Buffered Communication Analysis in Distributed Multiparty Sessions

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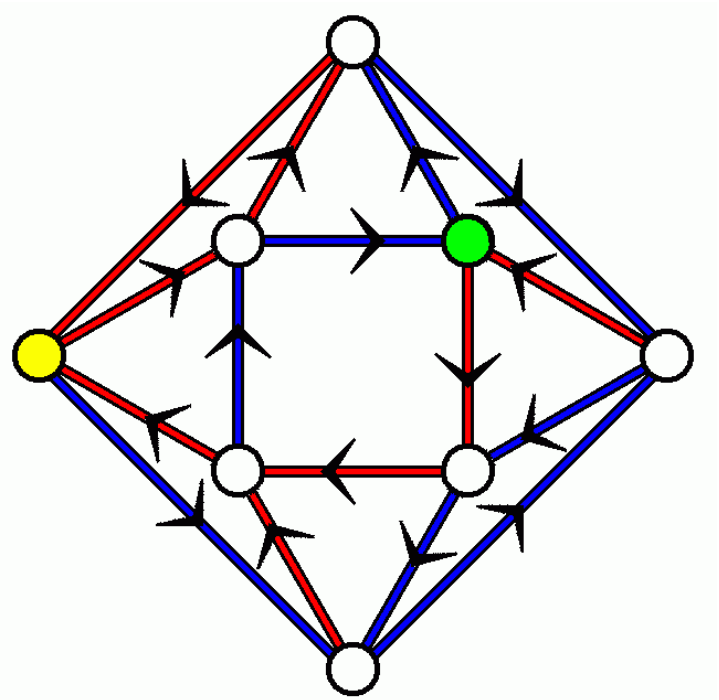

Buffer analysis and binary session types

Asynchrony and buffer analysis

- Asynchronous communications rely on communication buffers, which may grow over time and overflow.
- Preventing communication buffers to overflow is a well-studied area.

Binary session types (two-party) [Takeuchi&al.'94]

- Binary session types specify channel behaviour in an asynchronous π-calculus (with message-order preserving, non-blocking sends).
- Binary session types give some information about buffers:

$$P_0 = s!\langle 3\rangle.s!\langle Orange\rangle.s?(x) \qquad T_0 = !\langle \mathsf{nat}\rangle; !\langle \mathsf{string}\rangle; ?\langle \mathsf{real}\rangle; \mathsf{end}$$

$$P_1 = s!\langle 3\rangle.s?(x).s!\langle Orange\rangle \qquad T_1 = !\langle \mathsf{nat}\rangle; ?\langle \mathsf{real}\rangle; !\langle \mathsf{string}\rangle; \mathsf{end}$$

Multiparty sessions for protocol specification and analysis

- Today's distributed applications involve more and more agents that interact through complex communication patterns.
- Multiparty sessions types can describe these interactions and statically ensure type and communication safety and fidelity to a stipulated protocol.

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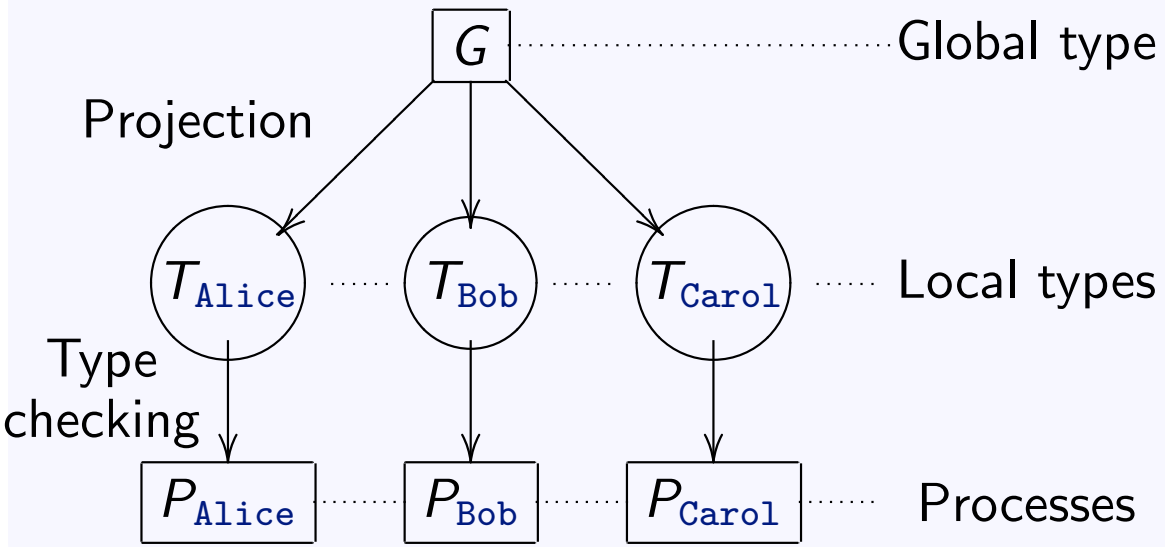
Multiparty session types in a nutshell



$$G = \texttt{Alice} \to \texttt{Bob}\colon s_1\,\langle \mathsf{nat}\rangle;\ \texttt{Bob} \to \texttt{Carol}\colon s_2\,\langle \mathsf{nat}\rangle; \mathsf{end}$$

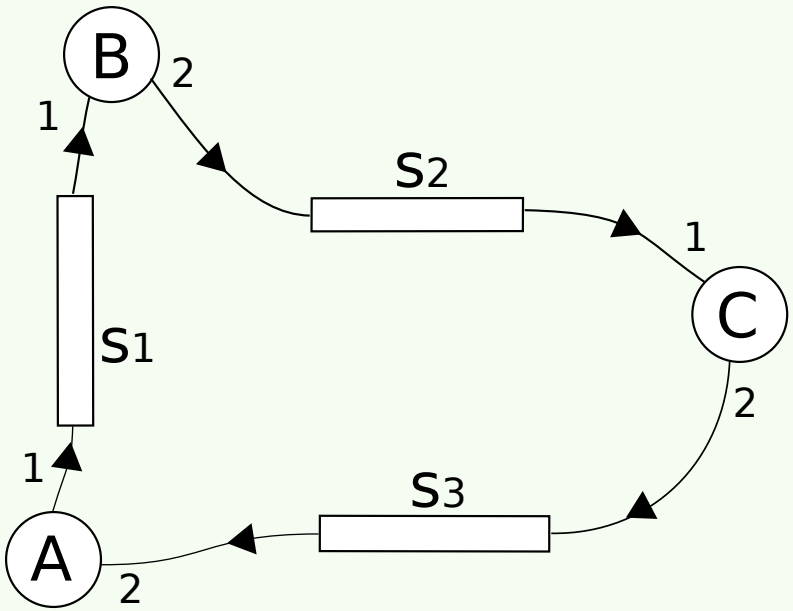
$$T_{\texttt{Bob}} = s_1?\langle \mathsf{nat}\rangle.s_2!\langle \mathsf{nat}\rangle.\mathsf{end}$$

$$P_{\texttt{Bob}} = s_1?(x).s_2!\,\langle x+1\rangle$$

Buffer analysis in the multiparty case

Binary session type techniques to analyse buffer usage do not apply directly.

Example (a)



(A) $\texttt{Alice} = \mu X.s_1!\langle 1\rangle; s_3?(x); X$

(B) $\texttt{Bob} = \mu X.s_1?(x); s_2!\langle \mathit{Orange}\rangle; X$

(C) $\texttt{Carol} = \mu X.s_2?(x); s_3!\langle 2.4\rangle; X$

$$G_a = \mu \mathbf{x}.\texttt{Alice} \to \texttt{Bob}: s_1\langle \mathsf{nat}\rangle; \texttt{Bob} \to \texttt{Carol}: s_2\langle \mathsf{string}\rangle; \texttt{Carol} \to \texttt{Alice}: s_3\langle \mathsf{real}\rangle; \mathbf{x}$$

- All three buffers need not hold more than one value.

Buffer analysis in the multiparty case

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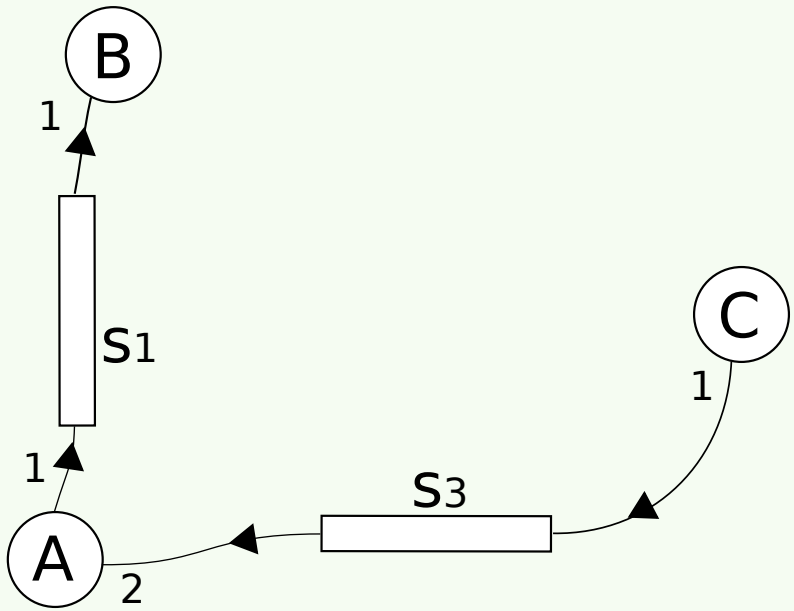
Example (b)



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$$G_b = \mu \mathbf{x}.\texttt{Alice} \to \texttt{Bob}: s_1\ \langle \mathsf{nat}\rangle;$$

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- Values can accumulate in the two remaining buffers.

Buffer analysis in the multiparty case

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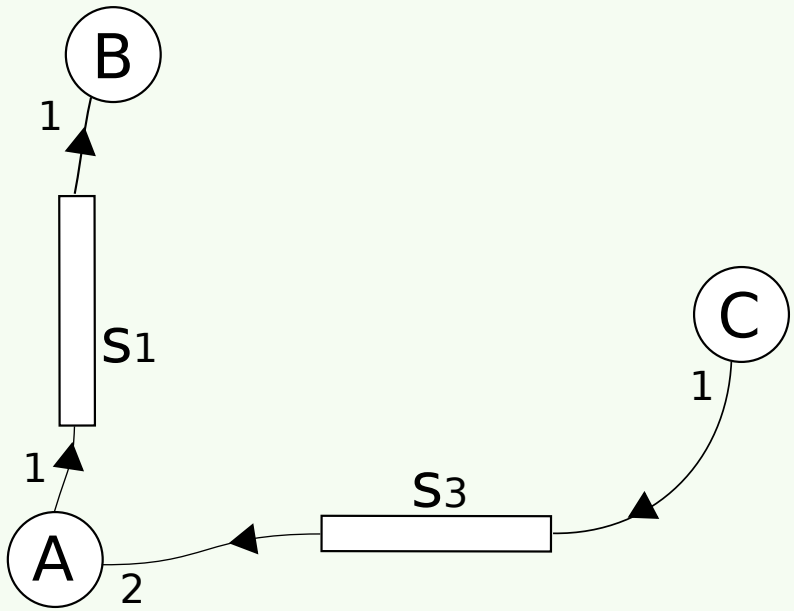

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- Values can accumulate in the two remaining buffers.
- `Alice`'s local behaviour is the same in example (a) and (b).

