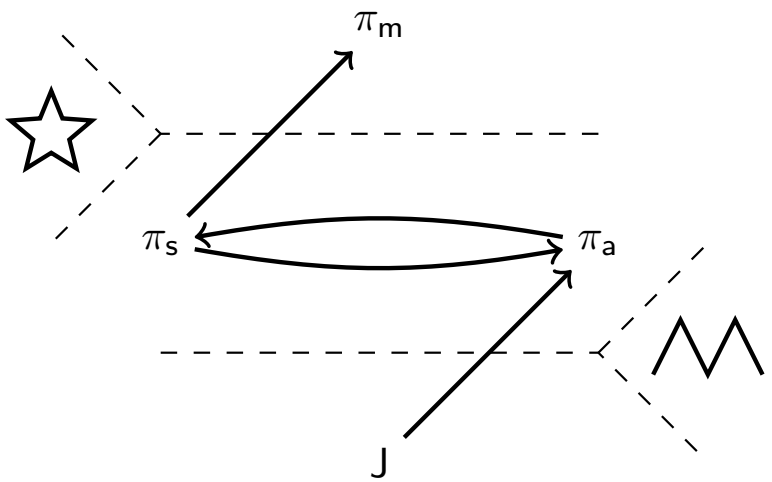
Kirstin Peters
Uwe Nestmann

"False Distribution"
Translational Expressiveness
Comparing Process Calculi Using Encodings



$$[\![P \mid Q]\!] \stackrel{?}{=} [\![P]\!] \mid [\![Q]\!]$$

Synchronous and Asynchronous Interaction in Dist. Sys.

(* joint project with TU Braunschweig [Goltz, Schicke, Glabbeek] *)

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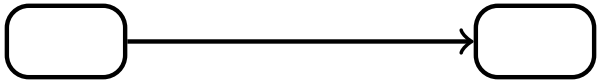

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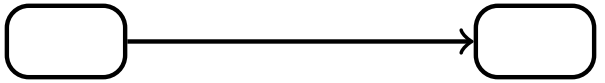
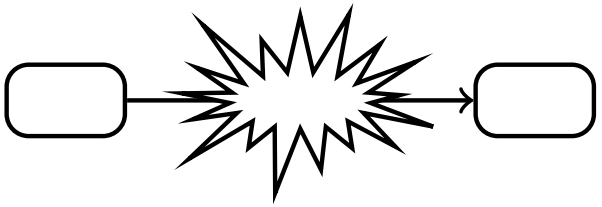


Synchronous Communication:



- instantaneous

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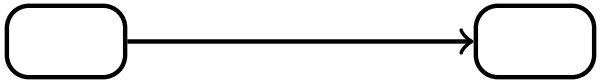

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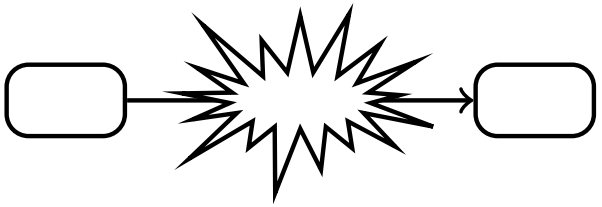

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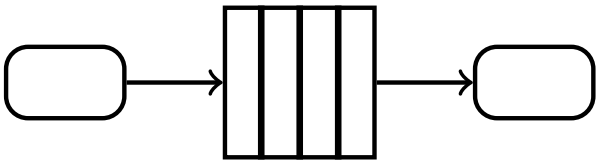
Asynchronous Communication:



- takes time

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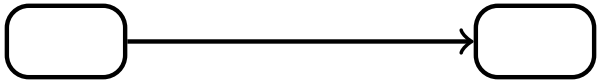

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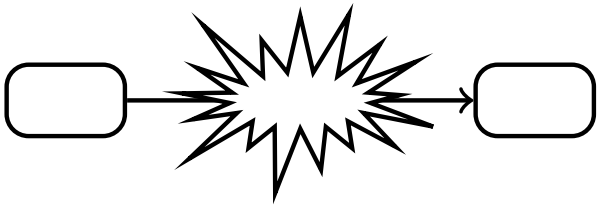

- instantaneous
- *abstract* specification

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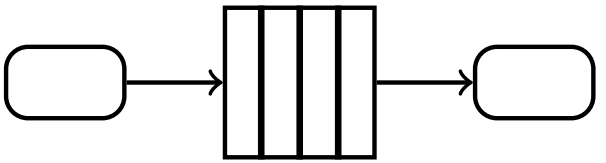

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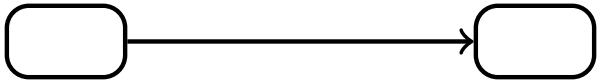

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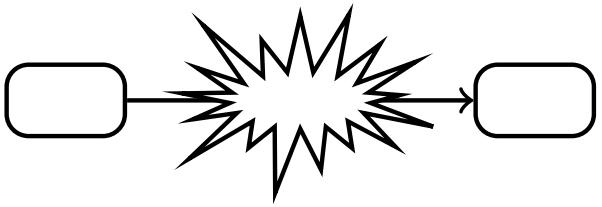

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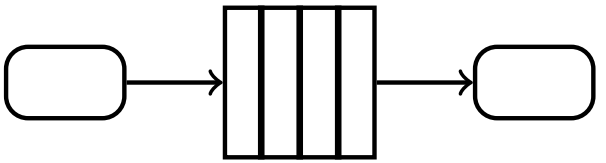

- takes time
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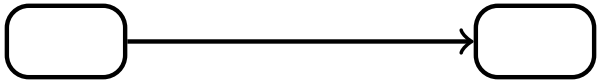

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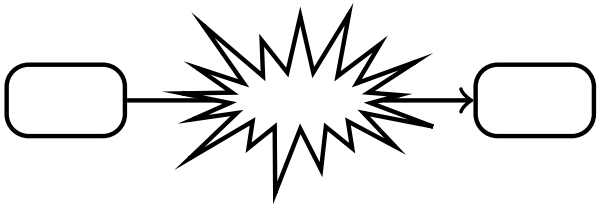

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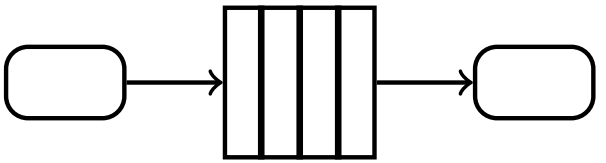

- takes time
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Implement asynchrony in synchrony while preserving distributability?

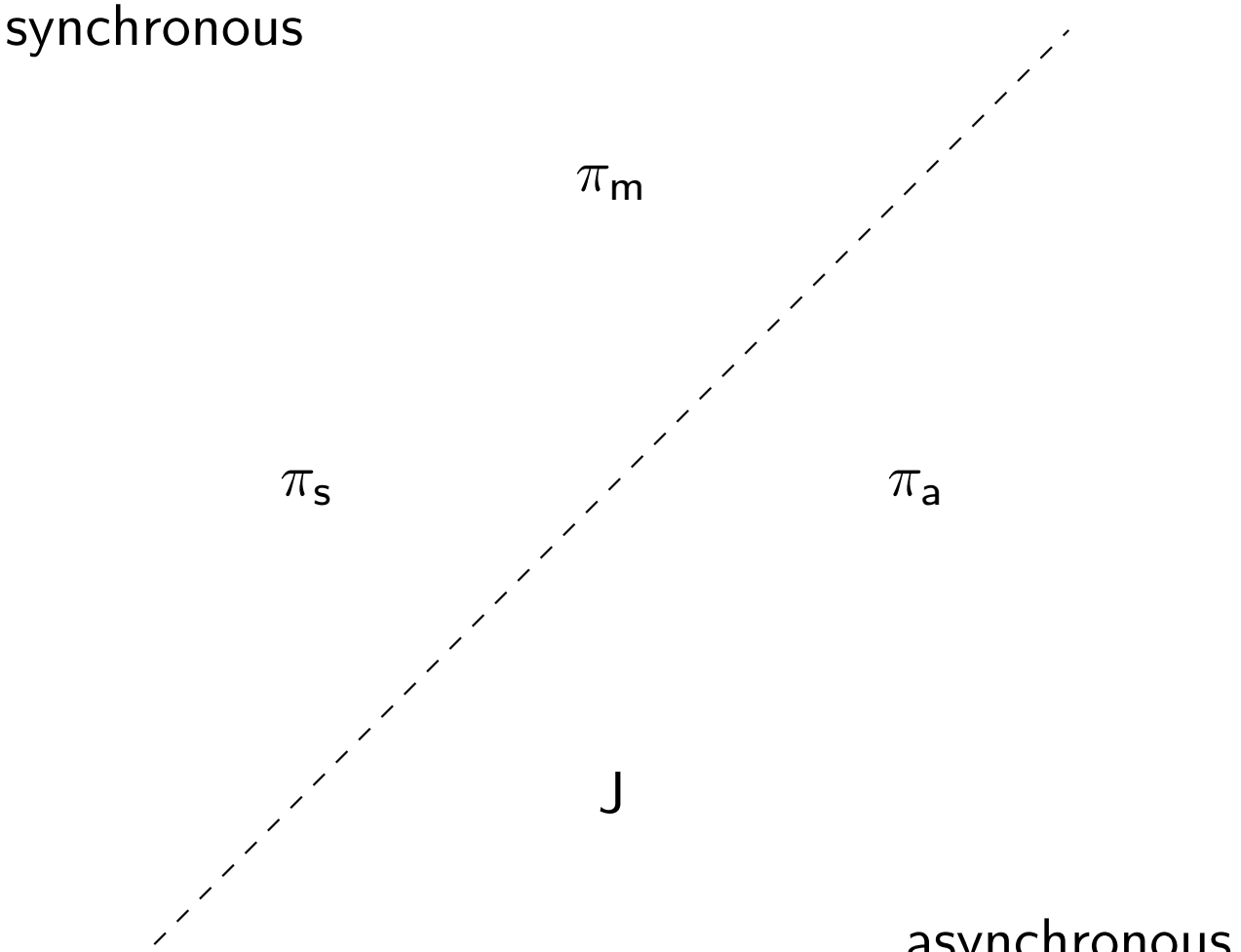
Distributability in Pi-like Calculi

π_m

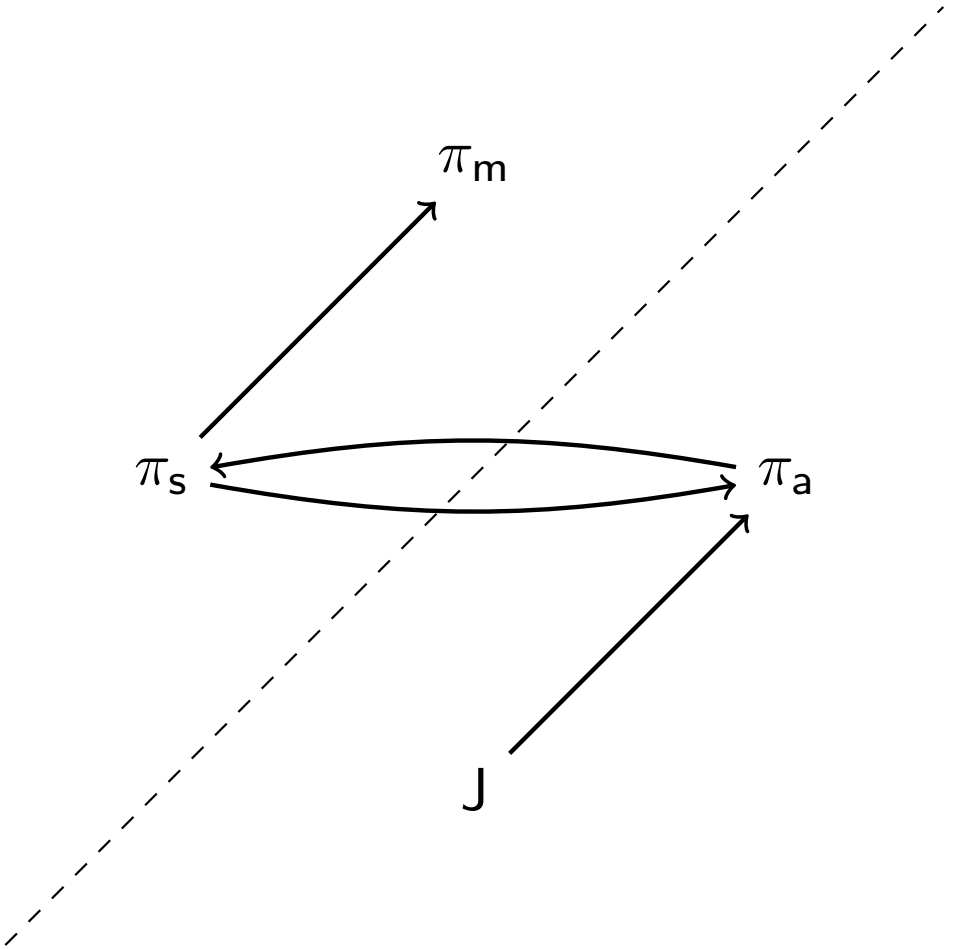
π_s π_a

J

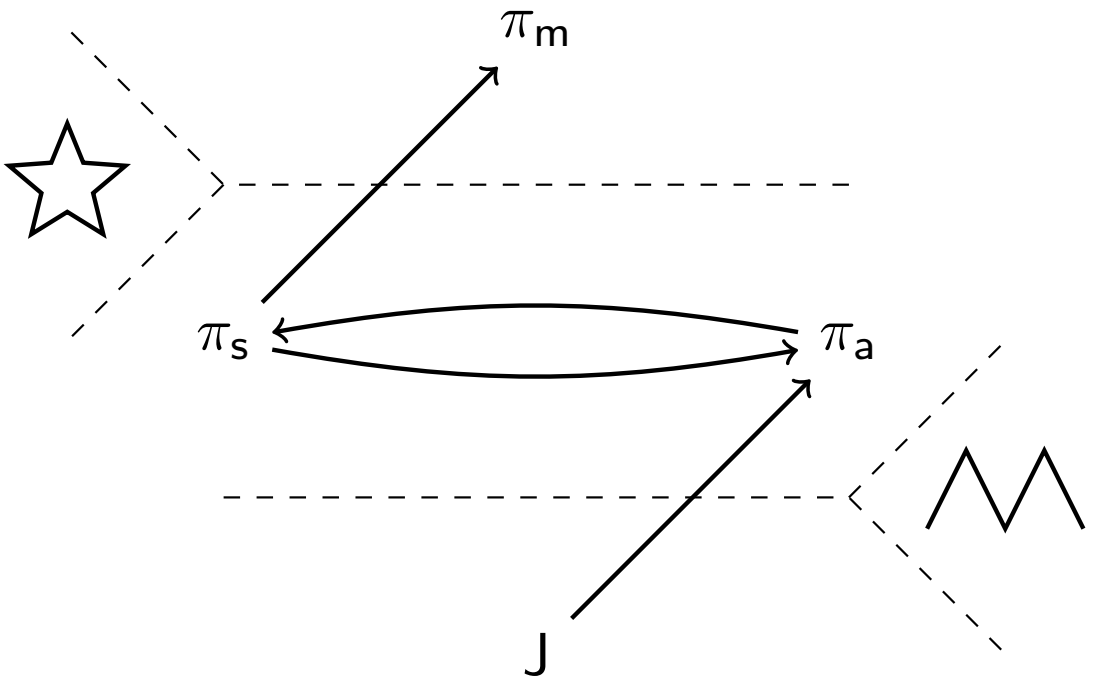
Distributability in Pi-like Calculi



Distributability in Pi-like Calculi



Distributability in Pi-like Calculi



Process Calculi—Variants of the Pi-Calculus

$$\mathcal{L} = \langle\, \mathcal{P}, \longmapsto \,\rangle$$

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Process Terms:

$$\mathcal{P}_{\mathsf{a}} ::= 0 \quad | \quad P_1 \mid P_2 \quad | \quad (\nu x)\, P \quad | \quad \overline{y}\langle z \rangle .0 \quad | \quad y(x) .P \quad | \quad y^{\star}(x) .P$$

