Domain Specific Formal Languages

– A Calculus for Orchestration of Web Services –

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A.A. 2016/2017

Motivation

Deficiency

Current software engineering technologies for SOC

- remain at a linguistic level
- do not support analytical tools for checking that SOC applications enjoy desirable correctness properties

Goal

Develop *formal reasoning mechanisms* and *analytical tools* for checking that services (possibly resulting from a *composition*) meet desirable properties and do not manifest unexpected behaviors

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Approach: rely on Process Calculi

- Convey in a distilled form the paradigm at the heart of SOC (being defined algebraically, they are inherently compositional)
- Provide linguistic formalisms for description of service-based applications and their composition
- Hand down a large set of reasoning mechanisms and analytical tools, e.g. typing systems and model checkers

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Process Calculi for SOC

- To model service composition, many process calculi-like formalisms have been designed
- Most of them only consider a few specific features separately, possibly by embedding ‘ad hoc’ constructs within some well-studied process calculus
  (e.g., the variants of CSP/π-calculus with transactions)
- One major goal is assessing the adequacy of diverse sets of primitives w.r.t. modelling, combining and analysing service-oriented systems

Process Calculi for SOC: an overview

Process calculi for SOC can be classified according to the approach used for maintaining the link between *caller* and *callee*

- **Sessions**: the link is determined by a private channel that is implicitly created when the first message exchange of a conversation takes place
- **Correlations**: the link is determined by correlation values included in the exchanged messages
- **No link**: some works do not take into account this aspect e.g. $\mathtt{web}\pi$, $\mathtt{web}\pi_\infty$, CSP/π-calculus + transactions, ...

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- **Sessions**: the link is determined by a private channel that is implicitly created when the first message exchange of a conversation takes place
  - *dyadic*: they can be further grouped according to the inter-session communication mechanism
    - CaSPiS: dataflow communication
    - SSCC: stream-based communication
    - π-calculus + sessions (in many works): session delegation
  - *multiparty*:
    - Conversation Calculus, μse, π-calculus + (asynchronous/synchronous) multiparty sessions
- **Correlations**: the link is determined by correlation values included in the exchanged messages
  - *stateful*: every service instance has an explicit state
    - WS-CALCULUS
    - SOCK
  - *stateless*: state is not explicitly modelled
    - COWS

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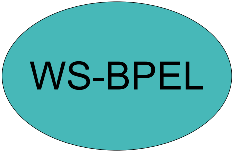
COWS [ESOP'07]

A process calculus for specifying and combining service-oriented applications, while modelling their dynamic behaviour

An introduction to COWS

COWS: a Calculus for Orchestration of Web Services



- Inspired by
  - the OASIS standard WS-BPEL for WS orchestration
  - previous work on process calculi
- Indeed, COWS intends to be a foundational model not specifically tight to Web services' current technologies
- COWS combines in an original way a number of constructs and features borrowed from well-known process calculi

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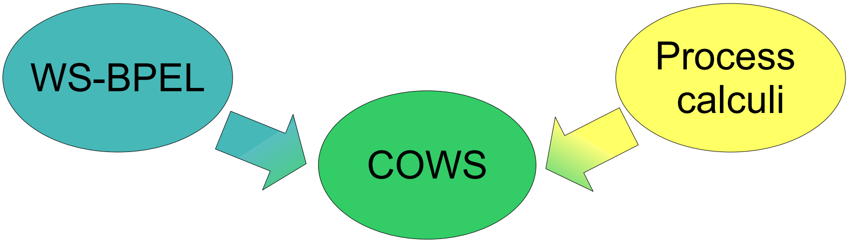

