Reversible Barbed Congruence on Configuration Structures

Séminaires de l'équipe LCR – LIPN

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[3] ANR-14-CE25-0005 ELICA & ANR-11-INSE-0007 REVER

5 juin 2015

$$P = (a.b.0) + (b.a.0)$$

$$Q = (a.0)|(b.0)$$

$$P = (a.b.0) + (b.a.0) \xrightarrow{a} b.0$$

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$$Q = (a.0)|(b.0)$$

$$P = (a.b.0) + (b.a.0) \begin{array}{l} \xrightarrow{a} b.0 \xrightarrow{b} 0 \\ \xrightarrow{b} a.0 \xrightarrow{a} 0 \end{array}$$

$$Q = (a.0)|(b.0)$$

$$\xrightarrow{a} \; b.0 \xrightarrow{b} 0$$

$$P = (a.b.0) + (b.a.0)$$

$$\xrightarrow{b} \; a.0 \xrightarrow{a} 0$$

$$\xrightarrow{a} \; 0|(b.0)$$

$$Q = (a.0)|(b.0)$$

$$P = (a.b.0) + (b.a.0)$$

$$P \xrightarrow{a} b.0 \xrightarrow{b} 0$$

$$P \xrightarrow{b} a.0 \xrightarrow{a} 0$$

$$P|0 \equiv P$$

$$P|Q \equiv Q|P$$

$$P + 0 \equiv P$$

$$Q = (a.0)|(b.0)$$

$$Q \xrightarrow{a} 0|(b.0)$$

$$Q \xrightarrow{b} (a.0)|0$$

$$P = (a.b.0) + (b.a.0)$$

$$P \xrightarrow{a} b.0 \xrightarrow{b} 0$$

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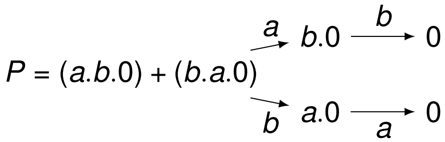
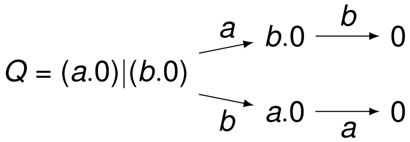
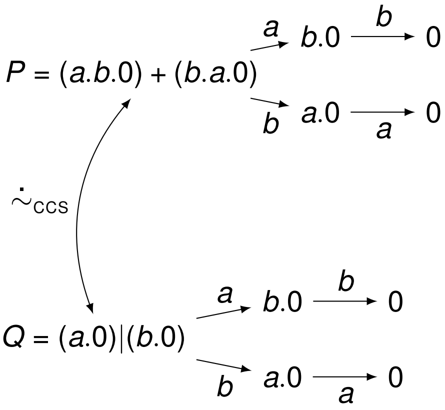
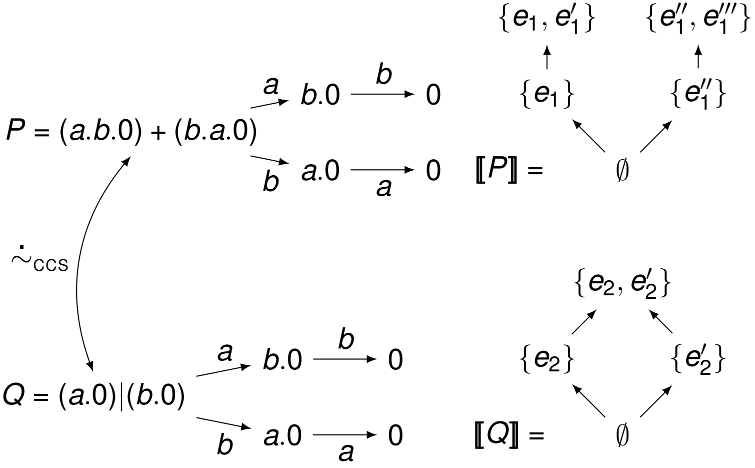

