An Aspect-Oriented Paradigm for Component-based Systems and its Application to RV

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COST Meeting

Outline

Component-Based Design

- Separation between computation and coordination:
  1. Design of individual components: components are white-boxes;
  2. Coordination between various components: components are black-boxes.

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  1. Design of individual components: components are white-boxes;
  2. Coordination between various components: components are black-boxes.
- Advantages:
  1. Re-usability of components
  2. Ability to make internal changes to components without affecting system
  3. Compositional construction, testing and verification

Aspect-Oriented Programming

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  "*domain used as a decomposition criterion for a system or another domain with that concern*"

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- Concerns can be:
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- Concerns that are spread out or overlap are called crosscutting.

Crosscutting Concerns

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- Aspect-Oriented Programming seeks to modularize crosscutting concerns.

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Aspect

The module that wraps a set of pointcuts, their associated advices and extra context information.

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- Motivation
  1. Reliability: correct-by-construction, verification, validation
  2. Maintenance: encapsulation of concerns
  3. Refinement: progressive building of complex systems

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- Behavior - automata extended with data and communication ports
- Interactions - synchronization and data transfer between components
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- Behavior - automata extended with data and communication ports
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Advantages

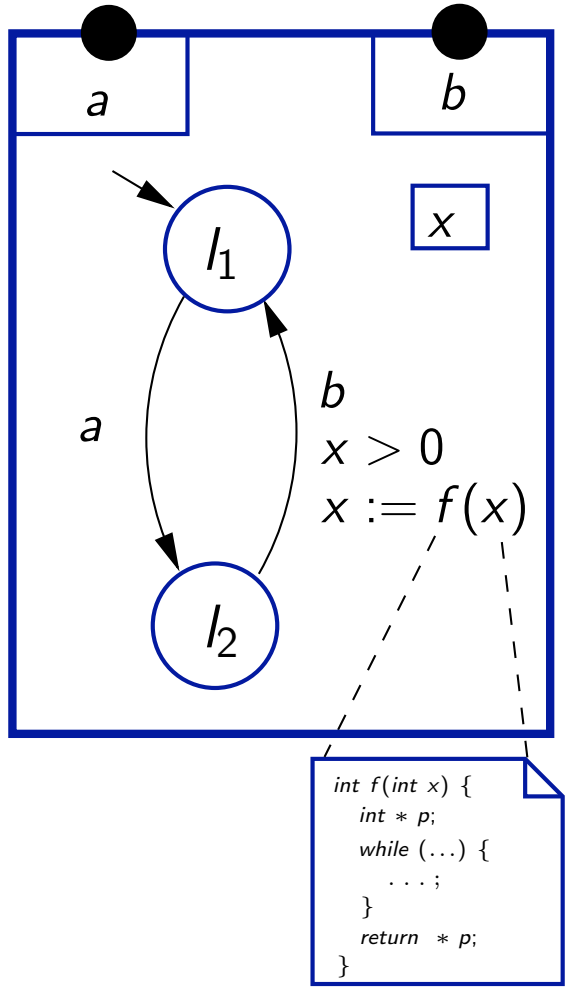
1. Specification of both atomic components and their coordination using well-defined operational semantics;
2. Efficient code generation.
3. Automatic verification and validation.

Behavior

Atomic Component

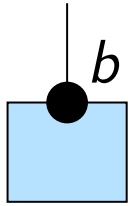
Labelled Transition System with data:

- *ports*, e.g, $\{a, b\}$
- *control locations*, e.g, $\{l_1, l_2\}$
- *variables*, e.g, $\{x\}$
- *transitions*
  - guards, e.g., $x > 0$
  - variable modifications (with external functions), e.g., $x := f(x)$



Interactions and Connectors: **Communication**

We consider the case of *synchron* (•) ports



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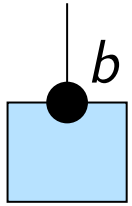

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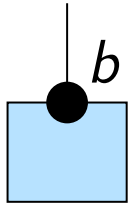

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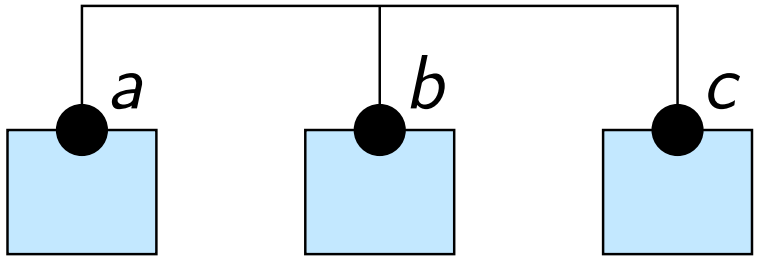
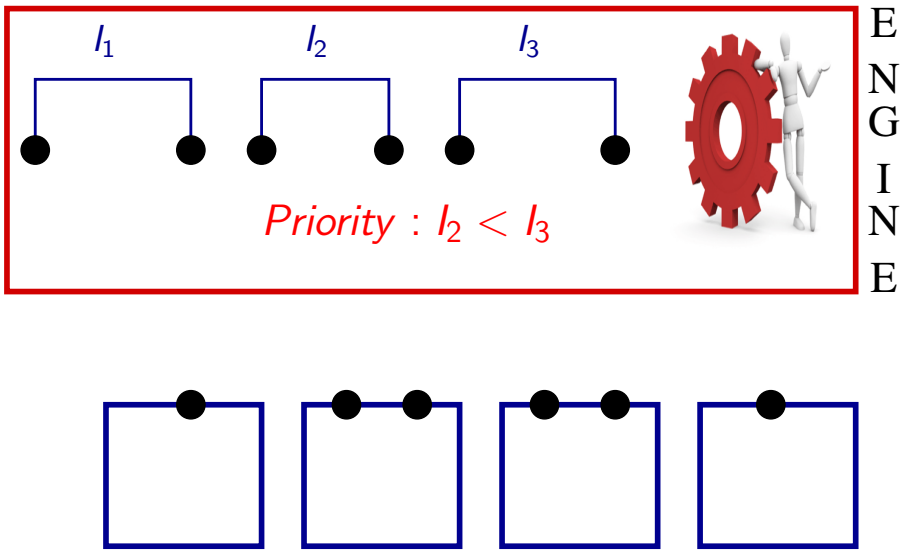


Composite component

Composite component

available atomic components + interactions + priority rules



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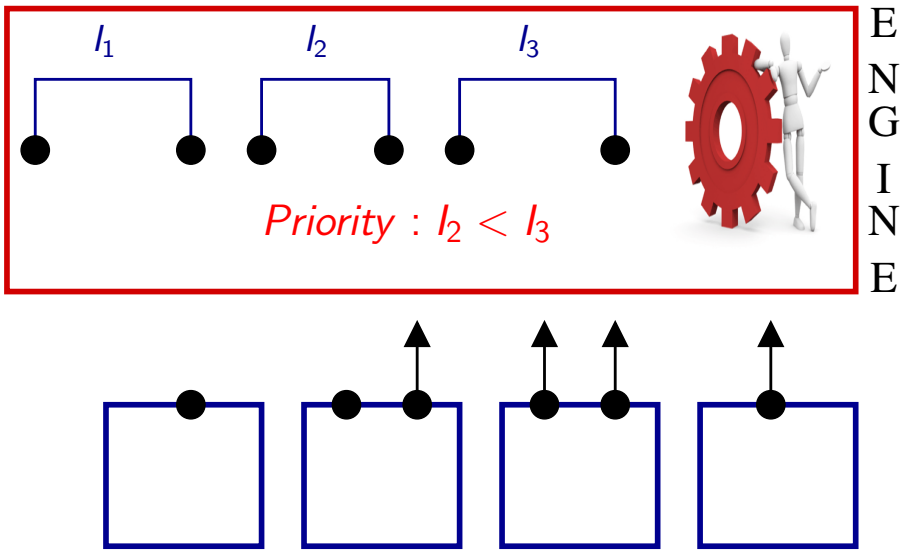

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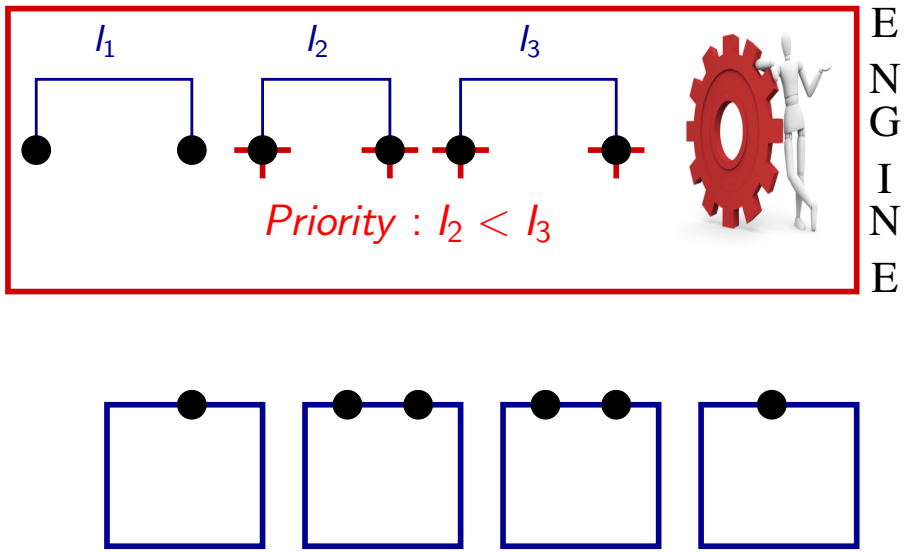

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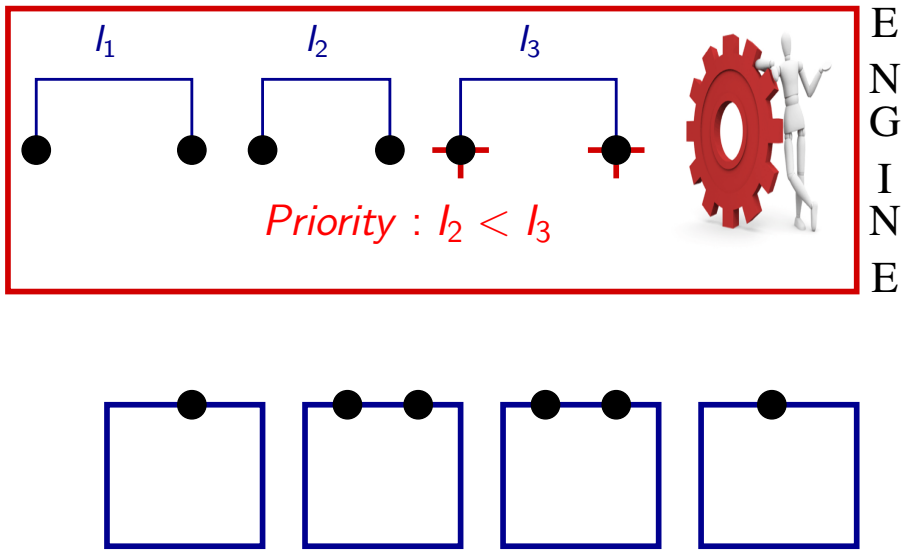

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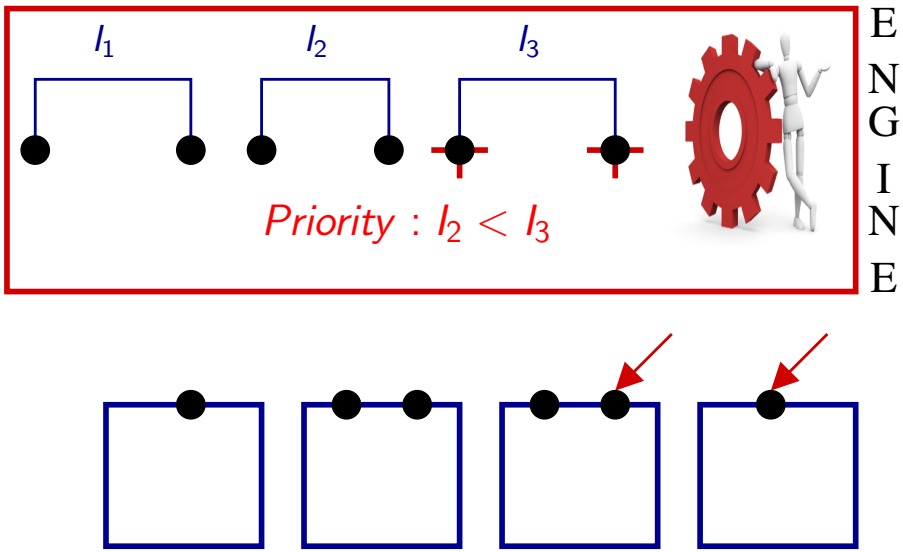

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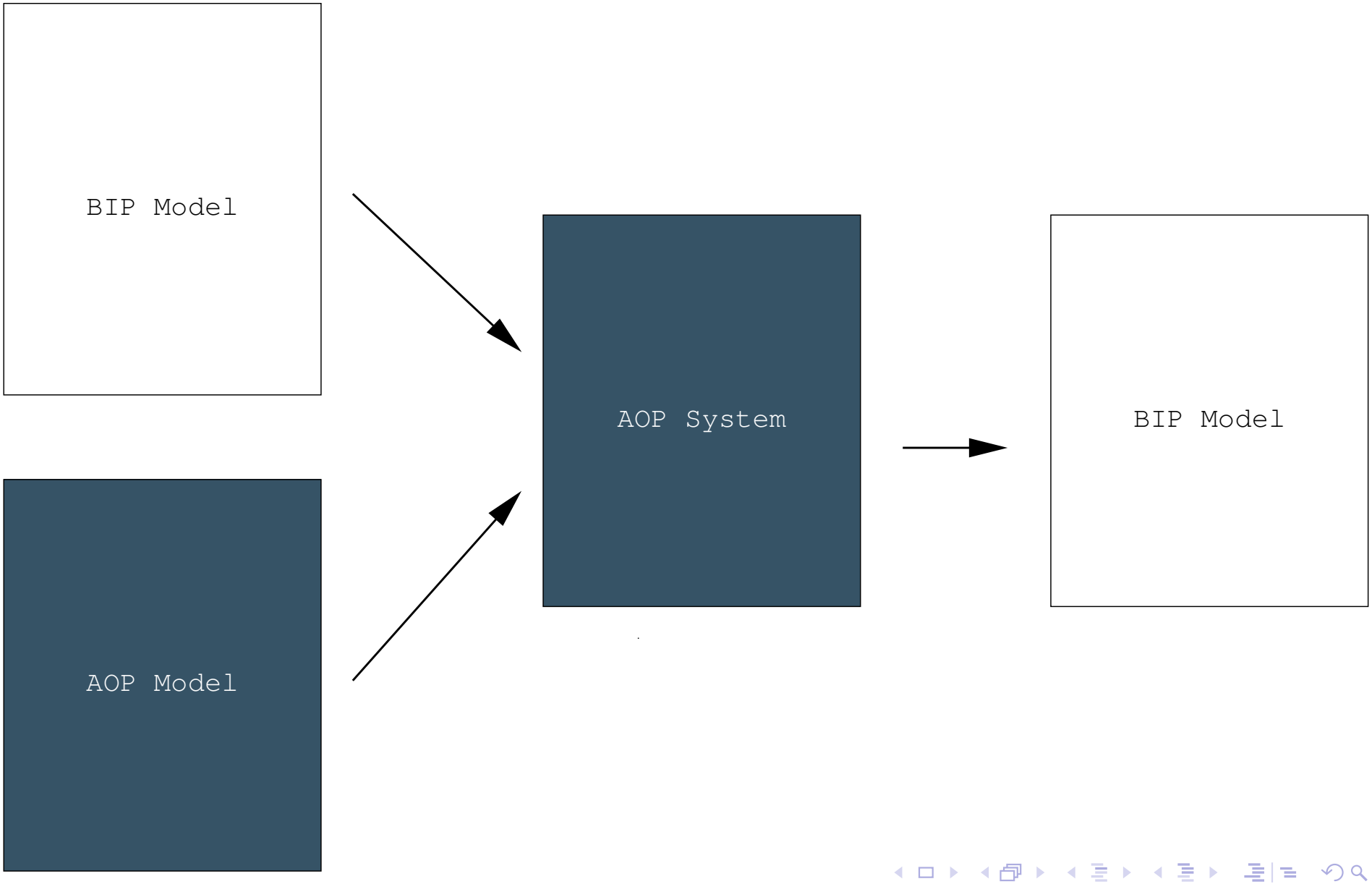
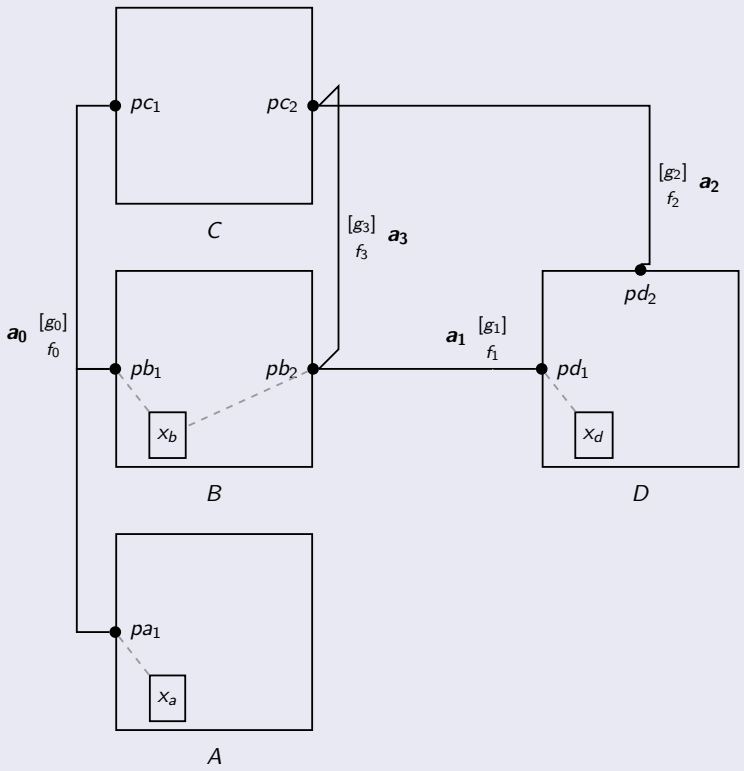
High-Level View