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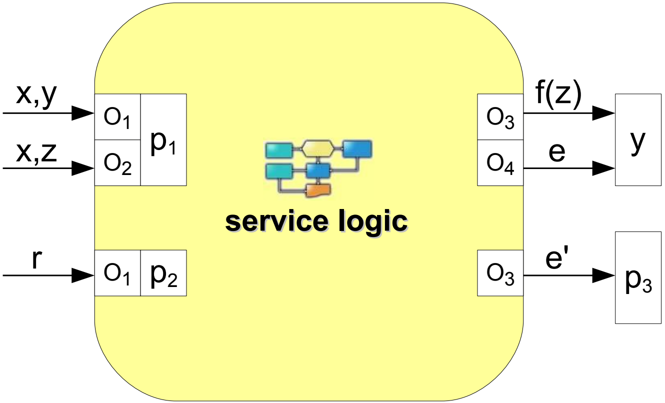
The notion of service in COWS



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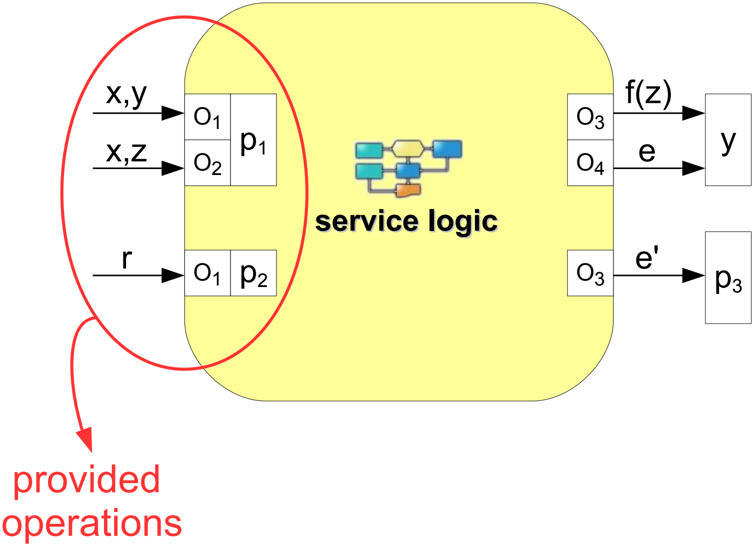

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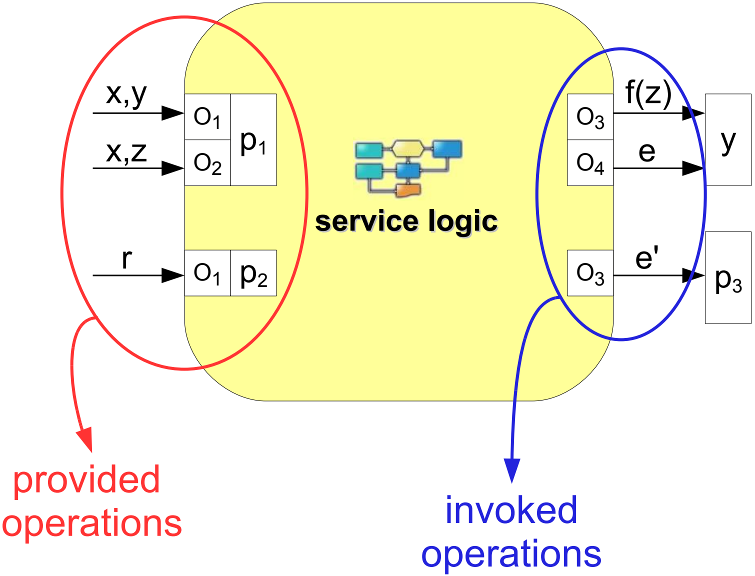

