Inference of Global Progress Properties for Dynamically Interleaved Multiparty Sessions

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COORDINATION 2013

On progress

$$a(y).b(z).y?(x).z!\langle x\rangle$$

$$\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle$$

- two distinct sessions
- each session is well typed
- the system gets stuck

On progress

$$a(y).b(z).y?(x).z!\langle x\rangle \qquad y : ?\mathtt{int} \qquad z : !\mathtt{int}$$

$$\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle \qquad y : !\mathtt{int} \qquad z : ?\mathtt{int}$$

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- each session is well typed
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The "interaction" type system

If $\vdash P$, then P never gets stuck

☺ Bettini, Coppo, D'Antoni, De Luca, Dezani-Ciancaglini, Yoshida, **Global Progress in Dynamically Interleaved Multiparty Sessions**, CONCUR 2008

The "interaction" type system

If $\vdash P$, then P never gets stuck

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- ☹ **not syntax-directed**

Outline

1. Defining progress
2. Key ideas of the syntax-directed type system
3. Two examples
4. Remarks

P has progress if. . .

$$\begin{array}{rl} \text{If} & P \rightarrow^* \mathcal{E}\,[\; s?(x).P' \;] \\ \text{Then} & \quad \rightarrow^* \mathcal{E}'[\; s?(x).P' \mid s : m \cdot h \;] \end{array}$$

$$\begin{array}{rl} \text{If} & P \rightarrow^* \mathcal{E}\,[\; s : m \cdot h \;] \\ \text{Then} & \quad \rightarrow^* \mathcal{E}'[\; s : m \cdot h \mid s?(x).P' \;] \end{array}$$

A process without progress

$$a(y).b(z).y?(x).z!\langle x\rangle \mid \overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle$$

A process without progress

$$a(y).b(z).y?(x).z!\langle x\rangle \mid \overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle$$

$$\downarrow_*$$

$$(\nu s)(\nu s')(s?(x).s'!\langle x\rangle \mid s'?(x).s!\langle c\rangle \mid s : \varnothing \mid s' : \varnothing)$$

A process without progress

$$a(y).b(z).y?(x).z!\langle x\rangle \mid \overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle$$

$$\downarrow_*$$

$$(\nu s)(\nu s')(s?(x).s'!\langle x\rangle \mid s'?(x).s!\langle c\rangle \mid s : \varnothing \mid s' : \varnothing)$$

Progress with catalyzers

A **good** process that looks like a **bad** one

$$P \to^* (\nu s)(\ s?(x).P' \mid \overline{b}(y).s!\langle 3\rangle.Q' \mid s : \varnothing\ )$$

A **bad** process that looks like a **good** one

$$c(y).(\text{a process that gets stuck})$$

Progress with catalyzers

A **good** process that looks like a **bad** one

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A **bad** process that looks like a **good** one

$$c(y).(\text{a process that gets stuck})$$

Idea

- define progress modulo **catalyzers**
- catalyzer = missing participant that never gets stuck

Consequence

- session initiation can be considered non-blocking

Interaction type system: basic ideas

1. associate processes with dependencies $a \prec b$

"an action of service a blocks an action of service b"

2. a process is well typed if it yields no circular dependencies

Computing service dependencies

$$a(y).b(z).y?(x).z!\langle x\rangle \qquad a \prec b$$

$$\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle \qquad b \prec a$$

Service names as messages

$$a(y).b(z).y?(x).z!\langle x\rangle \qquad a \prec b$$

$$\overline{c}(t).t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle$$

$$c(t).t!\langle a\rangle$$

Service names as messages

$$a(y).b(z).y?(x).z!\langle x\rangle \qquad a \prec b$$

$$t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle$$

$$t!\langle a\rangle$$

Service names as messages

$$a(y).b(z).y?(x).z!\langle x\rangle \qquad a \prec b$$

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Service names as messages

$$a(y).b(z).y?(x).z!\langle x\rangle \qquad a \prec b$$

$$\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle$$

Idea

- identify a class of safe services even if mutually dependent
- restrict messages to services in this class

Nested services

Definition

a is a nested service if $\lambda \prec a$ implies that λ is a nested service

		Nested?
$\overline{a}(y).\overline{a}(z).z?(x).y?(x')$	$a \prec a$	✔
$\overline{a}(y).\overline{b}(z).z?(x).y?(x')$ $\mid \overline{b}(z).\overline{a}(y).y?(x).z?(x')$	$b \prec a$ $a \prec b$	✔
$\overline{a}(y).\overline{b}(z).y?(x).z?(x')$	$y \prec b$	✖