P = (a.b.0) + (b.a.0)
a
b.0
b
0
b
a.0
a
0


Q = (a.0)|(b.0)
a
b.0
b
0
b
a.0
a
0

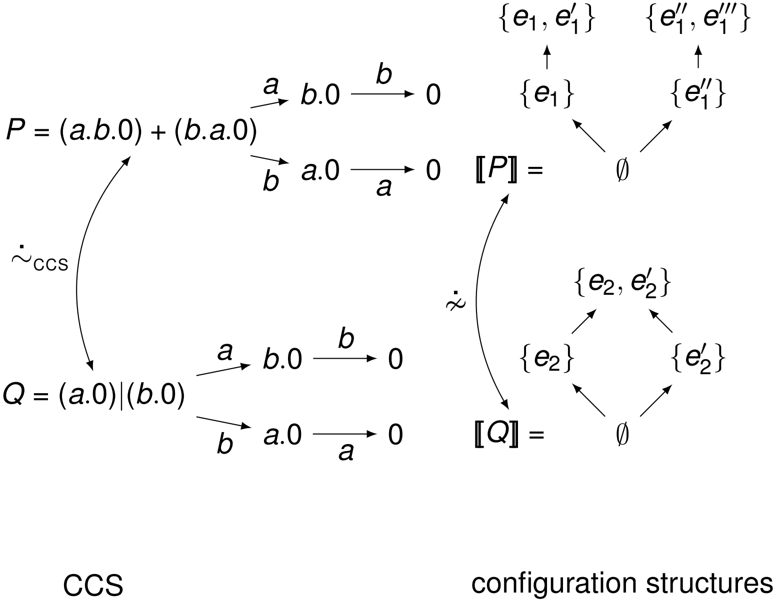


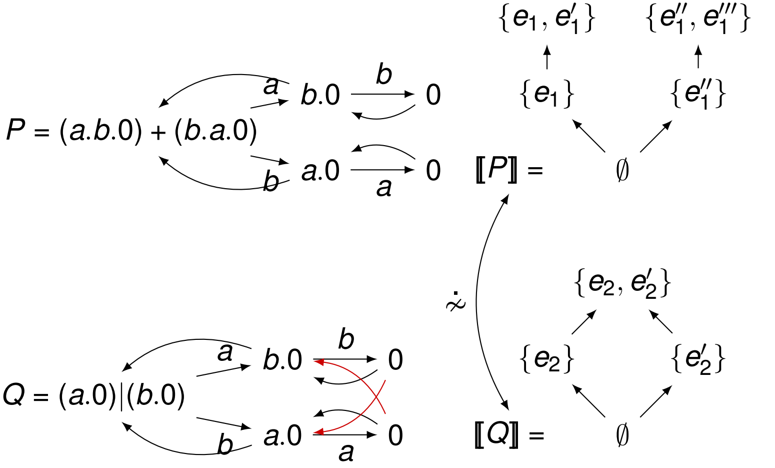
CCS



CCS

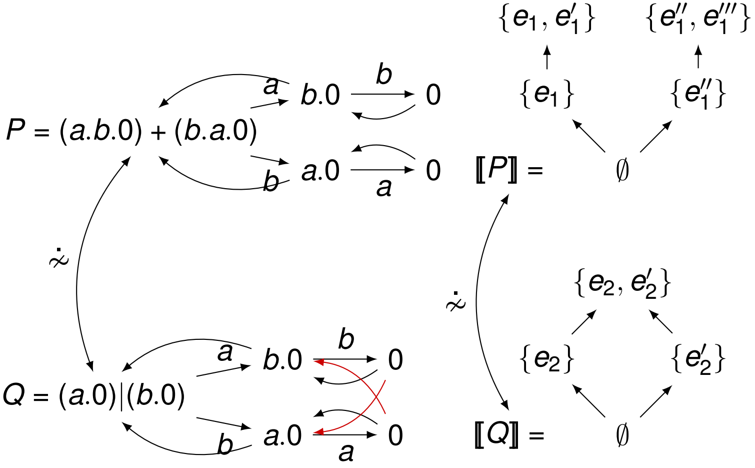
configuration structures


$P = (a.b.0) + (b.a.0)$
$b.0$
0
$a.0$
0
$\dot{\sim}_{\text{CCS}}$
$Q = (a.0)|(b.0)$
$b.0$
0
$a.0$
0
$\{e_1, e_1'\}$
$\{e_1''', e_1'''\}$
$\{e_1\}$
$\{e_1''\}$
$[\![P]\!] =$
$\emptyset$
$\dot{\not\approx}$
$\{e_2, e_2'\}$
$\{e_2\}$
$\{e_2'\}$
$[\![Q]\!] =$
$\emptyset$
CCS
configuration structures



RCCS

configuration structures



RCCS

configuration structures

Question 1

To what bisimulation on the LTS corresponds hereditary history-preserving bisimulation (hhpb)?