Outline

I A general causality analysis of global session types
   a An algorithm to detect infinite buffers
   b An algorithm to compute the buffer size of finite buffers
   c A type system to ensure communication, buffer and type safety and progress properties.

II A framework for session programming and analysis
   a Channel allocation
   b Global refinement
   c Local refinement (messaging optimisation)

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Global types and session graphs

Syntax of global types

$$
\begin{array}{rcll}
G & ::= & \mathtt{p} \to \mathtt{p}' : k\,\langle U \rangle ; G' & \text{values} \\
& | & \mathtt{p} \to \mathtt{p}' : k\,\{l_j : G_j\}_{j \in J} & \text{branching} \\
& | & \mu \mathbf{x}.G \mid \mathbf{x} \mid \text{end} & \text{recursion, end}
\end{array}
$$

Running example

$$
\mu \mathbf{x}.\mathtt{Alice} \to \mathtt{Bob} : s_1\,\langle \text{nat} \rangle ; \mathtt{Bob} \to \mathtt{Carol} : s_2 \left\{ \begin{array}{l} l_1 : \mathtt{Carol} \to \mathtt{Alice} : s_3 \{ l_3 : \mathtt{Alice} \to \mathtt{Carol} : s_2\,\langle \text{string} \rangle ; \mathbf{x} \} \\ l_2 : \mathtt{Carol} \to \mathtt{Alice} : s_3 \{ l_4 : \text{end} \} \end{array} \right\}
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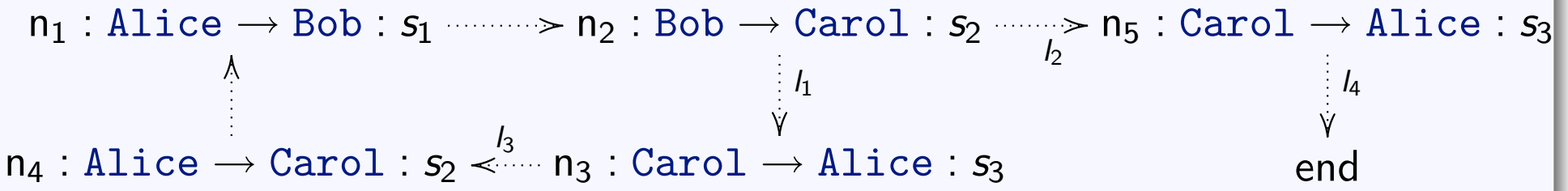
Session graph



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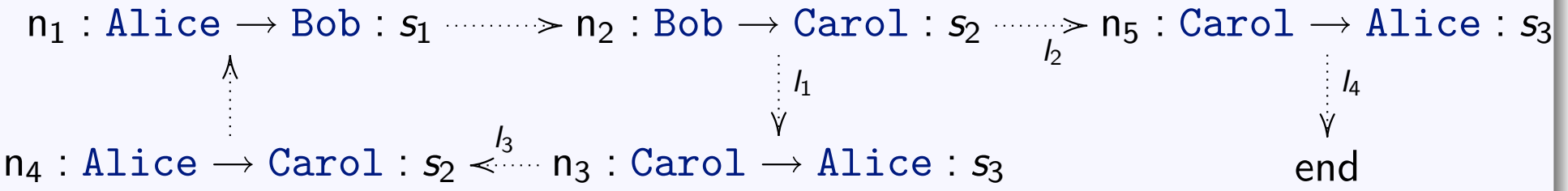

- Causality analysis = determining which edges stand up to asynchrony

Causality Analysis and Unbounded Buffers

- An IO-dependency links two communications when one guards the other.

$$\texttt{Alice} \longrightarrow \texttt{Bob} : s_1\ \langle \mathsf{nat} \rangle;$$
$$\texttt{Bob} \longrightarrow \texttt{Carol} : s_2\ \langle \mathsf{string} \rangle;$$

- IO-chains guarantee that a buffer is read before proceeding.

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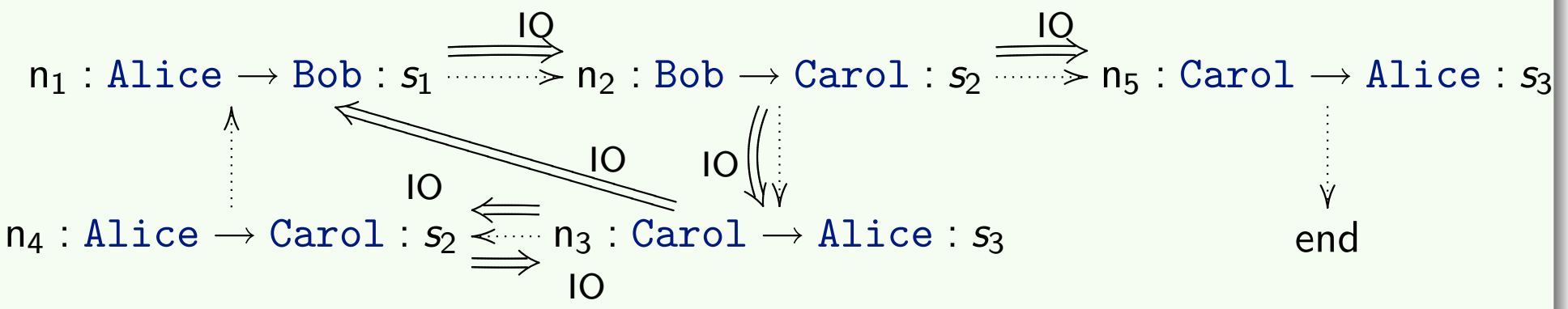

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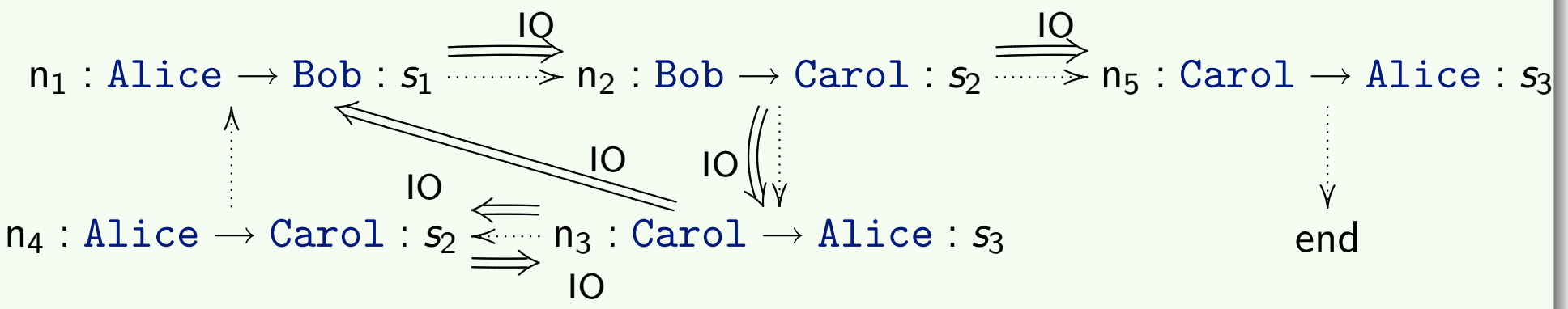

Infinite buffers

If a channel is used in a graph cycle that does not contain an IO-cycle, then this channel is infinite.

Reset Property

The Reset property characterises the paths in the session graph that see a buffer being emptied.

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A path satisfies the Reset property if its last node is the end of an IO-chain that starts with a node using the same buffer.

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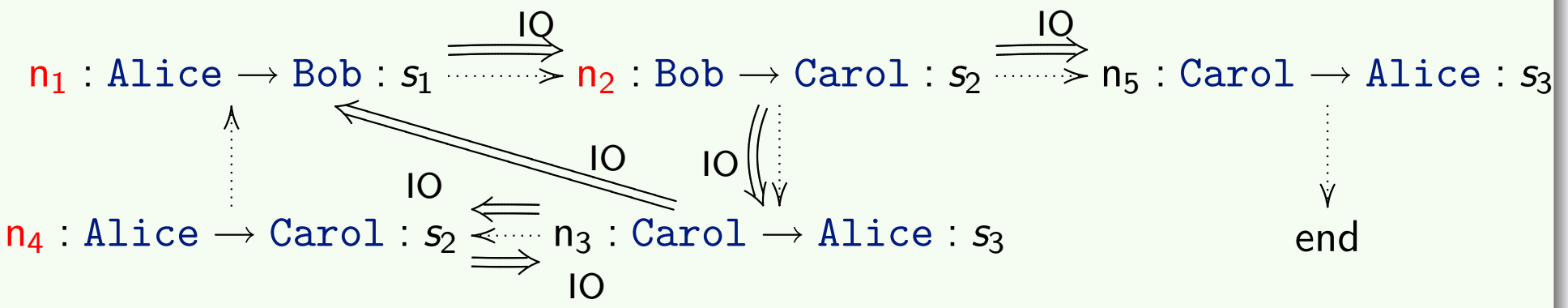

$\mathrm{Reset}(n_4 n_1 n_2)$

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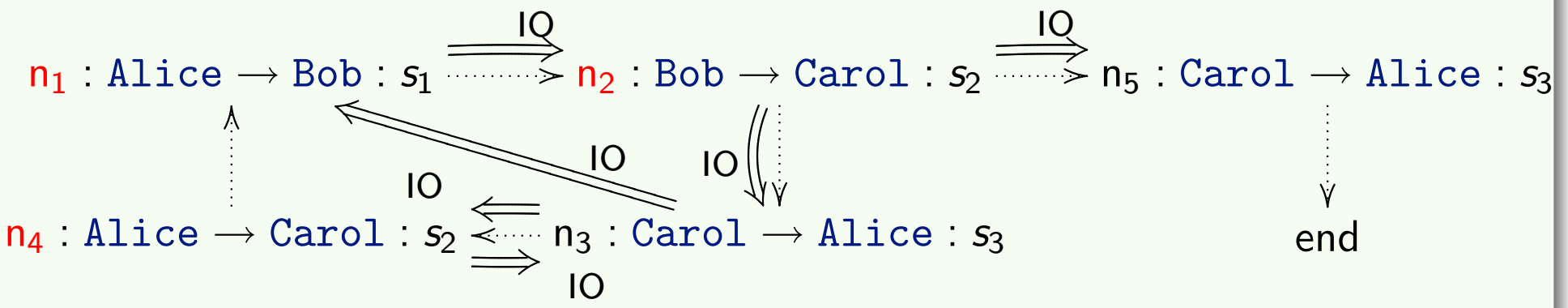