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Reduction Semantics:

$$y(x)\,.P \mid \overline{y}\langle z \rangle .Q + a(b)\,.R$$

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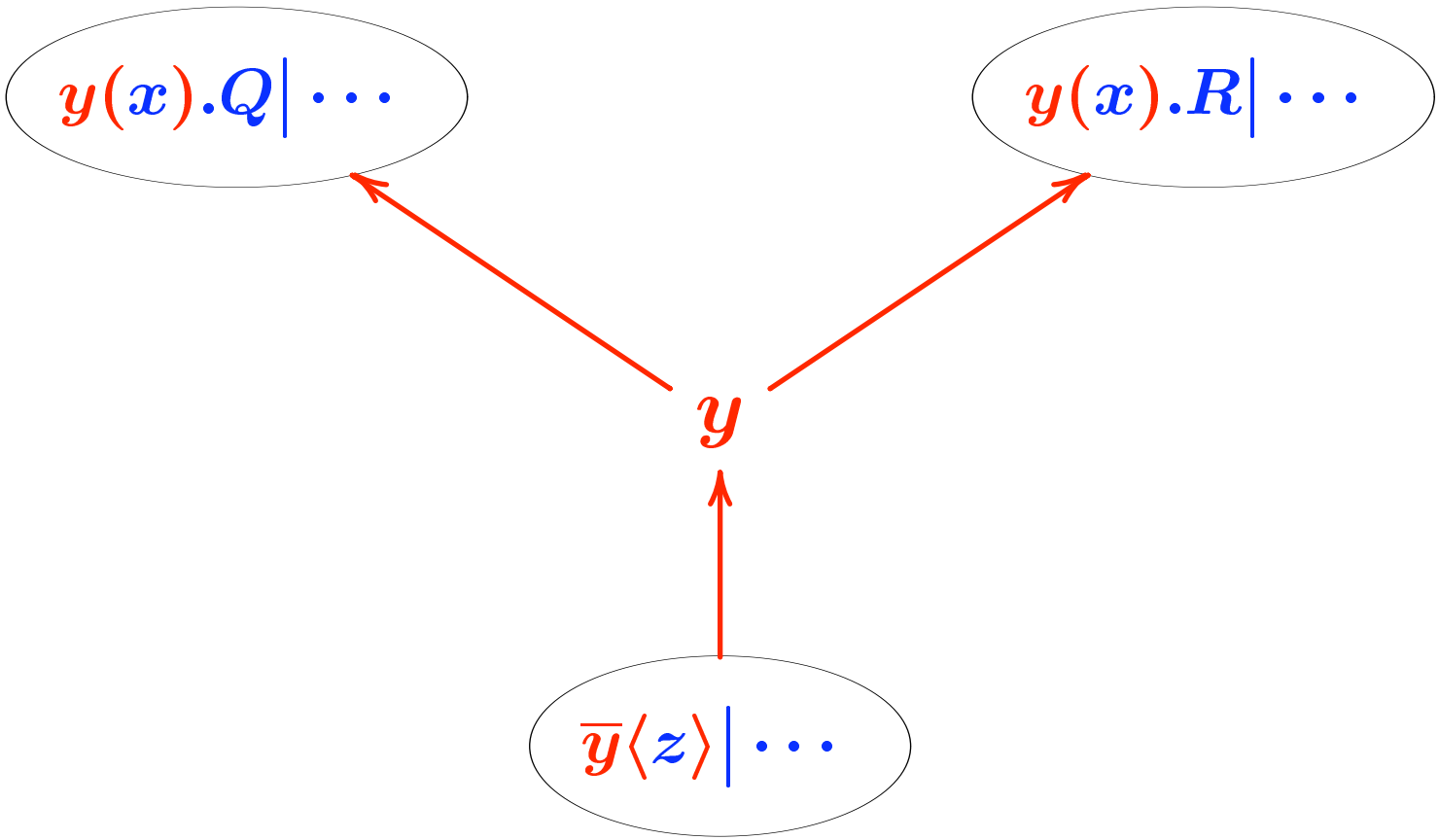
$$y(x) .P \mid \overline{y}\langle z \rangle .Q + a(b) .R \longmapsto \{\, {}^{z}/_{x} \,\}\, P \mid Q$$