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CCS: labelled equivalence $\Leftrightarrow$ contextual equivalence

$P \sim Q \Leftrightarrow$ if for all *context* C, $C[P]$ and $C[Q]$ have the same *observables*.

Question 2

Is there a contextual characterisation of hhpb?

CCS | RCCS [2] | Configuration Structures

$\dot{\sim}_{\text{CCS}}$
Strong bisimulation

$\updownarrow$ = [3]

$\sim^{\tau}_{\text{CCS}}$
Strong Barbed Congruence

$\dot{\sim}$
Forward-reverse bisimulation

" = " [4] $\leftrightarrow$

$\dot{\sim}$
HHPB [1]

" = " $\leftrightarrow$

$\sim^{\tau}$
Strong Back and Forth Barbed Congruence

[1] M. A. Bednarczyk. *Hereditary History Preserving Bisimulations or What is the Power of the Future Perfect in Program Logics*. Tech. rep. Instytut Po dstaw Informatyki PAN filia w Gdańsku, 1991

[2] V. Danos and J. Krivine. "Reversible Communicating Systems". In: *CONCUR*. ed. by P. Gardner and N. Yoshida. Vol. 3170. LNCS. Springer, 2004, pp. 292–307

[3] R. Milner and D. Sangiorgi. "Barbed Bisimulation". In: *ICALP*. ed. by W. Kuich. Vol. 623. LNCS. Springer, 1992, pp. 685–695

[4] I. Phillips and I. Ulidowski. "Reversibility and Models for Concurrency". In: *ENTCS* 192.1 (2007), pp. 93–108

$\alpha, \beta := a \;\|\; \overline{a} \;\|\; \ldots \;\|\; \tau$ (Actions)

$P, Q := 0 \;\|\; \alpha.P \;\|\; \alpha.P + \beta.Q \;\|\; P|Q$ (CCS processes)

$$\alpha, \beta := a \;\|\; \overline{a} \;\|\; \ldots \;\|\; \tau \qquad \text{(Actions)}$$

$$P, Q := 0 \;\|\; \alpha.P \;\|\; \alpha.P + \beta.Q \;\|\; P|Q \qquad \text{(CCS processes)}$$

$$\ldots \qquad \frac{}{a.P \xrightarrow{a} P} \qquad \frac{P \xrightarrow{a} P' \qquad Q \xrightarrow{\overline{a}} Q'}{P|Q \xrightarrow{\tau} P'|Q'} \text{ syn.} \qquad \ldots$$

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Contextual equivalence

$P \sim Q \Leftrightarrow$ if for every *context* C, $C[P]$ and $C[Q]$ have the same *observables*.

$$\alpha, \beta := a \;\|\; \overline{a} \;\|\; \dots \;\|\; \tau \qquad \text{(Actions)}$$

$$P, Q := 0 \;\|\; \alpha.P \;\|\; \alpha.P + \beta.Q \;\|\; P|Q \qquad \text{(CCS processes)}$$

$$\dots \qquad \frac{}{a.P \xrightarrow{a} P} \qquad \frac{P \xrightarrow{a} P' \qquad Q \xrightarrow{\overline{a}} Q'}{P|Q \xrightarrow{\tau} P'|Q'} \text{ syn.} \qquad \dots$$

Contextual equivalence

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Context

$$C := [\,] \;\|\; C|P \;\|\; \alpha.C \;\|\; C + P$$

Observable

the (internal) *reductions*

the *barbs*: $P \downarrow_\alpha$ if there exists P' such that $P \xrightarrow{\alpha} P'$.

$$\alpha, \beta := a \;\|\; \overline{a} \;\|\; \ldots \;\|\; \tau \qquad \text{(Actions)}$$

$$P, Q := 0 \;\|\; \alpha.P \;\|\; \alpha.P + \beta.Q \;\|\; P|Q \qquad \text{(CCS processes)}$$

$$\ldots \qquad \frac{}{a.P \xrightarrow{a} P} \qquad \frac{P \xrightarrow{a} P' \qquad Q \xrightarrow{\overline{a}} Q'}{P|Q \xrightarrow{\tau} P'|Q'} \text{ syn.} \qquad \ldots$$

