Contracts with roll-back

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CINA General Meeting - Torino, Feb 10-12, 2015 based on:

- F. Barbanera, M. Dezani, U. de'Liguoro,
  Compliance for reversible client/server interactions, BEAT'14.
- F. Barbanera, M. Dezani, I. Lanese, U. de'Liguoro,
  Retractable Contracts, PLACES'15.

- A *contract*[1] is the abstract description of the behaviour of either a *client* or a *server*.
- A client *complies* with a server if all her requirements are fulfilled, either by reaching a distinguished satisfaction state or by running an infinite communication without ever getting stuck.

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What about allowing client and server to change their mind, rolling back to some previous choice and progress differently?

There are at least two alternatives (but possibly more):

- the **conservative approach**, extending the contract language without making compliant more roll-back free contracts
- the **adaptive approach**, where roll-back makes more contracts compliant

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Contracts

Syntax

$$\sigma, \rho ::= \mathbf{1} \mid \sum_{i \in I} a_i.\sigma_i \mid \bigoplus_{i \in I} \bar{a}_i.\sigma_i \mid x \mid \mathsf{rec}\ x.\sigma$$

LTS

$$\textstyle\sum_{i \in I} a_i.\sigma_i \xrightarrow{a_i} \sigma_i \qquad \bigoplus_{i \in I} \bar{a}_i.\sigma_i \longrightarrow \bar{a}_j.\sigma_j \qquad \bar{a}.\sigma \xrightarrow{\bar{a}} \sigma$$

Communication semantics:

$$\frac{\rho \xrightarrow{\alpha} \rho' \qquad \sigma \xrightarrow{\overline{\alpha}} \sigma'}{\rho \| \sigma \longrightarrow \rho' \| \sigma'} \qquad \frac{\rho \longrightarrow \rho'}{\rho \| \sigma \longrightarrow \rho' \| \sigma} \qquad \frac{\sigma \longrightarrow \sigma'}{\rho \| \sigma \longrightarrow \rho \| \sigma'}$$

Compliance

The *client* ρ is *compliant* with the *server* σ, written $\rho \dashv \sigma$, if

$$\forall \rho', \sigma'.\ \rho \| \sigma \xrightarrow{*} \rho' \| \sigma' \not\longrightarrow \quad \Rightarrow \quad \rho' = \mathbf{1}$$

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Customer		Travel agency
$\texttt{sea}.(\texttt{house} + \texttt{bungalow})$		$\overline{\texttt{sea}}.\overline{\texttt{bungalow}}$
$+$	$\dashv$	$\oplus$
$\texttt{mountain}.\texttt{house}$		$\overline{\texttt{mountain}}.\overline{\texttt{house}}$

Duality

Definition

$$\overline{\mathbf{1}} = \mathbf{1}, \qquad \overline{\sum_{i \in I} a_i.\sigma_i} = \bigoplus_{i \in I} \overline{a}_i.\overline{\sigma}, \qquad \overline{\bigoplus_{i \in I} \overline{a}_i.\sigma_i} = \sum_{i \in I} a_i.\overline{\sigma}.$$

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Fact

Duality is involutive; moreover

1. $\forall \sigma.\ \overline{\sigma} \dashv \sigma \quad \& \quad \sigma \dashv \overline{\sigma},$
2. $\rho \dashv \sigma \quad \& \quad \overline{\sigma} \dashv \tau \Rightarrow \rho \dashv \tau.$

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Decidability theorem

The compliance relation is axiomatisable by an alogorithmic system, hence it is decidable.

Contracts with roll-back

A *wider* scenario: **in a communication cantracts can roll-back**:

- at any moment (for unpredictable reasons)
- to a checkpoint $\blacktriangle$ (the last crossed one)

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A *wider* scenario: **in a communication cantracts can roll-back**:

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$$\sigma, \rho ::= \mathbf{1} \mid \sum_{i \in I} a_i.\sigma_i \mid {}_\blacktriangle\sum_{i \in I} a_i.\sigma_i \mid \bigoplus_{i \in I} \overline{a}_i.\sigma_i \mid {}_\blacktriangle\bigoplus_{i \in I} \overline{a}_i.\sigma_i \mid x \mid \mathsf{rec}\ x.\sigma$$

LTS for contracts with roll-back

$$\sigma \prec \sigma' \xrightarrow{\mathsf{rbk}} \circ \prec \sigma \ (\mathsf{rbk})$$

where $\circ =$ *no checkpoint crossed yet, i.e. no roll-back is possible*

Implying:

No two consecutive roll-backs

So, memory can be cleared after "crossing" a '$\blacktriangle$'.