Process Calculi—The Join-Calculus

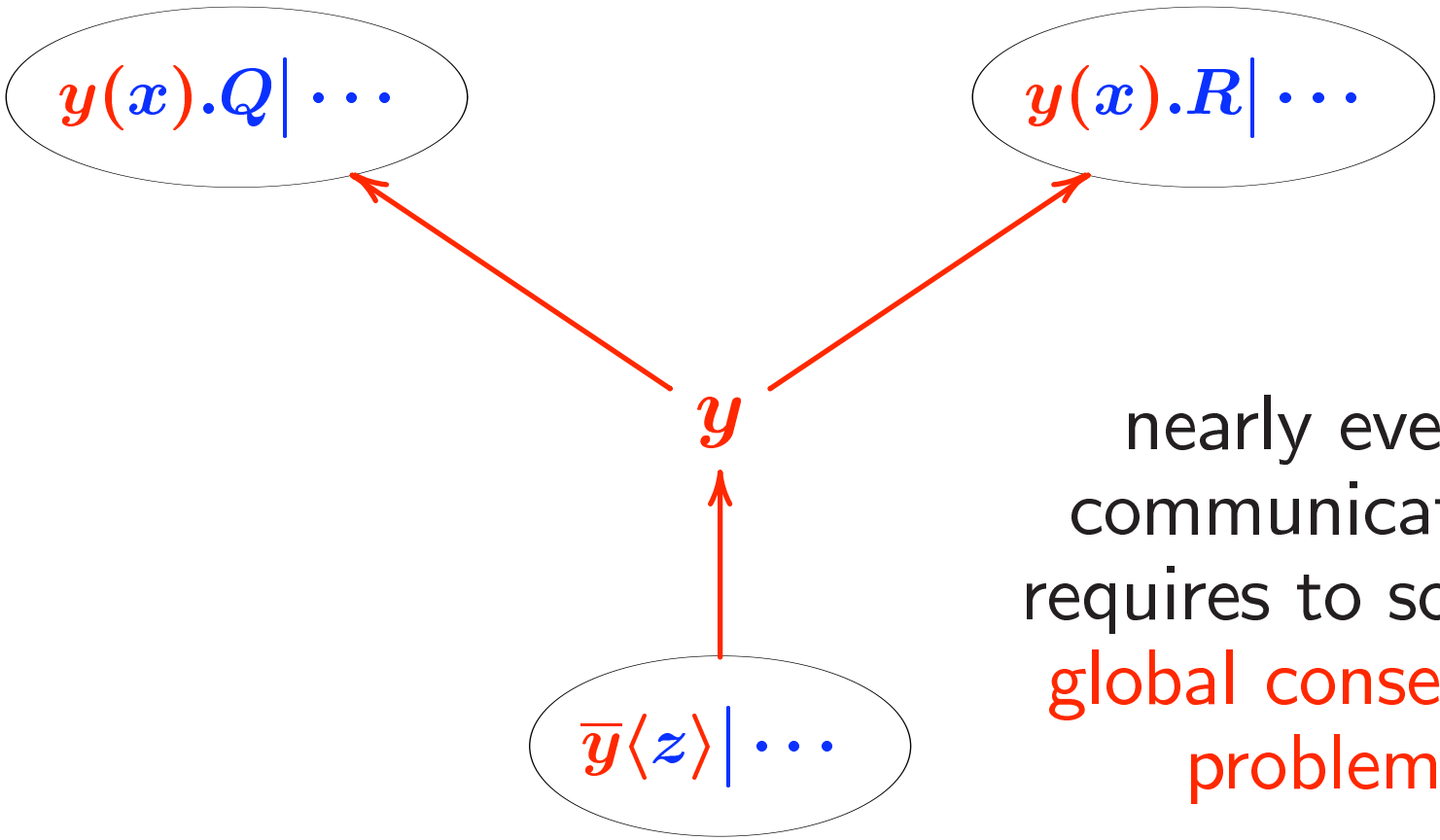
The Quest for Implementability

— Join —

Distributed Implementation

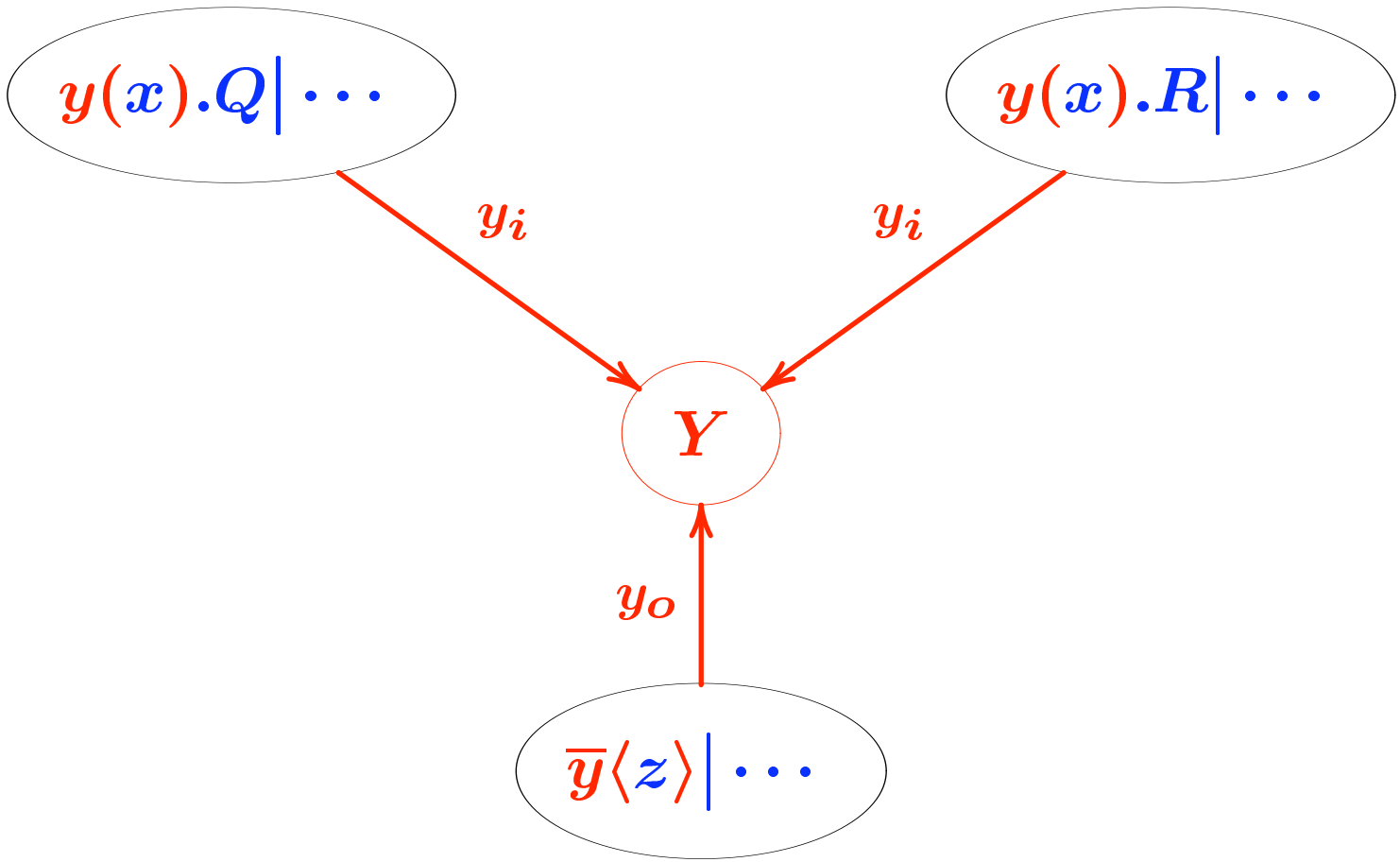


Distributed Implementation



nearly every communication requires to solve a global consensus problem

Unique Channel Managers



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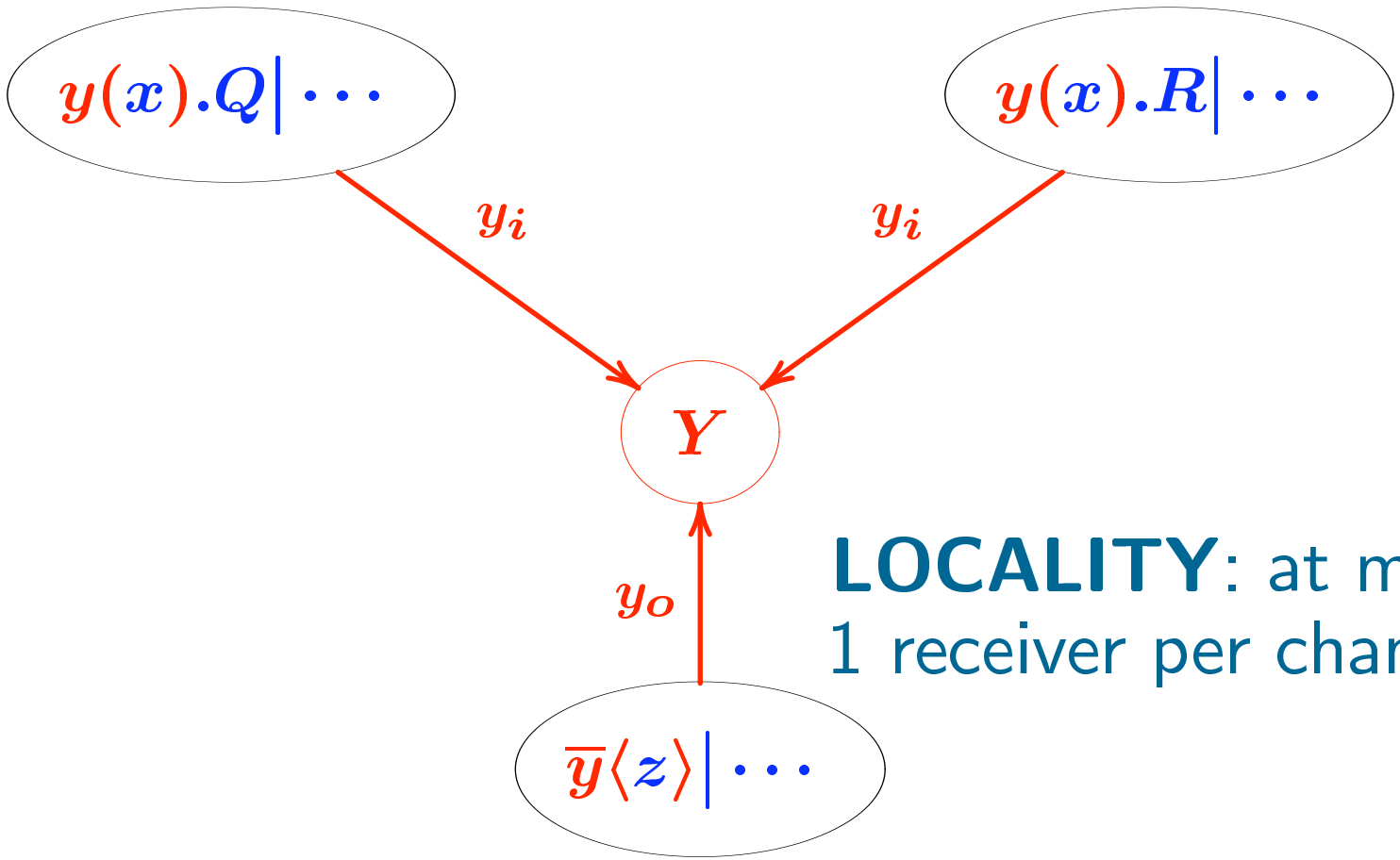
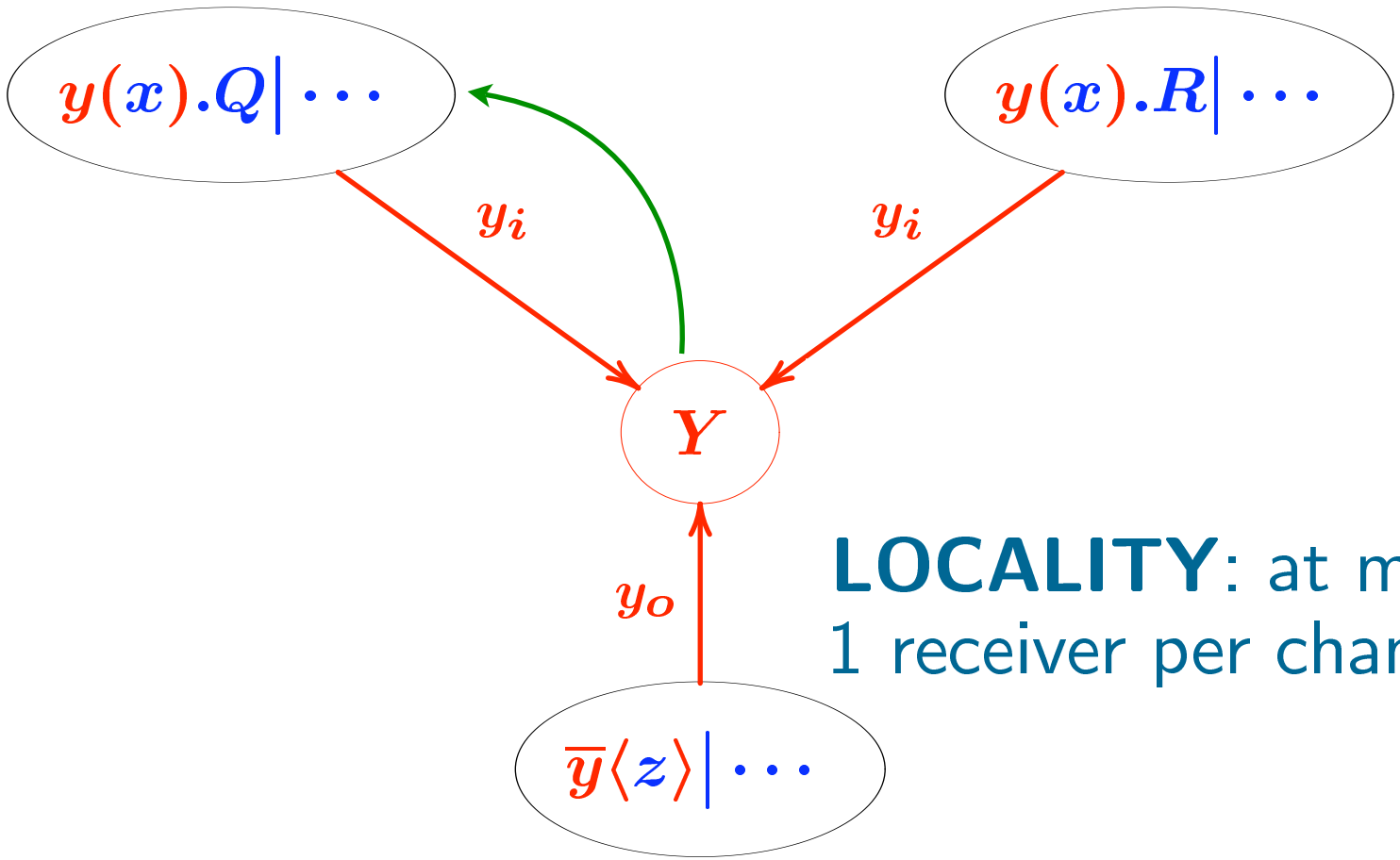


LOCALITY: at most 1 receiver per channel

Unique Channel Managers



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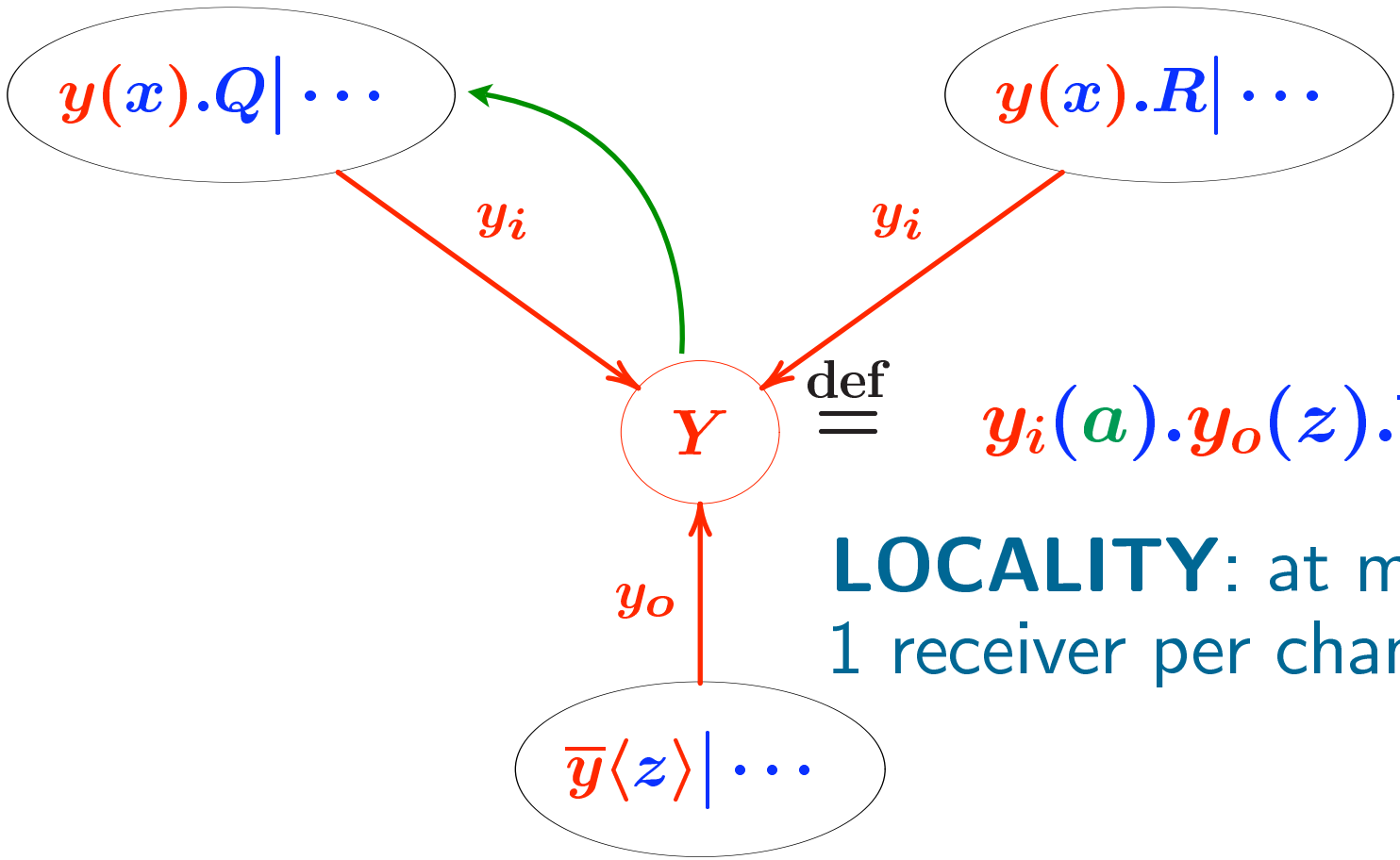

$y_i(a).y_o(z).\overline{a}\ z$

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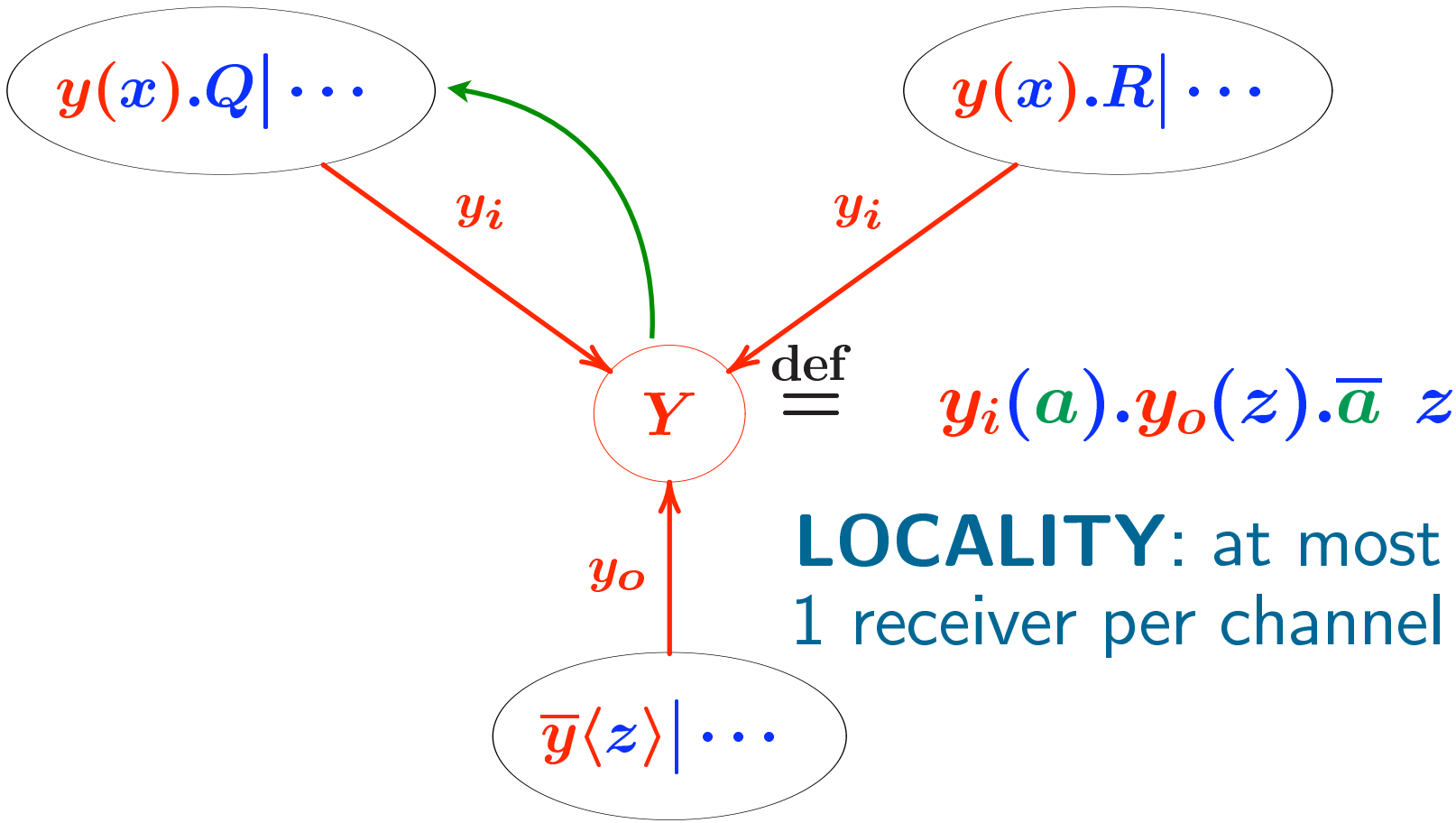
Unique Channel Managers