Strong barbed congruence

$$P \mathrel{\dot{\sim}^{\tau}_{\text{CCS}}} Q \Leftrightarrow \begin{cases} P \xrightarrow{\tau} P' \Rightarrow Q \xrightarrow{\tau} Q' \wedge P' \mathrel{\dot{\sim}^{\tau}_{\text{CCS}}} Q' \\ P \downarrow_{\alpha} \Rightarrow Q \downarrow_{\alpha} \\ Q \mathrel{\dot{\sim}^{\tau}_{\text{CCS}}} P \end{cases}$$

$$P \sim^{\tau}_{\text{CCS}} Q \Leftrightarrow \forall C, C[P] \mathrel{\dot{\sim}^{\tau}_{\text{CCS}}} C[Q]$$

$$R, S := m \triangleright P \;\parallel\; R|R \qquad \text{(RCCS processes)}$$

$$m := \emptyset \;\parallel\; \curlyvee .m \;\parallel\; \langle i, a, P\rangle.m \;\parallel\; \langle i, a\rangle.m \qquad \text{(Memories)}$$

$$R, S := m \triangleright P \;\parallel\; R|R \qquad \text{(RCCS processes)}$$

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Example

$$\emptyset \triangleright (a.P + b.Q)|(c.\overline{a}.P')$$

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$$\equiv (\curlyvee.\emptyset \triangleright (a.P + b.Q))|(\curlyvee.\emptyset \triangleright (c.\overline{a}.P'))$$

$$\rightarrow^{1:b}(\langle 1, b, a.P\rangle. \curlyvee .\emptyset \triangleright Q)|(\curlyvee.\emptyset \triangleright (c.\overline{a}.P'))$$

$$R, S := m \rhd P \;\|\; R|R \qquad \text{(RCCS processes)}$$

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$$\rightarrow^{2:c}(\langle 1, b, a.P\rangle.\curlyvee.\emptyset \rhd Q)|(\langle 2, c\rangle.\curlyvee.\emptyset \rhd (\overline{a}.P'))$$

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$$\xrightarrow{2:c}(\langle 1, b, a.P\rangle. \curlyvee .\emptyset \rhd Q)|(\langle 2, c\rangle. \curlyvee .\emptyset \rhd (\overline{a}.P'))$$
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$$\rightsquigarrow^{1:b} (\curlyvee.\emptyset \rhd (a.P + b.Q))|(\langle 2, c\rangle.\curlyvee.\emptyset \rhd (\overline{a}.P'))$$

$$\xrightarrow{3:\tau} (\langle 3, a, b.Q\rangle.\curlyvee.\emptyset \rhd P)|(\langle 3, \overline{a}\rangle.\langle 2, c\rangle.\curlyvee.\emptyset \rhd P')$$

$$R, S := m \triangleright P \parallel R|R \qquad \text{(RCCS processes)}$$

$$m := \emptyset \parallel \curlyvee .m \parallel \langle i, a, P\rangle.m \parallel \langle i, a\rangle.m \qquad \text{(Memories)}$$

Strong back-and-forth barbed bisimulation

$$R \dot{\sim}^{\tau} S \Leftrightarrow \begin{cases} R \rightarrow^{\tau} R' \Rightarrow S \rightarrow^{\tau} S' \wedge R' \dot{\sim}^{\tau} S' \\ R \rightsquigarrow^{\tau} R' \Rightarrow S \rightsquigarrow^{\tau} S' \wedge R' \dot{\sim}^{\tau} S' \\ R \downarrow_{\alpha} \Rightarrow S \downarrow_{\alpha} \\ S \dot{\sim}^{\tau} R \end{cases}$$

$$R, S := m \triangleright P \parallel R|R \qquad \text{(RCCS processes)}$$

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Strong back-and-forth barbed congruence

$\sim^{\tau} = \dot{\sim}^{\tau}$ closed by *context*

Origin of a process

$$O_R = P \text{ such that } \emptyset \triangleright P \rightarrow^* R$$

Simplest case: contexts and processes with an empty memory.

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$$R \sim^{\tau} S \Leftrightarrow \begin{cases} R \stackrel{\cdot}{\sim}^{\tau} S \\ \forall C[\cdot], C[O_R] \stackrel{\cdot}{\sim}^{\tau} C[O_S] \end{cases}$$

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Example

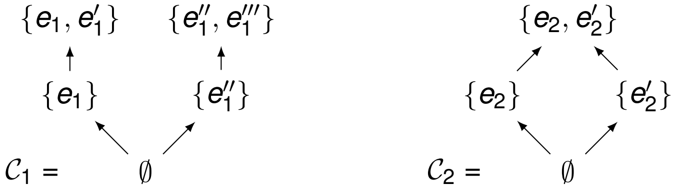
$$R = \langle i, b, a.P\rangle.\emptyset \rhd Q \qquad S = \langle j, a, b.Q\rangle.\emptyset \rhd P$$

$O_R = O_S = \emptyset \rhd a.P + b.Q$, so $O_R \sim^\tau O_S$ but $R \dot{\nsim}^\tau S$!