Boundable services

$$a(y).(\nu b)(b(z).z?(x).y!\langle x\rangle)$$

- no catalyzer can help starting the session on b

Boundable services

$$a(y).(\nu b)(b(z).z?(x).y!\langle x \rangle)$$

- no catalyzer can help starting the session on b

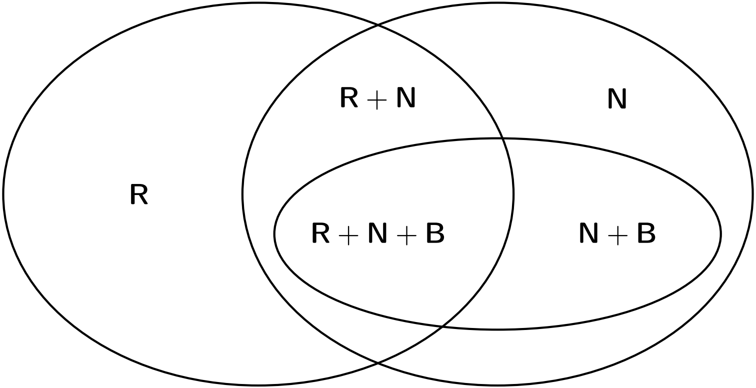
Definition

a is boundable if it is never followed by free channels

- b is nested but not boundable

Service classification

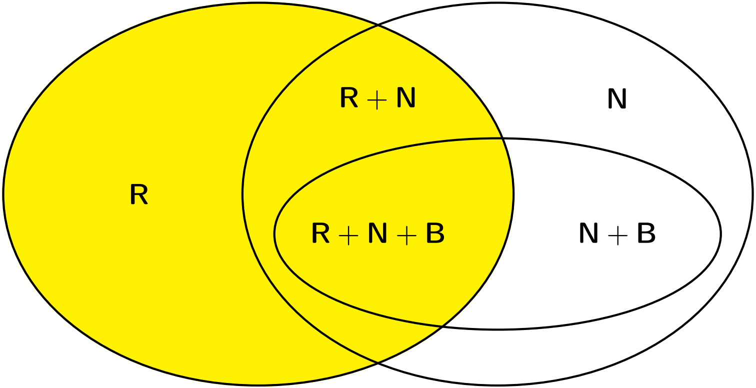
- each service can have up to three **features**



- inference = find the largest set of features for each service

Service classification

- each service can have up to three **features**



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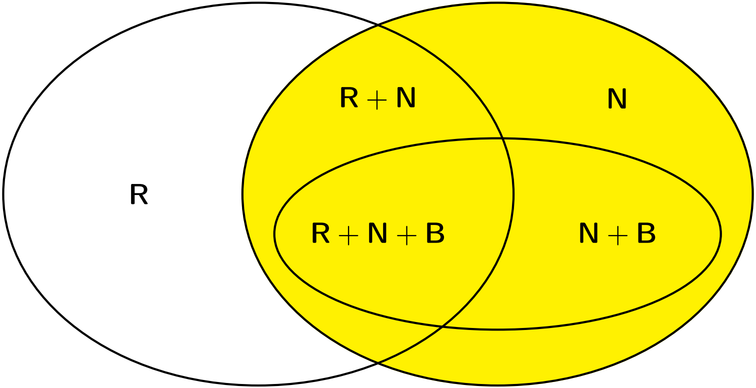

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Service classification

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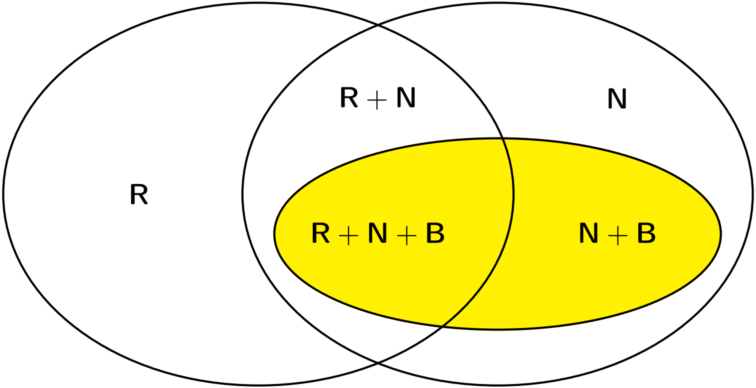

