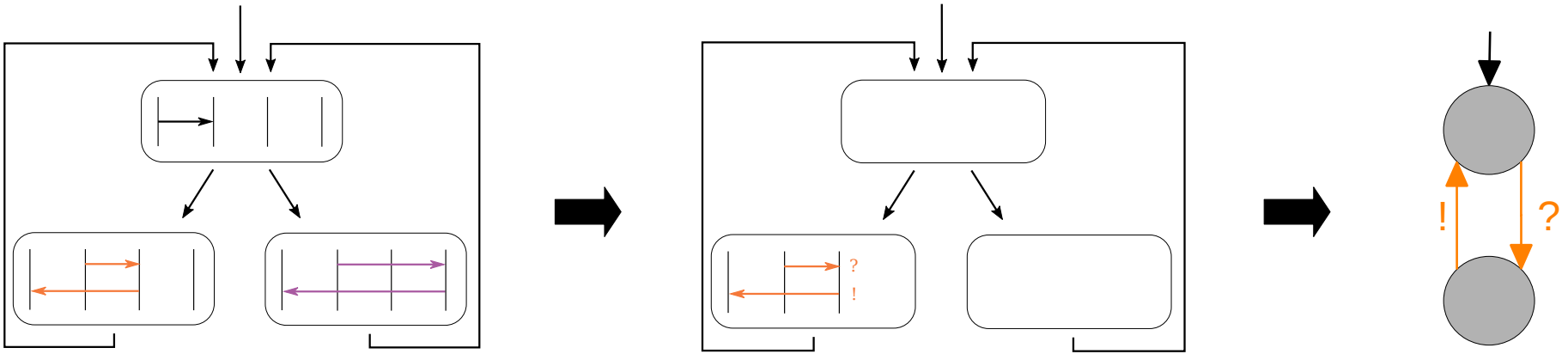
Available left branch: {←}
Available right branch: ∅

Potential confusion:
The right receive ← but it is also available on the left branch.

Empty Paths (Loops) Elimination

Each worker only appears in one branch.

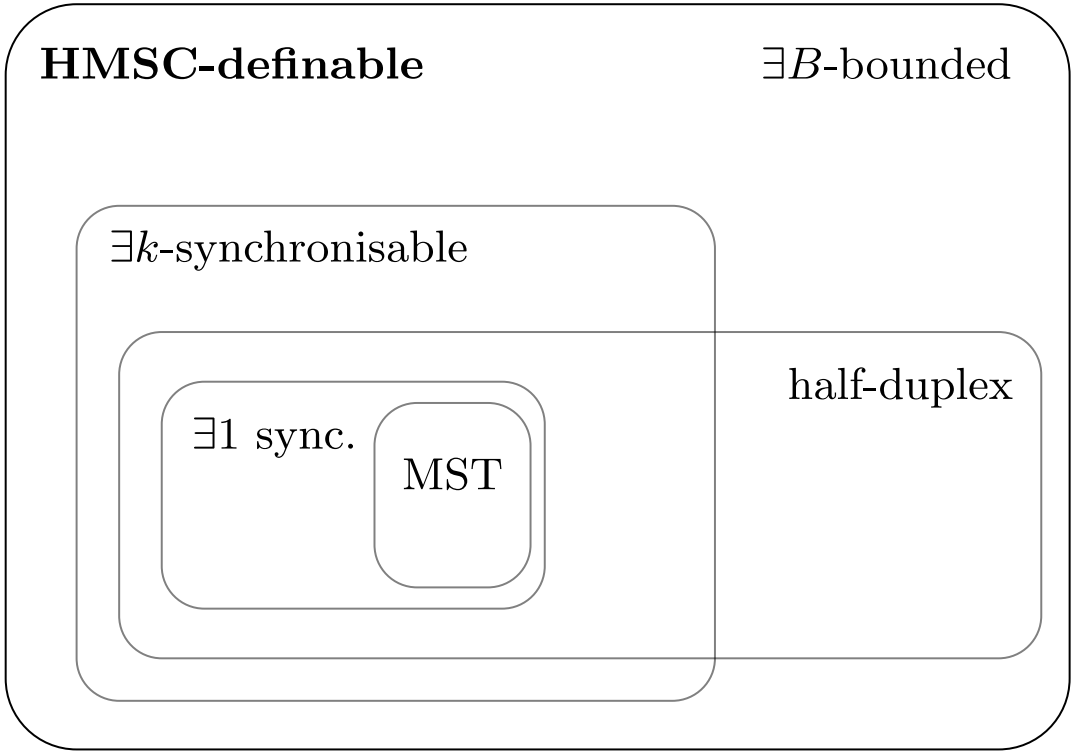
More general projection that allows loops where a process is not involved.