Labelled configuration structure [5]

$\mathcal{C} = \langle E, C, \ell \rangle$ with $C \subset \mathcal{P}(E)$ and $\ell : E \rightarrow$ labels.

Example



$\ell_1(e_1) = \ell_1(e_1''') = a$ $\qquad$ $\ell_2(e_2) = a$

$\ell_1(e_1') = \ell_1(e_1'') = b$ $\qquad$ $\ell_2(e_2') = b$

[5]: G. Winskel. "Event Structure Semantics for CCS and Related Languages". In: *ICALP*. ed. by M. Nielsen and E. M. Schmidt. Vol. 140. LNCS. Springer, 1982, pp. 561–576

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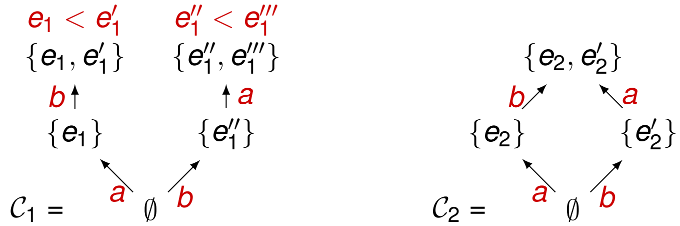

$\ell_1(e_1) = \ell_1(e'''_1) = a$

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Hereditary History Preserving Bisimulation [1]: $\mathcal{C}_1 \dot{\sim} \mathcal{C}_2$

$(\emptyset, \emptyset, \emptyset) \in \mathcal{R}$, and for $x_i \in C_i, e_i \in E_i, (x_1, x_2, f) \in \mathcal{R} \Rightarrow$

f label and order preserving bijection

[1] M. A. Bednarczyk. *Hereditary History Preserving Bisimulations or What is the Power of the Future Perfect in Program Logics*. Tech. rep. Instytut Po dstaw Informatyki PAN filia w Gdańsku, 1991

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$x_1 \rightarrow^{\alpha} x_1 \cup \{e_1\} \implies$
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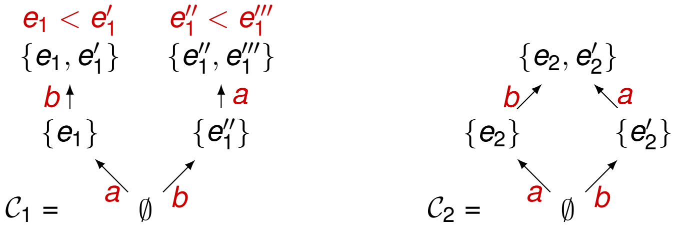
Example



$$\emptyset, \emptyset, \emptyset$$

$$\{e_1\}, \{e_2\}, e_1 \leftrightarrow e_2$$

$$\{e_1, e'_1\}, \{e_2, e'_2\}, e'_1 \leftrightarrow e'_2$$

Reversible Configuration Structures

$$O_R = P \text{ such that } \emptyset \triangleright \underbrace{P \xrightarrow{\alpha_1} \ldots \xrightarrow{\alpha_i}}_{x_R=\{e_1,\ldots,e_i\}} R \qquad [\![R]\!] = ([\![O_R]\!], x_R)$$

We can consider only forward transitions.

Reversible Configuration Structures

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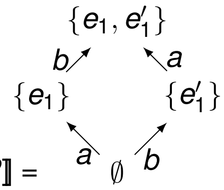
Example

$[\![P]\!] =$ 

$P = \qquad a.0| \qquad b.0$

Reversible Configuration Structures

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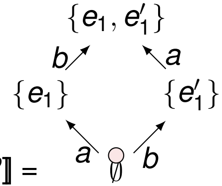
Example

$[\![R]\!] =$ 

$$\emptyset \rhd P \equiv \curlyvee.\emptyset \rhd a.0 | \curlyvee.\emptyset \rhd b.0$$

Reversible Configuration Structures

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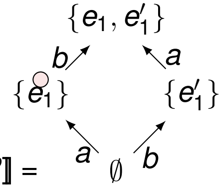
We can consider only forward transitions.