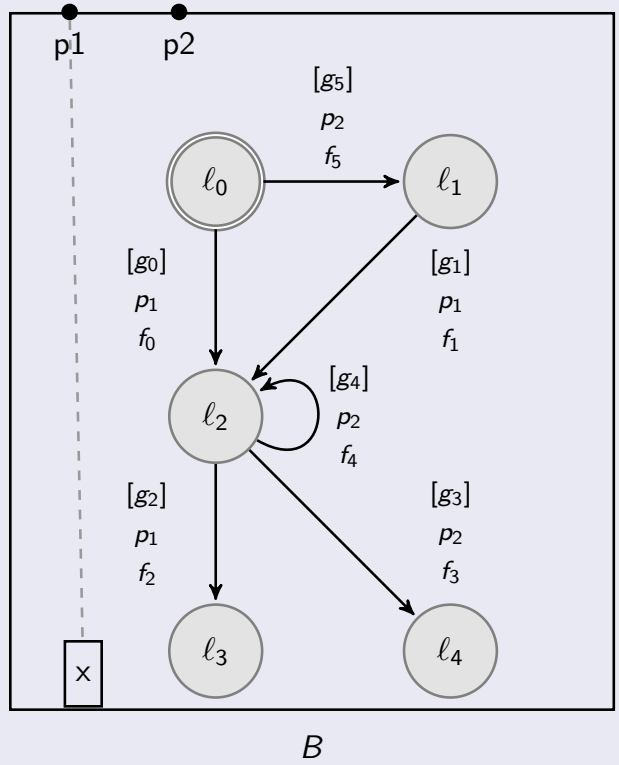


System Views

Global View



Local View



Execution Trace

Trace

- Alternating sequence of global state and interaction execution $(q_0, a_0, q_1, \ldots, q_{i-1}, a_{i-1}, q_i)$
- Global State: states of all atomic components
  - Location
  - Variable valuations

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Global Event

- Starting global state $\rightarrow$ Interaction execution $\rightarrow$ Next global state
- $\langle q_k, a_k, q_{k+1} \rangle$ for $k \in [0, i-1]$
- $a_k = \langle p_k, f_k, g_k \rangle$

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Global Joinpoint

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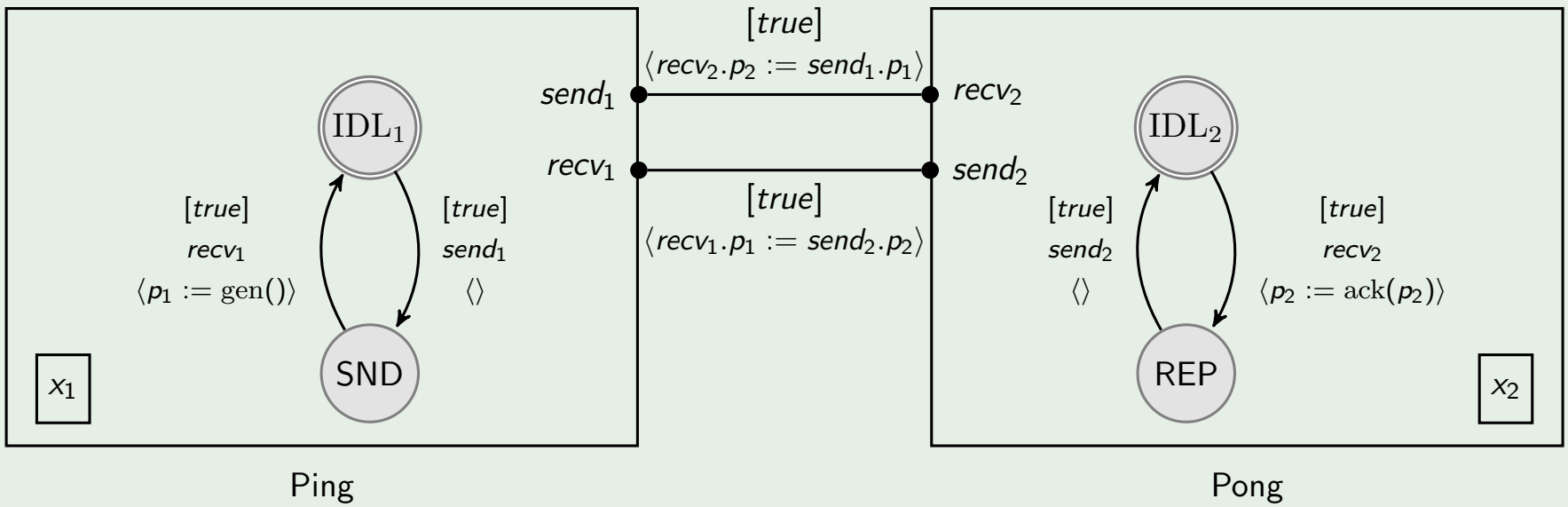
Example

Example (Global Event)



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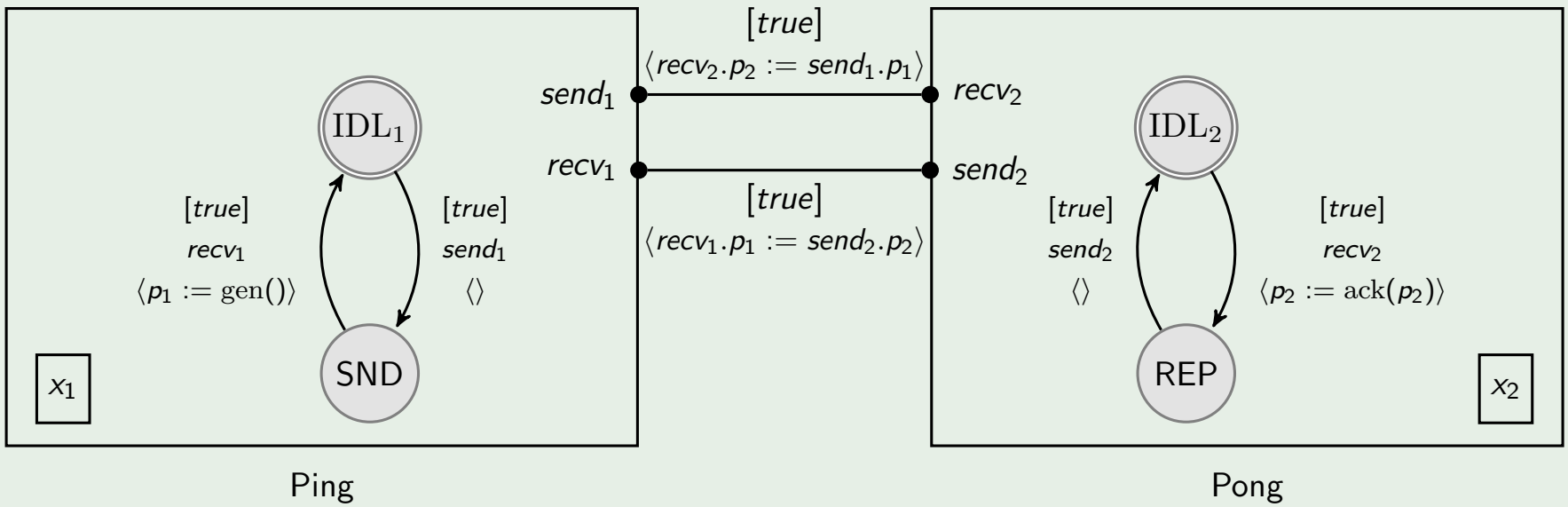

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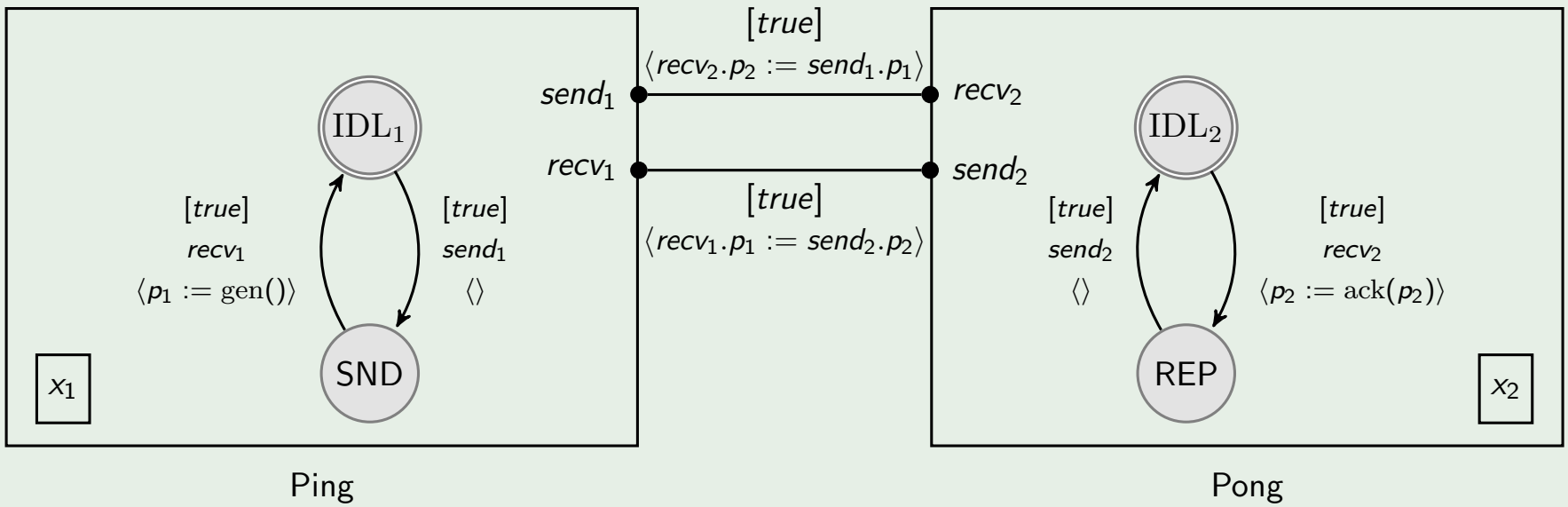

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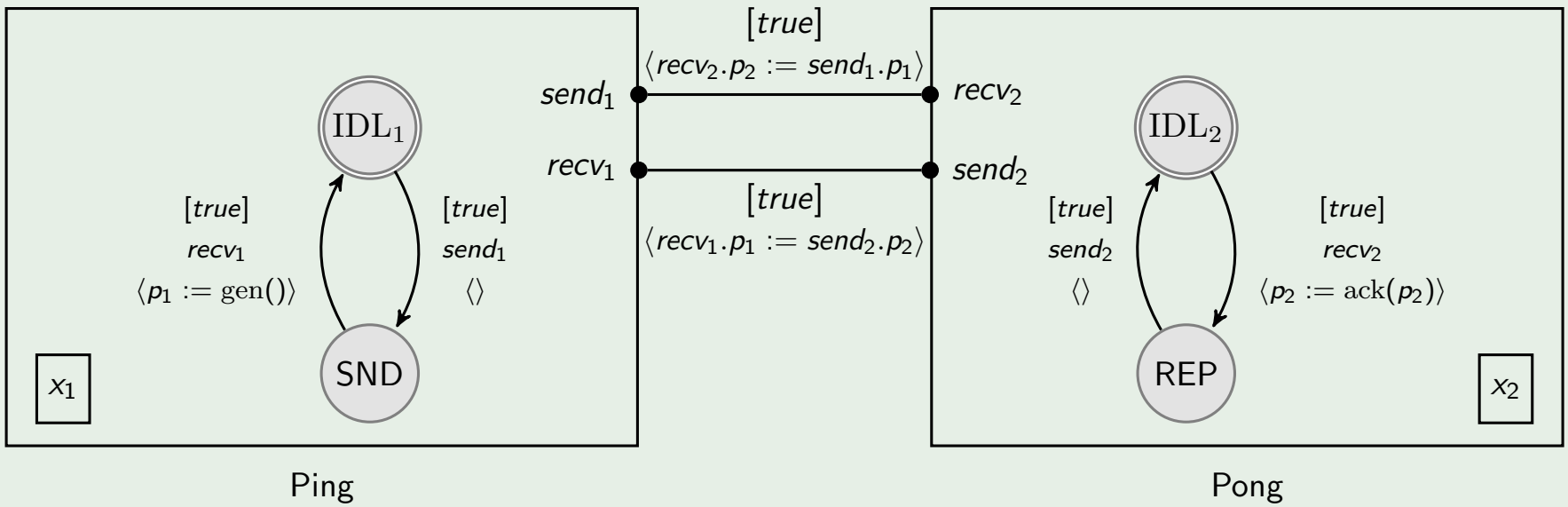

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- It can express the following:
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  2. Data transfer between various atomic components.
     1. One ore more components are sending data.
     2. One or more components are receiving data.

Global Pointcut

Global Pointcut Expression

A global pointcut expression is defined as $gpc = \langle p, v_r, v_w \rangle$:

1. p : matches a subset of ports associated with the matching interaction.
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Matching Global Joinpoints

$$\langle q, a, q' \rangle \vDash \langle p, v_r, v_w \rangle \text{ iff } p \subseteq a.ports \wedge v_r \subseteq \text{readvar}(a.func) \wedge v_w \subseteq \text{writevar}(a.func)$$

Global Advice

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- The functions f_b, f_a are only defined over:
  1. Extra inter-type variables V.
  2. The variables of the context: the variables of the ports in the pointcut expression.

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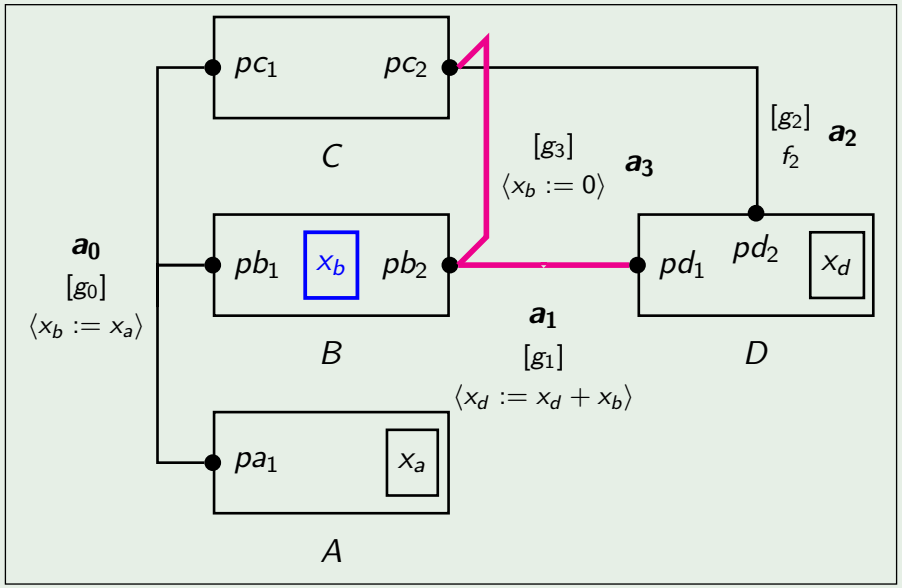

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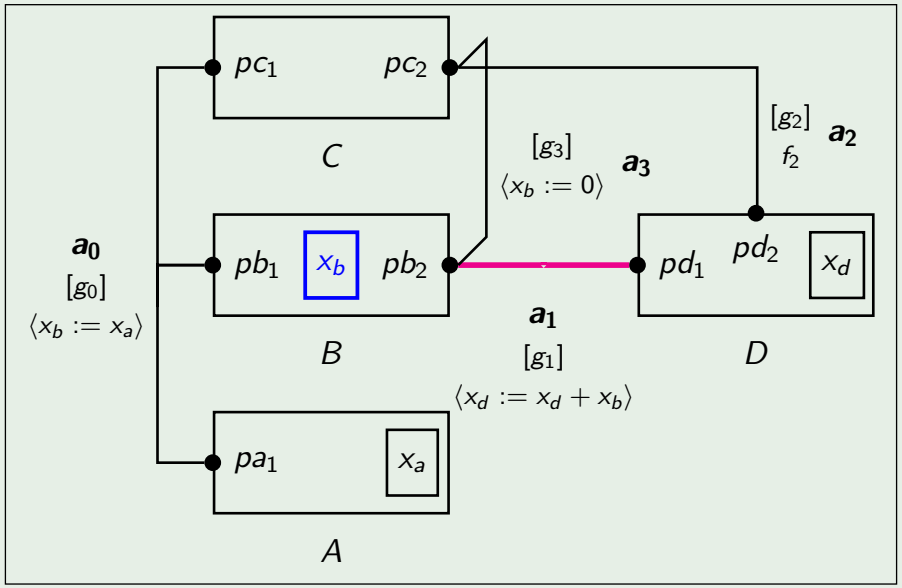

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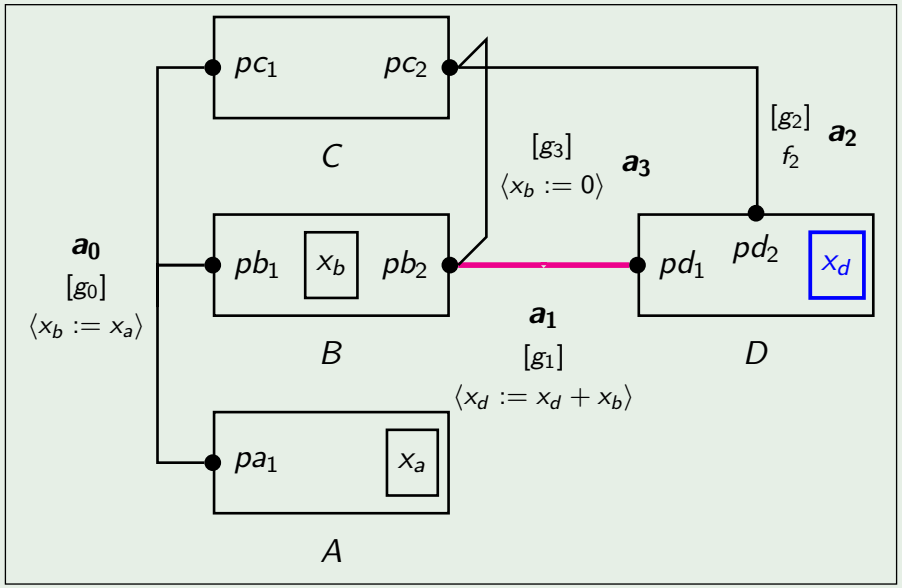