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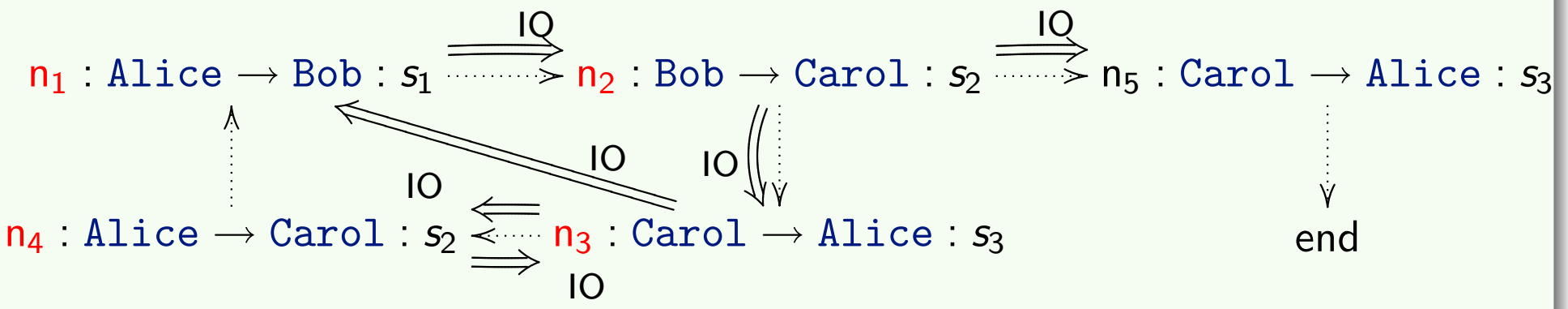

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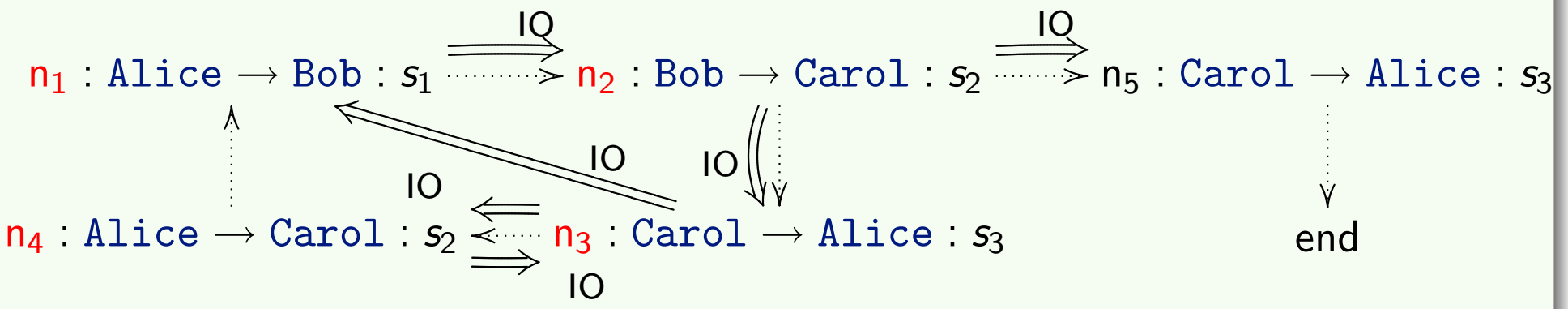


$\mathrm{Reset}(n_4 n_1 n_2)$ does not hold, $\mathrm{Reset}(n_1 n_2 n_3 n_4)$ holds.

An algorithm to compute buffer sizes

- An edge in a session graph between nodes n_1 and n_2 is noted $\mathsf{n}_1 \prec \mathsf{n}_2$
- All values are considered of size 1.

Algorithm (computes the bound for finite channel k)

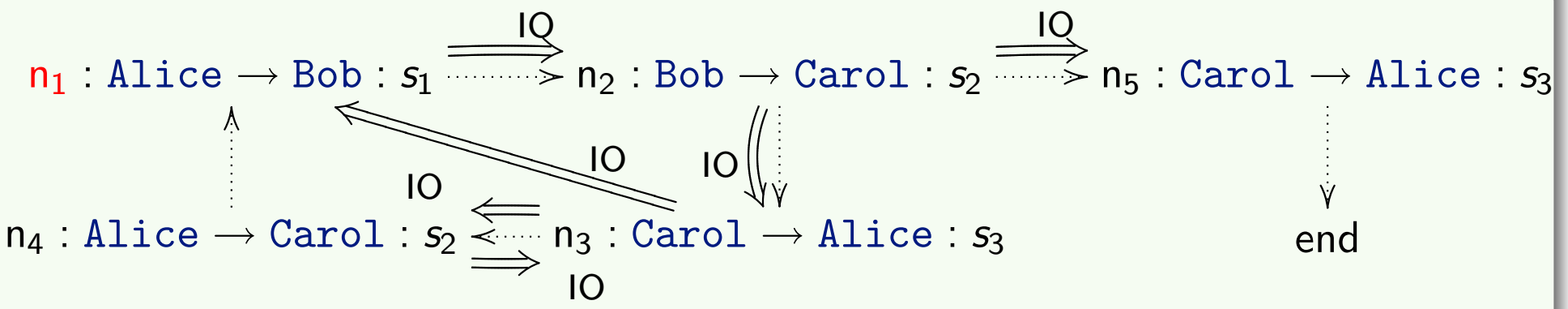
$$\mathcal{B}_k\langle m, \mathcal{P}, \tilde{\mathsf{n}}, \mathsf{n}\rangle = \begin{cases} 0 & \text{if } \mathsf{n} = \text{end or } \tilde{\mathsf{n}} \in \mathcal{P} \\ \max_{\mathsf{n} \prec \mathsf{n}'} \mathcal{B}_k\langle m, \{\tilde{\mathsf{n}}\} \cup \mathcal{P}, \tilde{\mathsf{n}}\mathsf{n}, \mathsf{n}'\rangle & \text{if } \mathtt{ch}(\mathsf{n}) = k', k \neq k' \\ \max_{\mathsf{n} \prec \mathsf{n}'} \mathcal{B}_k\langle 1, \{\tilde{\mathsf{n}}\} \cup \mathcal{P}, \mathsf{n}, \mathsf{n}'\rangle & \text{if } \mathtt{ch}(\mathsf{n}) = k, \mathrm{Reset}(\tilde{\mathsf{n}}\mathsf{n}) \\ \max(m+1, \max_{\mathsf{n} \prec \mathsf{n}'} \mathcal{B}_k\langle m+1, \{\tilde{\mathsf{n}}\} \cup \mathcal{P}, \tilde{\mathsf{n}}\mathsf{n}, \mathsf{n}'\rangle) & \text{if } \mathtt{ch}(\mathsf{n}) = k, \neg\mathrm{Reset}(\tilde{\mathsf{n}}\mathsf{n}) \end{cases}$$

- $\mathrm{Reset}(\tilde{\mathsf{n}})$ can be computed incrementaly
- the length of paths is bounded by linearity and the number of participants

This gives an efficient and practical algorithm.

Example of buffer bound computation

Example: bound of channel s_2



$\mathcal{B}_{s_2}\langle 0, \epsilon, \mathsf{n}_1 \rangle$

max	explanation

Example of buffer bound computation

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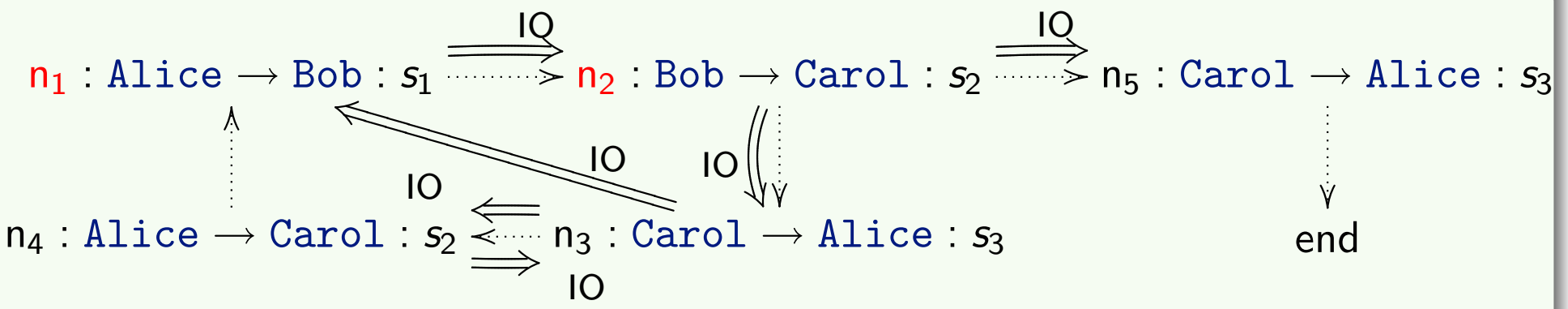

$$\begin{aligned} & \mathcal{B}_{s_2}\langle 0, \epsilon, \mathsf{n}_1\rangle \\ = \quad & \mathcal{B}_{s_2}\langle 0, \mathsf{n}_1, \mathsf{n}_2\rangle \end{aligned}$$

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0	$s_1 \neq s_2$

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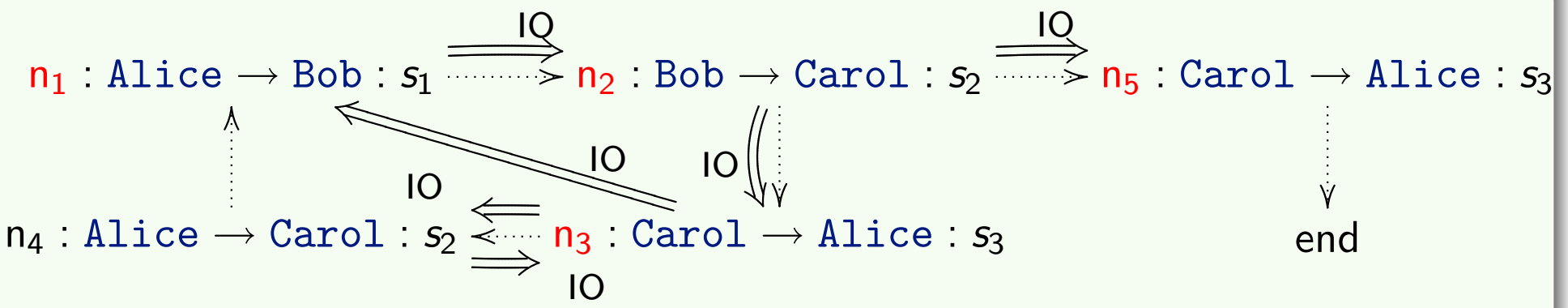