LOCALITY: at most
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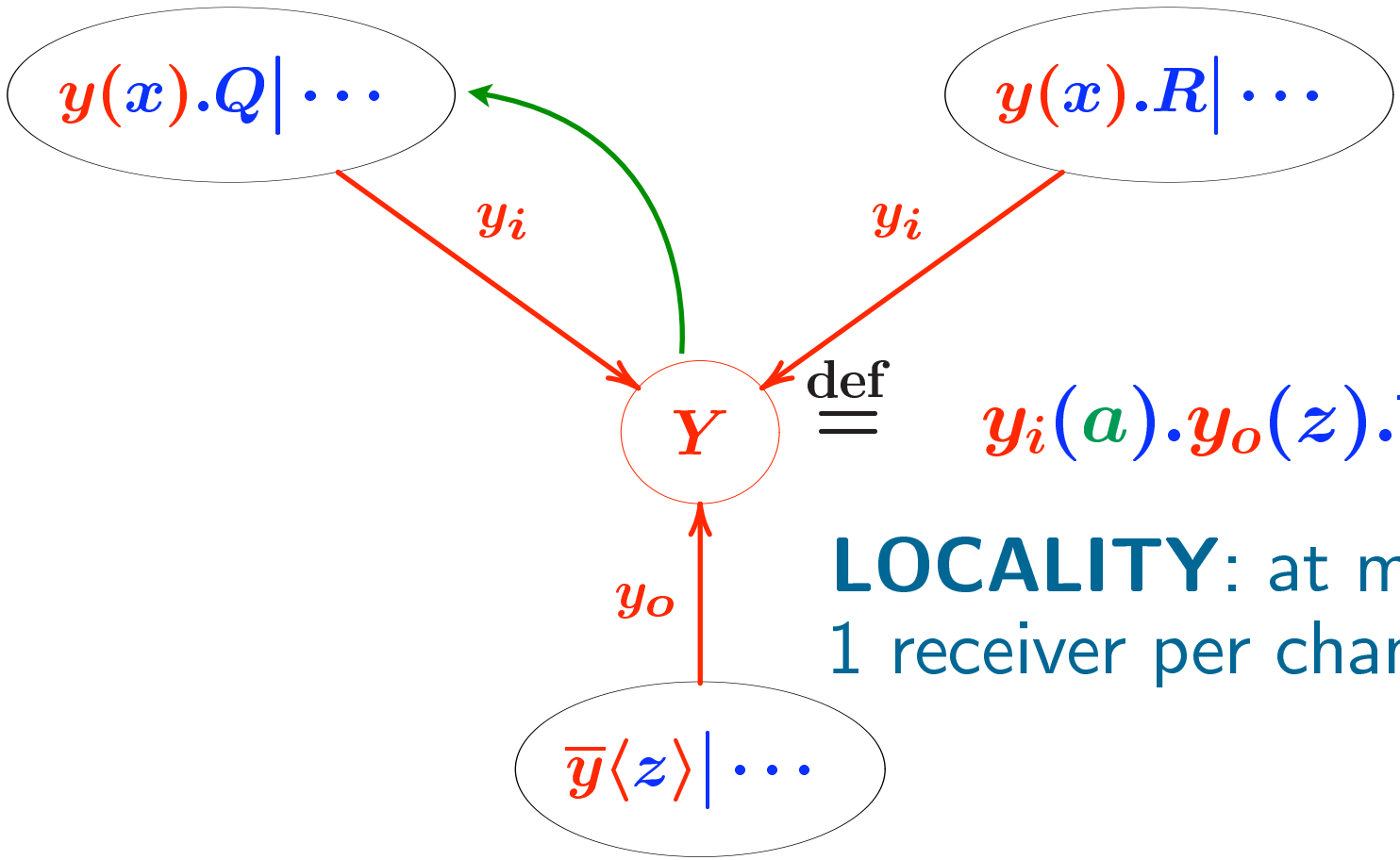
Note: the power and convenience of name-passing ...

Unique Channel Managers



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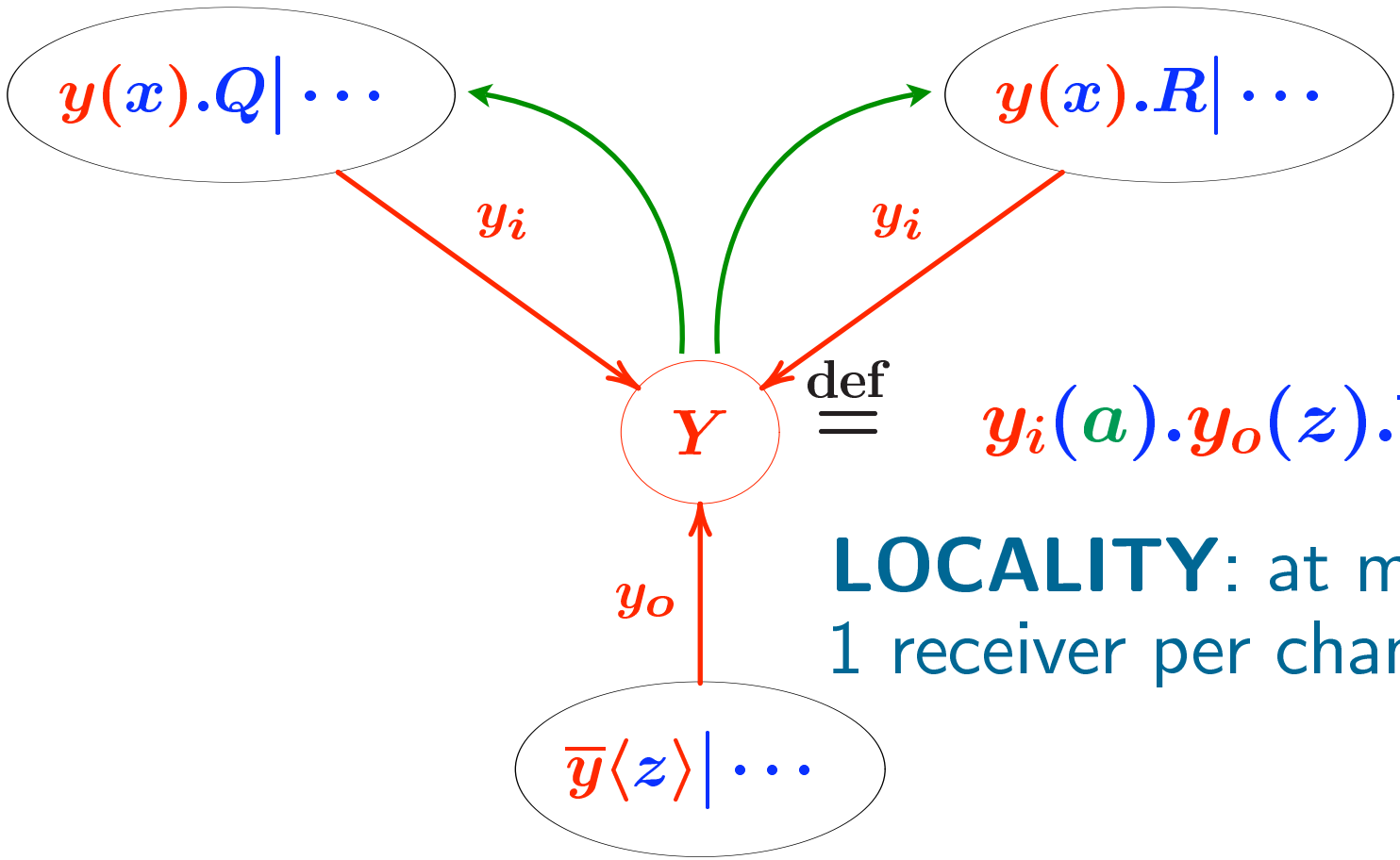

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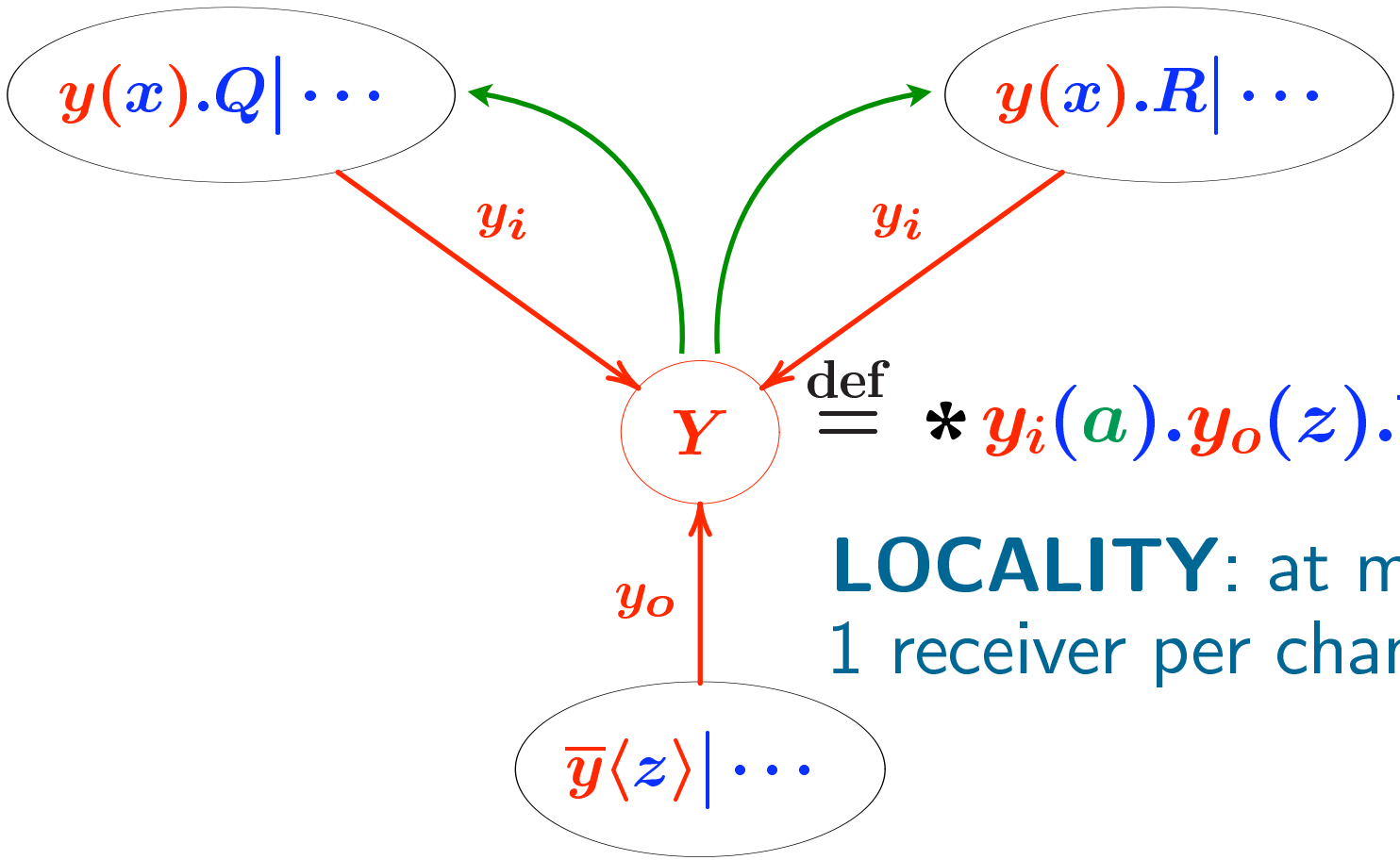

$\stackrel{\text{def}}{=} * y_i(a).y_o(z).\overline{a}\ z$

LOCALITY: at most 1 receiver per channel

$\pi^{\mathbf{def}}$

residence site = creation site
avoids unnecessary global communications

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$$(\nu y)\, P$$
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$$(\nu y)\,(\; *\, y(x).P \;\mid\; Q\;)$$

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$$\mathbf{def}\;\; y(x) = P \;\; \mathbf{in} \;\; Q$$

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channel managers are like function definitions
unique (replicated) receivers for the defined channels

Syntax and Reductions

Syntax and Reductions

$$
\begin{array}{rcl}
D & ::= & y(x) = P \\
P, Q & ::= & \textbf{def } D \textbf{ in } Q \mid y(x) \mid P|Q
\end{array}
$$

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$$\longrightarrow \quad \textsf{def } y(x)=P \textsf{ in } \left(Q \middle| P\{^{z}/_{x}\}\right)$$

Expressive Power ?

$$\textbf{def } D \textbf{ in } (P \mid Q) \triangleq \textbf{def } D \textbf{ in } P \mid \textbf{def } D \textbf{ in } Q$$

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$$\textbf{def } D \textbf{ in } (P \mid Q) \triangleq \textbf{def } D \textbf{ in } P \mid \textbf{def } D \textbf{ in } Q$$

- only local/functional computations
  by sending and receiving individual messages
- no synchronization over parallel composition !

Core Join

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[Fournet, Gonthier, Lévy, ... 1995-2000]

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simultaneous multi-channel reception

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$$D \quad ::= \quad \overbrace{y(x)|u(w)}^{J} = P$$

$$P, Q \quad ::= \quad \textbf{def } D \textbf{ in } Q \quad | \quad y(x) \quad | \quad P|Q$$

simultaneous multi-channel reception

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\end{array}
$$

simultaneous multi-channel reception

$$\textbf{def } J = P \textbf{ in } (Q|J\sigma)$$

$$\longrightarrow \quad \textbf{def } J = P \textbf{ in } (Q|P\sigma)$$

Expressive Power !

(* via mutual encodings *)

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$$[\![\, \textbf{def}\ y(x)|u(w)=P\ \textbf{in}\ Q \,]\!] \stackrel{\text{def}}{=} (\nu x, u)\,(y(x).u(w).[\![\, P \,]\!] \mid [\![\, Q \,]\!])$$

$$[\![\, x(u) \,]\!] \stackrel{\text{def}}{=} \overline{x}\langle u \rangle$$

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Expressive Power !

(* via mutual encodings *)

$$[\![\, \textsf{def}\ y(x)|u(w)=P\ \textsf{in}\ Q \,]\!] \stackrel{\text{def}}{=} (\nu x, u)\,(y(x).u(w).[\![\, P \,]\!] \mid [\![\, Q \,]\!])$$

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$$[\![\, (\nu y)\, P \,]\!] \stackrel{\text{def}}{=} \textsf{def}\ y_o(x_o, x_i)|y_i(\kappa)=\kappa(x_o, x_i)\ \textsf{in}\ [\![\, P \,]\!]$$

$$[\![\, \overline{y}\langle z \rangle \,]\!] \stackrel{\text{def}}{=} y_o(z_o, z_i)$$

$$[\![\, y(x).P \,]\!] \stackrel{\text{def}}{=} \textsf{def}\ \kappa(x_o, x_i)=[\![\, P \,]\!]\ \textsf{in}\ y_i(\kappa)$$

From Theory to Practice ...

Join patterns have been incorporated into **Polyphonic C#**, where *joins* are called *chords*, later on called **Cω**, as a .Net language.

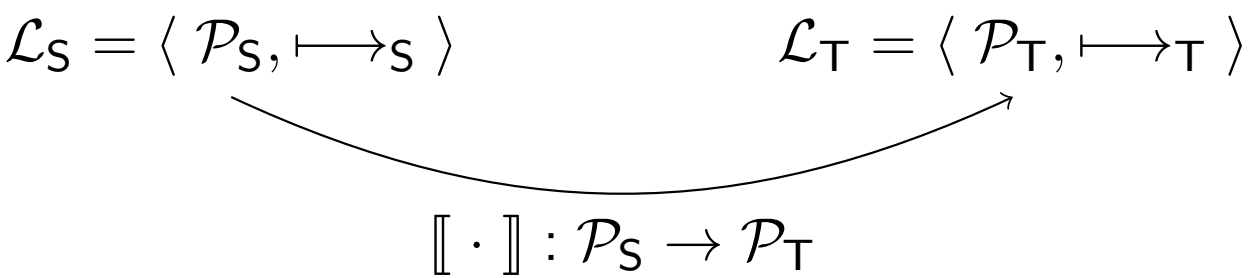
Keyword: "*modern concurrency abstractions*"

By now, there is also a **Join Java** ...