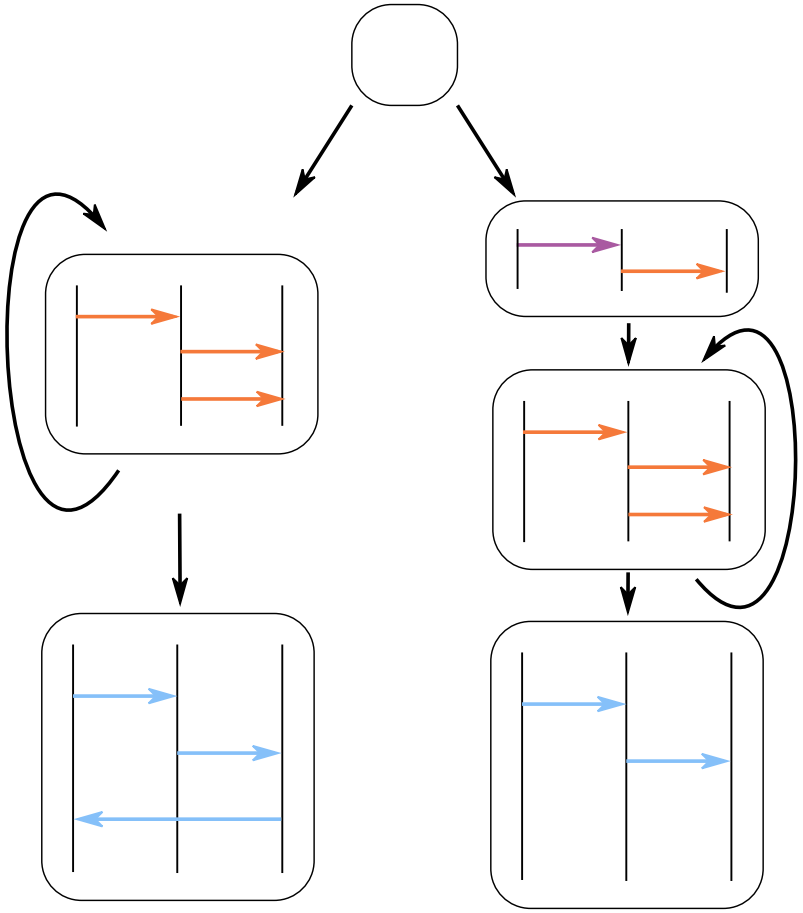
Future Work

- Understanding MST languages
- Completeness and loops
- Reordering of independent receive
- Subtyping

Understanding MST Languages



Completeness and Loops

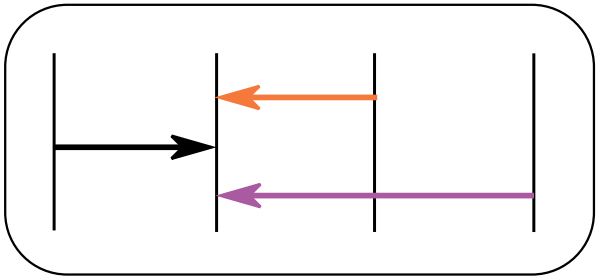


Implementable but rejected by MST.