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& \mathcal{B}_{s_2}\langle 0, \epsilon, \mathsf{n}_1\rangle \\
= \quad & \mathcal{B}_{s_2}\langle 0, \mathsf{n}_1, \mathsf{n}_2\rangle \\
= \quad & \max(\mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2, \mathsf{n}_3\rangle, \mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2, \mathsf{n}_5\rangle)
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0	$s_1 \neq s_2$
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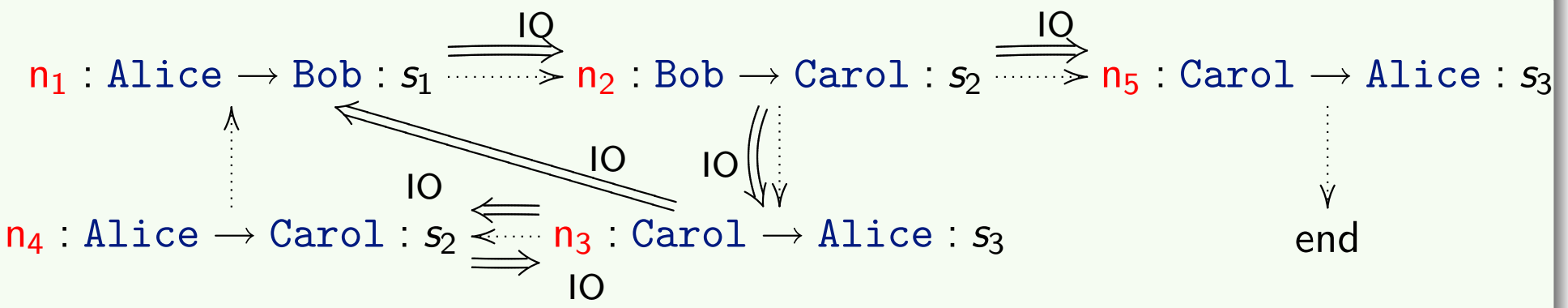

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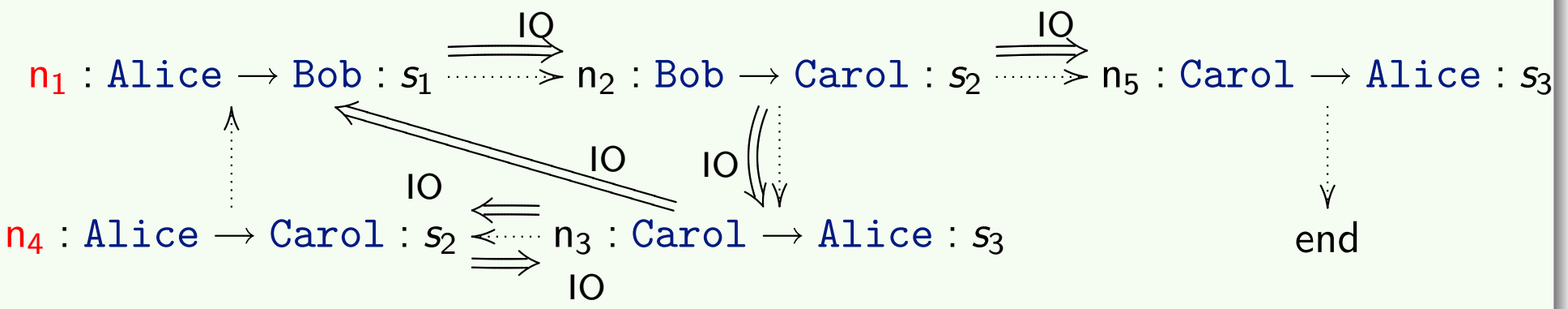

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= \quad & \max(\mathcal{B}_{s_2}\langle 1, \mathsf{n}_4, \mathsf{n}_1\rangle, 0)
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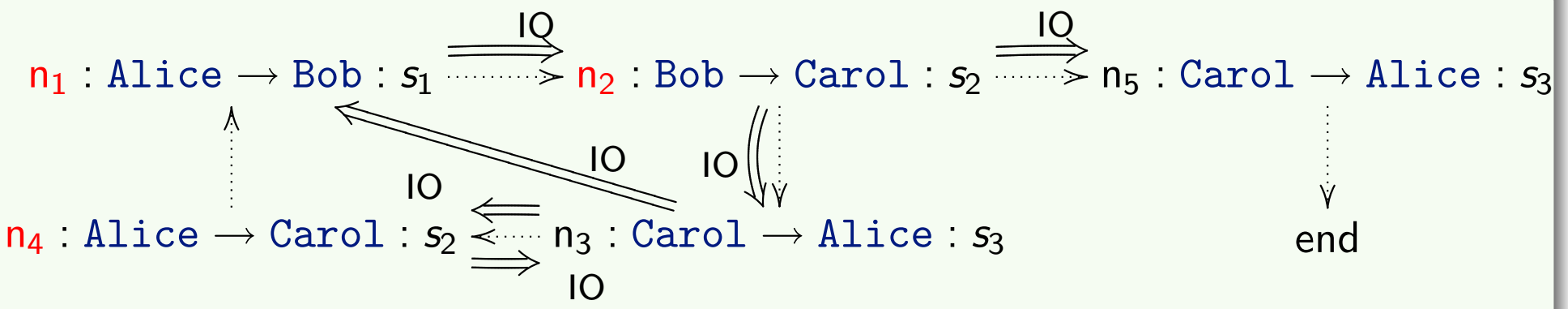

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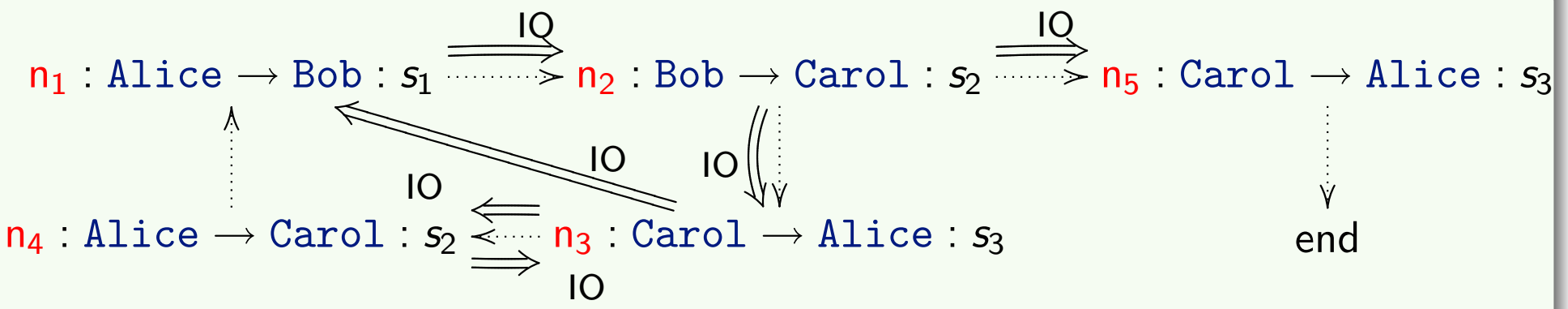

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= \;& \mathcal{B}_{s_2}\langle 1, \mathsf{n}_4\mathsf{n}_1, \mathsf{n}_2\rangle \\
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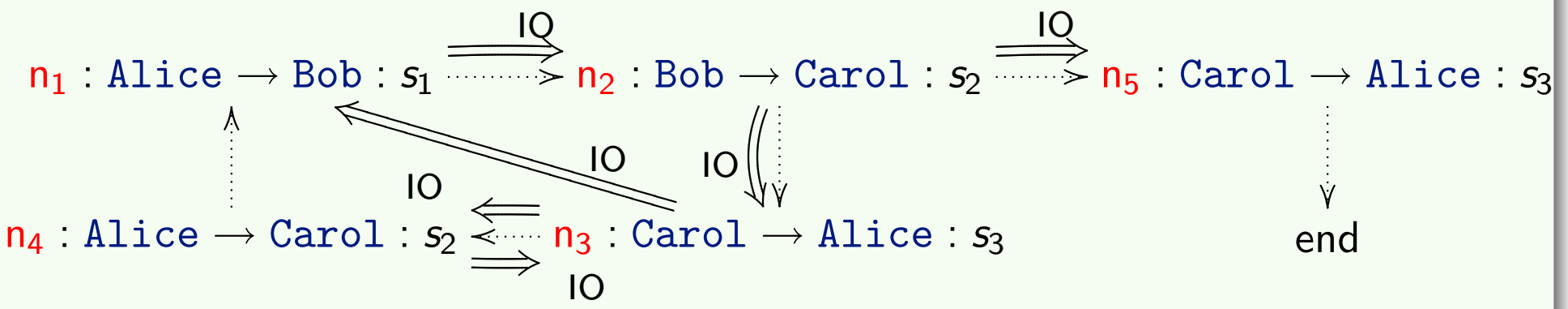
1	$\mathrm{Reset}(\mathsf{n}_1\mathsf{n}_2\mathsf{n}_3\mathsf{n}_4)$
1	$s_1 \neq s_2$
2	$\neg\mathrm{Reset}(\mathsf{n}_4\mathsf{n}_1\mathsf{n}_2)$

Example of buffer bound computation

Example: bound of channel s_2



	max	explanation
$\mathcal{B}_{s_2}\langle 0, \epsilon, \mathsf{n}_1\rangle$		
$= \mathcal{B}_{s_2}\langle 0, \mathsf{n}_1, \mathsf{n}_2\rangle$	0	$s_1 \neq s_2$
$= \max(\mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2, \mathsf{n}_3\rangle, \mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2, \mathsf{n}_5\rangle)$	1	$\neg\mathrm{Reset}(\mathsf{n}_1\mathsf{n}_2)$
$= \max(\mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2\mathsf{n}_3, \mathsf{n}_4\rangle, \mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2\mathsf{n}_5, \mathsf{end}\rangle)$	1	$s_3 \neq s_2$
$= \max(\mathcal{B}_{s_2}\langle 1, \mathsf{n}_4, \mathsf{n}_1\rangle, 0)$	1	$\mathrm{Reset}(\mathsf{n}_1\mathsf{n}_2\mathsf{n}_3\mathsf{n}_4)$
$= \mathcal{B}_{s_2}\langle 1, \mathsf{n}_4\mathsf{n}_1, \mathsf{n}_2\rangle$	1	$s_1 \neq s_2$
$= \max(\mathcal{B}_{s_2}\langle 2, \mathsf{n}_4\mathsf{n}_1\mathsf{n}_2, \mathsf{n}_3\rangle, \mathcal{B}_{s_2}\langle 2, \mathsf{n}_4\mathsf{n}_1\mathsf{n}_2, \mathsf{n}_5\rangle)$	2	$\neg\mathrm{Reset}(\mathsf{n}_4\mathsf{n}_1\mathsf{n}_2)$
$= \max(\mathcal{B}_{s_2}\langle 2, \mathsf{n}_4\mathsf{n}_1\mathsf{n}_2\mathsf{n}_3, \mathsf{n}_4\rangle, \mathcal{B}_{s_2}\langle 2, \mathsf{n}_4\mathsf{n}_1\mathsf{n}_2\mathsf{n}_5, \mathsf{end}\rangle)$	2	$s_3 \neq s_2$