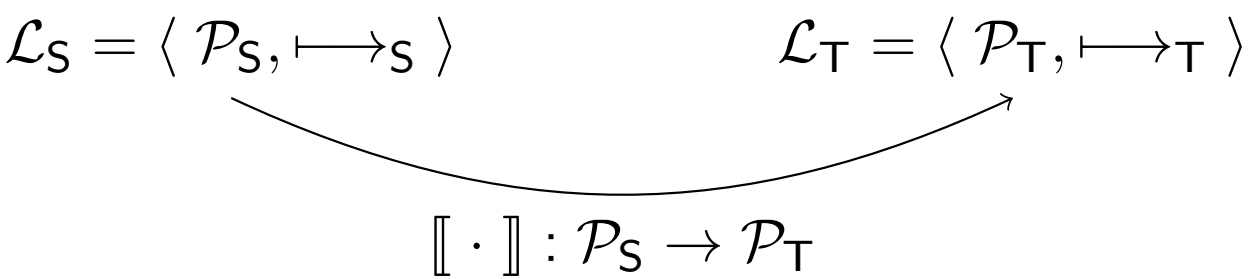
Encodings

$$\mathcal{L}_{\mathsf{S}} = \langle\, \mathcal{P}_{\mathsf{S}}, \longmapsto_{\mathsf{S}} \,\rangle \qquad \mathcal{L}_{\mathsf{T}} = \langle\, \mathcal{P}_{\mathsf{T}}, \longmapsto_{\mathsf{T}} \,\rangle$$

Encodings

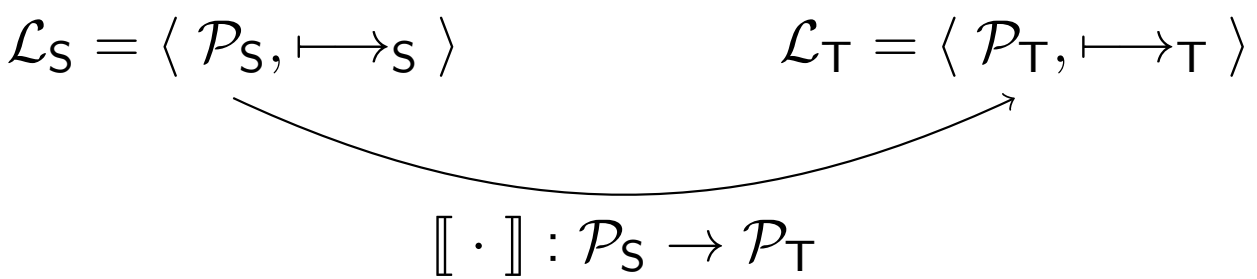

$\mathcal{L}_S = \langle \mathcal{P}_S, \longmapsto_S \rangle$
$\mathcal{L}_T = \langle \mathcal{P}_T, \longmapsto_T \rangle$
$[\![\cdot]\!] : \mathcal{P}_S \to \mathcal{P}_T$

Encodings



- quality criteria rule out trivial or meaningless encodings

Encodings



- quality criteria rule out trivial or meaningless encodings
  - preserve the "abstract" behaviour
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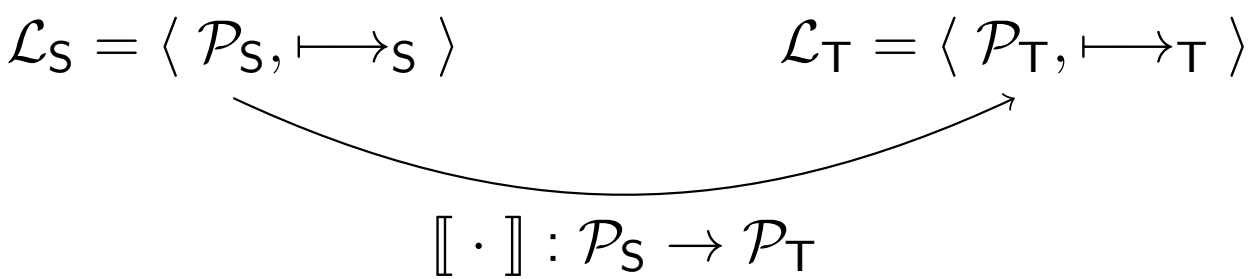

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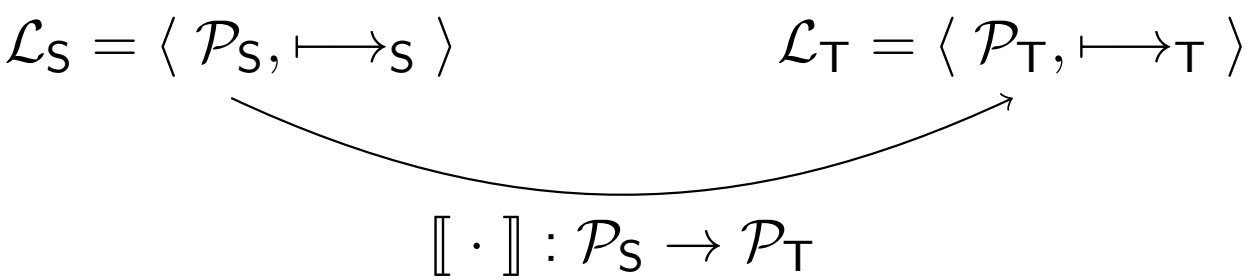
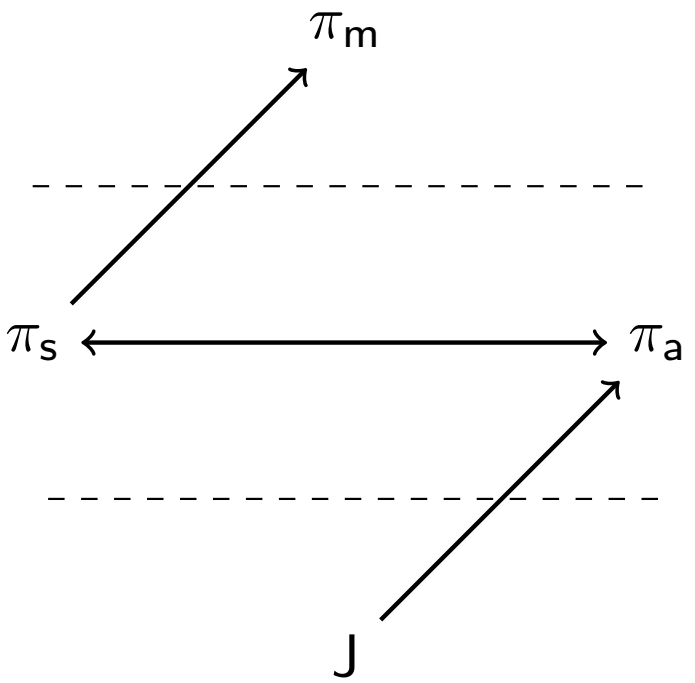


- quality criteria rule out trivial or meaningless encodings
  - preserve the "abstract" behaviour
  - reflect the "abstract" behaviour
  - do not introduce deadlock or divergence
- general framework [Gor10]
  - $[\![P \mid Q]\!] = C[\, [\![P]\!] \,|\, [\![Q]\!] \,]$ is allowed !

Abstract Expressive Power



Abstract Expressive Power

π_m

π_s π_a

J

Abstract Expressive Power

π_m π_s π_a J

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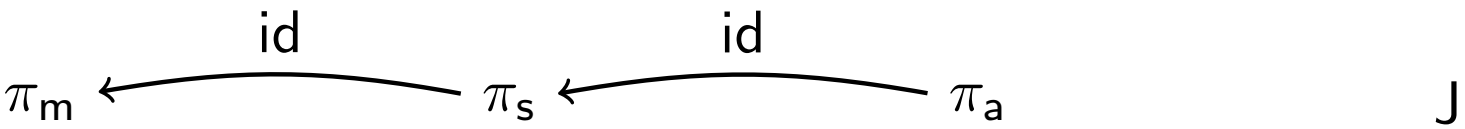

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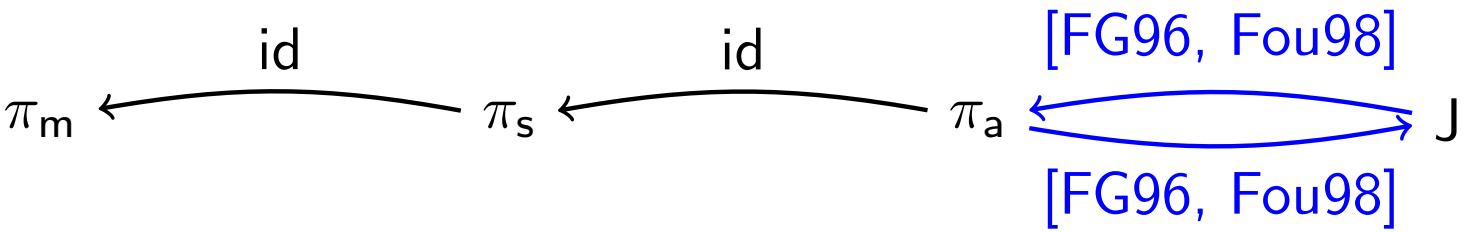

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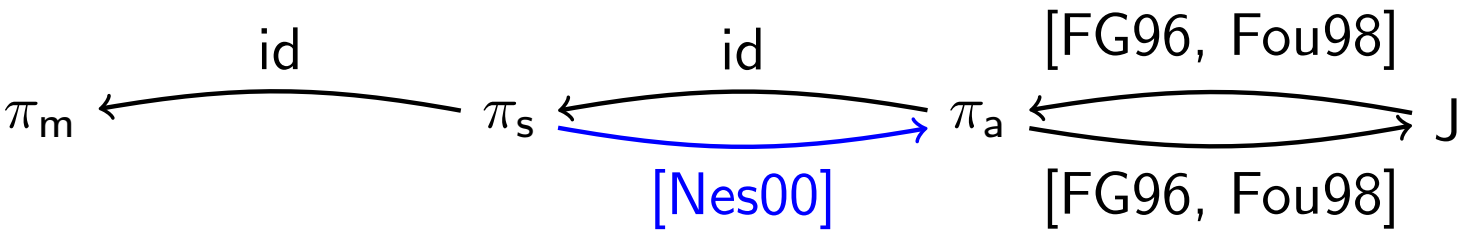

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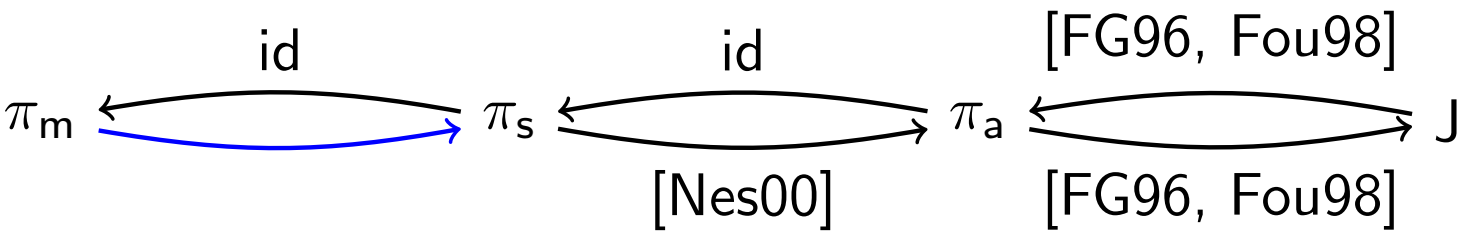

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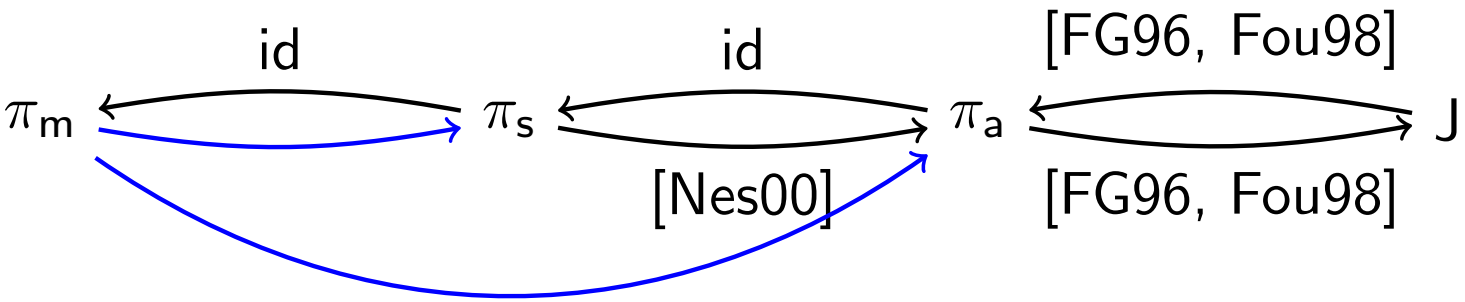

Good Encoding from π_m into π_a

$$[\![P \mid Q]\!] = [\![P]\!] \mid [\![Q]\!]$$

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$[\![P \mid Q]\!] \neq [\![P]\!] \mid [\![Q]\!]$ follows from [Pal03]

Good Encoding from π_m into π_a

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$$y(x).P \quad | \quad \overline{y}\langle z \rangle.Q + a(b).R \quad | \quad \overline{a}\langle c \rangle.S$$

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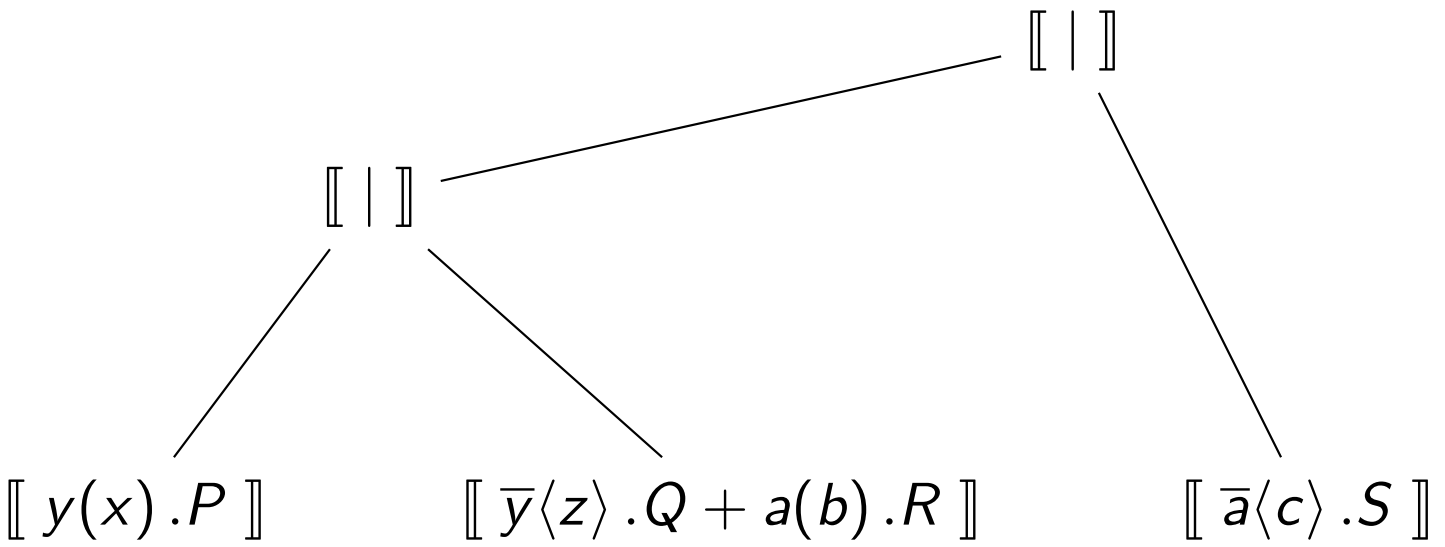