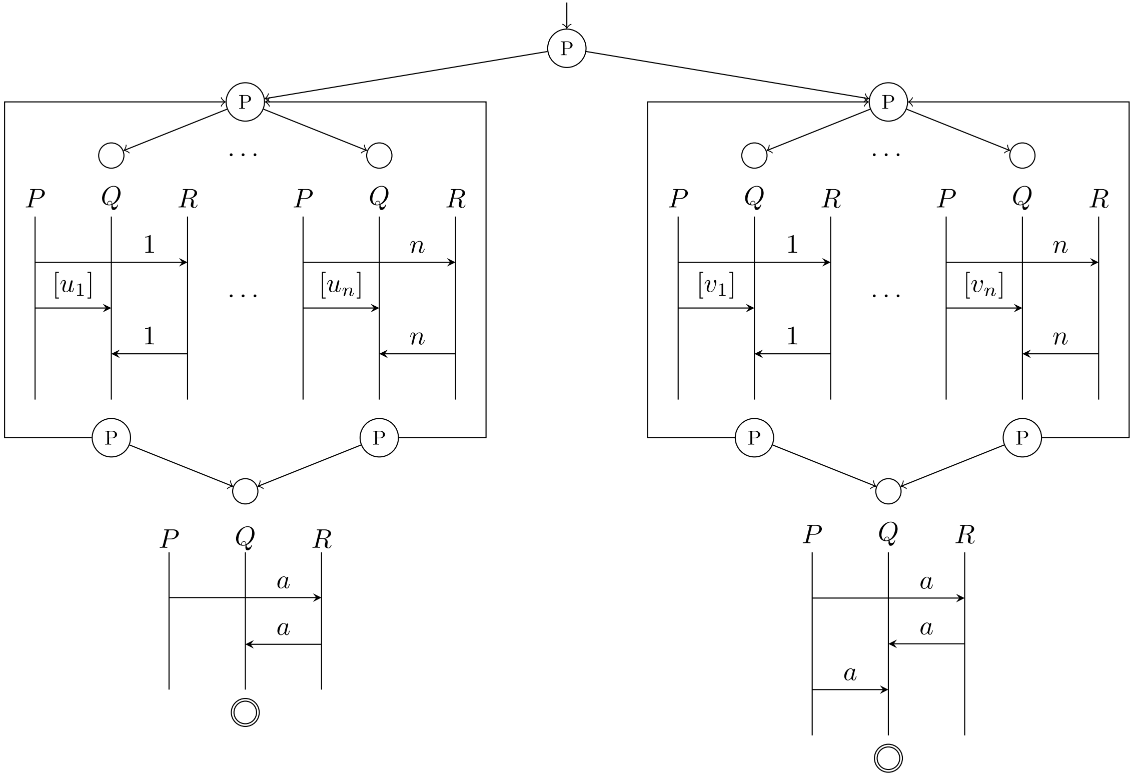
directed choice
∃1-bounded
∃1-sync
half-duplex

Intra-Process Reordering

- Somewhat similar to precise subtyping
- Motivation: performance, process independent messages in their order of arrival



Unfolding with Reordering ...