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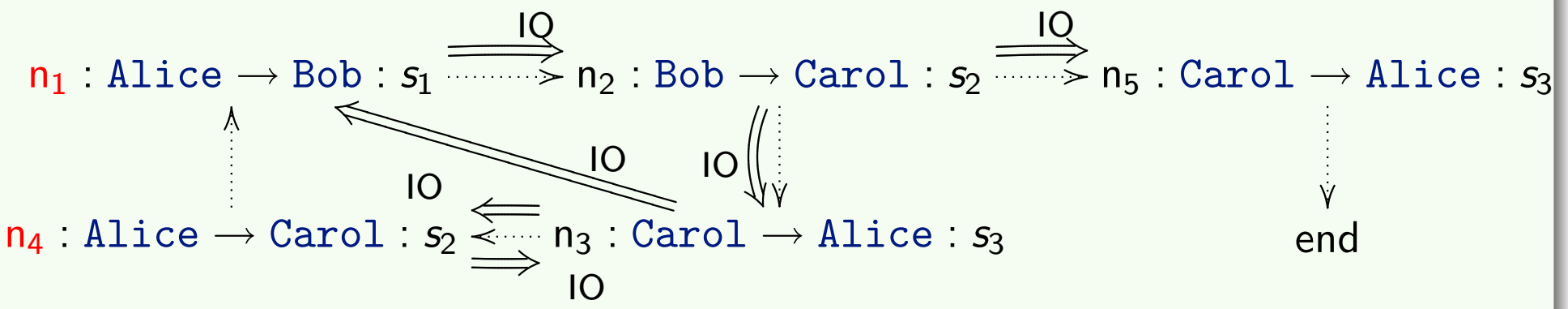

$$
\begin{array}{ll}
& \mathcal{B}_{s_2}\langle 0, \epsilon, \mathsf{n}_1\rangle \\
= & \mathcal{B}_{s_2}\langle 0, \mathsf{n}_1, \mathsf{n}_2\rangle \\
= & \max(\mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2, \mathsf{n}_3\rangle, \mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2, \mathsf{n}_5\rangle) \\
= & \max(\mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2\mathsf{n}_3, \mathsf{n}_4\rangle, \mathcal{B}_{s_2}\langle 1, \mathsf{n}_1\mathsf{n}_2\mathsf{n}_5, \mathsf{end}\rangle) \\
= & \max(\mathcal{B}_{s_2}\langle 1, \mathsf{n}_4, \mathsf{n}_1\rangle, 0) \\
= & \mathcal{B}_{s_2}\langle 1, \mathsf{n}_4\mathsf{n}_1, \mathsf{n}_2\rangle \\
= & \max(\mathcal{B}_{s_2}\langle 2, \mathsf{n}_4\mathsf{n}_1\mathsf{n}_2, \mathsf{n}_3\rangle, \mathcal{B}_{s_2}\langle 2, \mathsf{n}_4\mathsf{n}_1\mathsf{n}_2, \mathsf{n}_5\rangle) \\
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Processes, semantics and type system

Thanks to this algorithm, we can statically enforce buffer safety by typing.

Processes and semantics

$$\overline{a}_{[2..n]}\,(\tilde{s}\,\tilde{n}).P_1 \mid a_{[2]}\,(\tilde{s}).P_2 \mid \cdots \mid a_{[n]}\,(\tilde{s}).P_n \longrightarrow (\nu\,\tilde{s})(P_1 \mid P_2 \mid \ldots \mid P_n \mid s_1^{n_1} : \emptyset \mid \ldots \mid s_m^{n_m} : \emptyset)$$

$$s!\,\langle e \rangle; P \mid s^n : \tilde{h} \longrightarrow P \mid s^n : \tilde{h} \cdot v \qquad (n \gtrneqq |\tilde{h}|,\ e \downarrow v)$$

$$s?(x); P \mid s^n : v \cdot \tilde{h} \longrightarrow P[v/x] \mid s^n : \tilde{h}$$

Typing system

$$\frac{\Gamma \vdash a : G \qquad \Gamma \vdash P \triangleright \Delta, \tilde{s}^{\tilde{m}} : (G \upharpoonright 1) \qquad |\tilde{s}| = chan(G) \qquad \mathcal{B}_k\langle G \rangle = m_k}{\Gamma \vdash \overline{a}_{[2..n]}\,(\tilde{s}\,\tilde{m}).P \triangleright \Delta}$$

Type, buffer and communication safety, progress

Theorem (Subject reduction)

$\Gamma \vdash_\Sigma P \triangleright \Delta$ and $P \longrightarrow Q$ with $(\Gamma, \Sigma, P, \Delta)$ fully coherent imply $\Gamma \vdash_\Sigma Q \triangleright \Delta'$ for some Δ', s_k such that $\Delta = \Delta'$ or $\Delta(\xrightarrow{s_k})^* \Delta'$ and $\mathcal{B}\langle G(k)\rangle \geq \mathcal{B}\langle G'(k)\rangle$ with $\Delta(\tilde{s}) = [\![G]\!]$, $\Delta'(\tilde{s}) = [\![G']\!]$ and $(\Gamma, \Sigma, Q, \Delta')$ fully coherent.

We define the *buffer overflow error* as follows:

$$n \leq |\tilde{h}| \quad \Rightarrow \quad s!\langle \tilde{e} \rangle; P \mid s^n : \tilde{h} \longrightarrow \mathsf{Err}$$

Corollary (Buffer safety)

If $\Gamma \vdash_\Sigma P \triangleright \Delta$, then for all P' s.t. $P \longrightarrow^* P'$, $P' \not\rightarrow \mathsf{Err}$.

We can also derive using standard techniques:

- Communication safety
- Progress

Outline

I A general causality analysis of global session types
   a An algorithm to detect infinite buffers
   b An algorithm to compute the buffer size of finite buffers
   c A type system to ensure communication, buffer and type safety and progress properties.

II A framework for session programming and analysis
   a Channel allocation
   b Global refinement
   c Local refinement (messaging optimisation)

Outline

II A framework for session programming and analysis

a Channel allocation
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Channel Allocation (by example)

When designing a session, our buffer analysis can help allocate channels

- with constrains such as a maximun number of channels or
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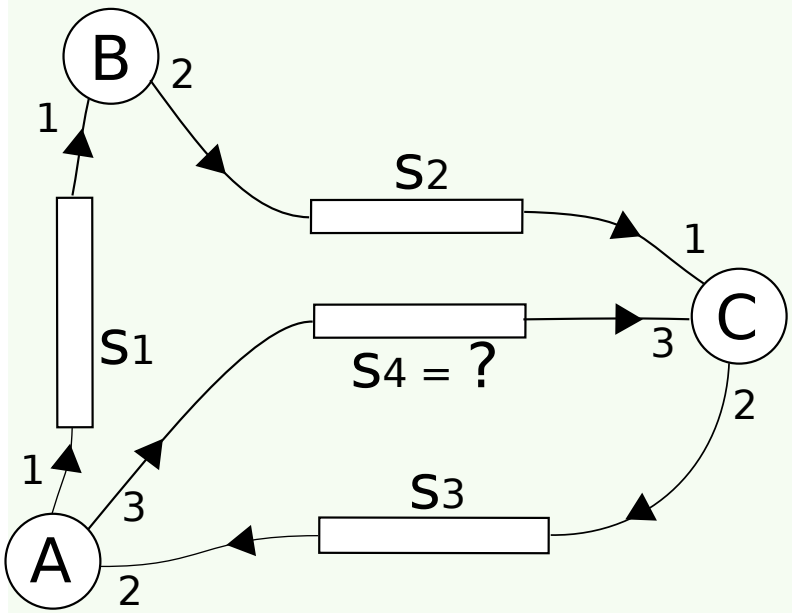
Example (c)



$$(A_2)\quad \mathtt{Alice}_2 = \mu X.s_1!\langle 1\rangle; s_3?(x); s_4!\langle x+1\rangle; X$$

$$(B)\quad \mathtt{Bob} = \mu X.s_1?(x); s_2!\langle \mathit{Orange}\rangle; X$$

$$(C_2)\quad \mathtt{Carol}_2 = \mu X.s_2?(x); s_3!\langle 2.4\rangle; s_4?(y); X$$

$$\begin{aligned} G_c = \mu \mathbf{x}.\ & \mathtt{Alice} \to \mathtt{Bob}: s_1\langle \mathsf{nat}\rangle; \\ & \mathtt{Bob} \to \mathtt{Carol}: s_2\langle \mathsf{string}\rangle; \\ & \mathtt{Carol} \to \mathtt{Alice}: s_3\langle \mathsf{real}\rangle; \\ & \mathtt{Alice} \to \mathtt{Carol}: s_4\langle \mathsf{nat}\rangle; \mathbf{x} \end{aligned}$$

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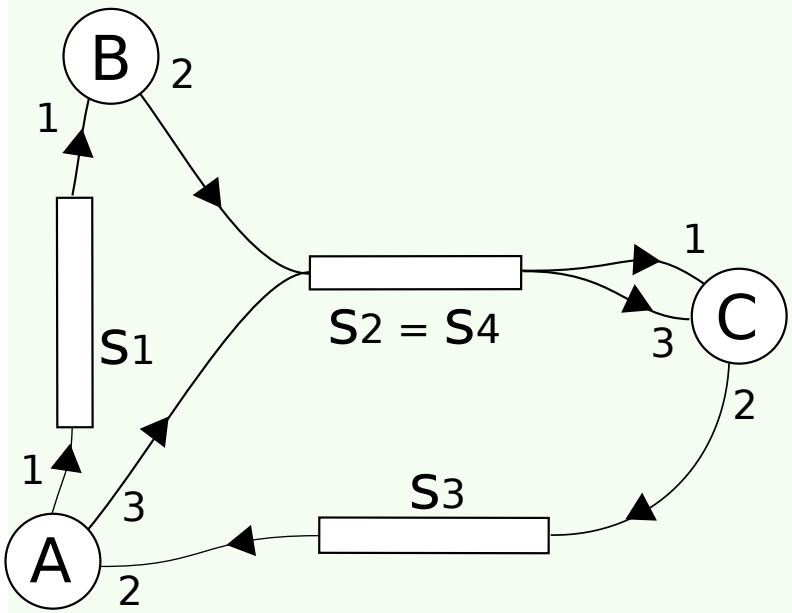
Example (d)



$$(A_3)\quad \texttt{Alice}_3 = \mu X.s_1!\langle 1\rangle; s_3?(x); s_2!\langle x+1\rangle; X$$

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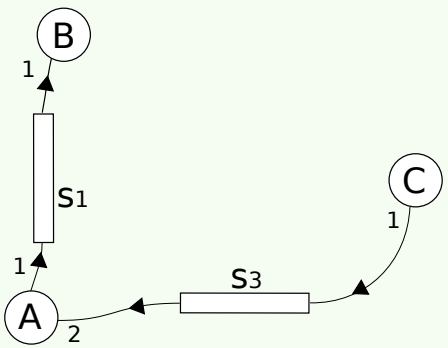
Global refinement (by example)

How do we fix overflowing buffers?