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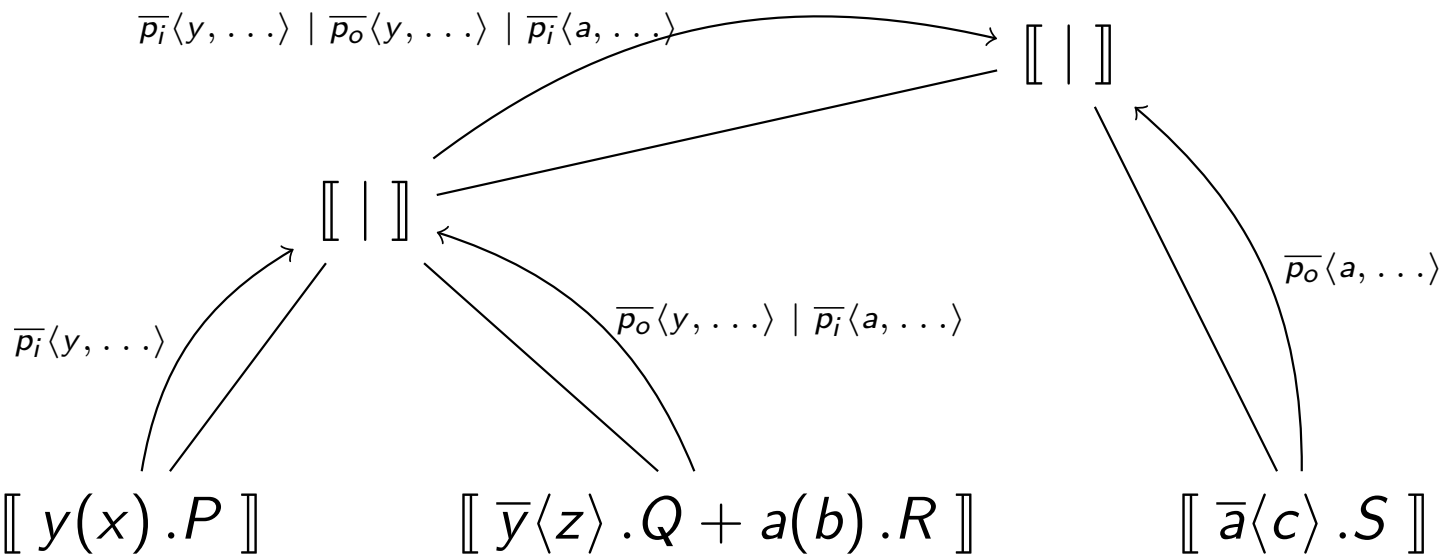

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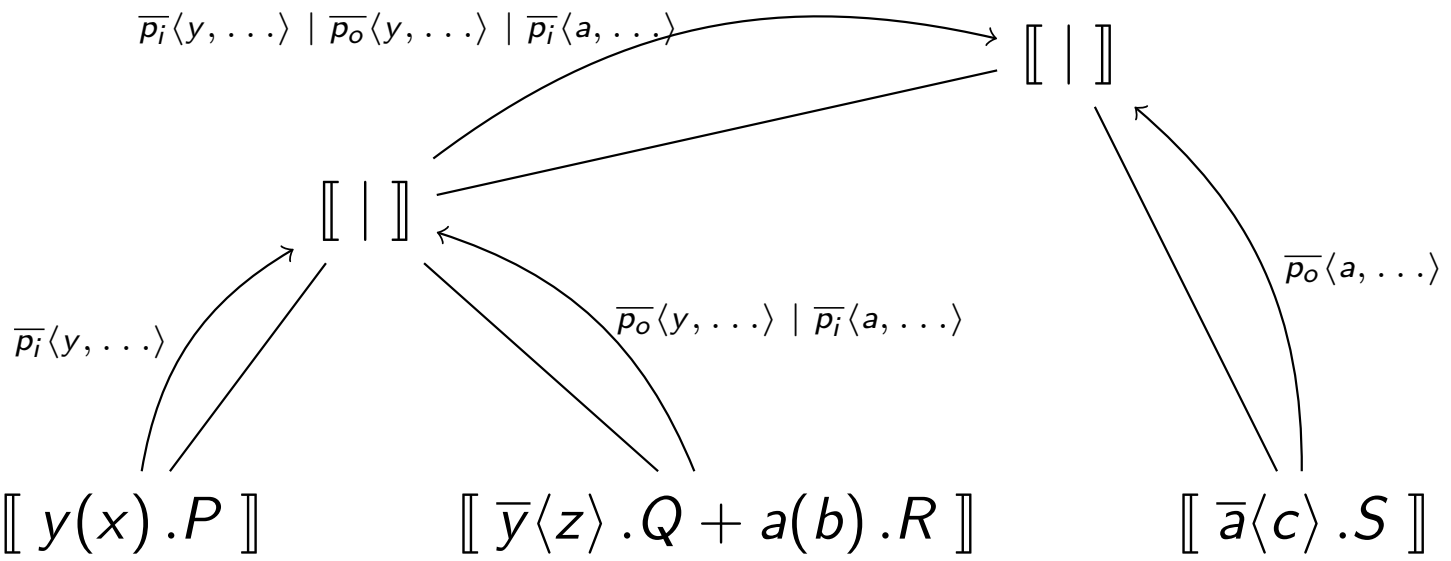

Contribution

There is a "good" encoding of mixed choice into π_a.
Formalisation of an additional criterion: *preservation of distributability*.

Abstract Expressive Power

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All four process calculi have the same abstract expressive power.

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However, they can be distinguished w.r.t. distributibility.
(Some encodings are not *distributability-preserving*.)

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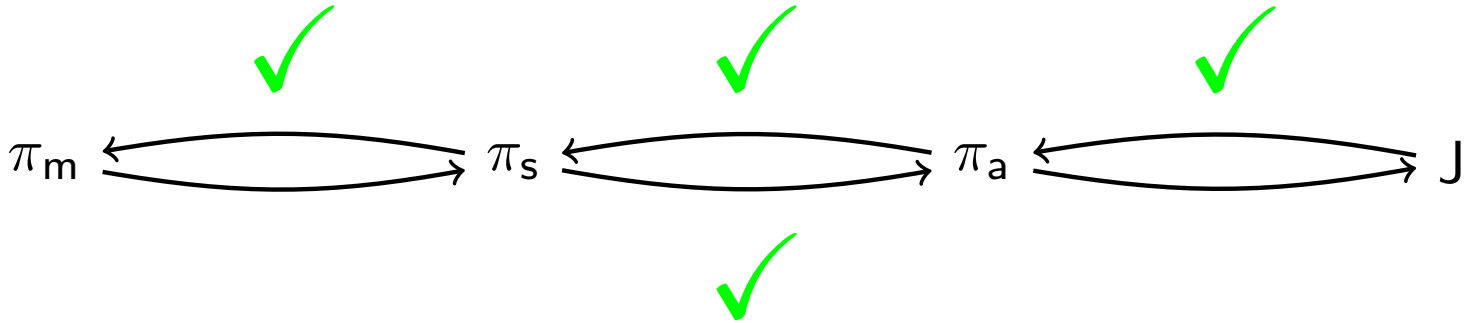

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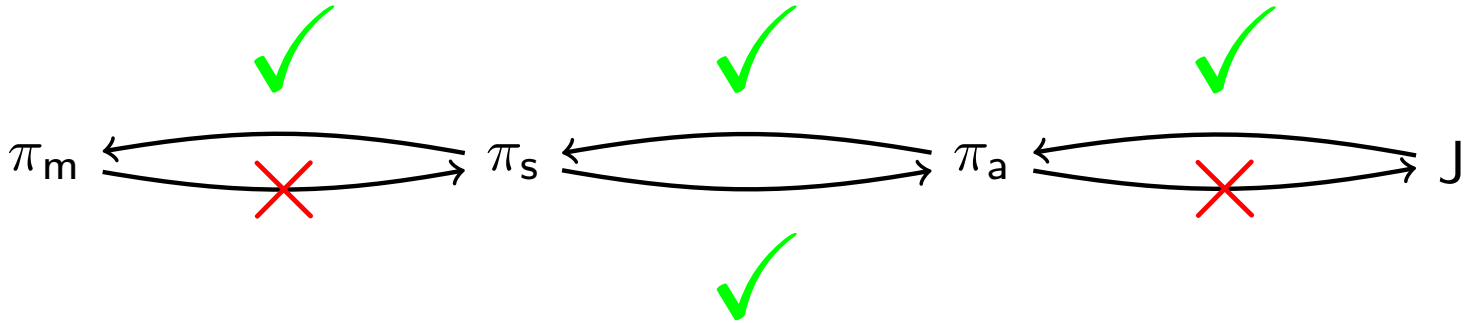

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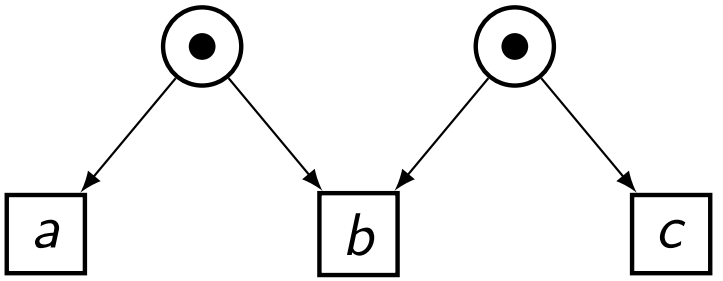
Synchronisation Pattern M

A fully reachable pure M in Petri nets [vGGS08, vGGS12]:



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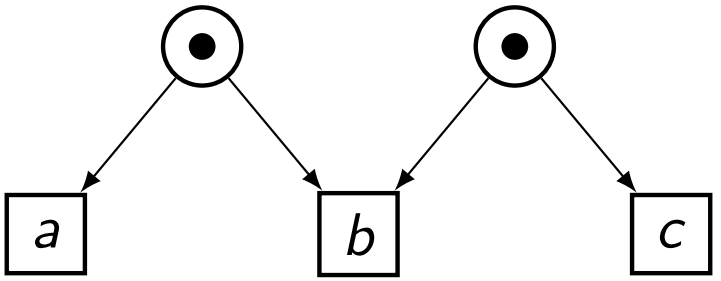

Theorem

A Petri net is distributable if it does not contain a fully reachable pure M.

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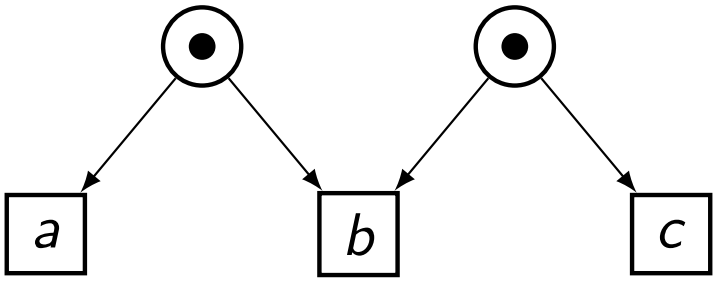


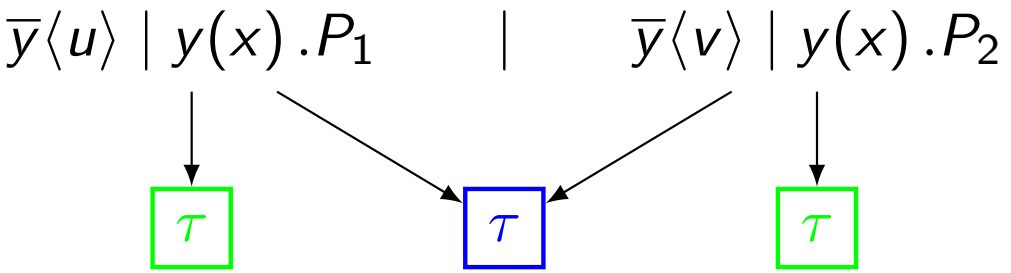
Theorem

A Petri net is distributable if it does not contain a fully reachable pure M.

Contributions

Transferring this result on Petri nets into a result between process calculi.
A proof method for separation results based on synchronisation patterns.

Translational Separation Result: $\pi_a \not\longrightarrow J$



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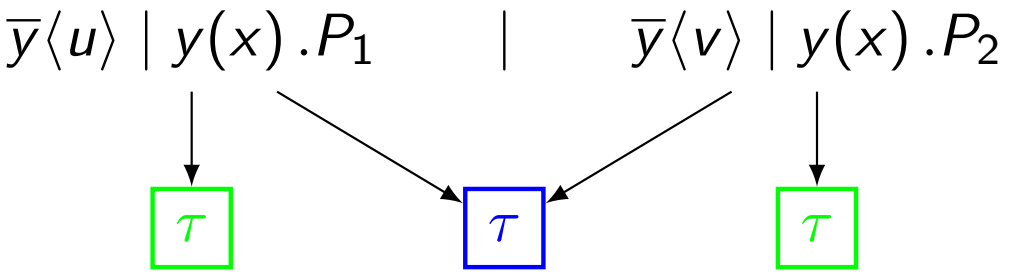

Example

There are M in π_a.

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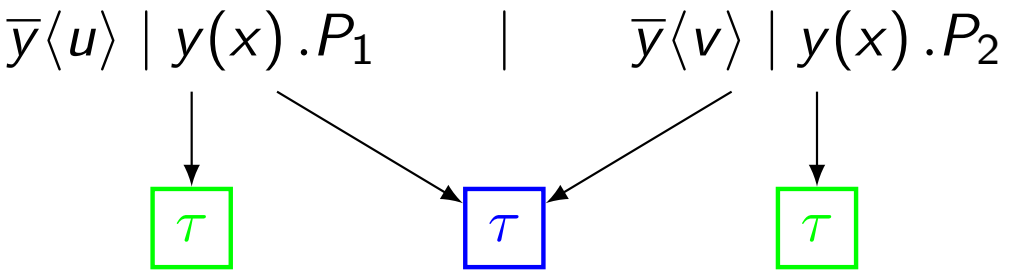

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All M in the Join-Calculus are local.