- inference = find the largest set of features for each service

Algorithm judgments

$$P \Mapsto \mathsf{D}; \mathsf{R}; \mathsf{N}; \mathsf{B}$$

If. . .

$$\begin{aligned} \mathsf{D}^{\infty} &\subseteq \mathsf{N} \setminus \mathsf{R} \\ \mathsf{D} \downarrow \mathsf{N} &\subseteq \mathsf{N} \\ \mathsf{fs}(P) &\subseteq \mathsf{R} \cup \mathsf{N} \end{aligned}$$

Example 1

$$\frac{}{a(y).b(z).y?(x).z!\langle x\rangle \mapsto}$$

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$$\dfrac{\dfrac{\dfrac{\dfrac{0 \Mapsto}{z!\langle x\rangle \Mapsto}}{y?(x).z!\langle x\rangle \Mapsto}}{b(z).y?(x).z!\langle x\rangle \Mapsto}}{a(y).b(z).y?(x).z!\langle x\rangle \Mapsto}$$

Example 1

all services have all features

$$\cfrac{\cfrac{\cfrac{\cfrac{0 \mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{z!\langle x\rangle \mapsto}}{y?(x).z!\langle x\rangle \mapsto}}{b(z).y?(x).z!\langle x\rangle \mapsto}}{a(y).b(z).y?(x).z!\langle x\rangle \mapsto}$$

Example 1

$$
\cfrac{\cfrac{\cfrac{\cfrac{0 \Mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{z!\langle x \rangle \Mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{y?(x).z!\langle x \rangle \Mapsto}}{b(z).y?(x).z!\langle x \rangle \Mapsto}}{a(y).b(z).y?(x).z!\langle x \rangle \Mapsto}
$$

Example 1

$$\cfrac{\cfrac{\cfrac{\cfrac{0 \Mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{z!\langle x\rangle \Mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{y?(x).z!\langle x\rangle \Mapsto \{y \prec z\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{b(z).y?(x).z!\langle x\rangle \Mapsto}}{a(y).b(z).y?(x).z!\langle x\rangle \Mapsto}$$

Example 1

$$\dfrac{\dfrac{\dfrac{\dfrac{0 \Mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{z!\langle x\rangle \Mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{y?(x).z!\langle x\rangle \Mapsto \{y \prec z\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{b(z).y?(x).z!\langle x\rangle \Mapsto \{y \prec b\}; \mathcal{S}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\}}}{a(y).b(z).y?(x).z!\langle x\rangle \Mapsto}$$

$\mathsf{B} \subseteq \mathsf{N}$

$\mathsf{D} \downarrow \mathsf{N} \subseteq \mathsf{N}$

Example 1

$$\dfrac{\dfrac{\dfrac{\dfrac{0 \mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{z!\langle x\rangle \mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{y?(x).z!\langle x\rangle \mapsto \{y \prec z\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{b(z).y?(x).z!\langle x\rangle \mapsto \{y \prec b\}; \mathcal{S}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\}}}{a(y).b(z).y?(x).z!\langle x\rangle \mapsto \{a \prec b\}; \mathcal{S}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\}}$$

Example 1 (cont.)

$$\frac{}{\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle}$$

$$\frac{}{a(y)\cdots \mid \overline{a}(y)\cdots \Mapsto}$$

Example 1 (cont.)

$$\dfrac{\dfrac{\dfrac{\dfrac{0 \Mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{y!\langle x\rangle \Mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{z?(x).y!\langle x\rangle \Mapsto \{z \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto \{b \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto \{b \prec a\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}$$

$$\dfrac{}{a(y)\cdots \mid \overline{a}(y)\cdots \Mapsto}$$

Example 1 (cont.)

$$\dfrac{\dfrac{\dfrac{\dfrac{0 \Rrightarrow \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{y!\langle x\rangle \Rrightarrow \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{z?(x).y!\langle x\rangle \Rrightarrow \{z \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec a\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}$$

$$\dfrac{a(y)\cdots \Rrightarrow \{a \prec b\}; \mathcal{S}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\}}{a(y)\cdots \mid \overline{a}(y)\cdots \Rrightarrow}$$

Example 1 (cont.)