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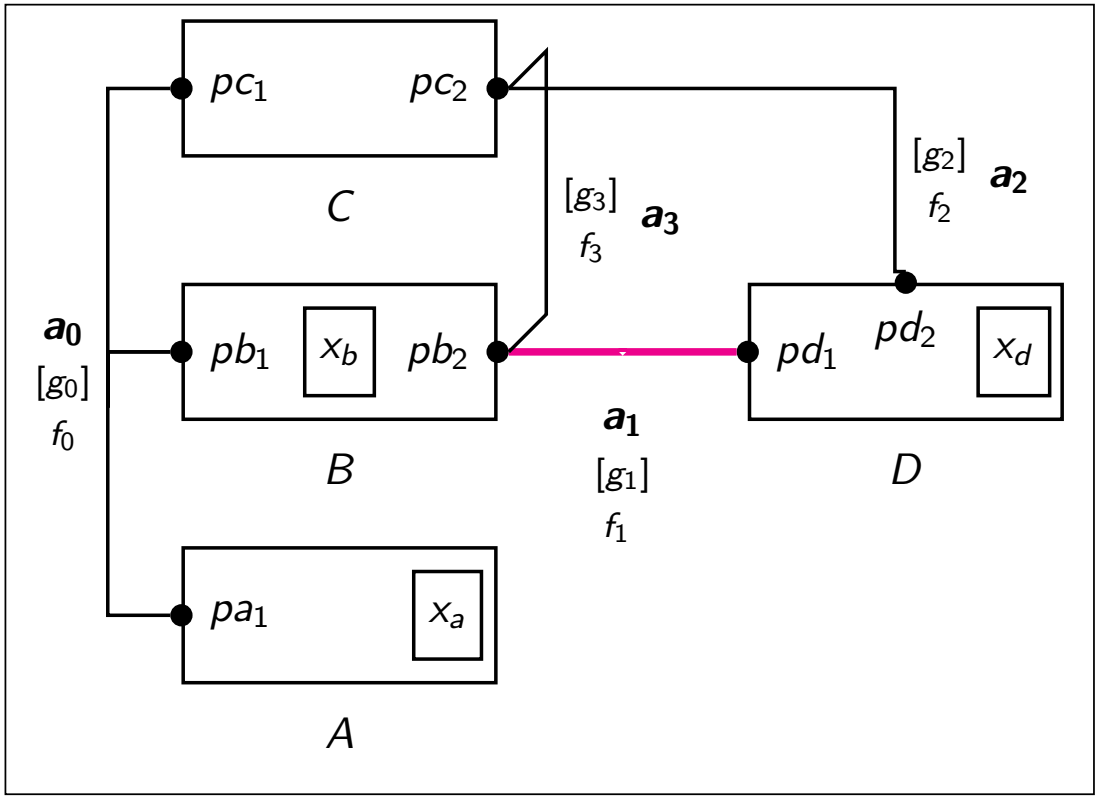

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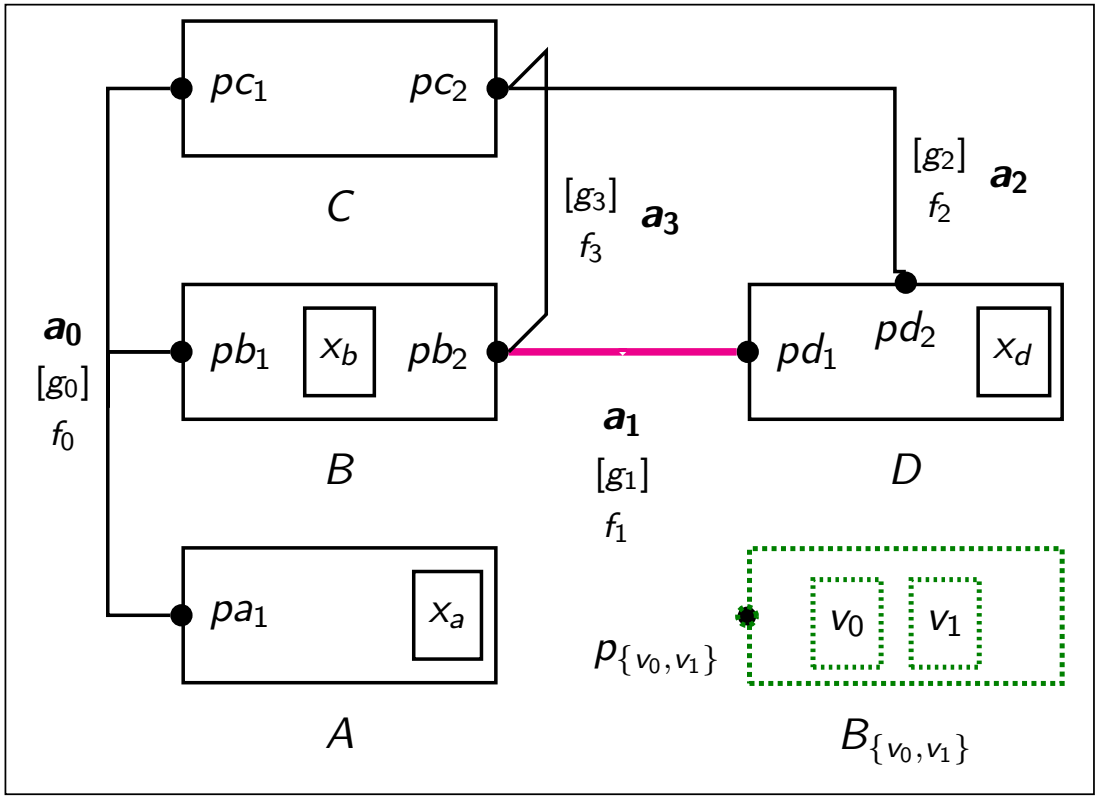
1. Select the match (set of interactions)
2. Add the inter-type component



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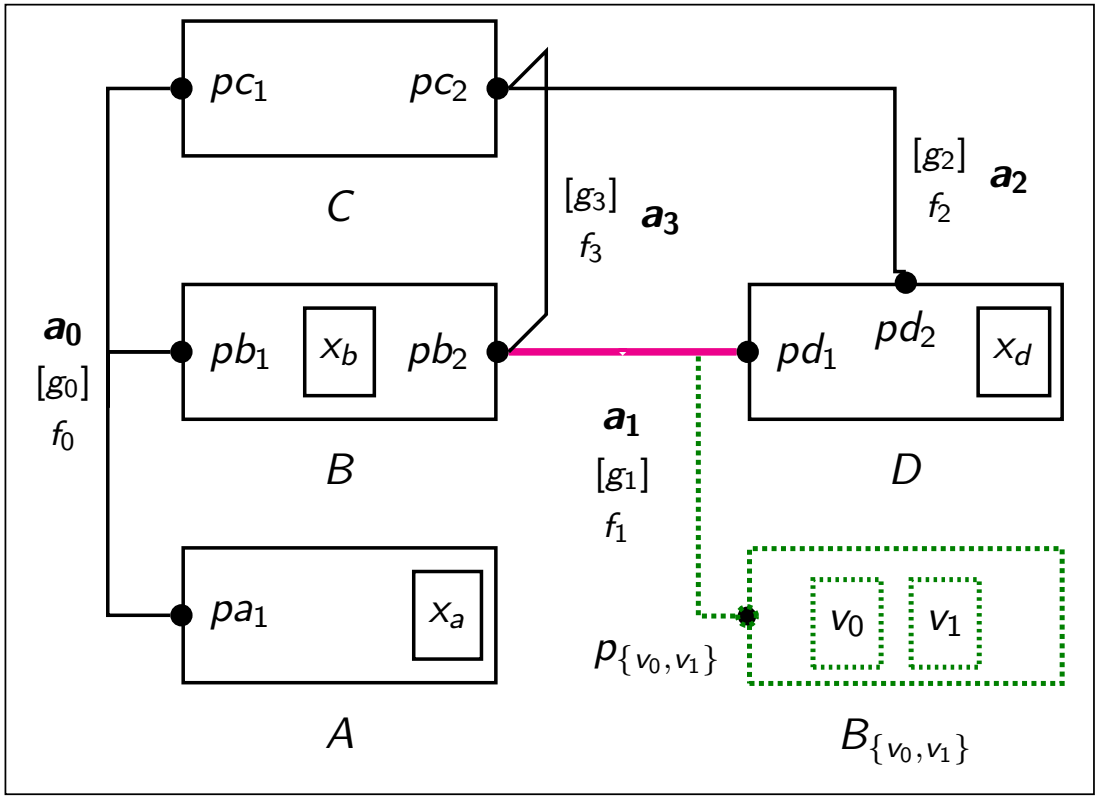

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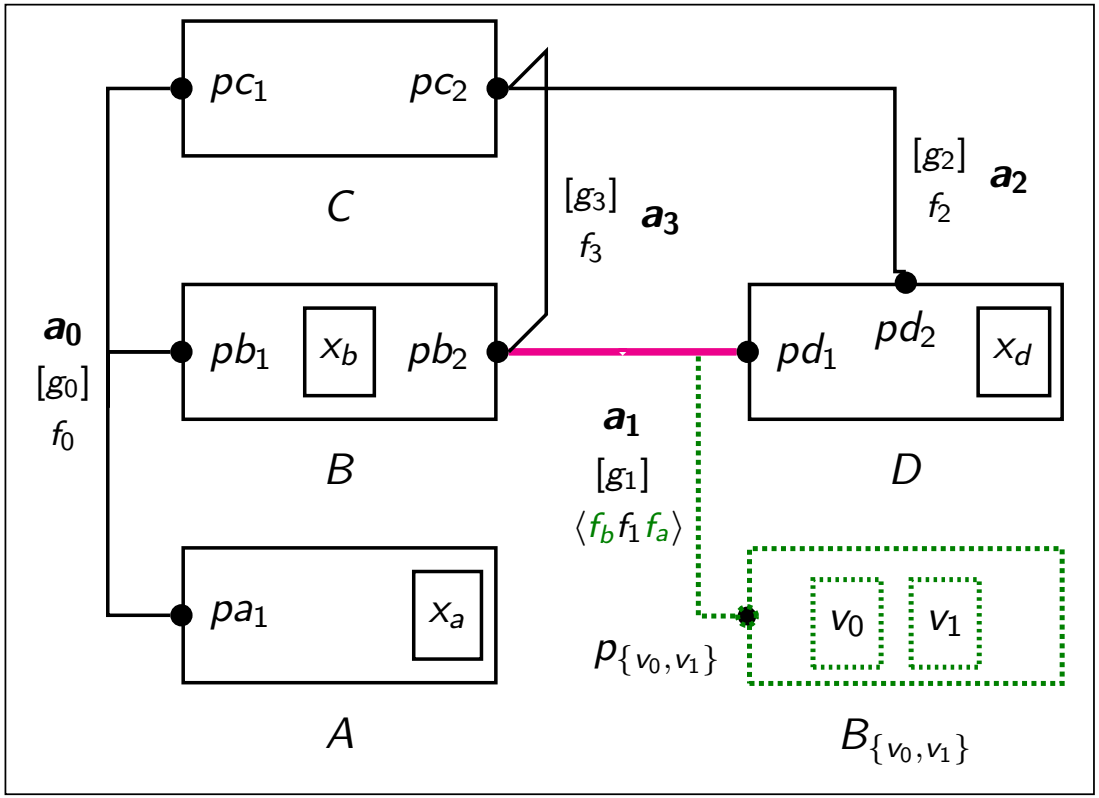

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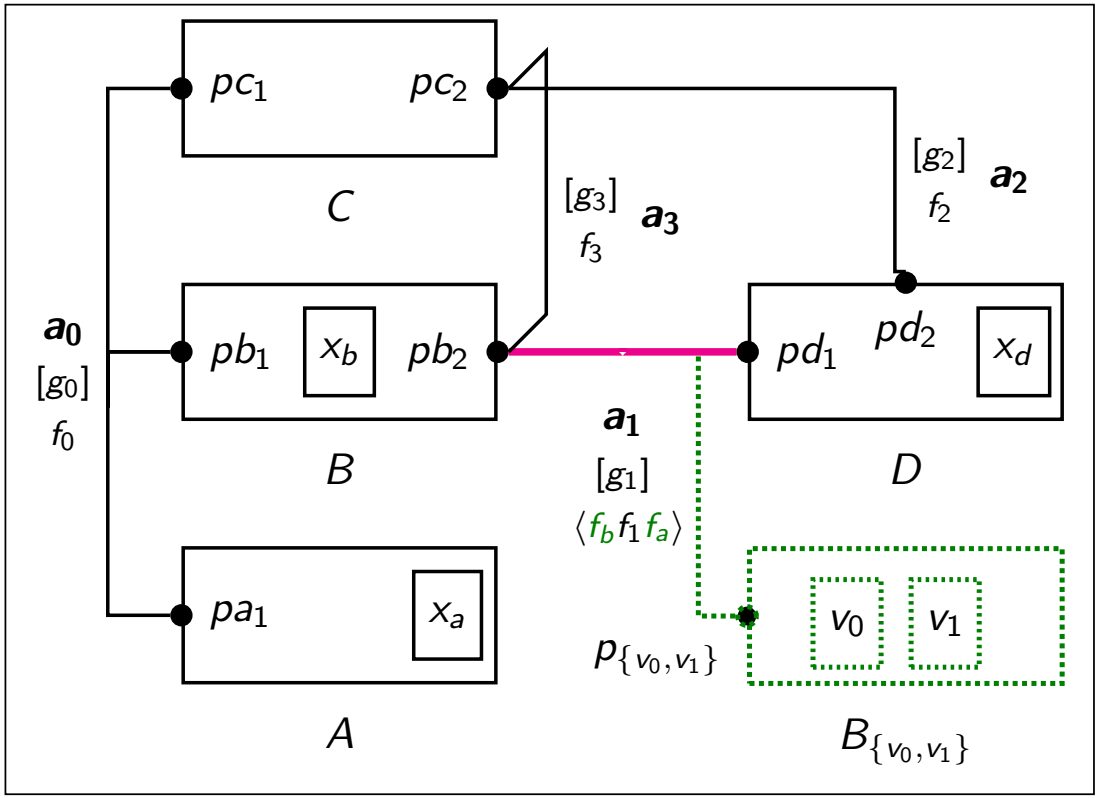

Global Aspect and Correctness

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Proposition: Correctness of a Single Weave

- Consider all events in the resulting system
- Define rem_g that removes the advice from the global event (if it exists)
- Verify that the advice is applied to an event e iff $\mathrm{rem}_g(e) \vDash gpc$