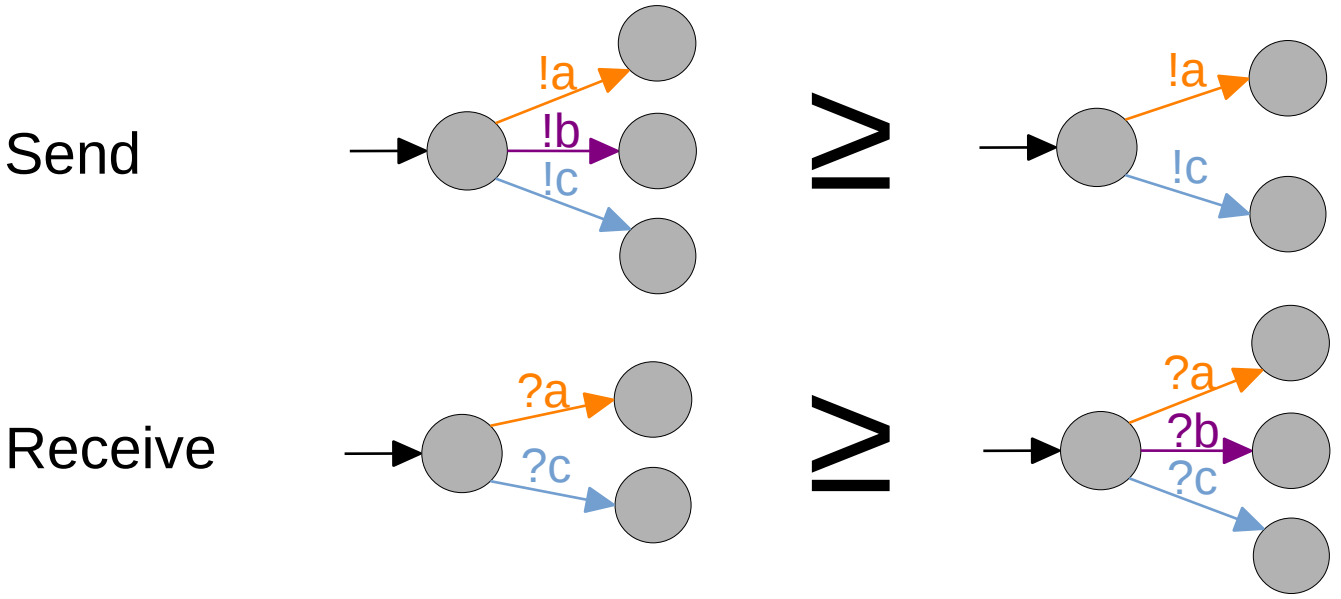


PCP encoding

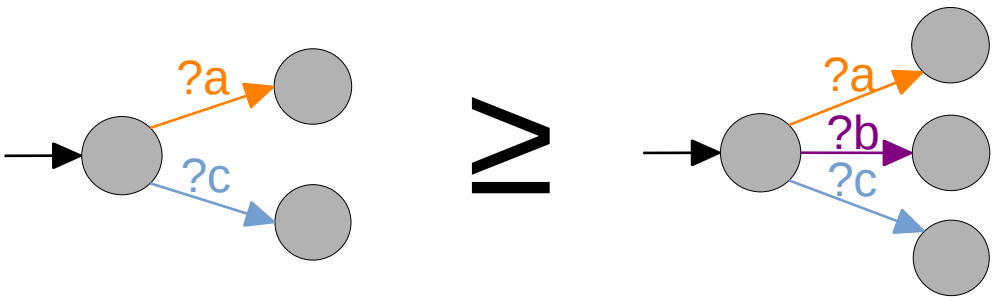
… is hard.