$$\dfrac{\dfrac{\dfrac{\dfrac{0 \Rrightarrow \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{y!\langle x\rangle \Rrightarrow \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{z?(x).y!\langle x\rangle \Rrightarrow \{z \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec a\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}$$

$$\dfrac{a(y)\cdots \Rrightarrow \{a \prec b\}; \mathcal{S}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\} \quad \overline{a}(y)\cdots \Rrightarrow \{b \prec a\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}{a(y)\cdots \mid \overline{a}(y)\cdots \Rrightarrow}$$

Example 1 (cont.)

$$\dfrac{\dfrac{\dfrac{\dfrac{0 \Rrightarrow \emptyset;\mathcal{S};\mathcal{S};\mathcal{S}}{y!\langle x\rangle \Rrightarrow \emptyset;\mathcal{S};\mathcal{S};\mathcal{S}}}{z?(x).y!\langle x\rangle \Rrightarrow \{z \prec y\};\mathcal{S};\mathcal{S};\mathcal{S}}}{\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec y\};\mathcal{S};\mathcal{S};\mathcal{S}}}{\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec a\};\mathcal{S};\mathcal{S};\mathcal{S}}$$

$\mathsf{D}^\infty \subseteq \mathsf{N} \setminus \mathsf{R}$

$$\dfrac{a(y)\cdots \Rrightarrow \{a \prec b\};\mathcal{S};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\} \qquad \overline{a}(y)\cdots \Rrightarrow \{b \prec a\};\mathcal{S};\mathcal{S};\mathcal{S}}{a(y)\cdots \mid \overline{a}(y)\cdots \Rrightarrow \{a \prec b, b \prec a\};\mathcal{S}\setminus\{a,b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\}}$$

Example 1 (cont.)

$$\dfrac{\dfrac{\dfrac{\dfrac{0 \mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}{y!\langle x\rangle \mapsto \emptyset; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{z?(x).y!\langle x\rangle \mapsto \{z \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{b}(z).z?(x).y!\langle x\rangle \mapsto \{b \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{a}(y).\overline{b}(z).z?(x).y!\langle x\rangle \mapsto \{b \prec a\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}$$

$$\dfrac{a(y)\cdots \mapsto \{a \prec b\}; \mathcal{S}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\} \quad \overline{a}(y)\cdots \mapsto \{b \prec a\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}{a(y)\cdots \mid \overline{a}(y)\cdots \mapsto \{a \prec b, b \prec a\}; \mathcal{S} \setminus \{a, b\}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\}}$$

Example 2

$$\frac{}{\overline{c}(t).t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow}$$

$$\frac{a(y)\cdots \Rrightarrow \{a \prec b\};\mathcal{S};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\} \quad \overline{c}(t)\cdots \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}{a(y)\cdots \mid \overline{c}(t)\cdots \Rrightarrow \{a \prec b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\}}$$

Example 2

$$\dfrac{\dfrac{\dfrac{\dfrac{\vdots}{\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec y\};\mathcal{S};\mathcal{S};\mathcal{S}}}{\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow}}{t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow}}{\overline{c}(t).t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow}$$

$$\dfrac{a(y)\cdots \Rrightarrow \{a \prec b\};\mathcal{S};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\} \quad \overline{c}(t)\cdots \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}{a(y)\cdots \mid \overline{c}(t)\cdots \Rrightarrow \{a \prec b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\}}$$

Example 2

$$\vdots$$

$$\frac{\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto \{b \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}{\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto \emptyset; \mathcal{S} \setminus \{b\}; \mathcal{S}; \mathcal{S}}$$

x must be nested, so b too

$t?(x).\overline{x}(y).\overline{b}(\ldots$

$\overline{c}(t).t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto$

dependencies discharged

$$\frac{a(y)\cdots \Mapsto \{a \prec b\}; \mathcal{S}; \mathcal{S}\setminus\{b\}; \mathcal{S}\setminus\{b\} \quad \overline{c}(t)\cdots \Mapsto \emptyset; \mathcal{S}\setminus\{b\}; \mathcal{S}; \mathcal{S}}{a(y)\cdots \mid \overline{c}(t)\cdots \Mapsto \{a \prec b\}; \mathcal{S}\setminus\{b\}; \mathcal{S}\setminus\{b\}; \mathcal{S}\setminus\{b\}}$$