In fact

$$\frac{\gamma \prec \sigma \xrightarrow{\alpha} \gamma \prec \sigma' \quad \alpha \in \mathcal{N} \cup \overline{\mathcal{N}}}{\gamma \prec {}_{\blacktriangle}\sigma \xrightarrow{\alpha} {}_{\blacktriangle}\sigma \prec \sigma'}$$

Possible extension: multiple roll-backs handling $\boldsymbol{\gamma} = \gamma_1 : \cdots : \gamma_k$ as a stack.

Roll-back is synchronous

Roll-back from a partner should not be hidden to the other one: it is a *synchronous* transition:

$$\frac{\rho \prec \rho' \xrightarrow{\mathsf{rbk}} \circ \prec \rho \qquad \sigma \prec \sigma' \xrightarrow{\mathsf{rbk}} \circ \prec \sigma}{\rho \prec \rho' \parallel \sigma \prec \sigma' \xrightarrow{\mathsf{rbk}} \circ \prec \rho \parallel \circ \prec \sigma}$$

Many difficulties of reversible computations are overcomed in our context, where, for instance, both client and server reduce in a sequential way.

Checkpoint compliance $\dashv_{\blacktriangle}$

$$
\begin{array}{rrcl}
 & {}_{\blacktriangle}(a.b.c + b) & \parallel & \overline{a}.{}_{\blacktriangle}\overline{b}.\overline{c} \\
\longrightarrow & b.c & \parallel & {}_{\blacktriangle}\overline{b}.\overline{c} \\
\longrightarrow & c & \parallel & \overline{c} \\
\xrightarrow{\text{rbk}} & {}_{\blacktriangle}(a.b.c + b) & \parallel & {}_{\blacktriangle}\overline{b}.\overline{c} \\
\longrightarrow & \mathbf{1} & \parallel & \overline{c}
\end{array}
$$

✓

Relating $\dashv^{\blacktriangle}$ to $\dashv$

We expect the following to hold:

Duality $\forall \sigma, \rho.\ \overline{\sigma} \dashv^{\blacktriangle} \sigma \ \ \& \ \ \rho \dashv^{\blacktriangle} \overline{\rho}$

Conservativity $\forall \sigma, \rho.\ \rho \dashv^{\blacktriangle} \sigma \Rightarrow \mathit{erase}(\rho) \dashv \mathit{erase}(\sigma)$

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But

$$
\begin{array}{ll}
 & \circ \prec_{\blacktriangle} a.{}_{\blacktriangle}(b+c) \parallel \circ \prec {}_{\blacktriangle}\overline{a}.{}_{\blacktriangle}(\overline{b} \oplus \overline{c}) \\
\longrightarrow & {}_{\blacktriangle}a.{}_{\blacktriangle}(b+c) \prec {}_{\blacktriangle}(b+c) \parallel {}_{\blacktriangle}\overline{a}.{}_{\blacktriangle}(\overline{b} \oplus \overline{c}) \prec {}_{\blacktriangle}(\overline{b} \oplus \overline{c}) \\
\longrightarrow & {}_{\blacktriangle}a.{}_{\blacktriangle}(b+c) \prec_{\blacktriangle} (b+c) \parallel {}_{\blacktriangle}(\overline{b} \oplus \overline{c}) \prec \overline{b} \\
\xrightarrow{\text{rbk}} & \circ \prec_{\blacktriangle} a.{}_{\blacktriangle}(b+c) \parallel \circ \prec {}_{\blacktriangle}(\overline{b} \oplus \overline{c}) \\
\not\longrightarrow &
\end{array}
$$

hence

$$
{}_{\blacktriangle}a.{}_{\blacktriangle}(b+c) \not\dashv^{\blacktriangle} {}_{\blacktriangle}\overline{a}.{}_{\blacktriangle}(\overline{b} \oplus \overline{c}) = \overline{{}_{\blacktriangle}a.{}_{\blacktriangle}(b+c)}
$$