Subtyping

What we expect for “typical” subtyping rules



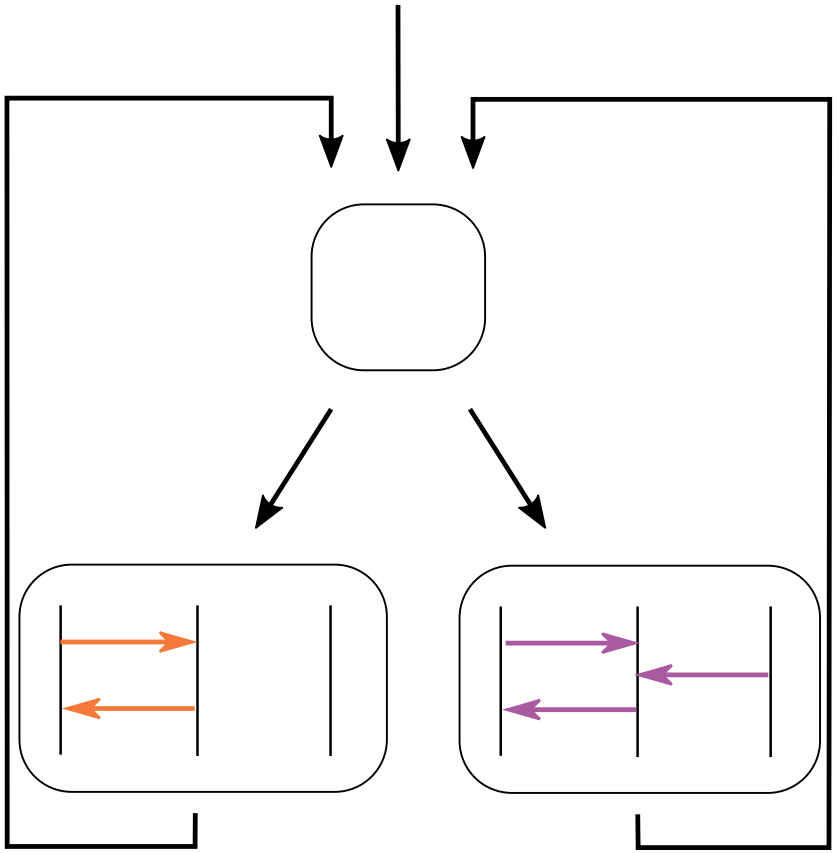
Subtyping: Receive



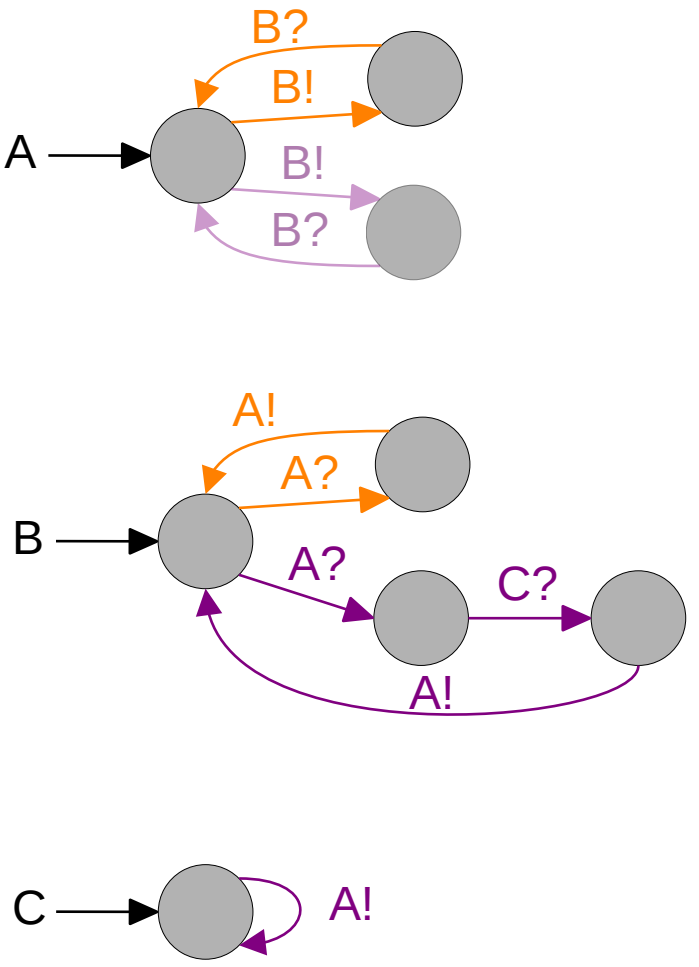
If ?b is an available messages.

Subtyping is not local but needs global information.

Subtyping: Send

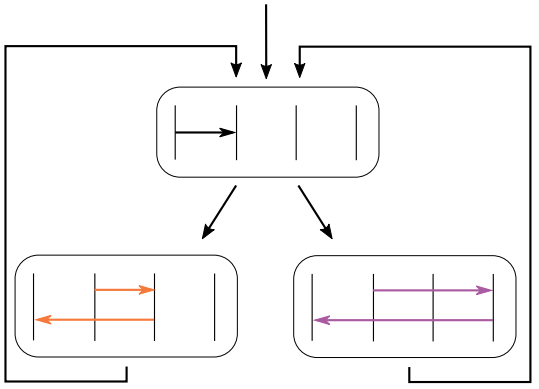


project



Conclusion

- Understanding how to specify communication protocols
- Finding the balance between expressiveness and complexity
- Generalized choice with projection that computes the available messages.



https://gitlab.mpi-sws.org/fstutz/async-mpst-gen-choice