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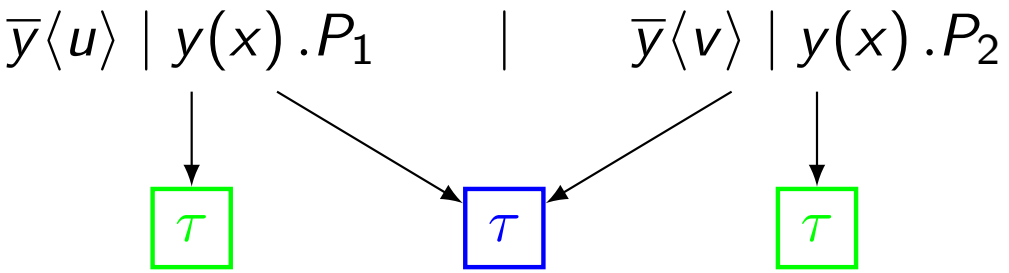

Example

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All M in the Join-Calculus are local.

Contribution

The join-calculus is distributable, but the (asynchronous) pi-calculus is not.

Translational Separation Result: $\pi_a \not\rightarrow J$

Lemma

Every good and distributability-preserving encoding from π_a into J has to split up the conflict between the blue step and the green steps.

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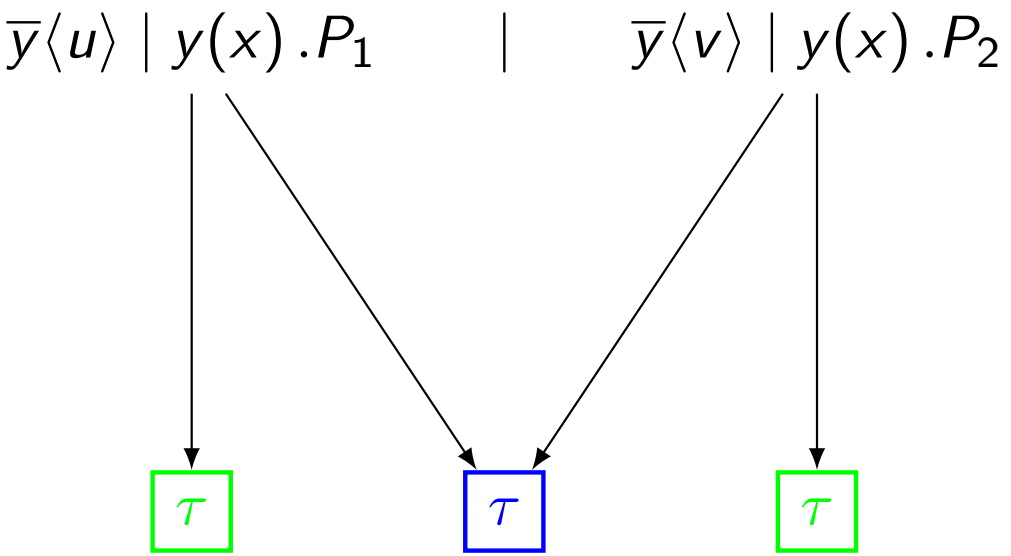

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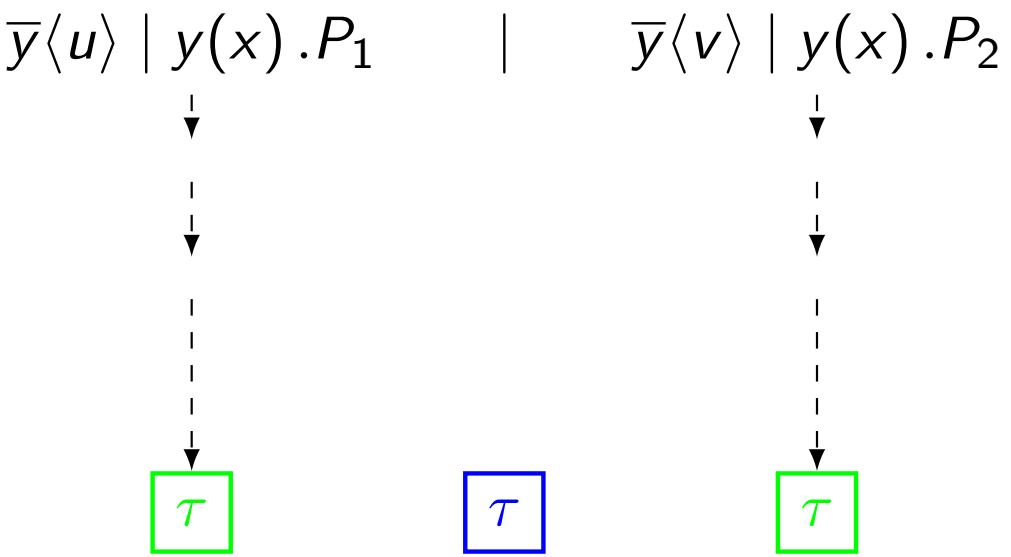

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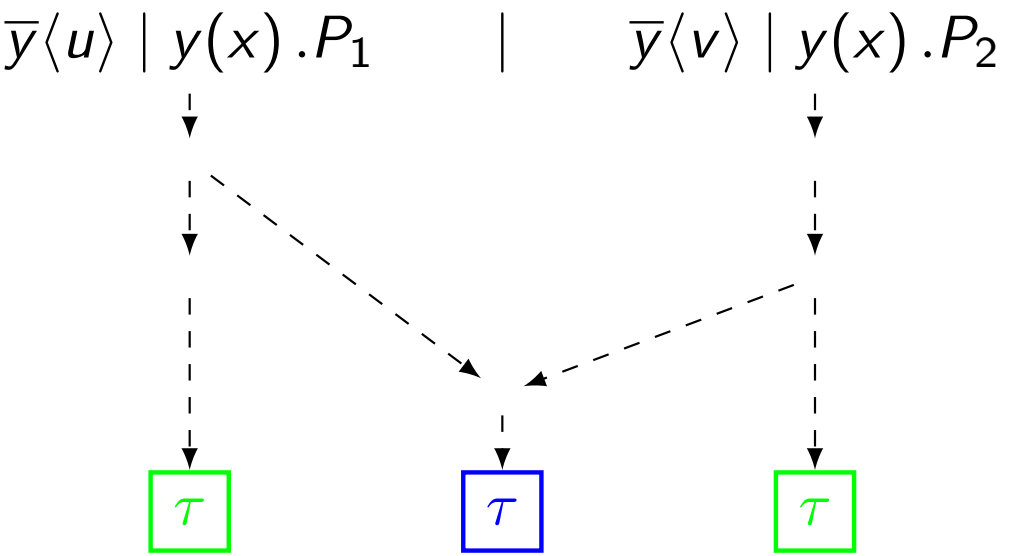

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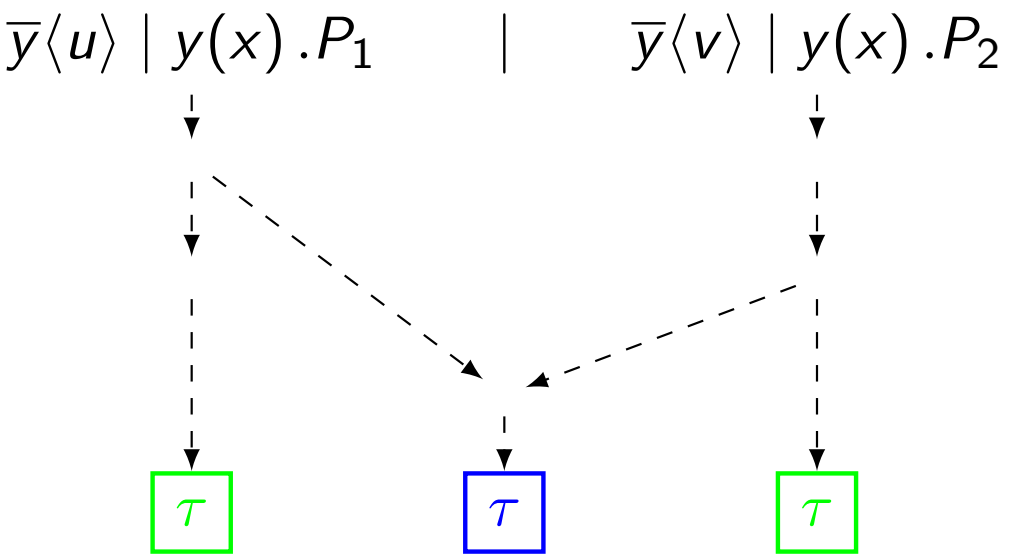

Contribution

There is no good and distributability-preserving encoding from π_a into J.

Distributability in Pi-like Calculi

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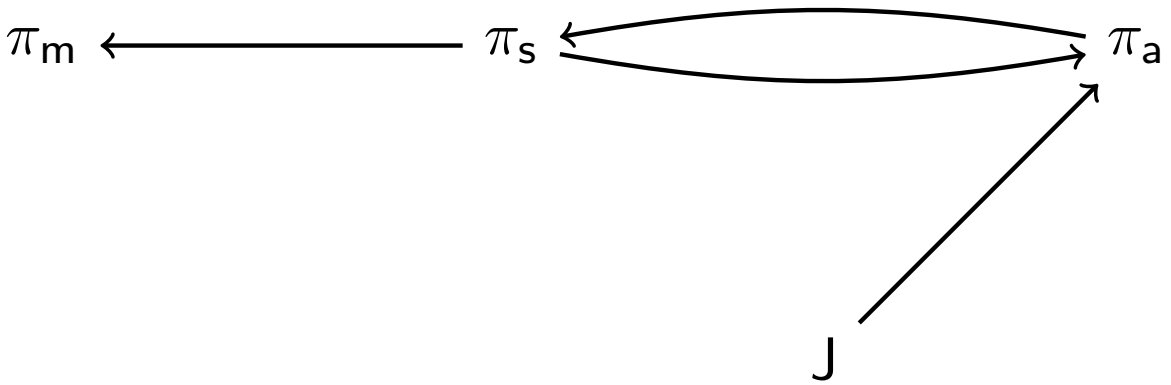

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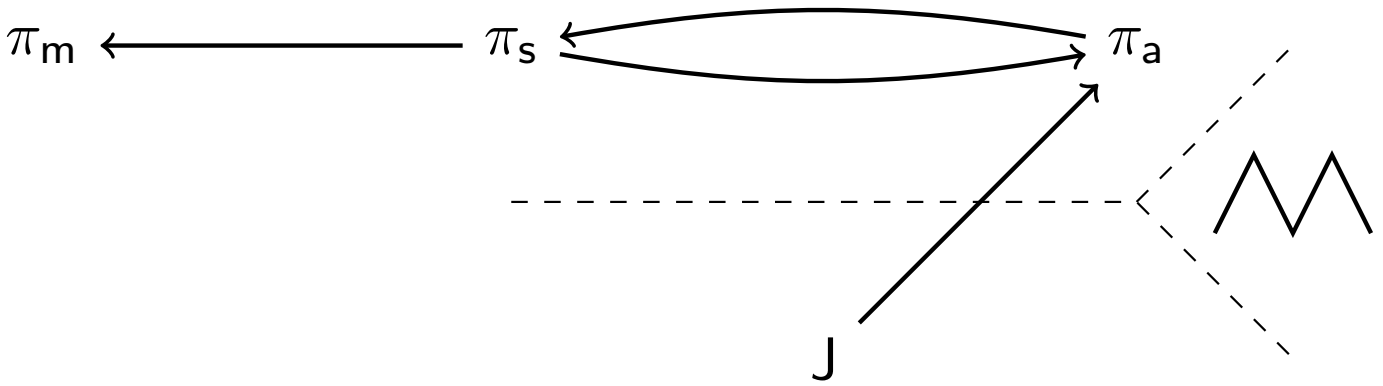
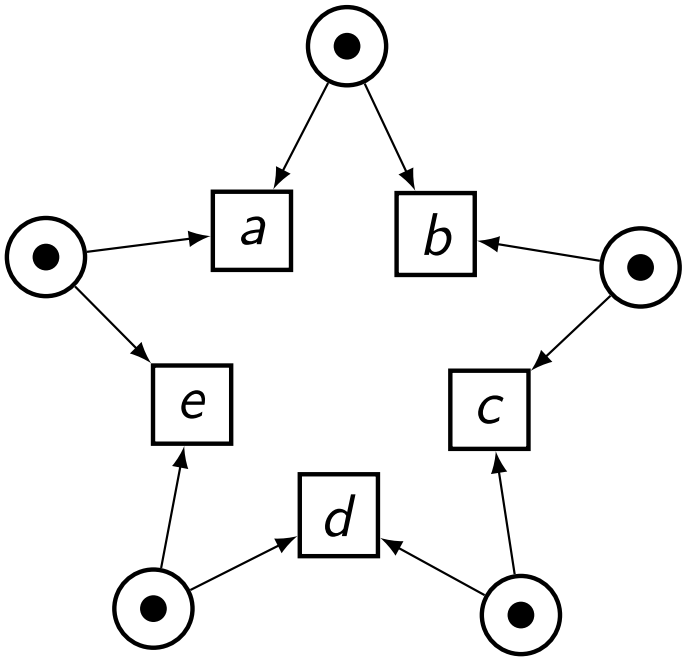


Synchronisation Pattern ⋆



- more complex synchronisation pattern
- several M that overlap in a cycle
- instance of dinning philosophers

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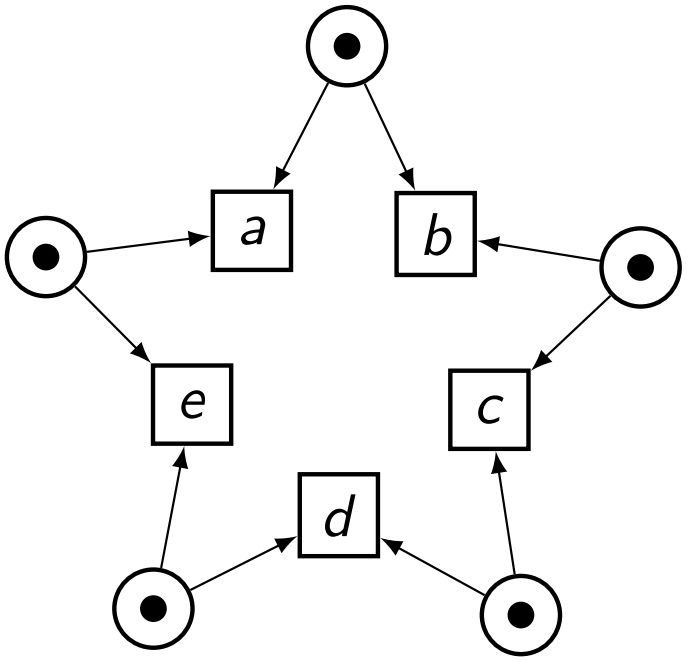

- more complex synchronisation pattern
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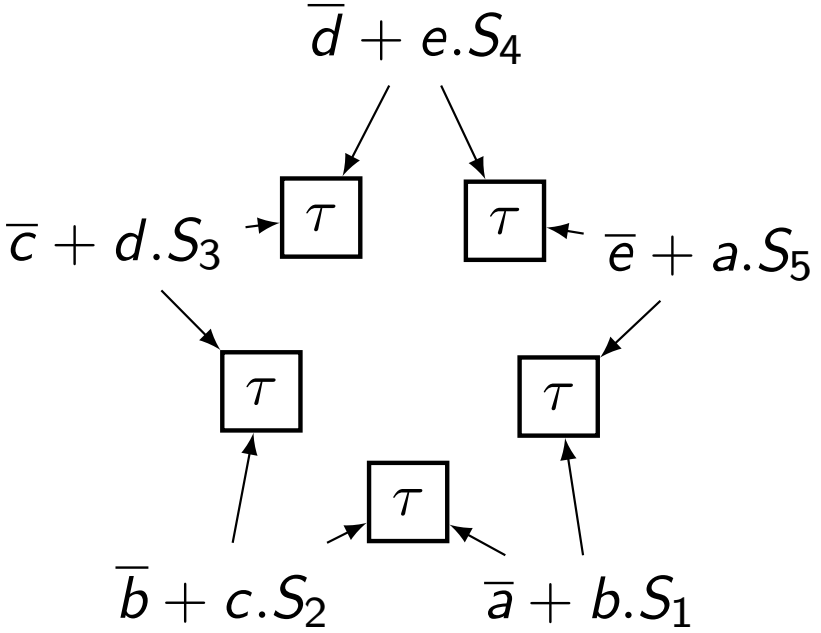
Contribution

New synchronisation pattern to capture the difference of mixed and separate choice.