- when there is an infinite buffer or
- when a buffer size does not occupy the available space

We can insert *confirmation* (synchronisation, acknowledgement) messages

We set buffers to be of size at most 2



$$G_b = \mu \mathbf{x}.\texttt{Alice} \to \texttt{Bob}: s_1\,\langle \mathsf{nat} \rangle; \texttt{Carol} \to \texttt{Alice}: s_3\,\langle \mathsf{real} \rangle; \mathbf{x}$$

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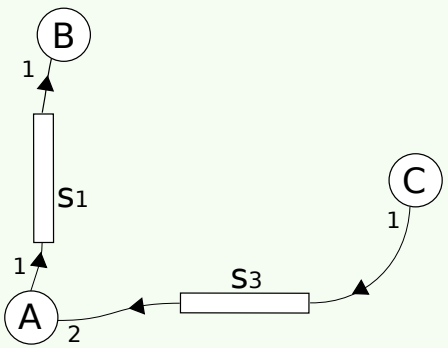

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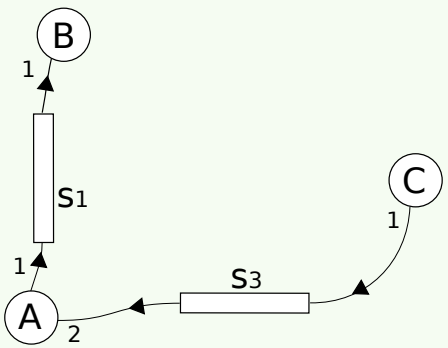

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Messaging optimisation

Messaging optimisation by example

$$P_1 = \mathbf{t}?(\mathbf{y}); \mathbf{s}!\langle \mathbf{5} \rangle; \mathbf{s}!\langle \mathrm{Orange} \rangle \qquad P_2 = \mathbf{s}?(\mathbf{z_1}); \mathbf{s}?(\mathbf{z_2})$$

$$P_3 = b?(y); \mathbf{t}!\langle \mathbf{7} \rangle$$

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$$P_3 = b?(y); \mathbf{t}!\langle \mathbf{7} \rangle$$

$b?(y)$ blocks the communication.

Messaging optimisation

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$$P_1' = \mathbf{s}!\,\langle \mathbf{5} \rangle; \mathbf{s}!\,\langle \mathrm{Orange} \rangle; \mathbf{t}?(\mathbf{y}) \qquad P_2 = \mathbf{s}?(\mathbf{z_1}); \mathbf{s}?(\mathbf{z_2})$$

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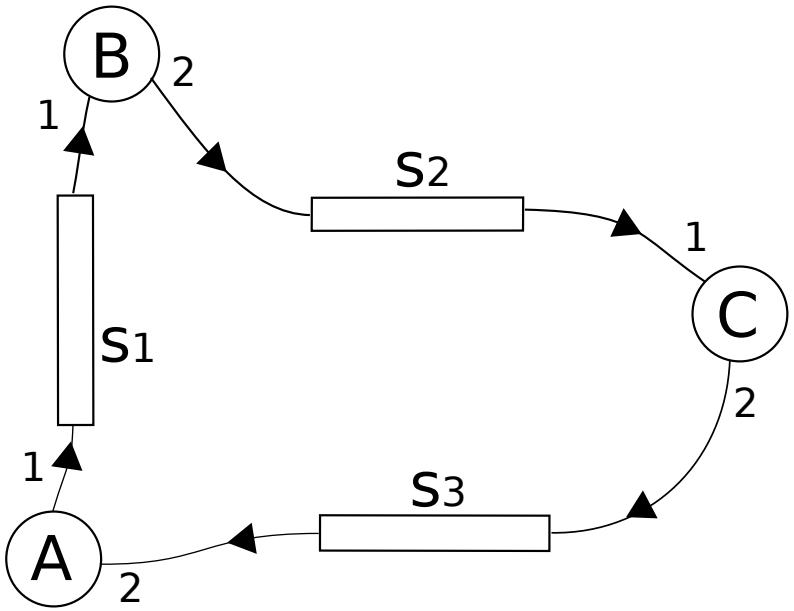
Communication subtyping [ESOP'09]

$$!\langle U \rangle; ?\langle T \rangle \leq ?\langle T \rangle; !\langle U \rangle$$

Local refinement does not preserve buffer sizes



$$G \quad = \quad \mu \mathbf{x}.\texttt{Alice} \to \texttt{Bob}\colon s_1\,\langle \mathsf{nat}\rangle;\ \texttt{Bob} \to \texttt{Carol}\colon s_2\,\langle \mathsf{string}\rangle;\ \texttt{Carol} \to \texttt{Alice}\colon s_3\,\langle \mathsf{real}\rangle;\mathbf{x}$$

(A) $\texttt{Alice} = \mu X.s_1!\langle 1\rangle; s_3?(x); X$

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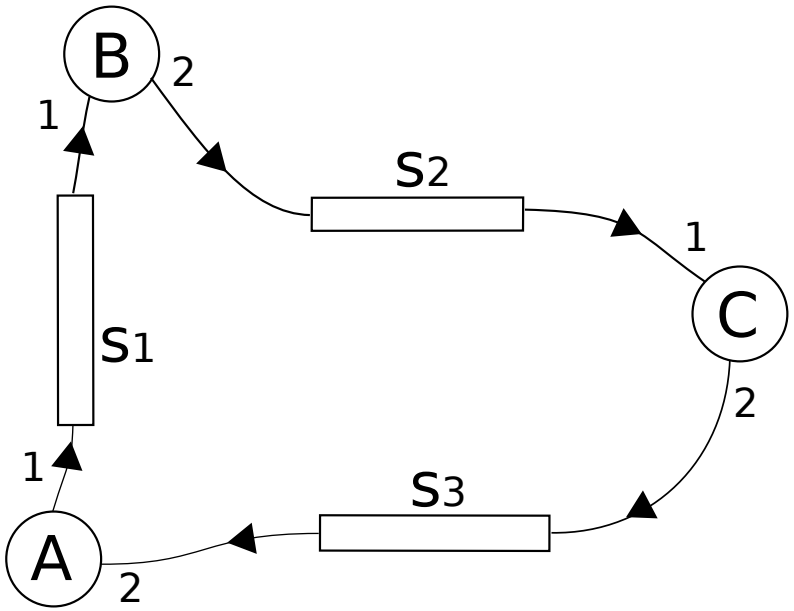

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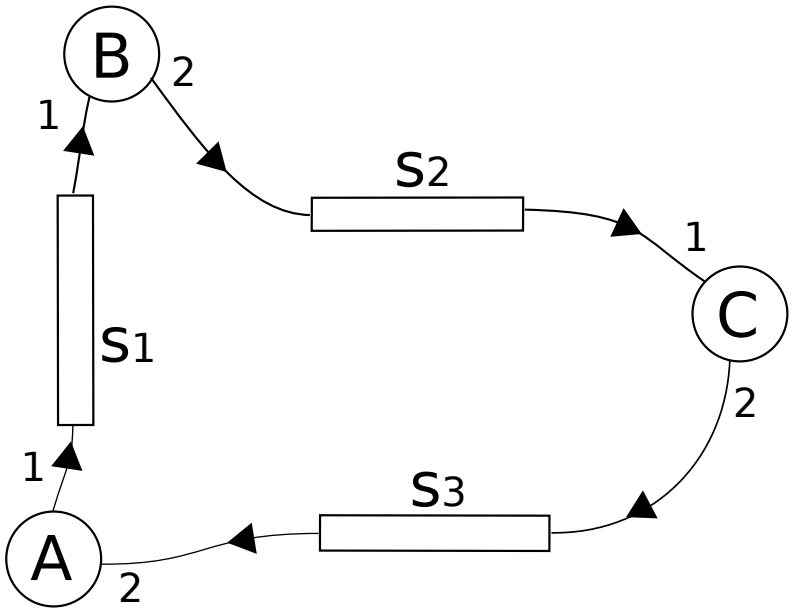

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- Local refinement can potentially change any buffer requirement.
- How can we determine which optimisations are safe?

Acceptable local refinement

We define a new subtyping relation that respect established buffer bounds.

Dependent nodes of a channel k

- Reset nodes: nodes that are part of an IO-chain that resets a path
- Minimal resetting paths:
  Paths that satisfy the reset property while none of their suffix does
- Dependent nodes $\mathtt{dep}(k)$:
  Union of the reset nodes of the minimal resetting paths that end with k

Dependent nodes are guards of a communication and control buffer sizes.

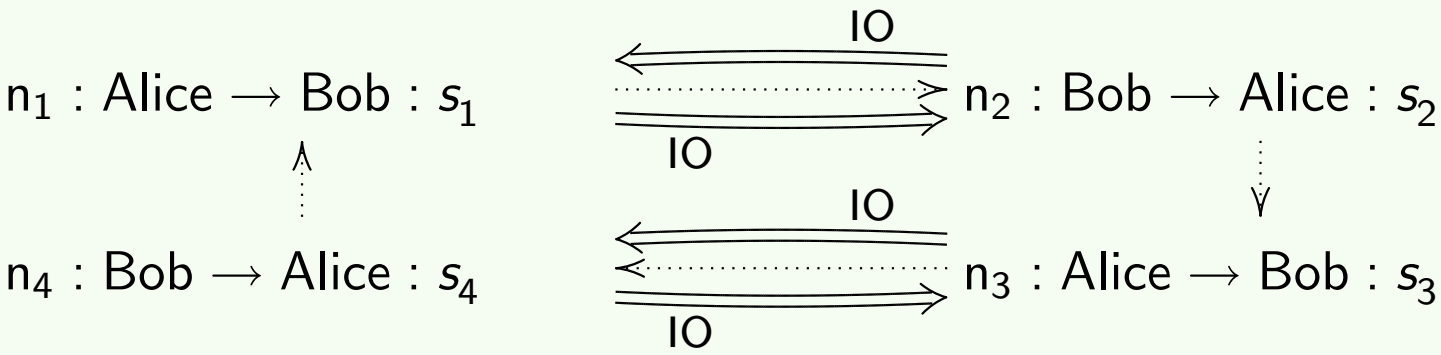
For a global type G, we choose a partitioning $\{N_0, \ldots, N_n\}$ of the set of nodes of G. This partition should satisfy the two properties:
$\forall \mathtt{n} \in N_i, \mathtt{n}' \in N_j, \mathtt{ch}(\mathtt{n}) = \mathtt{ch}(\mathtt{n}') \Rightarrow N_i = N_j$ and $\forall \mathtt{n} \in N_i, \mathtt{dep}(\mathtt{ch}(\mathtt{n})) \subset N_i$.