Local Execution Trace

Projection

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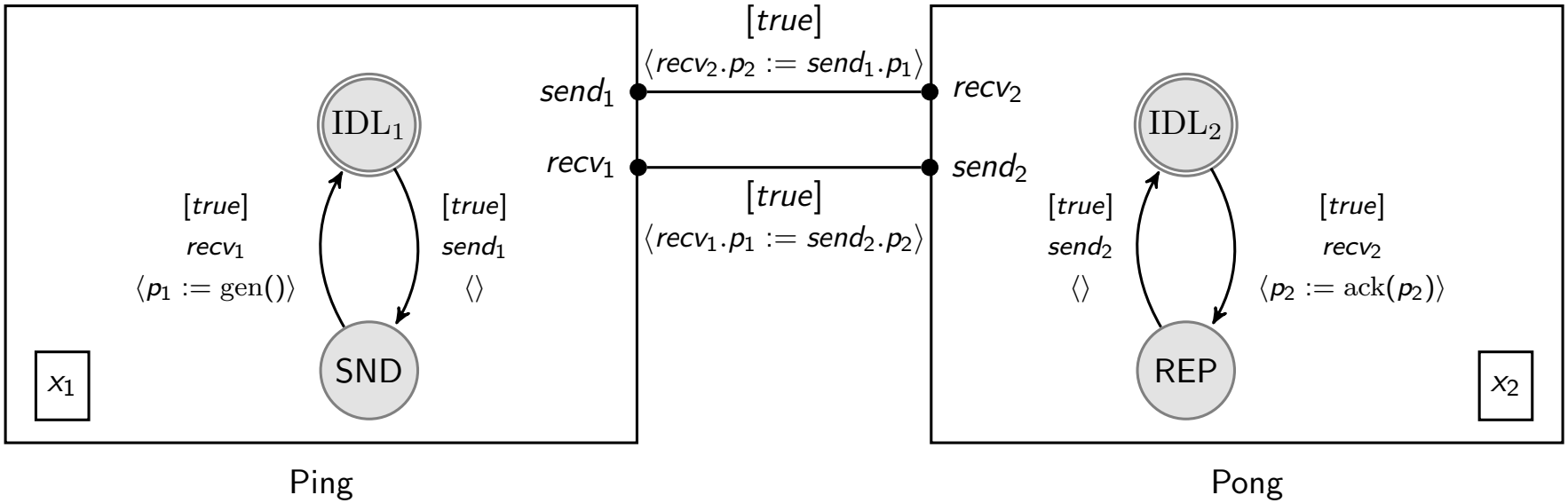
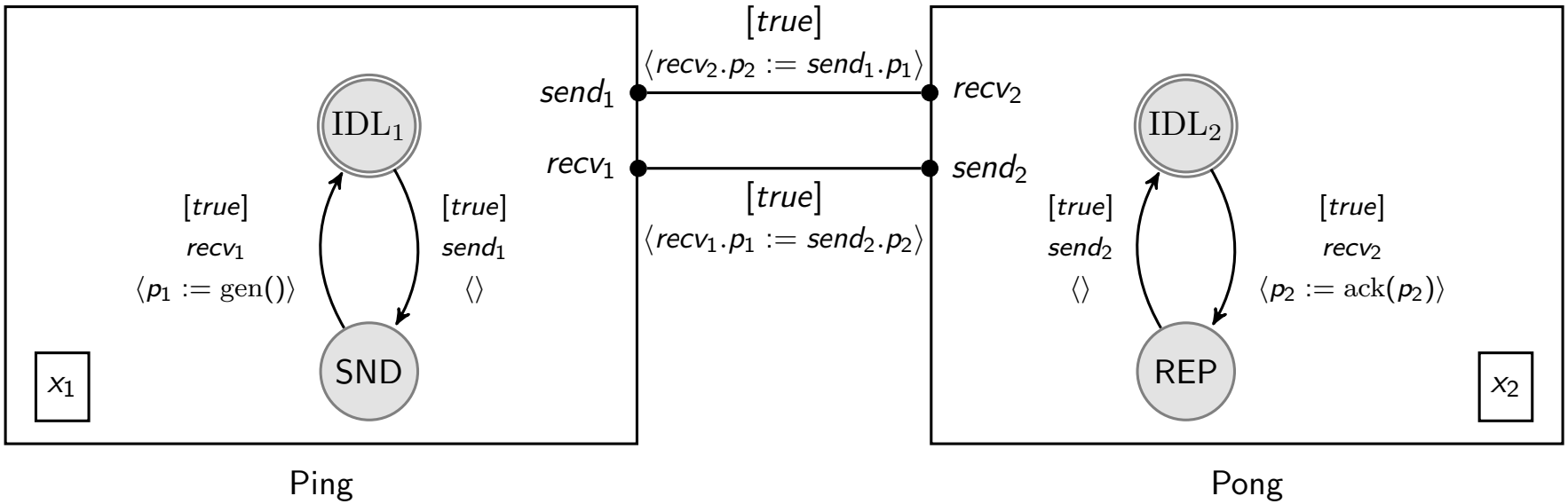
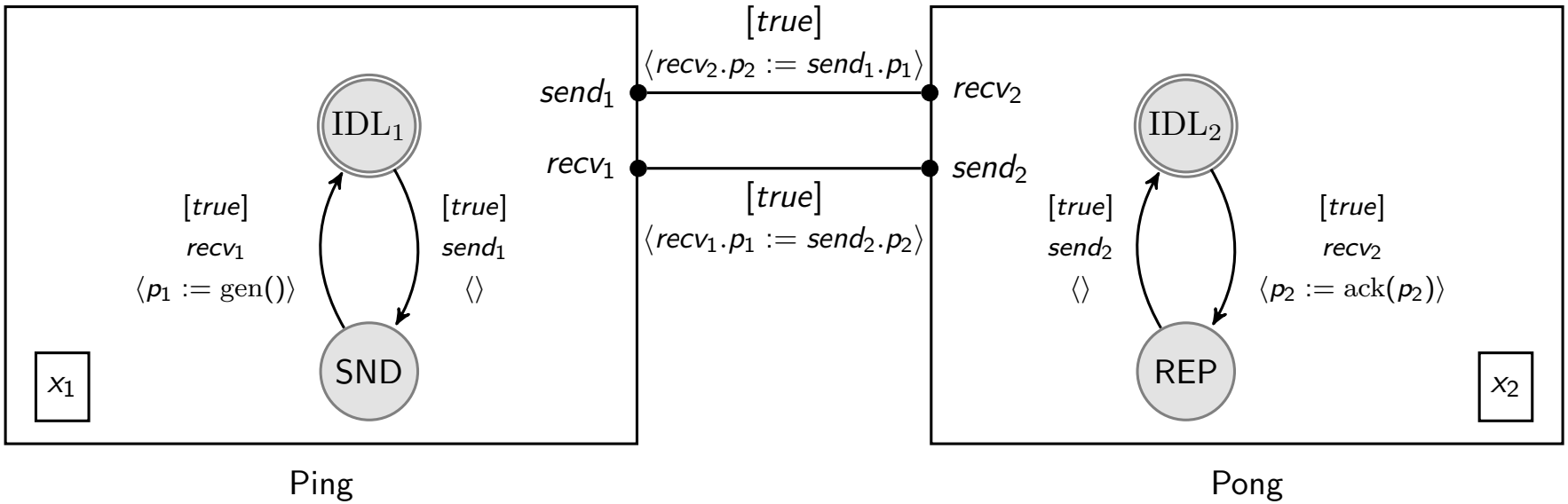

[true]
⟨recv2.p2 := send1.p1⟩
send1
recv2
recv1
send2
[true]
⟨recv1.p1 := send2.p2⟩
IDL1
[true]
recv1
⟨p1 := gen()⟩
[true]
send1
⟨⟩
SND
x1
Ping
IDL2
[true]
send2
⟨⟩
[true]
recv2
⟨p2 := ack(p2)⟩
REP
x2
Pong

Example



- $E_0 = \langle\langle\langle \mathtt{IDL}_1, \langle 1\rangle\rangle, \langle \mathtt{IDL}_2, \langle 0\rangle\rangle\rangle, \{\mathtt{send}_1, \mathtt{recv}_2\}, \langle\langle \mathtt{SND}, \langle 1\rangle\rangle, \langle \mathtt{REP}, \langle 2\rangle\rangle\rangle\rangle$

Example



- $E_0 = \langle\langle\langle \mathtt{IDL}_1, \langle 1\rangle\rangle, \langle \mathtt{IDL}_2, \langle 0\rangle\rangle\rangle, \{\mathtt{send}_1, \mathtt{recv}_2\}, \langle\langle \mathtt{SND}, \langle 1\rangle\rangle, \langle \mathtt{REP}, \langle 2\rangle\rangle\rangle\rangle$
- $\mathrm{map}(E_0, B_0) = \langle\langle \mathtt{IDL}_1, \langle 1\rangle\rangle, \mathtt{send}_1, \langle \mathtt{SND}, \langle 1\rangle\rangle\rangle$
- $\mathrm{map}(E_0, B_1) = \langle\langle \mathtt{IDL}_2, \langle 0\rangle\rangle, \mathtt{recv}_2, \langle \mathtt{REP}, \langle 2\rangle\rangle\rangle$

Local Pointcuts

Location

$e = \langle\langle l, v\rangle, \tau, \langle l', v'\rangle\rangle \vDash lpc$ iff match lpc with:

$$\mid \text{atLocation}(\ell) \qquad \rightarrow (l = \ell)$$

Local Pointcuts

Variables

$e = \langle \langle l, v \rangle, \tau, \langle l', v' \rangle \rangle \vDash lpc$ iff match lpc with:

$$
\begin{array}{ll}
\mid \mathrm{atLocation}(\ell) & \rightarrow (l = \ell) \\
\mid \mathrm{readVarGuard}(x) & \rightarrow (\exists t \in B_k.trans : t.src = l \wedge x \in \mathsf{readguard}(t)) \\
\mid \mathrm{readVarFunc}(x) & \rightarrow (x \in \mathsf{readvar}(\tau.func)) \\
\mid \mathrm{write}(x) & \rightarrow (x \in \mathsf{writevar}(\tau.func))
\end{array}
$$

Local Pointcuts

Ports

$e = \langle \langle l, v \rangle, \tau, \langle l', v' \rangle \rangle \vDash lpc$ iff match lpc with:

$$
\begin{array}{ll}
\mid \mathrm{atLocation}(\ell) & \rightarrow (l = \ell) \\
\mid \mathrm{readVarGuard}(x) & \rightarrow (\exists t \in B_k.trans : t.src = l \wedge x \in \mathsf{readguard}(t)) \\
\mid \mathrm{readVarFunc}(x) & \rightarrow (x \in \mathsf{readvar}(\tau.func)) \\
\mid \mathrm{write}(x) & \rightarrow (x \in \mathsf{writevar}(\tau.func)) \\
\mid \mathrm{portEnabled}(p) & \rightarrow (\exists q' : \langle \langle l, v \rangle, p, q' \rangle \in \rightarrow_{B_k})
\end{array}
$$

Local Pointcuts

Ports

$e = \langle \langle l, v \rangle, \tau, \langle l', v' \rangle \rangle \vDash lpc$ iff match lpc with:

$$
\begin{array}{ll}
\mid \mathrm{atLocation}(\ell) & \rightarrow (l = \ell) \\
\mid \mathrm{readVarGuard}(x) & \rightarrow (\exists t \in B_k.trans : t.src = l \wedge x \in \mathsf{readguard}(t)) \\
\mid \mathrm{readVarFunc}(x) & \rightarrow (x \in \mathsf{readvar}(\tau.func)) \\
\mid \mathrm{write}(x) & \rightarrow (x \in \mathsf{writevar}(\tau.func)) \\
\mid \mathrm{portEnabled}(p) & \rightarrow (\exists q' : \langle \langle l, v \rangle, p, q' \rangle \in \rightarrow_{B_k}) \\
\mid \mathrm{portExecute}(p) & \rightarrow (\tau.port = p)
\end{array}
$$

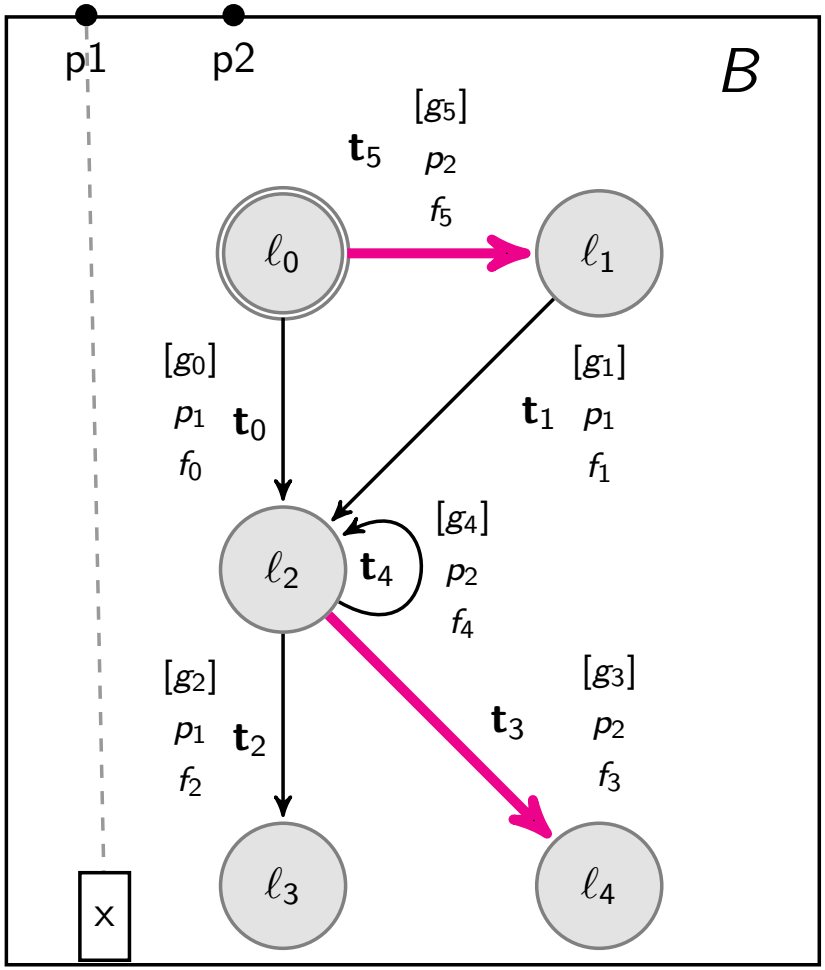
Local Pointcuts

Combination

$e = \langle \langle l, v \rangle, \tau, \langle l', v' \rangle \rangle \vDash lpc$ iff match lpc with:

$$
\begin{array}{ll}
\mid \mathrm{atLocation}(\ell) & \rightarrow (l = \ell) \\
\mid \mathrm{readVarGuard}(x) & \rightarrow (\exists t \in B_k.trans : t.src = l \wedge x \in \mathsf{readguard}(t)) \\
\mid \mathrm{readVarFunc}(x) & \rightarrow (x \in \mathsf{readvar}(\tau.func)) \\
\mid \mathrm{write}(x) & \rightarrow (x \in \mathsf{writevar}(\tau.func)) \\
\mid \mathrm{portEnabled}(p) & \rightarrow (\exists q' : \langle \langle l, v \rangle, p, q' \rangle \in \rightarrow_{B_k}) \\
\mid \mathrm{portExecute}(p) & \rightarrow (\tau.port = p) \\
\mid \phi \text{ and } \phi' & \rightarrow e \vDash \phi \wedge e \vDash \phi'
\end{array}
$$

Syntactic Representation



$$M = \{t_3, t_5\}$$

ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$\mathbf{t_5} : \langle \mathbf{g_5}, \mathbf{p_2}, \mathbf{f_5} \rangle$	ℓ_1

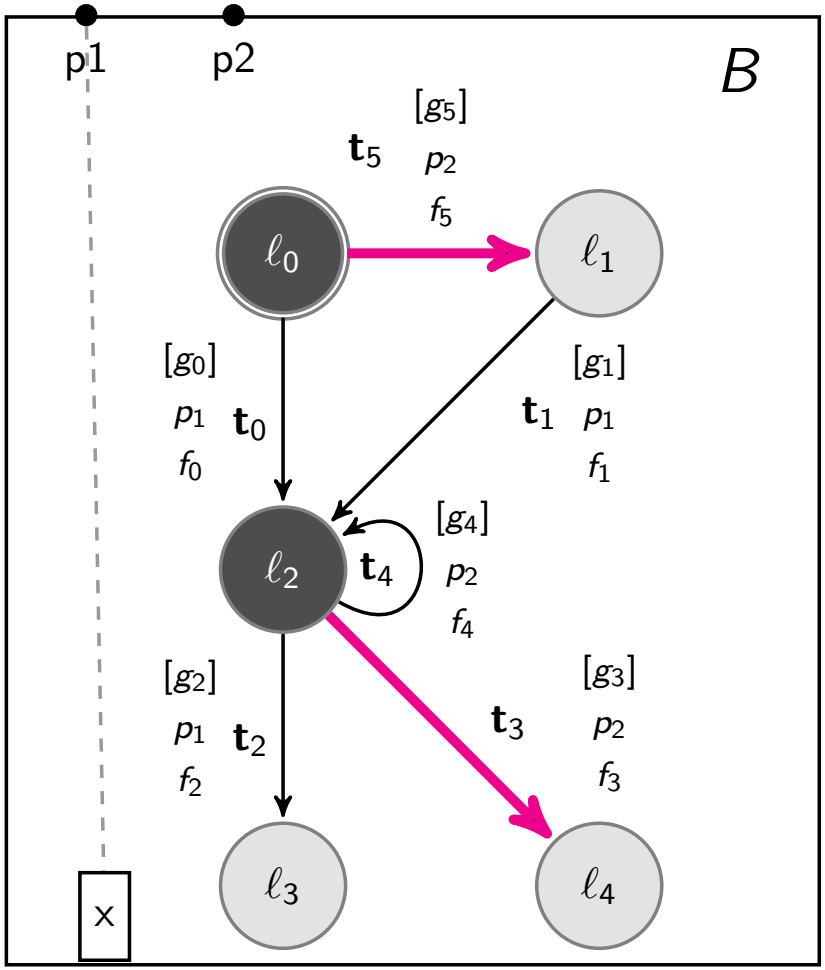
ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$\mathbf{t_3} : \langle \mathbf{g_3}, \mathbf{p_2}, \mathbf{f_3} \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3

ℓ_4

Syntactic Representation



origin(M)

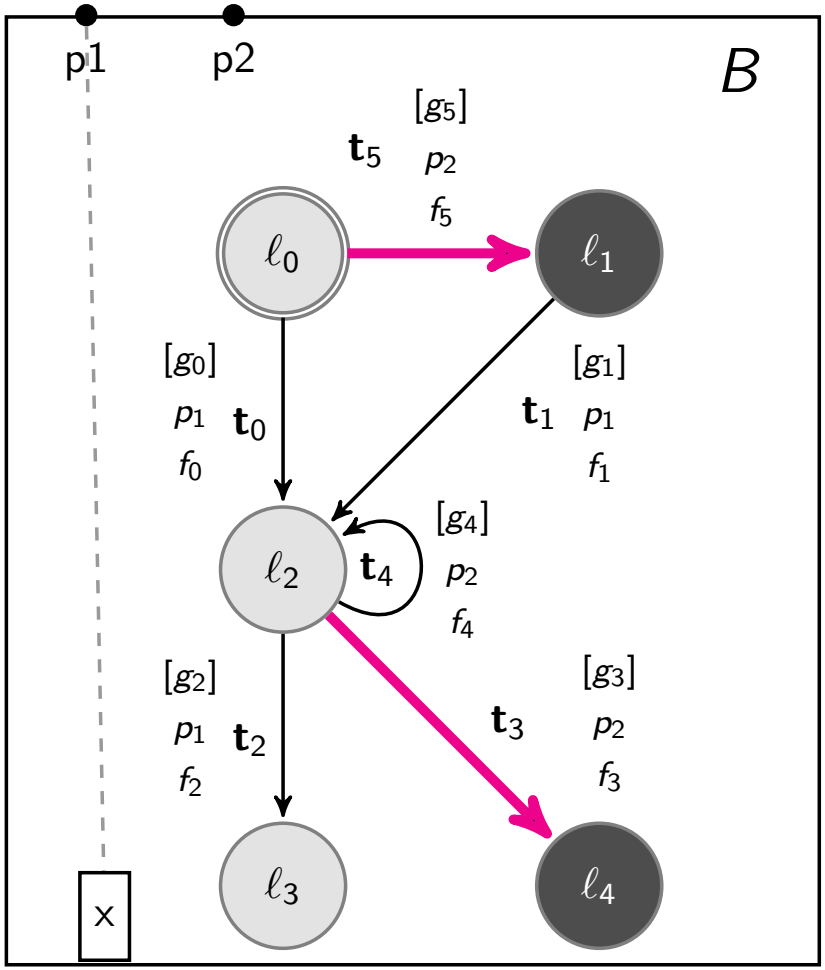
ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$\mathbf{t_5 : \langle g_5, p_2, f_5 \rangle}$	ℓ_1

ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$\mathbf{t_3 : \langle g_3, p_2, f_3 \rangle}$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3
ℓ_4

Syntactic Representation



$\mathrm{dest}(M)$

ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$\mathbf{t_5 : \langle g_5, p_2, f_5 \rangle}$	ℓ_1