Example

$[\![R]\!] =$



$$\emptyset \rhd P \equiv \; \curlyvee.\emptyset \rhd a.0 \,|\, \curlyvee.\emptyset \rhd b.0$$

$$\xrightarrow{1:a} \langle 1, a\rangle.\curlyvee.\emptyset \rhd 0 \,|\, \curlyvee.\emptyset \rhd b.0$$

Reversible Configuration Structures

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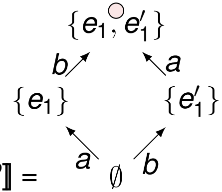
Example

$[\![R]\!] =$



$$\begin{aligned}\emptyset \rhd P &\equiv \Upsilon.\emptyset \rhd a.0 \mid \Upsilon.\emptyset \rhd b.0\\ &\xrightarrow{1:a} \langle 1, a\rangle.\Upsilon.\emptyset \rhd 0 \mid \Upsilon.\emptyset \rhd b.0\\ &\xrightarrow{2:b} \langle 1, a\rangle.\Upsilon.\emptyset \rhd 0 \mid \langle 2, b\rangle.\Upsilon.\emptyset \rhd 0\end{aligned}$$

Reversible Configuration Structures

$$O_R = P \text{ such that } \emptyset \rhd P \underbrace{\xrightarrow{\alpha_1} \dots \xrightarrow{\alpha_i}}_{x_R=\{e_1,\dots,e_i\}} R \qquad [\![R]\!] = ([\![O_R]\!], x_R)$$

We can consider only forward transitions.

Operational correspondence

let $[\![R]\!] = (\mathcal{C}, x)$:

$$R \xrightarrow{i:\alpha} S \Rightarrow (\mathcal{C}, x) \xrightarrow{\alpha} (\mathcal{C}, x \cup \{e\})$$

$$(\mathcal{C}, x) \xrightarrow{\alpha} (\mathcal{C}, x \cup \{e\}) \Rightarrow R \xrightarrow{i:\alpha} S$$

where $[\![S]\!] = (\mathcal{C}, x \cup \{e\})$, $\ell(e) = \alpha$ and the similarly for $\rightsquigarrow$.

RCCS | Configuration Structures

$R \sim^{\tau} S$ | $(\llbracket O_R \rrbracket, x_R)" \sim "(\llbracket O_S \rrbracket, x_S)$

$O_R \sim^{\tau} O_S \longleftrightarrow$ " = " $\llbracket O_R \rrbracket \dot{\sim} \llbracket O_S \rrbracket$

A correspondence between two worlds

RCCS | Configuration Structures

$R \sim^{\tau} S$ | $(\llbracket O_R \rrbracket, x_R)" \sim "(\llbracket O_S \rrbracket, x_S)$

$O_R \sim^{\tau} O_S \quad \overset{"="}{\longleftrightarrow} \quad \llbracket O_R \rrbracket \dot{\sim} \llbracket O_S \rrbracket$

$O_R \sim^{\tau} O_S \Longleftrightarrow \llbracket O_R \rrbracket \sim^{\tau} \llbracket O_S \rrbracket$

$\llbracket O_R \rrbracket \dot{\sim} \llbracket O_S \rrbracket \Updownarrow \llbracket O_R \rrbracket \sim^{\tau} \llbracket O_S \rrbracket$

+ inductive approximations of hhpb

contextual characterisation of hhpb

$\llbracket O_R \rrbracket \dot{\sim} \llbracket O_S \rrbracket \Leftrightarrow$ for every context C, $\llbracket C[O_R] \rrbracket \dot{\sim} \llbracket C[O_S] \rrbracket$.

CCS	Restricted RCCS	Configuration Structures
$\dot{\sim}_{\text{CCS}}$ Strong bisimulation	$\dot{\sim}$ Strong Back and Forth Barbed bisimulation	" = " $\dot{\sim}$ HHPB
=		
$\sim^{\tau}_{\text{CCS}}$ Strong Barbed Congruence	$\sim^{\tau}$ Strong Back and Forth Barbed Congruence	" = " $\dot{\sim}$ HHPB

CCS	Restricted RCCS	Configuration Structures
$\dot{\sim}_{\text{CCS}}$ Strong bisimulation	$\dot{\sim}$ Strong Back and Forth Barbed bisimulation	↔ " = " ↔ $\dot{\sim}$ HHPB
=		
$\sim^{\tau}_{\text{CCS}}$ Strong Barbed Congruence	$\sim^{\tau}$ Strong Back and Forth Barbed Congruence	↔ " = " ↔ HHPB

Future work

More general context for RCCS

Weak case

What to observe? directions?