Translational Separation Result: $\pi_m \not\hookrightarrow \pi_s$



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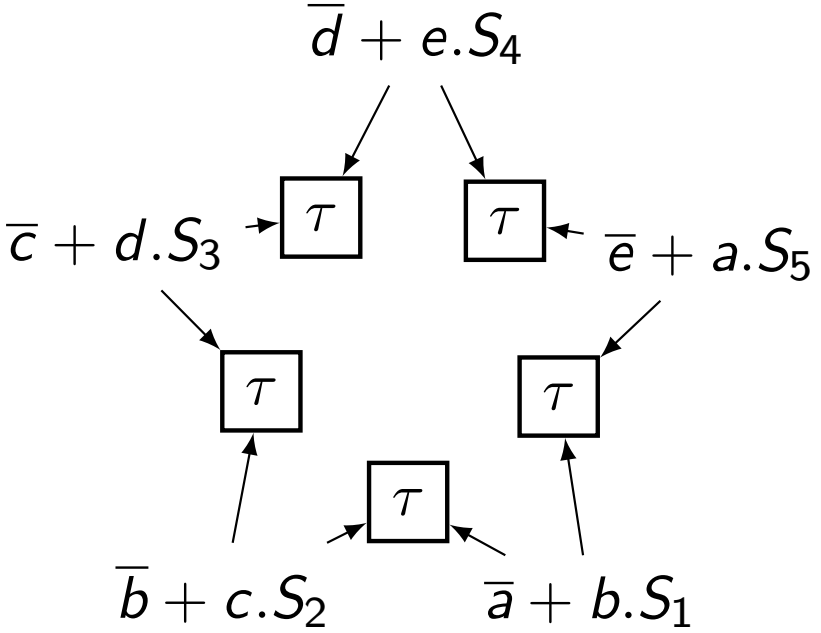
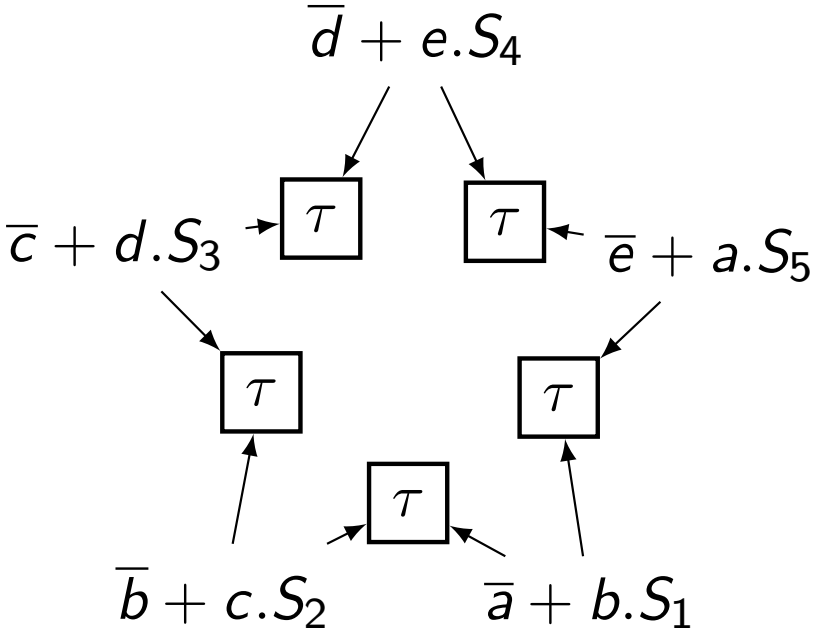


Lemma

There are no $\star$ in π_s.

Translational Separation Result: $\pi_m \not\hookrightarrow \pi_s$



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There are no $\star$ in π_s.

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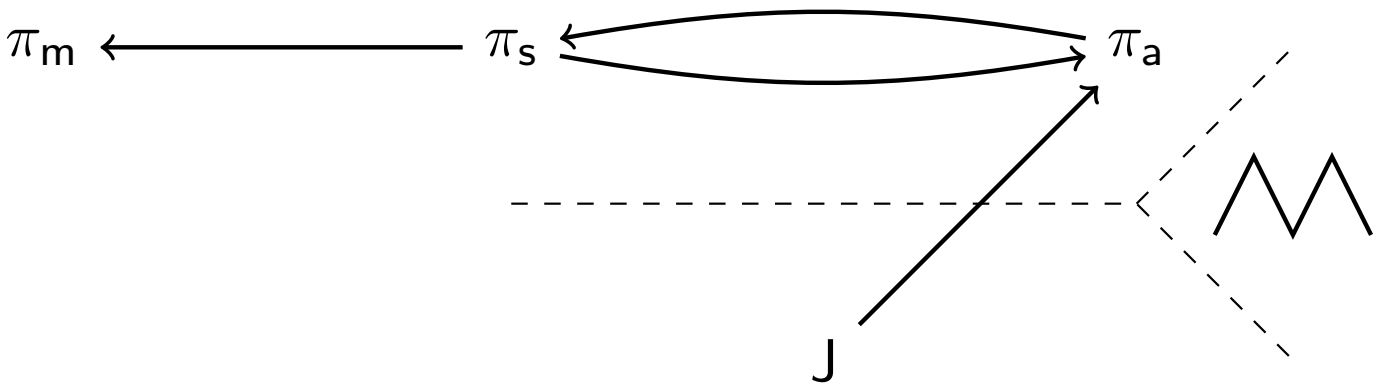
There is no good and distributability-preserving encoding from π_m into π_s.

Distributability in Pi-like Calculi



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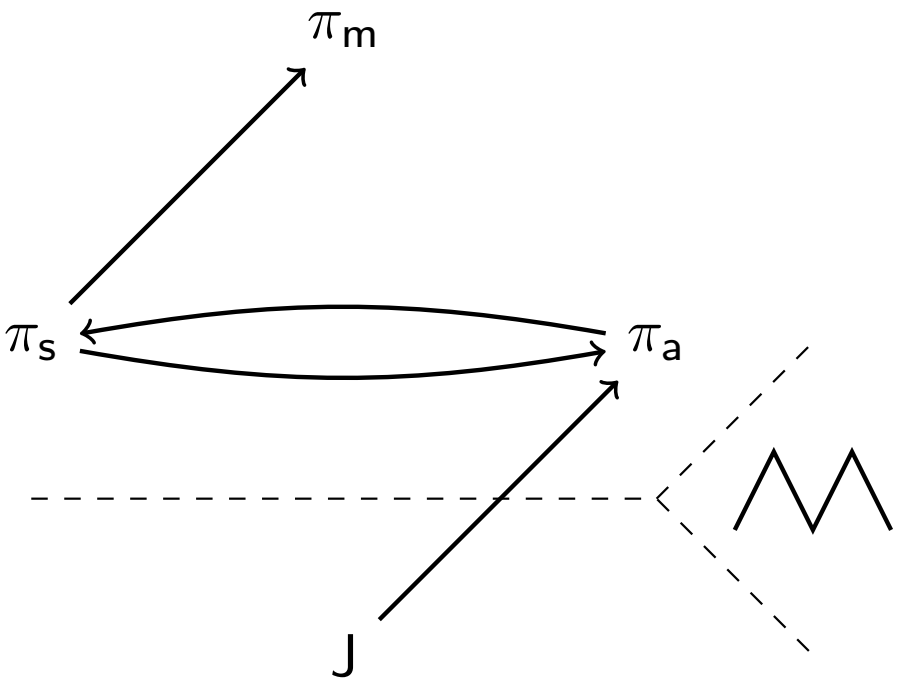

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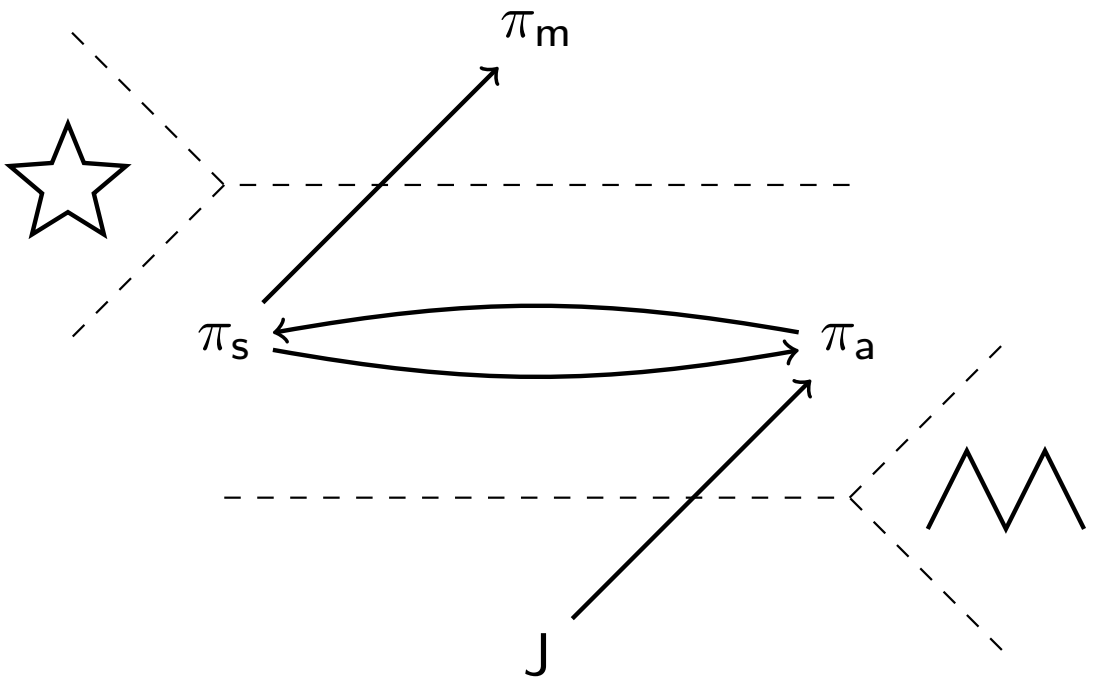

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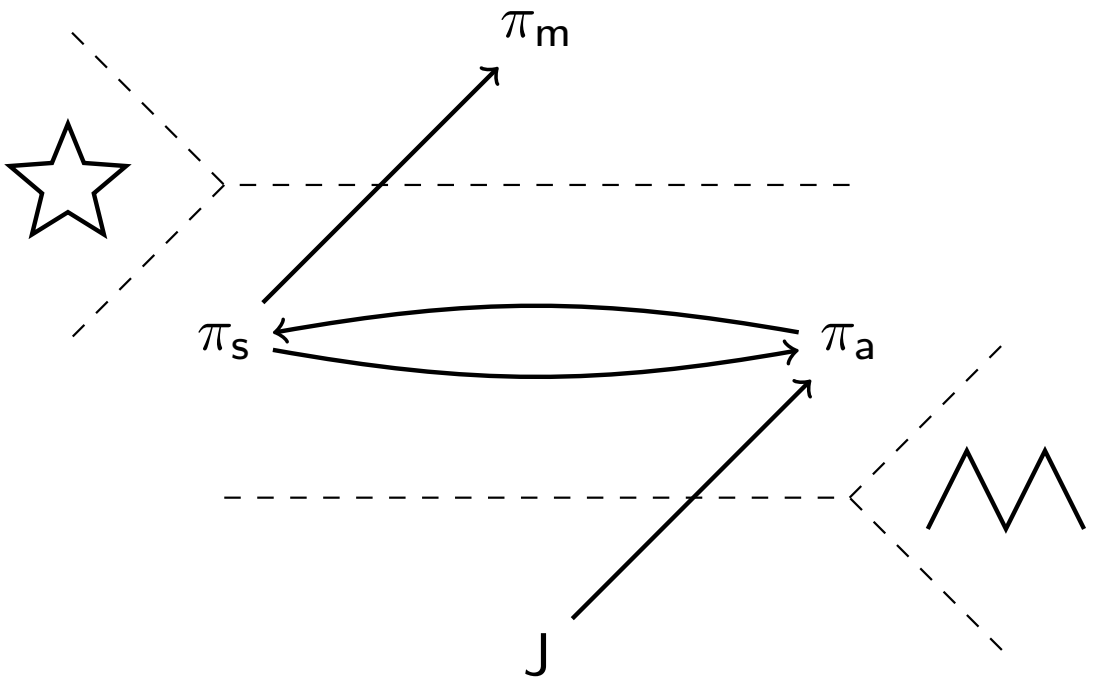

Contribution

Three-level hierarchy.

Some Directions of Further Research

Which synchronisation pattern describes
polyadic synchronisation of Carbone+Maffeis [CM03]?

How much of the asynchronous pi-calculus is distributable?

Which system requirements are implicitly required
by the asynchronous/synchronous pi-calculus?

How can other process calculi be classified in this hierarchy?

Questions . . .


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