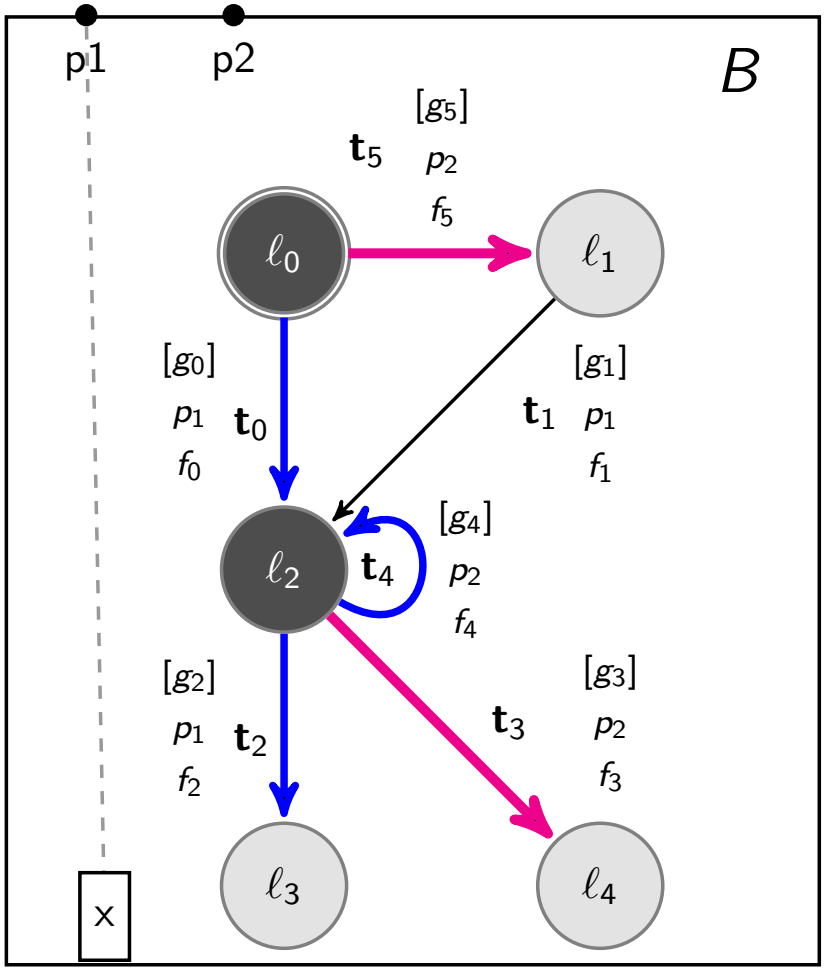
ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$\mathbf{t_3 : \langle g_3, p_2, f_3 \rangle}$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3

ℓ_4

Syntactic Representation



siblings(M)

ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$\mathbf{t_5} : \langle \mathbf{g_5}, \mathbf{p_2}, \mathbf{f_5} \rangle$	ℓ_1

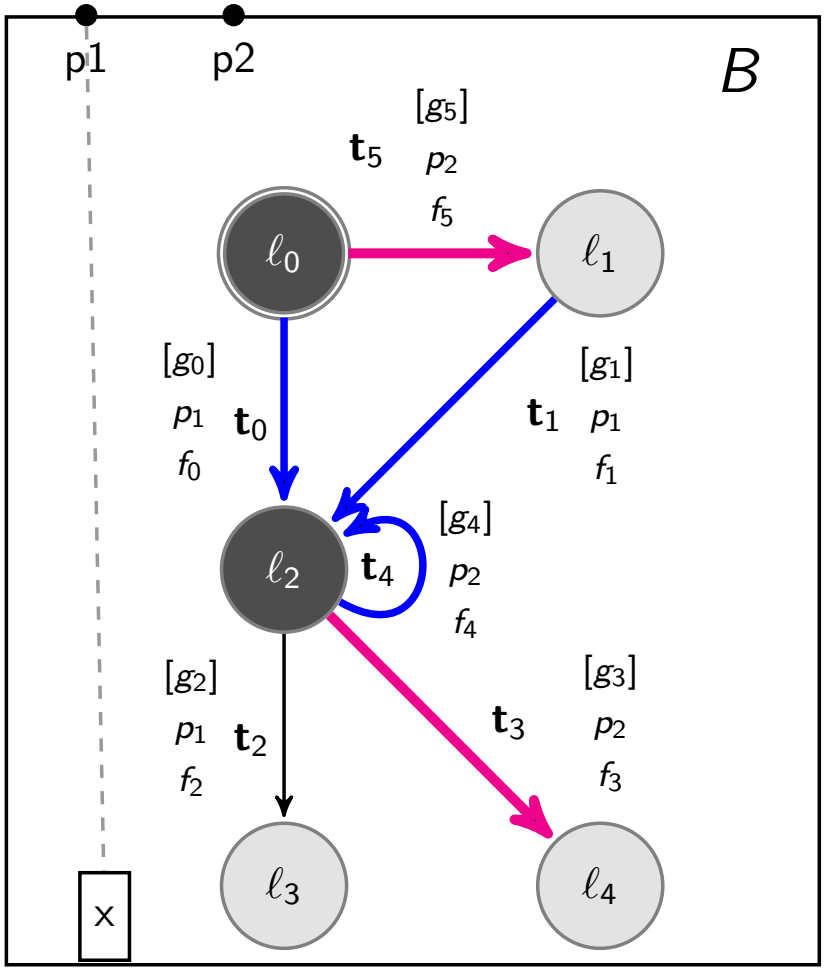
ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$\mathbf{t_3} : \langle \mathbf{g_3}, \mathbf{p_2}, \mathbf{f_3} \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3

ℓ_4

Syntactic Representation



previous(M)

ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$\mathbf{t_5} : \langle \mathbf{g_5}, \mathbf{p_2}, \mathbf{f_5} \rangle$	ℓ_1

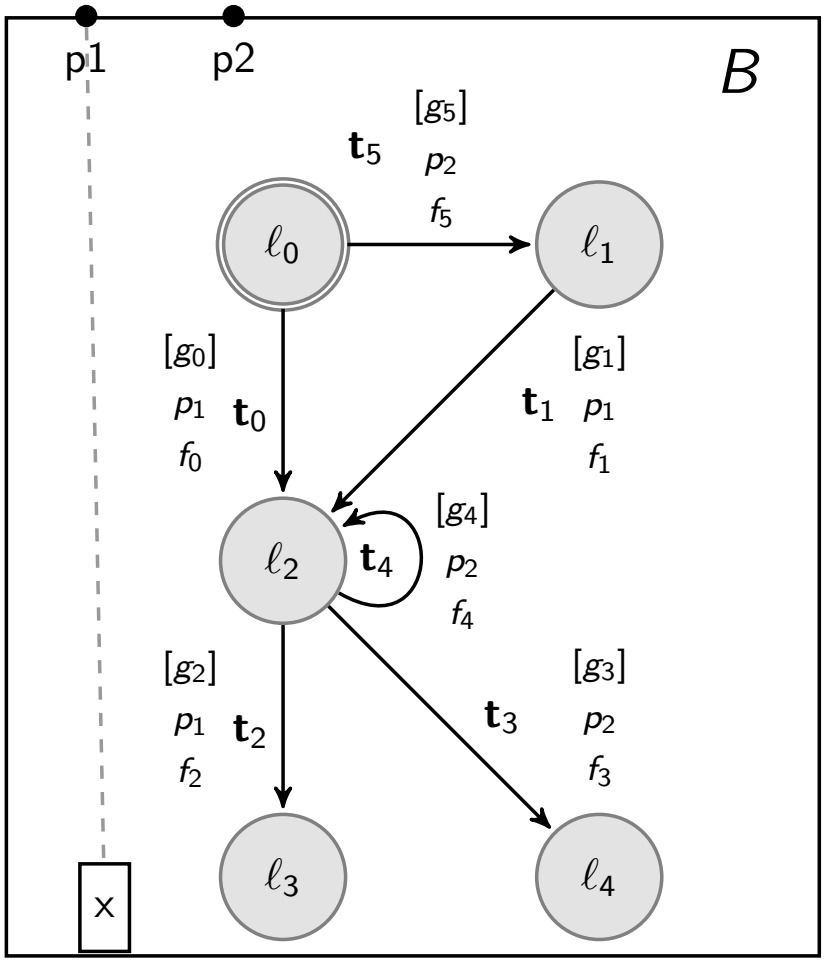
ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$\mathbf{t_3} : \langle \mathbf{g_3}, \mathbf{p_2}, \mathbf{f_3} \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3

ℓ_4

Matching Pointcuts



$$g_3 = x > 3$$

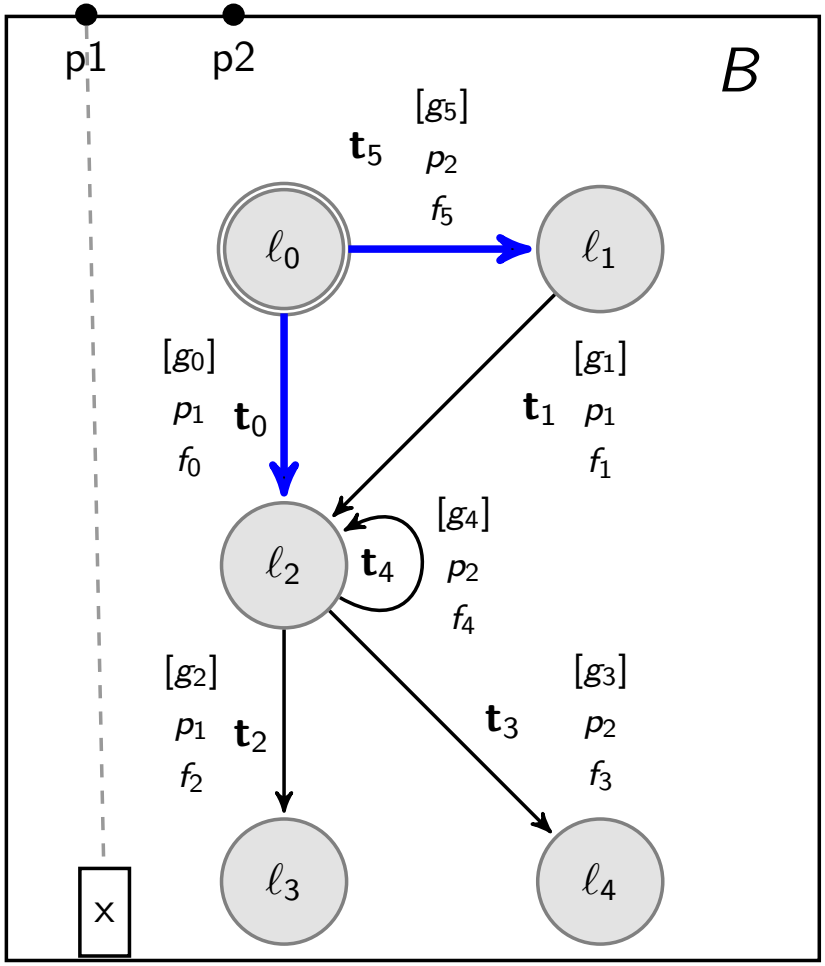
ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$t_5 : \langle g_5, p_2, f_5 \rangle$	ℓ_1

ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$t_3 : \langle g_3, p_2, f_3 \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3
ℓ_4

Matching Pointcuts



$$g_3 = x > 3$$

$\text{atLocation}(\ell_0)$

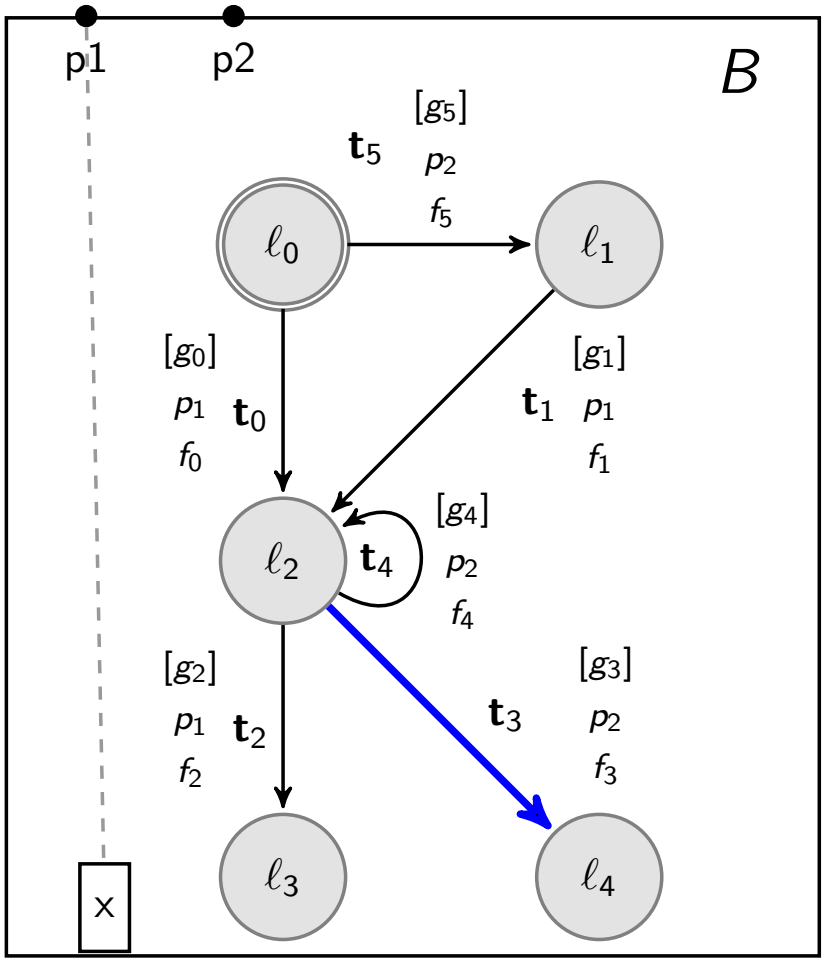
ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$t_5 : \langle g_5, p_2, f_5 \rangle$	ℓ_1

ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$t_3 : \langle g_3, p_2, f_3 \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3
ℓ_4

Matching Pointcuts



$$g_3 = x > 3$$

$\mathrm{readVarGuard}(x)$

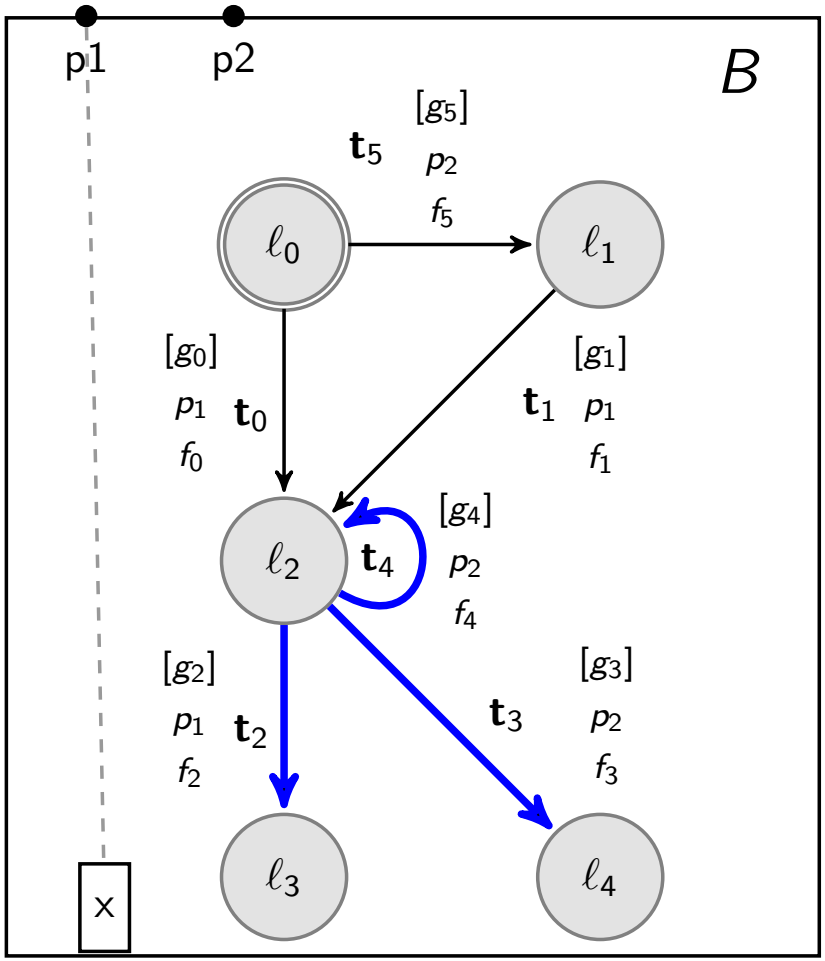
ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$t_5 : \langle g_5, p_2, f_5 \rangle$	ℓ_1

ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$t_3 : \langle g_3, p_2, f_3 \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3
ℓ_4

Matching Pointcuts



$$g_3 = x > 3$$

readVarGuard(x) [Siblings]

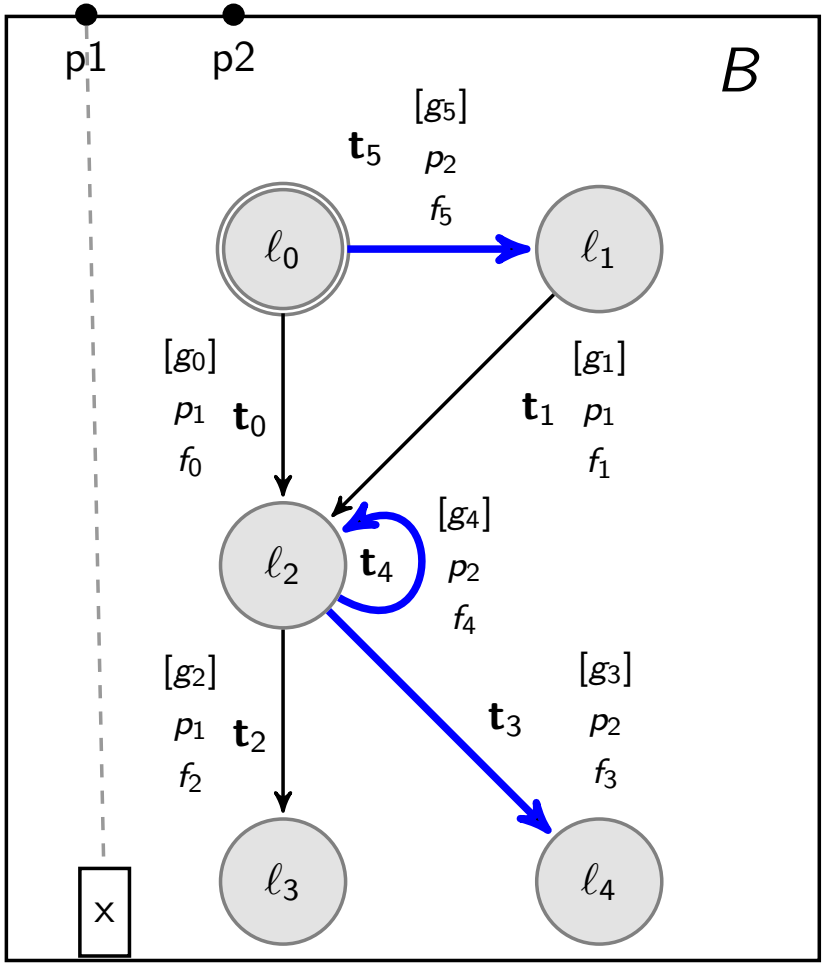
ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$t_5 : \langle g_5, p_2, f_5 \rangle$	ℓ_1

ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$t_3 : \langle g_3, p_2, f_3 \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3
ℓ_4

Matching Pointcuts



$$g_3 = x > 3$$

portExecute(p_2)

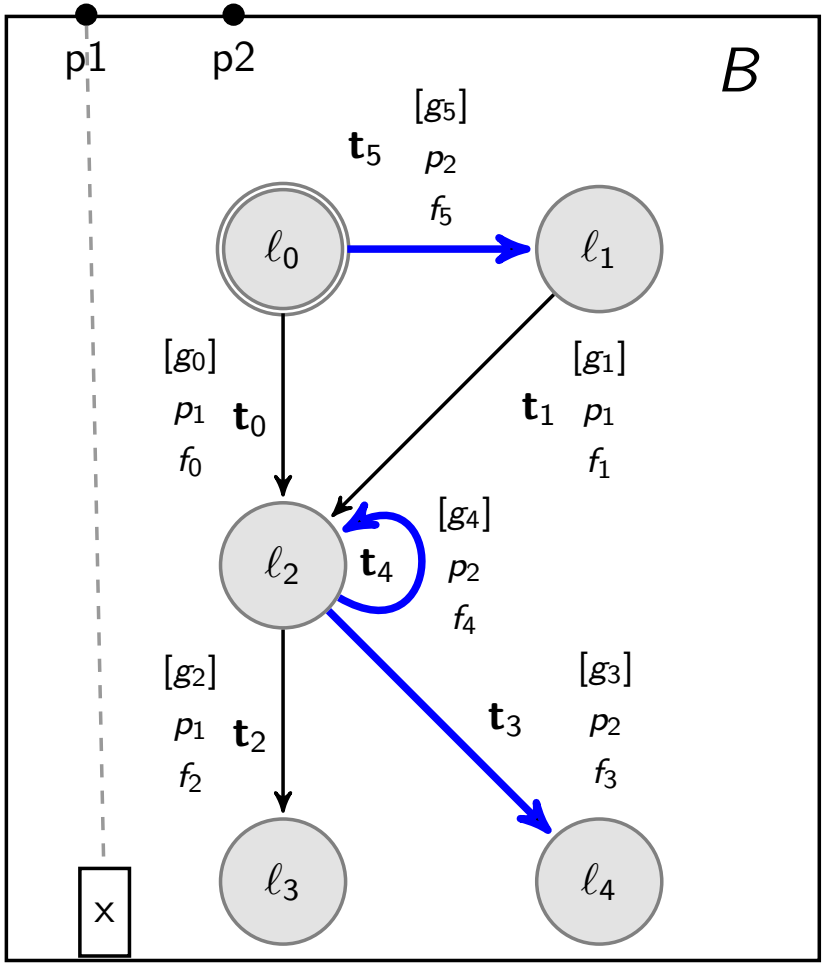
ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$t_5 : \langle g_5, p_2, f_5 \rangle$	ℓ_1

ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$t_3 : \langle g_3, p_2, f_3 \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3
ℓ_4

Matching Pointcuts



$$g_3 = x > 3$$

$\text{portEnabled}(p_2)$

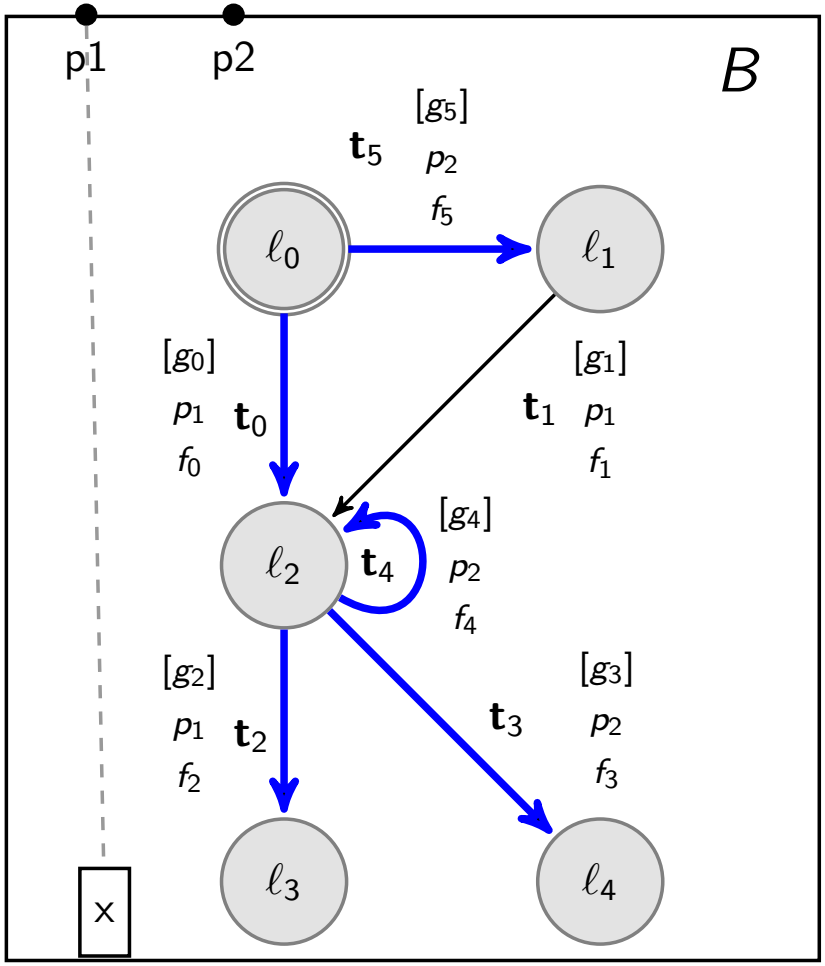
ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$t_5 : \langle g_5, p_2, f_5 \rangle$	ℓ_1

ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$t_3 : \langle g_3, p_2, f_3 \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3
ℓ_4

Matching Pointcuts



$$g_3 = x > 3$$

$\mathrm{portEnabled}(p_2)[\mathrm{Siblings}]$

ℓ_0	
$t_0 : \langle g_0, p_1, f_0 \rangle$	ℓ_2
$t_5 : \langle g_5, p_2, f_5 \rangle$	ℓ_1

ℓ_2	
$t_2 : \langle g_2, p_1, f_2 \rangle$	ℓ_3
$t_3 : \langle g_3, p_2, f_3 \rangle$	ℓ_4
$t_4 : \langle g_4, p_2, f_4 \rangle$	ℓ_2

ℓ_1	
$t_1 : \langle g_1, p_1, f_1 \rangle$	ℓ_2

ℓ_3
ℓ_4

Local Advice

1. A function f_b to execute before the update function.
2. A function f_a to execute after the update function.

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1. A function f_b to execute before the update function.
2. A function f_a to execute after the update function.
3. A set of "reset location" pairs $\langle l, g \rangle$: after joinpoint move to l if g holds.

Local Weaving

- Add inter-type variables to the component directly

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- Add inter-type variables to the component directly
- Determine what is before and after the element selection

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- Determine what is before and after the element selection
- Dynamic behavior: portEnabled, reset location

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  - Use an extra boolean variable to denote entry/exit of a pointcut area

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- Add inter-type variables to the component directly
- Determine what is before and after the element selection
- Dynamic behavior: portEnabled, reset location
  - Use an extra boolean variable to denote entry/exit of a pointcut area
  - Pre-evaluate guards in an earlier temporary location
  - Simulate if/else construct by duplicating transitions

Composition (Overview)

- Conditions for interference
  - Multiple concerns can overlap one region
  - Not all concerns are independant
  - Possibility to have non-determinism or unwanted side-effects

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  - Multiple concerns can overlap one region
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- Dealing with interference
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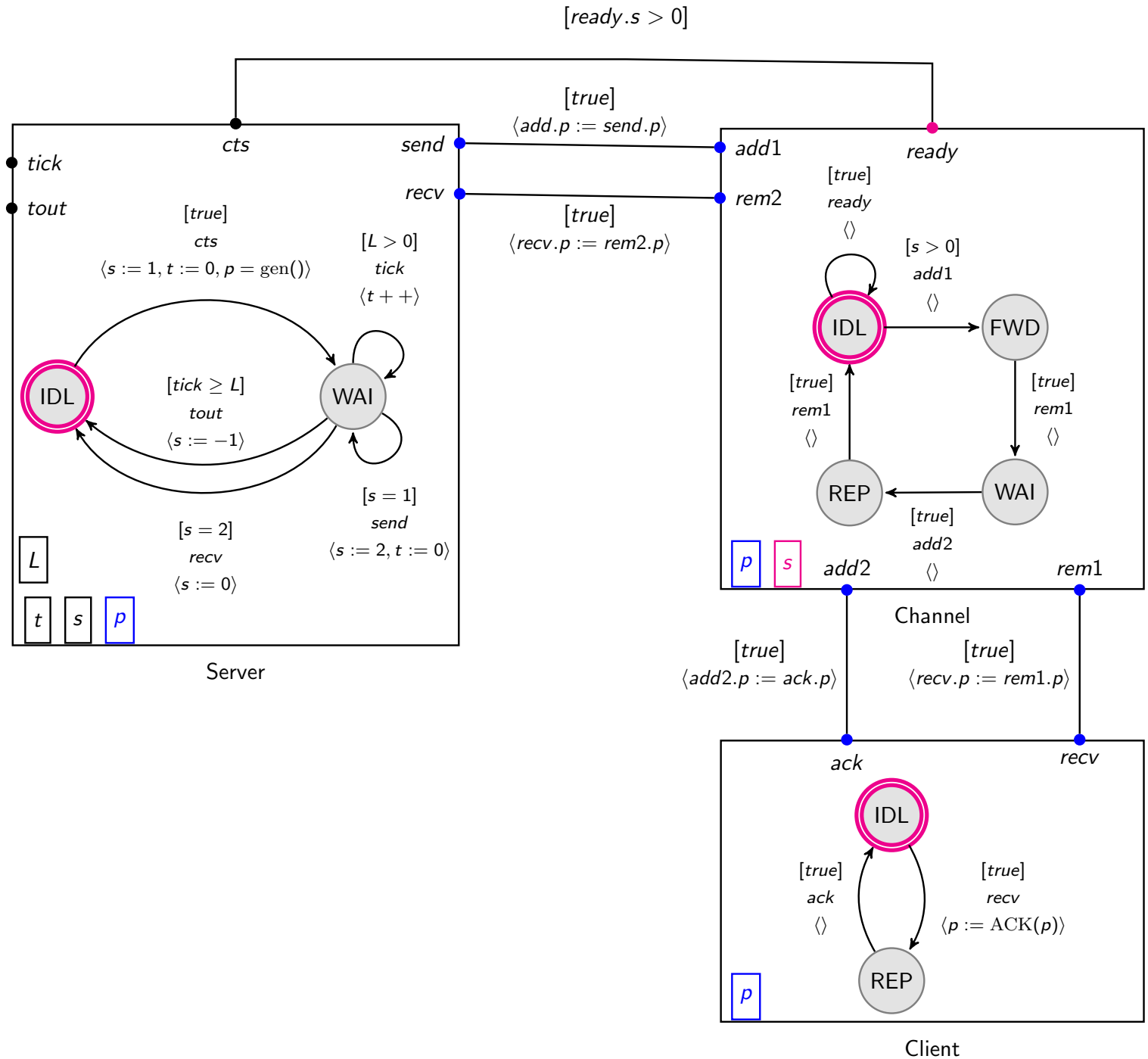
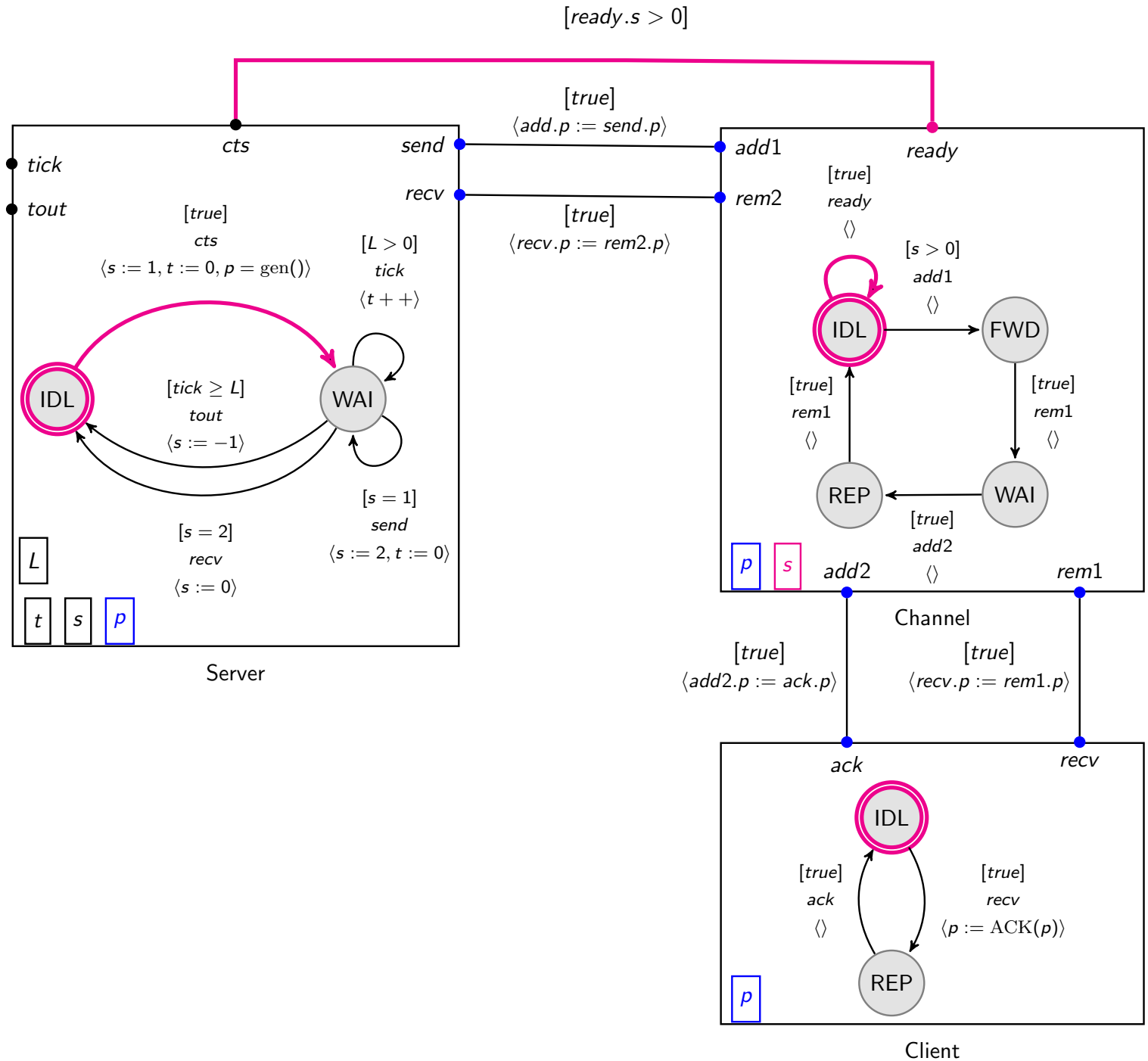
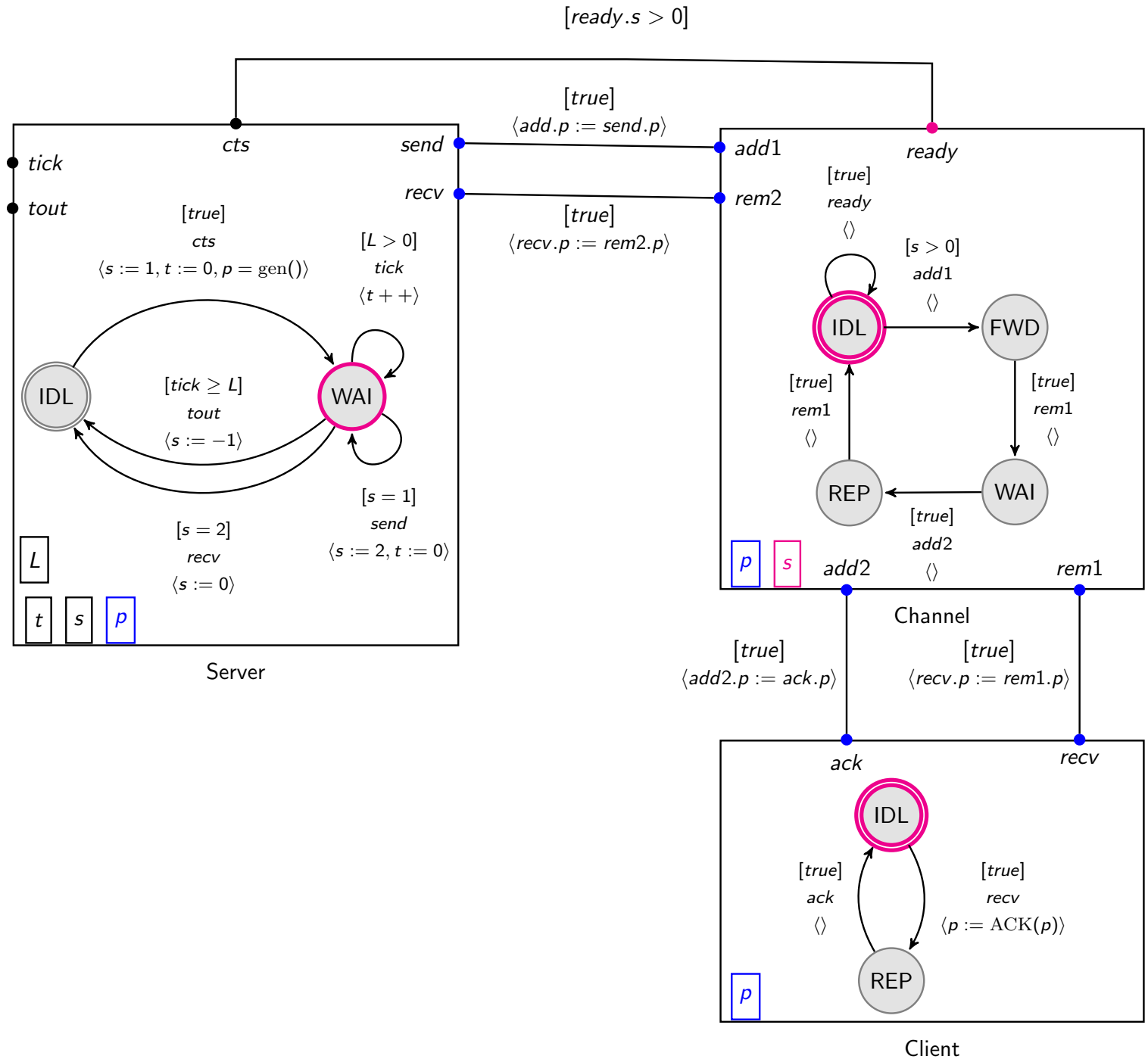
  - Not all concerns are independant
  - Possibility to have non-determinism or unwanted side-effects
- Dealing with interference
  - Aspect containers: extra constraints on the aspects (ordering and sharing)
  - Weaving procedures: match/weave strategy