Relating $\dashv^{\blacktriangle}$ to $\dashv$

To solve the problem of saving **Duality**, we may redefine the LTS by putting:

$$\gamma \prec \sum_{i\in I} a_i.\sigma_i \xrightarrow{a_k} \gamma \prec \sigma_k \qquad \gamma \prec \bigoplus_{i\in I} \overline{a}_i.\sigma_i \xrightarrow{\overline{a}_k} \gamma \prec \sigma_k$$

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but this immediately breaks **Conservativity**:

$$a \dashv^{\blacktriangle} \overline{a} \oplus \overline{b} \quad \text{where} \quad a \not\dashv \overline{a} \oplus \overline{b}$$

Constraining communication

With the new LTS we constrain communication rules:

$$\frac{\rho \xrightarrow{a} \rho' \qquad \sigma \xrightarrow{\bar{a}} \sigma' \qquad \mathcal{A}^{\oplus}(\sigma) \subseteq \mathcal{A}^{+}(\rho)}{\rho \parallel \sigma \longrightarrow \rho' \parallel \sigma'}$$

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where

$$\begin{array}{rclrcl}
\mathcal{A}^{+}(\mathbf{1}) = \mathcal{A}^{+}(\bigoplus_{i\in I} \bar{a}_i.\sigma_i) & = & \emptyset & \quad \mathcal{A}^{+}(\sum_{i\in I} a_i.\sigma_i) & = & \{a_i \mid i \in I\} \\
\mathcal{A}^{\oplus}(\mathbf{1}) = \mathcal{A}^{\oplus}(\sum_{i\in I} a_i.\sigma_i) & = & \emptyset & \quad \mathcal{A}^{\oplus}(\bigoplus_{i\in I} \bar{a}_i.\sigma_i) & = & \{a_i \mid i \in I\}
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Results

Definition

Define $\dashv^{\blacktriangle}$ exactly as $\dashv$ but w.r.t. the semantics of contracts with checkpoint

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Results

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Theorem

- $\dashv^{\blacktriangle}$ satisfies both Duality and Conservativity principles
- $\dashv^{\blacktriangle}$ can be characterized coinductively
- there is a formal system for deducing whether $\rho \dashv^{\blacktriangle} \sigma$, which is sound and complete
- derivability in the system is decidable, hence $\dashv^{\blacktriangle}$ is decidable

Retractable contracts

A different motivation for rolling back is to recover from a failure:

$$
\begin{aligned}
\text{Buyer} &= \overline{\text{bag}}.\text{price}.(\overline{\text{card}} \oplus \overline{\text{cash}}) \oplus \overline{\text{belt}}.\text{price}.(\overline{\text{card}} \oplus \overline{\text{cash}}) \\
\text{Seller} &= \text{bag}.\overline{\text{price}}.(\text{card} + \text{cash}) + \text{belt}.\overline{\text{price}}.\text{cash}
\end{aligned}
$$

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Then Buyer $\not\dashv$ Seller because, by choosing $\overline{\text{belt}}$.price on Buyer's side

$$\text{Buyer} \parallel \text{Seller} \xrightarrow{*} \overline{\text{card}} \oplus \overline{\text{cash}} \parallel \text{cash} \longrightarrow \overline{\text{card}} \parallel \text{cash}$$

If Buyer will insist in paying by card, we could change her contract

$$\text{Buyer}' = \overline{\text{bag}}.\text{price}.(\overline{\text{card}} \oplus \overline{\text{cash}}) \color{red}{+} \overline{\text{belt}}.\text{price}.(\overline{\text{card}} \oplus \overline{\text{cash}})$$

and allow roll-back to (all) external choices whenever a **communication failure** occurs.