Asynchronous subtyping

$$\text{(OI)} \qquad k^N!\langle U\rangle; k_0^{N_0}?\langle U'\rangle; T \;\ll\; k_0^{N_0}?\langle U'\rangle; k^N!\langle U\rangle; T \qquad (N \cap N_0 = \emptyset)$$

Examples of local refinement

Annotation of session channels and messaging optimisation



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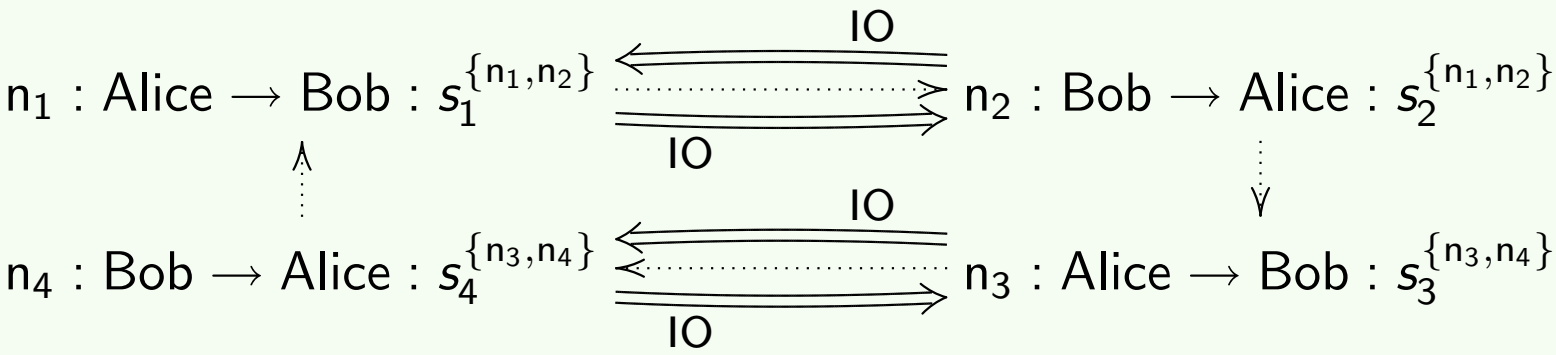

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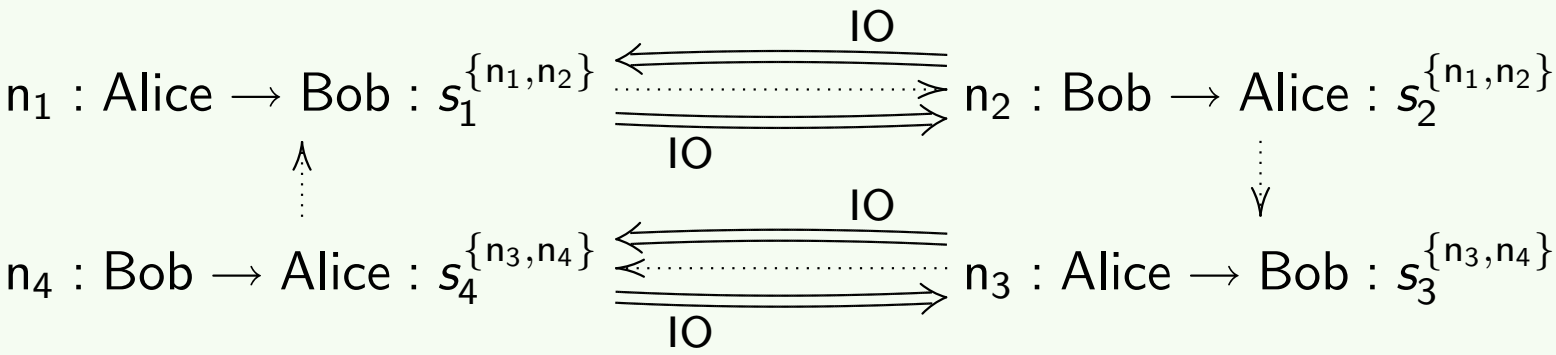

$$\texttt{Alice} \;=\; \mu \mathbf{x}.s_1^{\{n_1,n_2\}}!\langle \text{nat} \rangle; s_2^{\{n_1,n_2\}}?\langle \text{string} \rangle; s_3^{\{n_3,n_4\}}!\langle \text{nat} \rangle; s_4^{\{n_3,n_4\}}?\langle \text{real} \rangle; \mathbf{x}$$

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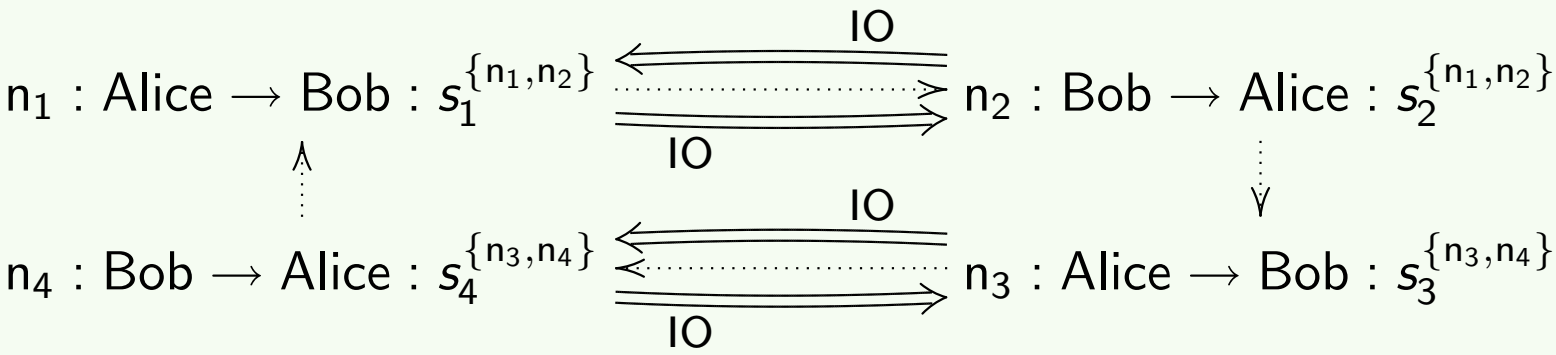

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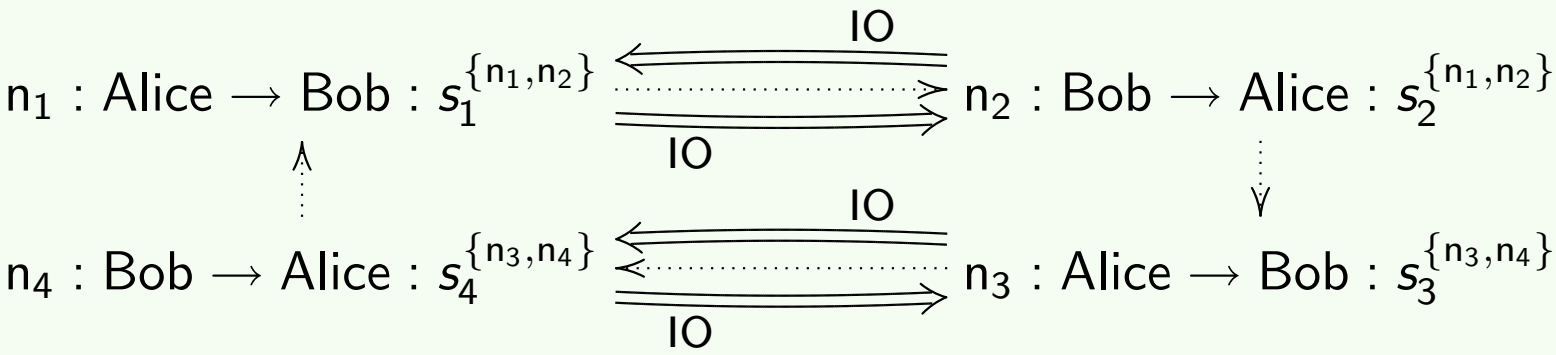

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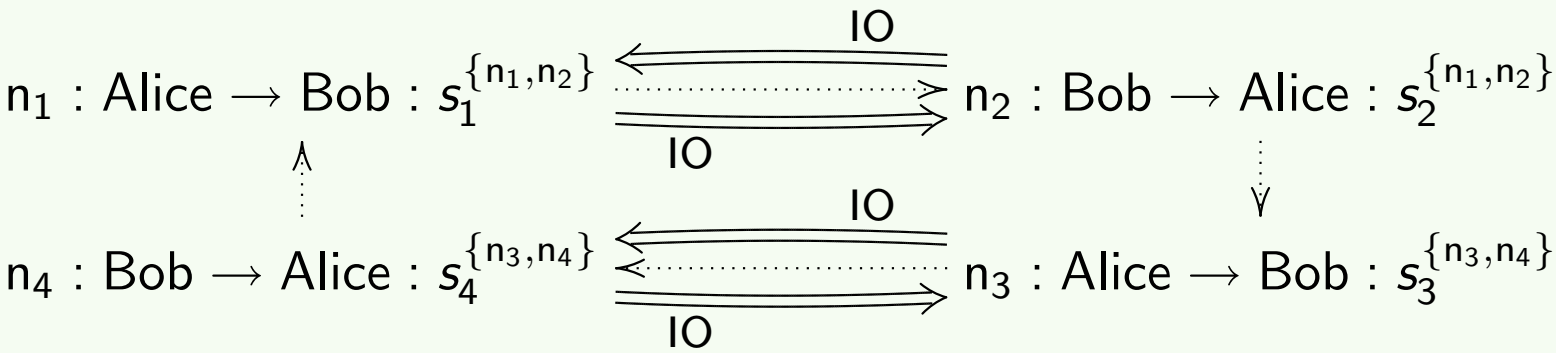
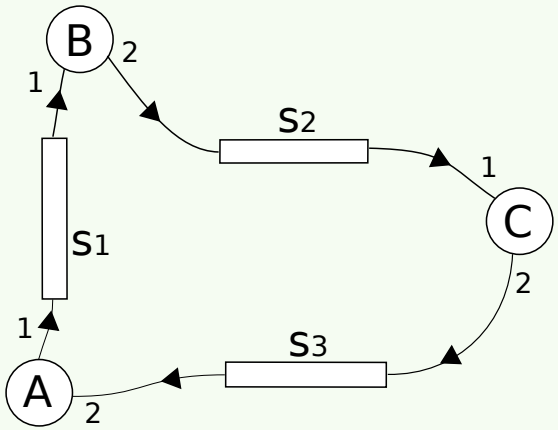
Examples of local refinement

Annotation of session channels and messaging optimisation



$$\texttt{Alice} = \mu \mathbf{x}.s_1^{\{n_1,n_2\}}!\langle \text{nat} \rangle; s_3^{\{n_3,n_4\}}!\langle \text{nat} \rangle; s_2^{\{n_1,n_2\}}?\langle \text{string} \rangle; s_4^{\{n_3,n_4\}}?\langle \text{real} \rangle; \mathbf{x}$$