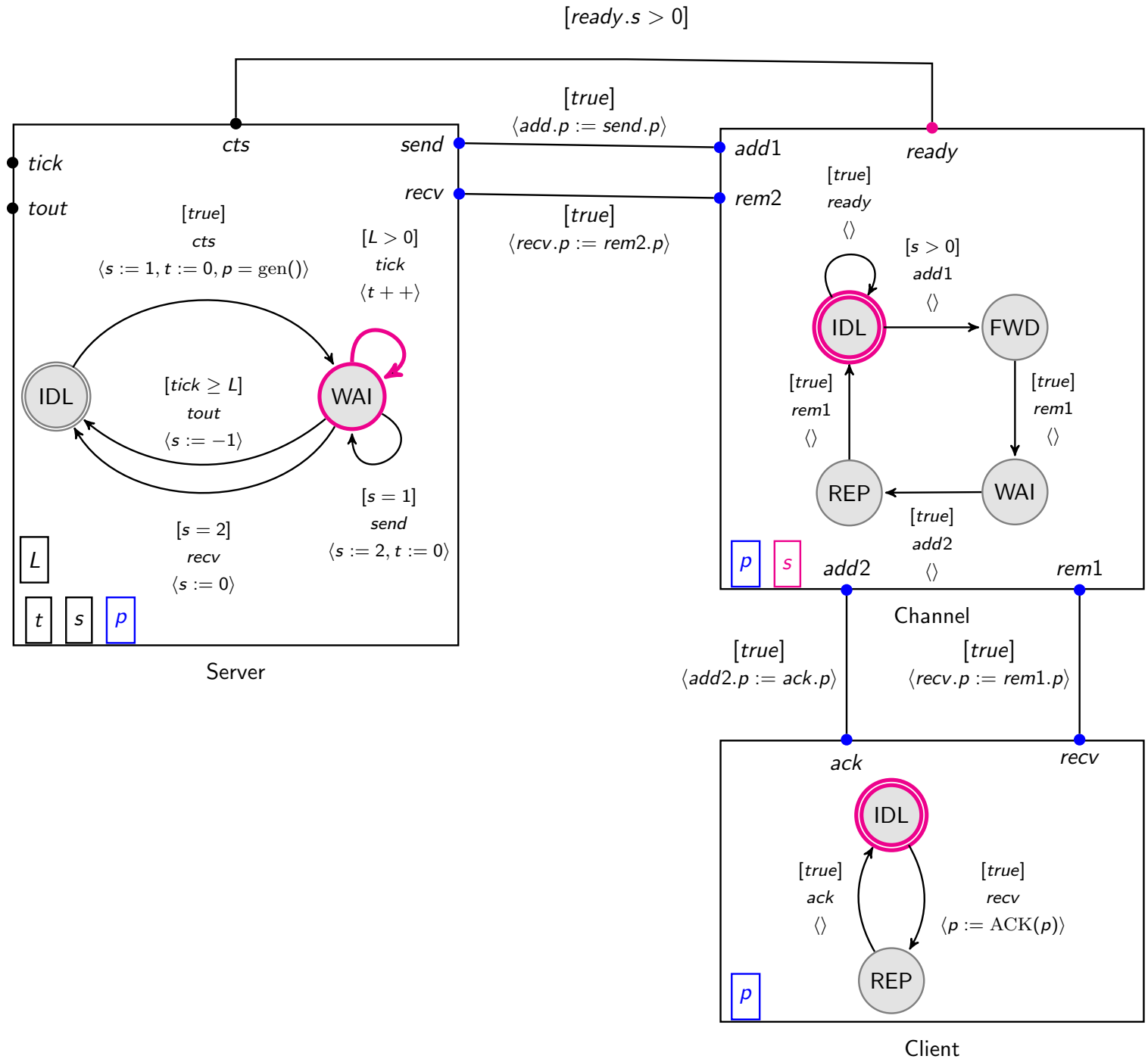
Using AOP-BIP
Network Example [1]

[1] A modified version of the network in [Bonakdarpour et al., 2012]


[ready.s > 0]
[true]
⟨add.p := send.p⟩
[true]
⟨recv.p := rem2.p⟩
cts
send
recv
tick
tout
add1
rem2
ready
[true]
cts
⟨s := 1, t := 0, p = gen()⟩
[L > 0]
tick
⟨t++⟩
IDL
WAI
[tick ≥ L]
tout
⟨s := −1⟩
[s = 1]
send
⟨s := 2, t := 0⟩
[s = 2]
recv
⟨s := 0⟩
L
t
s
p
Server
[true]
ready
⟨⟩
[s > 0]
add1
⟨⟩
IDL
FWD
[true]
rem1
⟨⟩
[true]
rem1
⟨⟩
REP
WAI
[true]
add2
⟨⟩
p
s
add2
rem1
Channel
[true]
⟨add2.p := ack.p⟩
[true]
⟨recv.p := rem1.p⟩
ack
recv
IDL
[true]
ack
⟨⟩
[true]
recv
⟨p := ACK(p)⟩
REP
p
Client


[ready.s > 0]
[true]
⟨add.p := send.p⟩
cts
send
add1
ready
tick
tout
recv
rem2
[true]
⟨recv.p := rem2.p⟩
[true]
cts
⟨s := 1, t := 0, p = gen()⟩
[L > 0]
tick
⟨t++⟩
[true]
ready
⟨⟩
[s > 0]
add1
⟨⟩
IDL
FWD
[tick ≥ L]
tout
⟨s := −1⟩
WAI
[true]
rem1
⟨⟩
[true]
rem1
⟨⟩
REP
WAI
[true]
add2
⟨⟩
[s = 1]
send
⟨s := 2, t := 0⟩
[s = 2]
recv
⟨s := 0⟩
L
t
s
p
p
s
add2
rem1
Server
Channel
[true]
⟨add2.p := ack.p⟩
[true]
⟨recv.p := rem1.p⟩
ack
recv
IDL
[true]
ack
⟨⟩
[true]
recv
⟨p := ACK(p)⟩
REP
p
Client


[ready.s > 0]
[true]
⟨add.p := send.p⟩
cts
send
add1
ready
tick
tout
recv
rem2
[true]
⟨recv.p := rem2.p⟩
[true]
cts
⟨s := 1, t := 0, p = gen()⟩
[L > 0]
tick
⟨t++⟩
IDL
WAI
[tick ≥ L]
tout
⟨s := −1⟩
[s = 1]
send
⟨s := 2, t := 0⟩
[s = 2]
recv
⟨s := 0⟩
L
t
s
p
Server
[true]
ready
⟨⟩
[s > 0]
add1
⟨⟩
IDL
FWD
[true]
rem1
⟨⟩
[true]
rem1
⟨⟩
REP
WAI
[true]
add2
⟨⟩
p
s
add2
rem1
Channel
[true]
⟨add2.p := ack.p⟩
[true]
⟨recv.p := rem1.p⟩
ack
recv
IDL
[true]
ack
⟨⟩
[true]
recv
⟨p := ACK(p)⟩
REP
p
Client


[ready.s > 0]
[true]
⟨add.p := send.p⟩
cts
send
add1
ready
tick
recv
rem2
tout
[true]
⟨recv.p := rem2.p⟩
[true]
cts
⟨s := 1, t := 0, p = gen()⟩
[L > 0]
tick
⟨t++⟩
[true]
ready
⟨⟩
[s > 0]
add1
⟨⟩
IDL
FWD
[tick ≥ L]
tout
⟨s := −1⟩
WAI
[true]
rem1
⟨⟩
[true]
rem1
⟨⟩
REP
WAI
[true]
add2
⟨⟩
[s = 1]
send
⟨s := 2, t := 0⟩
[s = 2]
recv
⟨s := 0⟩
L
t
s
p
p
s
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Channel
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[true]
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Server
ack
recv
IDL
[true]
ack
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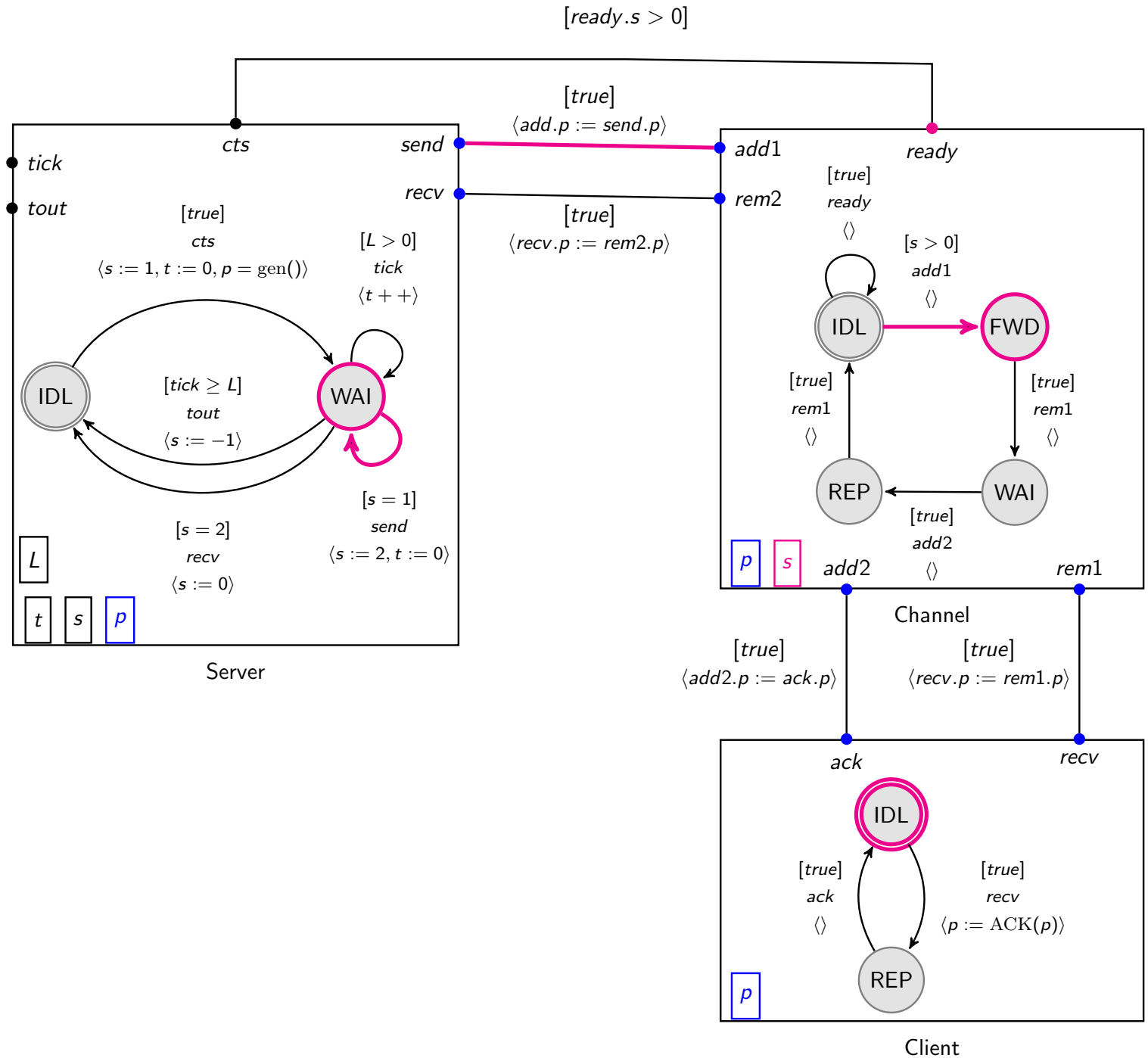
[true]
recv
⟨p := ACK(p)⟩
REP
p
Client