Example 2

$$
\dfrac{\dfrac{\dfrac{\dfrac{\vdots}{\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec y\};\mathcal{S};\mathcal{S};\mathcal{S}}}{\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}}{t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}}{\overline{c}(t).t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}
$$

$$
\dfrac{a(y)\cdots \Rrightarrow \{a \prec b\};\mathcal{S};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\} \quad \overline{c}(t)\cdots \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}{a(y)\cdots \mid \overline{c}(t)\cdots \Rrightarrow \{a \prec b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\}}
$$

Example 2

$$\dfrac{\dfrac{\dfrac{\dfrac{\vdots}{\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \{b \prec y\};\mathcal{S};\mathcal{S};\mathcal{S}}}{\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}}{t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}}{\overline{c}(t).t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}$$

$$\frac{a(y)\cdots \Rrightarrow \{a \prec b\};\mathcal{S};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\} \quad \overline{c}(t)\cdots \Rrightarrow \emptyset;\mathcal{S}\setminus\{b\};\mathcal{S};\mathcal{S}}{a(y)\cdots \mid \overline{c}(t)\cdots \Rrightarrow \{a \prec b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\};\mathcal{S}\setminus\{b\}}$$

Example 2

$$\dfrac{\dfrac{\dfrac{\dfrac{\vdots}{\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto \{b \prec y\}; \mathcal{S}; \mathcal{S}; \mathcal{S}}}{\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto \emptyset; \mathcal{S} \setminus \{b\}; \mathcal{S}; \mathcal{S}}}{t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto \emptyset; \mathcal{S} \setminus \{b\}; \mathcal{S}; \mathcal{S}}}{\overline{c}(t).t?(x).\overline{x}(y).\overline{b}(z).z?(x).y!\langle x\rangle \Mapsto \emptyset; \mathcal{S} \setminus \{b\}; \mathcal{S}; \mathcal{S}}$$

$$\dfrac{a(y)\cdots \Mapsto \{a \prec b\}; \mathcal{S}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\} \quad \overline{c}(t)\cdots \Mapsto \emptyset; \mathcal{S} \setminus \{b\}; \mathcal{S}; \mathcal{S}}{a(y)\cdots \mid \overline{c}(t)\cdots \Mapsto \{a \prec b\}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\}; \mathcal{S} \setminus \{b\}}$$

Result

Theorem

If $P \Mapsto \mathsf{D}; \mathsf{R}; \mathsf{N}; \mathsf{B}$, *then* P *has progress*

Proof.

The algorithm is sound and complete wrt the interaction type system (cf. CONCUR 2008) □

Result

Theorem

If $P \mapsto \mathsf{D}; \mathsf{R}; \mathsf{N}; \mathsf{B}$, *then* P *has progress*

Proof.

The algorithm is sound and complete wrt the interaction type system (cf. CONCUR 2008) (for finite processes only) □

Soon to come

Inference for recursive processes

Wrap up

- static analysis for (multiparty) session interleaving
- progress $\neq$ absence of deadlock
  - diverging systems do not necessarily have progress
  - catalyzers may help reduction
- quadratic inference algorithm

Problem #1: simple programs are **ill typed**

$$\overline{a}(y).\overline{b}(z).y?(x).z!\langle x\rangle.z?(x').y!\langle x'\rangle \qquad a \prec b, b \prec a$$

- Naoki Kobayashi. **A Type System for Lock-Free Processes**, Inf. & Comp. 2002
- Luca Padovani. **From Lock Freedom to Progress Using Session Types**, PLACES 2013
- Hugo Torres Vieira and Vasco T. Vasconcelos. **Typing Progress in Communication-Centred Systems**

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☛ **next talk!**

Problem #2: π processes $\neq$ **real programs**

$$\frac{P \Mapsto \mathsf{D}; \mathsf{R}; \mathsf{N}; \mathsf{B}}{y?(x).P \Mapsto (\mathsf{pre}(y, \mathsf{fc}(P)) \cup \mathsf{D})^{+}; \mathsf{R}; \mathsf{N}; \mathsf{B}}$$

Problem #2: π processes $\neq$ **real programs**

$$\frac{P \;\Rrightarrow\; \mathsf{D}; \mathsf{R}; \mathsf{N}; \mathsf{B}}{y?(x).P \;\Rrightarrow\; (\mathsf{pre}(y, \mathsf{fc}(P)) \cup \mathsf{D})^{+}; \mathsf{R}; \mathsf{N}; \mathsf{B}}$$

What if this occurs inside a function?