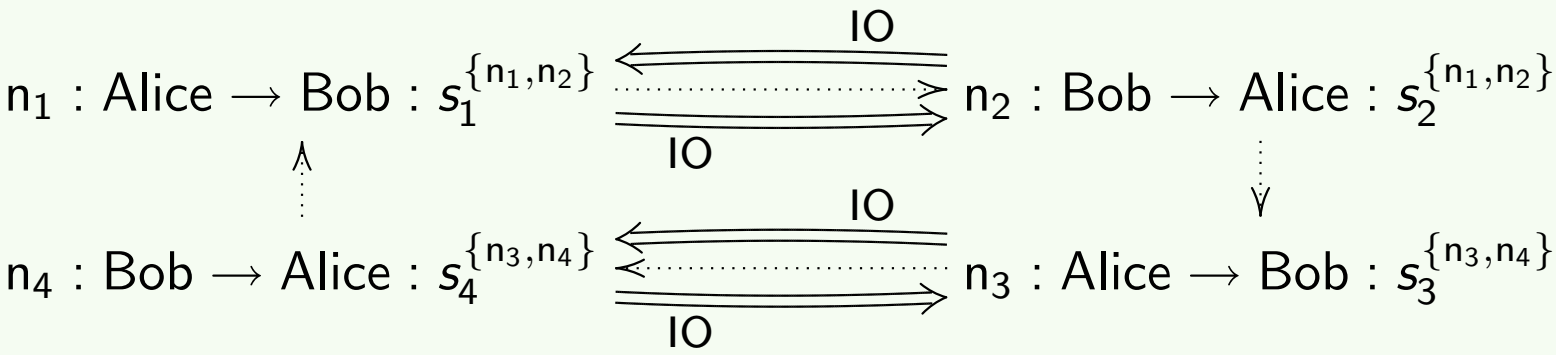
Unsafe optimisation



$$\begin{aligned} G = \mu \mathbf{x}.&\texttt{Alice} \to \texttt{Bob}: s_1 \langle \text{nat} \rangle; \\ &\texttt{Bob} \to \texttt{Carol}: s_2 \langle \text{string} \rangle; \\ &\texttt{Carol} \to \texttt{Alice}: s_3 \langle \text{real} \rangle; \mathbf{x} \end{aligned}$$

Examples of local refinement

Annotation of session channels and messaging optimisation



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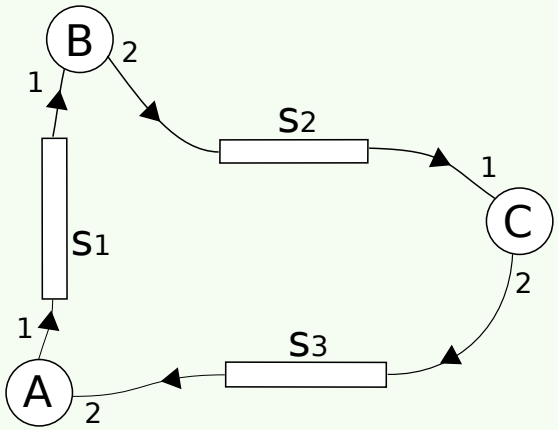
Unsafe optimisation



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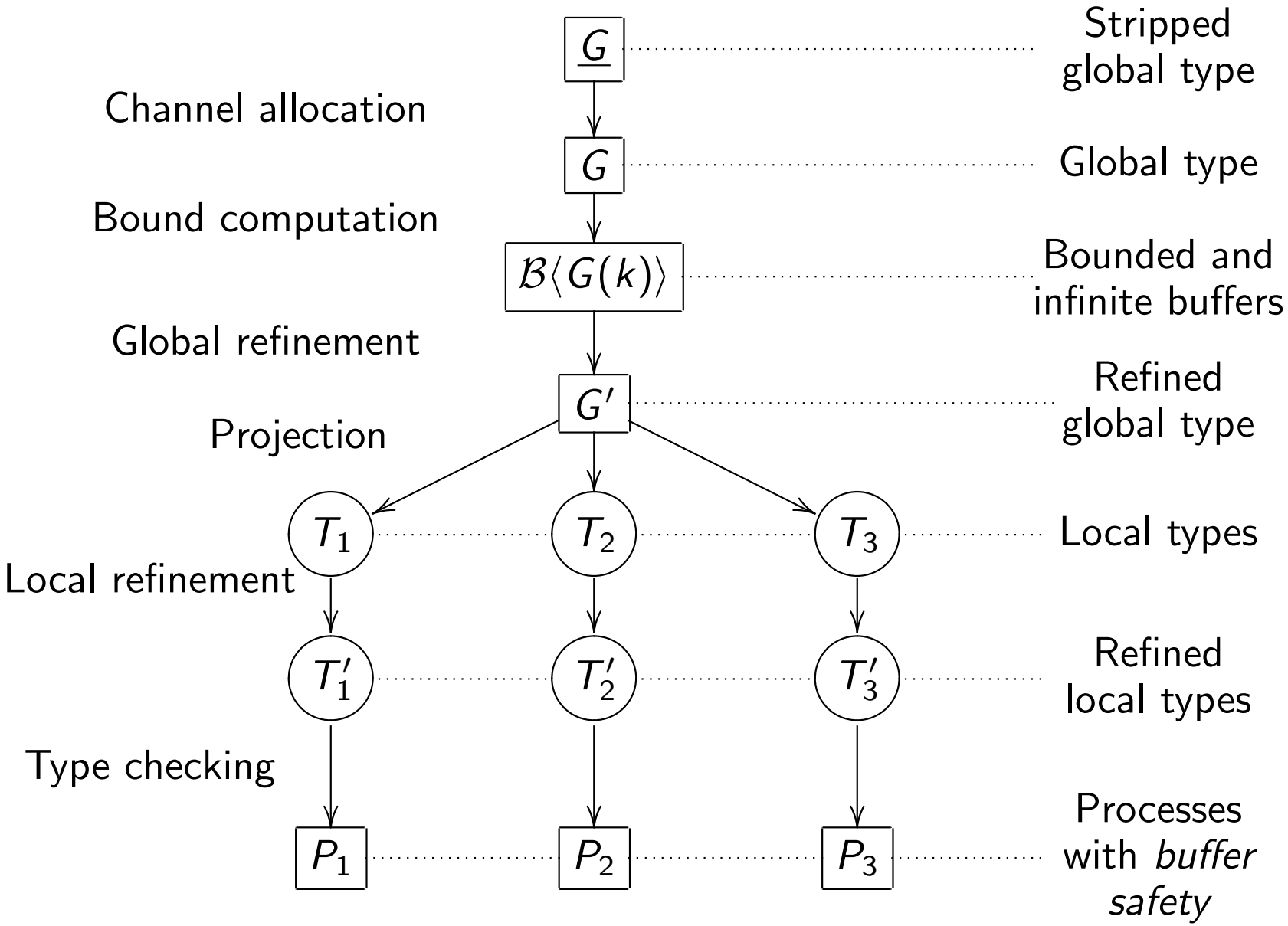
Only the trivial partition is possible!

Overview


Channel allocation
Bound computation
Global refinement
Projection
Local refinement
Type checking
$\underline{G}$
G
$\mathcal{B}\langle G(k)\rangle$
G'
T_1
T_2
T_3
T_1'
T_2'
T_3'
P_1
P_2
P_3
Stripped global type
Global type
Bounded and infinite buffers
Refined global type
Local types
Refined local types
Processes with *buffer safety*

Application

- Multi-buffering algorithm [ESOP'09] which used unsafe optimisation.

Application

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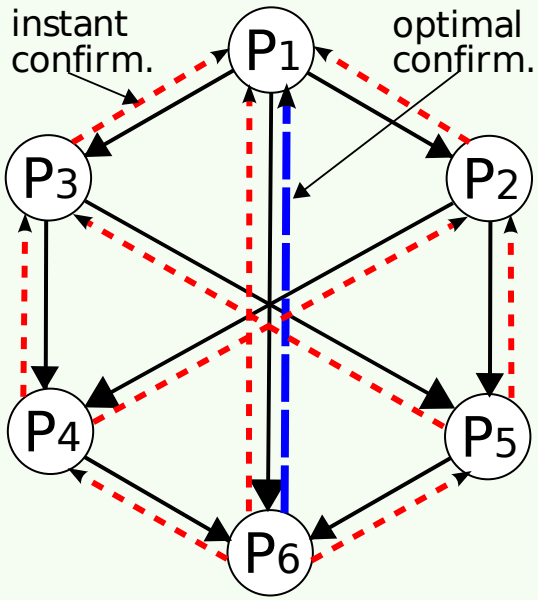
Multiprocessor SoC [Cheung&al. HLDTV'07]



Six processes connected by nine FIFOs

$$G = \mu \mathbf{x}.(\ \texttt{foreach}(i \in \{2,3\})\{G[i]\}; \mathrm{p}[1] \to \mathrm{p}[6] : \mathrm{on}); \mathbf{x}$$

$$G[i] = \mathrm{p}[1] \to \mathrm{p}[i] : \left\{ \begin{array}{l} \mathrm{on} : \mathrm{p}[i] \to \mathrm{p}[4] : \mathrm{on};\ \ \mathrm{p}[4] \to \mathrm{p}[6] : \mathrm{on}; \\ \mathrm{off} : \mathrm{p}[i] \to \mathrm{p}[5] : \mathrm{off};\ \ \mathrm{p}[5] \to \mathrm{p}[6] : \mathrm{off} \end{array} \right\}$$

Proposition

The above MPSoC six processes are communication-safe, buffer safe and satisfy progress (after global and local refinements).

Related Work

- Buffer analysis
  - Petri Nets, Kahn Networks [Geilen&Basten ESOP'03]
  - Binary session types [Gay&Vasconcelos JFP'09]
  - Static analysis [Nielson&Nielson POPL'94, Kobayashi&al. SAS'95, Teraushi&Megasz ESOP'08]
- Multiparty Session types
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  - Session Java [Hu, Yoshida, Honda, ECOOP'08, ECOOP'10]
- Other session type system
  - Conversation Types [Caires, Vieira, ESOP'09]
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- Long version and prototype implementation
  - `http://www.doc.ic.ac.uk/~malo/multianalysis/`

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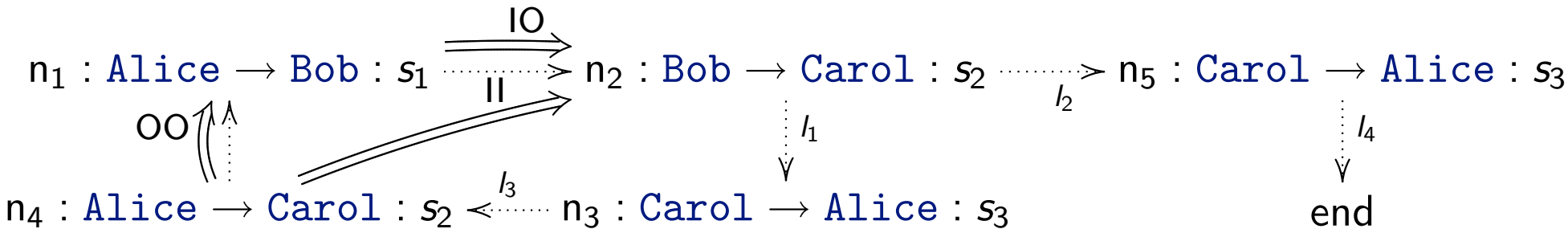
Thanks!

Extra slides

- Linearity

Causality Analysis and Linearity



- OO-dependency: local sends are ordered.
- II-dependency: local receives are ordered.
- IO-dependency: reception is a guard for sends.
- Linearity property: two uses of the same channels cannot be in conflict
  The senders should be ordered by OO-chains and the receivers by II-chains.