[ready.s > 0]
[true]
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send
add1
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tick
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recv
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[true]
cts
⟨s := 1, t := 0, p = gen()⟩
[L > 0]
tick
⟨t + +⟩
[true]
ready
⟨⟩
[s > 0]
add1
⟨⟩
IDL
FWD
[tick ≥ L]
tout
⟨s := −1⟩
WAI
[true]
rem1
⟨⟩
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⟨⟩
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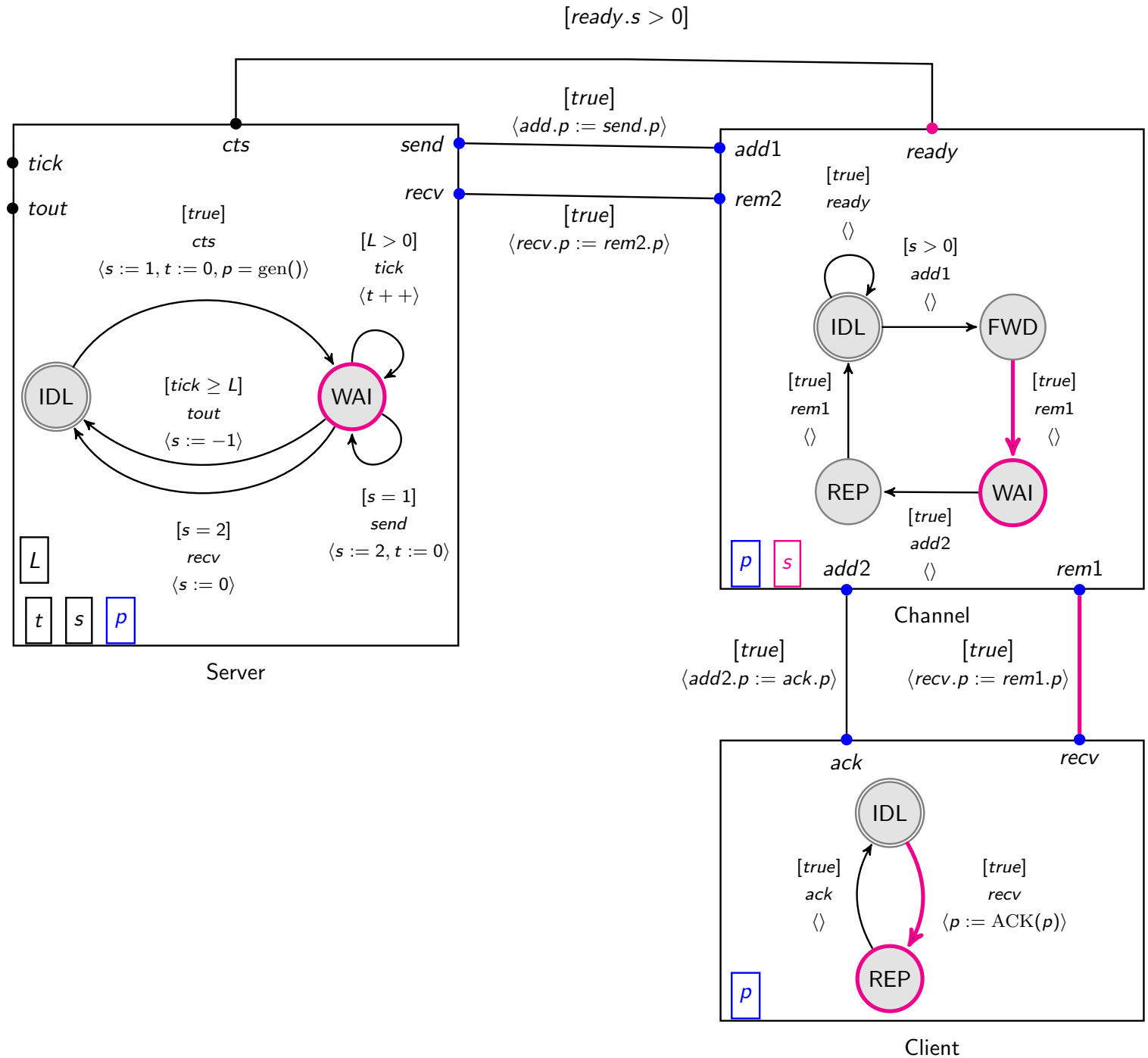
Client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⟨⟩
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add1
⟨⟩
IDL
FWD
[tick ≥ L]
tout
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[true]
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⟨⟩
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⟨s := 2, t := 0⟩
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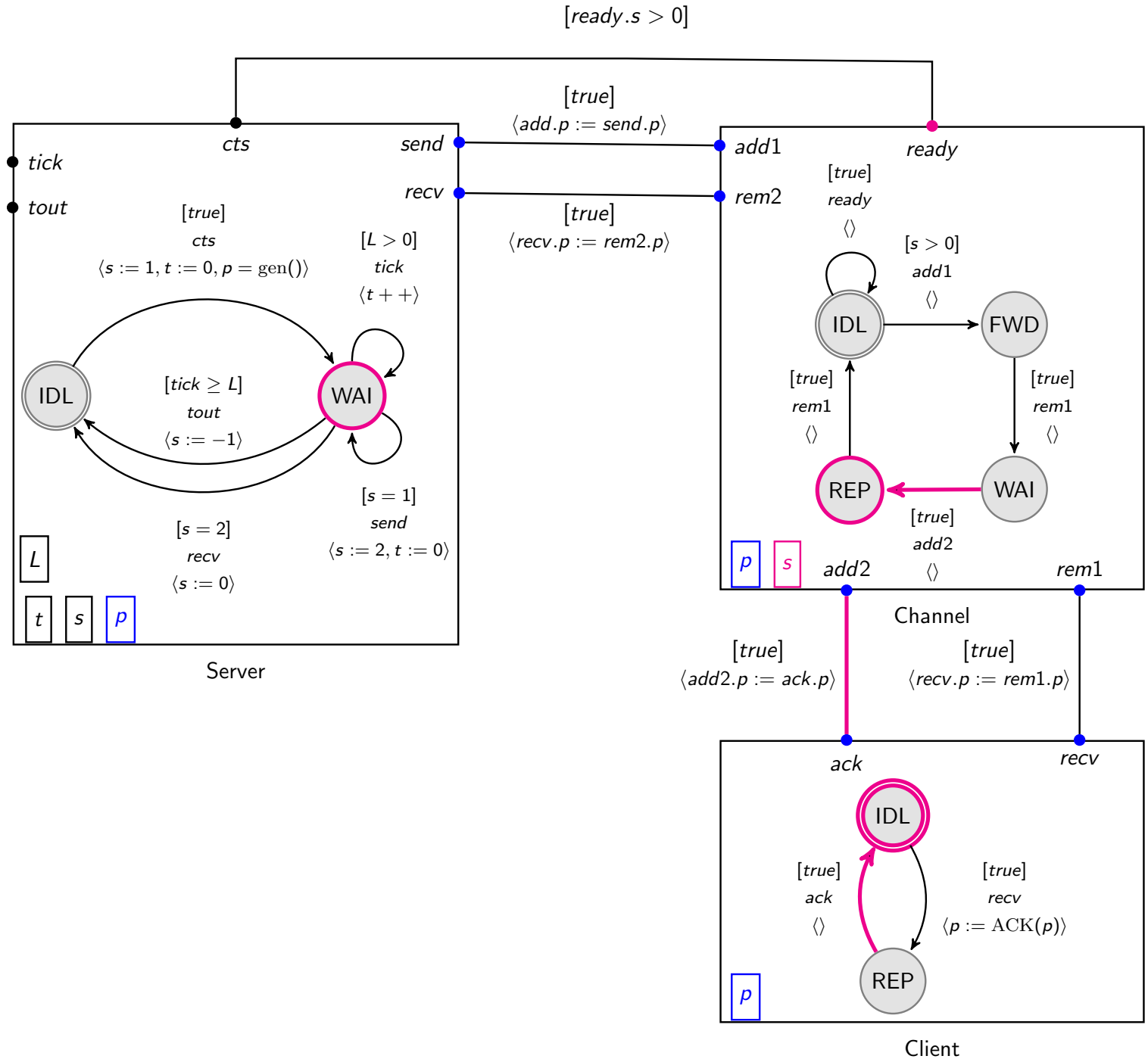
p
Client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⟨s := 2, t := 0⟩
[s = 2]
recv
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L
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Channel
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[true]
⟨recv.p := rem1.p⟩
Server
ack
recv
IDL
[true]
ack
⟨⟩
[true]
recv
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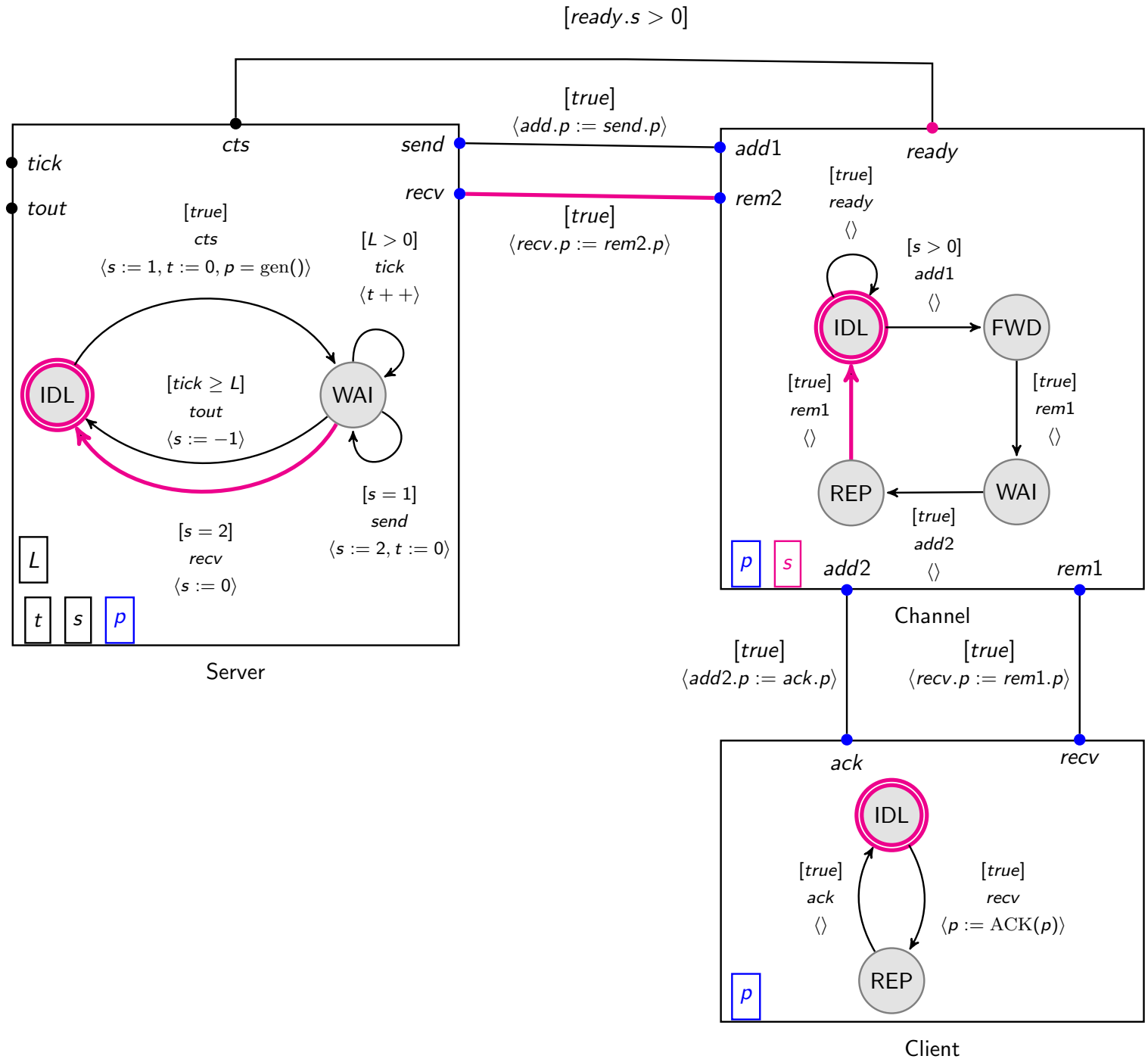
REP
p
Client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send
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⟨⟩
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FWD
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[true]
rem1
⟨⟩
REP
WAI
[s = 1]
send
⟨s := 2, t := 0⟩
[true]
add2
⟨⟩
[s = 2]
recv
⟨s := 0⟩
L
p
s
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rem1
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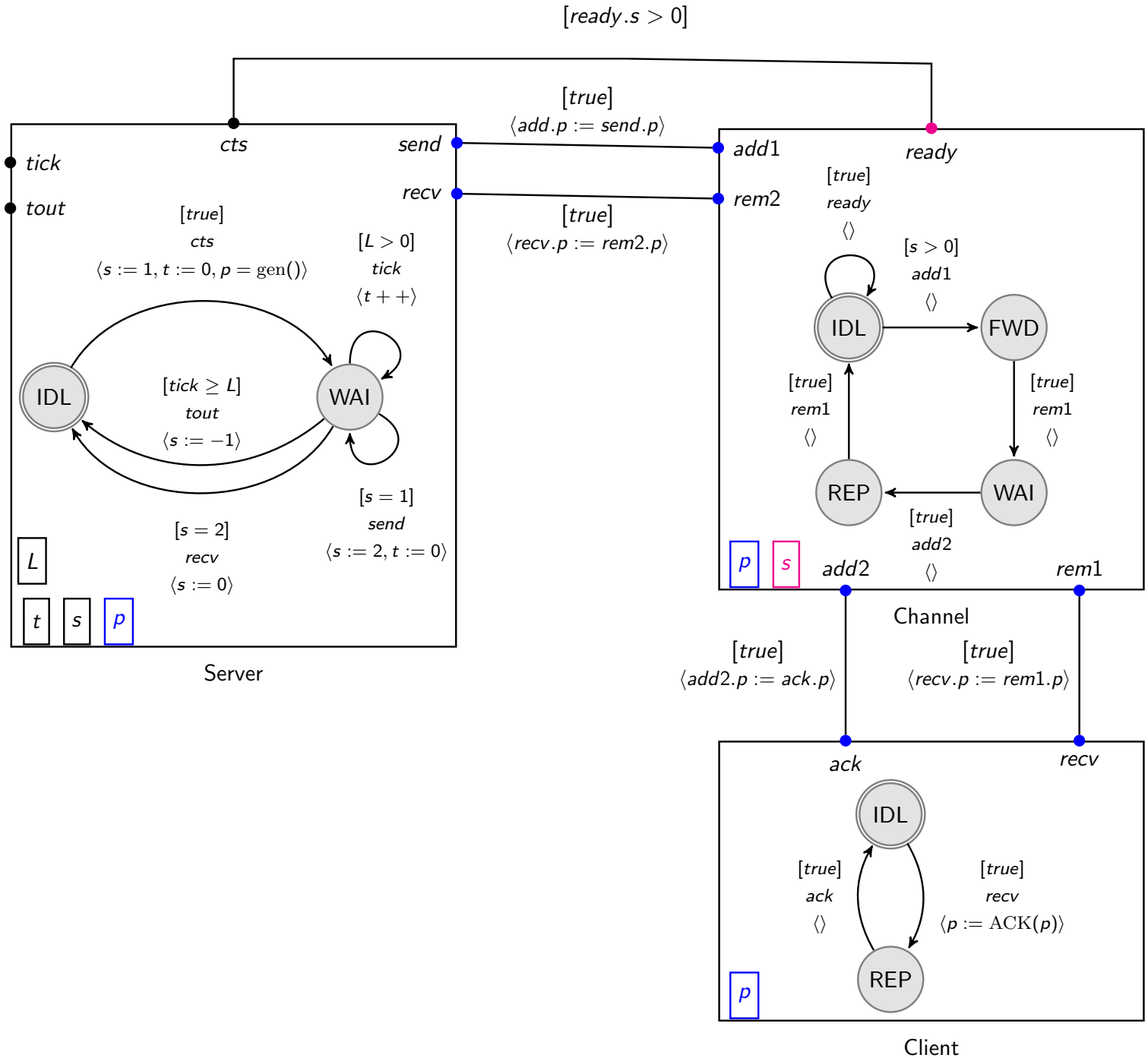
[true]
recv
⟨p := ACK(p)⟩
REP
p
Server
Client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[s = 1]
send
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recv
⟨s := 0⟩
L
t
s
p
Server
[true]
⟨recv.p := rem2.p⟩
add1
rem2
ready
[true]
ready
⟨⟩
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[true]
ack
⟨⟩
[true]
recv
⟨p := ACK(p)⟩
REP
p
Client

Authentication Concern

```
Aspect AddHash (server)  {
  portExecute(cts)
  do {} {p = wrap(p); }
}
Aspect VerifyHash (channel) {
  data int clear = 0
  portExecute(add1)
  do {} {clear = check(p); p = unwrap(p);}
  {(IDL, clear == 0)}
}
Aspect Carol {
  ports(a:server.send b:channel.add1)
  readPortVars(a.r)
  do {} {b.r = pfake(a.r);}
}
```

Authentication Concern

```
Aspect AddHash (server)  {
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Aspect Carol {
  ports(a:server.send b:channel.add1)
  readPortVars(a.r)
  do {} {b.r = pfake(a.r);}
}
```

```
[Server.cts  ] Clear to Send
[Server.send ] -> 886|6 (Time: 0)
[Channel.add1] <- 386|6
[Channel.rem1] -> 386
[Client.recv ] <- ACK
[Client.ack  ] -> ACK
[Channel.add2] <- ACK
[Channel.rem2] -> ACK
[Server.recv ] <- ACK (Time: 3)

[Server.cts  ] Clear to Send
[Server.send ] -> 763|3 (Time: 0)
[Channel.add1] <- 736|3
[Server.tout ] Timeout
```

Concern Coverage

- Complexity to implement a crosscutting concern
- Scattering and Tangling

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- Scattering and Tangling

		Scattering		Tangling		
#	**Concern**	**Transitions**	**Interactions**	**OT**	**OI**	**OC**
1	Logging	10	0	5	0	2, 3
2	Authentication	2	1	2	1	1, 3, 4
3	Congestion	5	0	4	0	1, 2
4	Fault Tolerance	0	3	0	1	2
	`Network`	12	5			

OT: Overlapping Transitions | OI: Overlapping Interactions | OC: Overlapping Concerns

Applications to RV

- Runtime Verification is a crosscutting concern $\rightarrow$ use `AOP-BIP` for RV

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  1. Use pointcuts to describe joinpoints that are of interest (generate events)
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  3. Use inter-type to store monitor state

Applications to RV

- Runtime Verification is a crosscutting concern $\rightarrow$ use `AOP-BIP` for RV
  1. Use pointcuts to describe joinpoints that are of interest (generate events)
  2. Use advice functions to process events and also output trace (for offline)
  3. Use inter-type to store monitor state
- Considerations:
  - Simpler to describe transformations
  - Not as expressive as RV-BIP
    (improves with extending pointcuts, advices and composition)

RV Example

- Data Robot: modules consisting of services
- Examples of existing tools `RV – BIP` [Falcone et al., 2015]
- Simplified simulation:
  1. `clock` : components providing the global clock (`getTime`)
  2. `poster`: interface to exchange data with other services
  3. `reader`: reads data of a poster (`read`)
  4. `writer`: writes data to a poster (`writev` → `finishWrite`)
- Data exchanged is: `time` and `taskid`

RV Example - Monitors

```
Aspect MonMutex (poster) {
  data int c = 0;

  portExecute(writev)
  do {checkConcurrent(c); c++;} {}

  portExecute(finishWrite)
  do {}{c--;}
}

Aspect MonFresh {
  ports(r:reader.read p:poster.read c:clck.getTime)
  do  { checkFresh(c.x, p.x); } {}
}

Aspect MonOrder {
  data int lastTask = 0

  ports(p:poster.writev) writePortVars(p.x)
  do {} { checkOrder(p.x, lastTask); lastTask = p.x; }
}
```

```
void checkConcurrent(int c) {
  if(c > 0)
    //Print violation
}
void checkFresh(int clock, int poster) {
  if(clock - poster > 2)
    //Print violation
}
void checkOrder(int task, int lastTask) {
  if (task != lastTask + 1)
    //Print violation
}
```

Conclusion

Summary

- Proposed a framework for crosscutting concerns in the BIP framework
- Focused on concerns at the level of the coordination between components
- Briefly overviewed local aspects and aspect composition
- Presented `AOP-BIP` and used it on a network example
  (More details in the technical report and ujf-aub.bitbucket.org/aop-bip)
- Showed how it can be used for runtime verification of CBSs

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Summary

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Future Work

1. Expand the expressiveness of both pointcuts and advices
2. Study in more detail aspect composition (strategies, designs)
3. Implement Model-to-Model transformation using Domain Specific Languages (DSLs) inspired form ATL and compare expressiveness.

Related Work

- AOP for CBS (not formal)
  1. [Pessemier et al., 2008] Defining extra *advice* interfaces and using separate components for aspects.
  2. [Duclos et al., 2002] Applying AOP to CBS by defining two languages
  3. [Lieberherr et al., 2003] Investigating aspects in modules (Java Packages)
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  4. [David and Ledoux, 2006] Using AOP in Fractal to define adaptation policies
- Formal Approaches (not as simple/expressive)
  1. [Katz, 2006, Djoko et al., 2012] Categorizing aspects and studying which properties are preserved for which classes of aspects
  2. [Altisen et al., 2006] AOP for reactive systems presented as Mealy automata
  3. [Dihego and Sampaio, 2015] AOP for BRIC component model presented as Communicating Sequential Processes (CSP)

Language

```
aspect    : pointcuts 'do' advice;
pointcuts : (pointcut)+ ;
pointcut  : pctype '(' IDENTIFIER ')';

pctype    : 'atLocation'
          | 'readVarGuard'
          | 'readVarFunc'
          | 'write'
          | 'portEnabled'
          | 'portExecute'
          ;

advice    : (before) (after) (resetlocs)? ;
before    : '{' actions '}';
after     : '{' actions '}';
resetlocs : '{' (rlocpair (',' rlocpair)*)? };
rlocpair  : '(' IDENTIFIER ',' expression  );

gaspect   : gpoint 'do' before after
          ;
gpoint    : 'ports' '(' (portspec)+ ')' (gread)? (gwrite)?
          | 'ports' '(' (portspec)+ ')' (gwrite)? (gread)?
          ;

gwrite    : 'writePortVars' '(' port_var+ ')';
gread     : 'readPortVars'  '(' port_var+ ')';

portspec  : IDENTIFIER ':' port_name ;
port_name : IDENTIFIER '.' IDENTIFIER;
port_var  : IDENTIFIER '.' IDENTIFIER;
```

Language

```
file      : (CODE)? (container)+  ;

container : 'Aspect' IDENTIFIER '{' intertype (gaspect)+  '}'
          | 'Aspect' IDENTIFIER '(' IDENTIFIER ')'
            '{' intertype (aspect)+ '}'
          ;
CODE      : '{#' .*? '#}';
intertype : (intertypedef)*
              ;
intertypedef
          : 'data' IDENTIFIER IDENTIFIER
          | 'data' IDENTIFIER IDENTIFIER '=' literal_expression
          ;
```

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