Retractable contracts: syntax

$$\sigma, \rho ::= \mathbf{1} \mid \sum_{i \in I} a_i.\sigma_i \mid \sum_{i \in I} \overline{a}_i.\sigma_i \mid \bigoplus_{i \in I} \overline{a}_i.\sigma_i \mid x \mid \mathsf{rec}\ x.\sigma$$

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LTS (where $\boldsymbol{\gamma} = \gamma_1 : \cdots : \gamma_k$):

$$(+) \quad \boldsymbol{\gamma} \prec \alpha.\sigma + \sigma' \xrightarrow{\alpha} \boldsymbol{\gamma} : \sigma' \prec \sigma \qquad (\oplus) \quad \boldsymbol{\gamma} \prec \overline{a}.\sigma \oplus \sigma' \longrightarrow \boldsymbol{\gamma} \prec \overline{a}.\sigma$$

$$(\alpha) \quad \boldsymbol{\gamma} \prec \alpha.\sigma \xrightarrow{\alpha} \boldsymbol{\gamma} : \circ \prec \sigma \qquad (\mathsf{rbk}) \quad \boldsymbol{\gamma} : \sigma' \prec \sigma \xrightarrow{\mathsf{rbk}} \boldsymbol{\gamma} \prec \sigma'$$

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Communication:

$$\frac{\boldsymbol{\gamma} \prec \rho \xrightarrow{\mathsf{rbk}} \boldsymbol{\gamma}' \prec \rho' \qquad \boldsymbol{\delta} \prec \sigma \xrightarrow{\mathsf{rbk}} \boldsymbol{\delta}' \prec \sigma'}{\boldsymbol{\gamma} \prec \rho \parallel \boldsymbol{\delta} \prec \sigma \longrightarrow \boldsymbol{\gamma}' \prec \rho' \parallel \boldsymbol{\delta}' \prec \sigma'}$$

that applies only if ρ and σ are in the **failure condition**:

$\rho \neq \mathbf{1}$ & neither communication nor internal actions may occur.

Derivation system for $\dashv^{\mathsf{rbk}}$

$$\frac{}{\Gamma \rhd \mathbf{1} \dashv \sigma} \qquad \frac{}{\Gamma, \rho \dashv \sigma \rhd \rho \dashv \sigma} \qquad \frac{\Gamma, \alpha.\rho + \rho' \dashv \overline{\alpha}.\sigma + \sigma' \rhd \rho \dashv \sigma}{\Gamma \rhd \alpha.\rho + \rho' \dashv \overline{\alpha}.\sigma + \sigma'}$$

$$\frac{\forall i \in I.\ \Gamma, \bigoplus_{i \in I} \overline{a}_i.\rho_i \dashv \sum_{j \in I \cup J} a_j.\sigma_j \rhd \rho_i \dashv \sigma_i}{\Gamma \rhd \bigoplus_{i \in I} \overline{a}_i.\rho_i \dashv \sum_{j \in I \cup J} a_j.\sigma_j}$$

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Decidability of $\dashv^{\mathsf{rbk}}$

Definition (Compliance of retractable contracts)

$\boldsymbol{\gamma} \prec \rho \dashv^{\mathsf{rbk}} \boldsymbol{\delta} \prec \sigma$ if and only if

$$\forall \boldsymbol{\gamma}' \prec \rho', \boldsymbol{\delta}' \prec \sigma'.\ \boldsymbol{\gamma} \prec \rho \parallel \boldsymbol{\delta} \prec \sigma \xrightarrow{*} \boldsymbol{\gamma}' \prec \rho' \parallel \boldsymbol{\delta}' \prec \sigma' \not\longrightarrow$$

implies $\rho' = \mathbf{1}$.

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implies $\rho' = \mathbf{1}$.

Theorem

The derivation system is sound and complete w.r.t. $\dashv^{\mathsf{rbk}}$, and derivability is decidable, hence $\dashv^{\mathsf{rbk}}$ is decidable.

Further directions

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- The sub-contract relation is defined:

$$\sigma_1 \leq \sigma_2 \iff \forall \rho.\ \rho \dashv \sigma_1 \Rightarrow \rho \dashv \sigma_2$$

Bernardi, Hennessy [MSCS 20??] have established that it coincides with must-testing preorder.
How can be characterized $\leq^{\blacktriangle}$ and $\leq^{\mathsf{rbk}}$?

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- Can the compliance relation be refined w.r.t. infinite contracts, while remaining decidable?
- Are contracts with roll-back and reversible processes related?
- To what extent roll-back compliance can model adaptability?

Thanks

Thank you!