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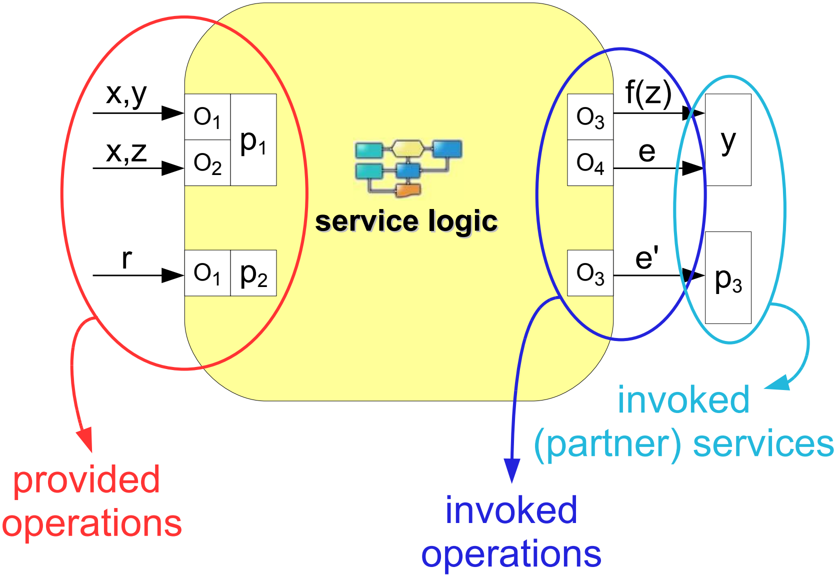

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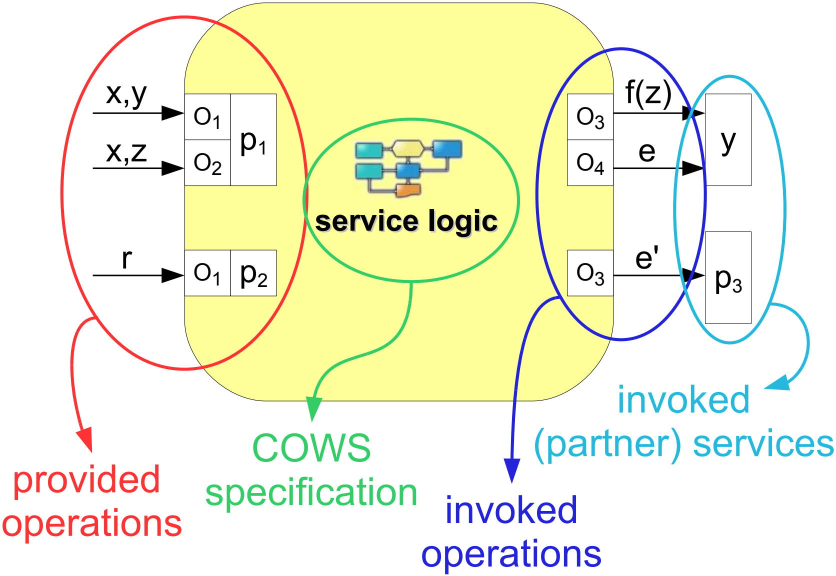

COWS in three steps

μCOWS^m (micro COWS minus priority)

Communication activities

- Invoke
- Receive

Control flow activities

- Parallel composition
- Replication
- Choice
- Delimitation

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Termination activities

- Kill activity
- Protection

COWS in three steps

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Termination activities

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Syntax of μCOWS^m

$s ::=$		(services)
	$u \bullet u' ! \bar{\epsilon}$	(invoke)
$\mid$	$\sum_{i=0}^{r} g_i . s_i$	(receive-guarded choice)
$\mid$	$s \mid s$	(parallel composition)
$\mid$	$[u]\, s$	(delimitation)
$\mid$	$* s$	(replication)
$g ::=$		(guards)
	$p \bullet o ? \bar{w}$	(receive)

(notations)
ϵ: *expressions*
x: *variables*
v: *values*
n, p, o: *names*
u: *variables* | *names*
w: *variables* | *values*

μCOWS^m vs. π-calculus, fusion, Value-passing CCS, Dπ, ...

$$\left.\begin{array}{l} \bullet \text{ asynchronous and polyadic communication} \\ \bullet \text{ input} - \text{guarded choice} \\ \bullet \text{ polyadic synchronization} \\ \bullet \text{ localised channels} \end{array}\right\} \pi\text{-calculus}$$

$$\bullet \text{ global scoping (and non} - \text{binding input)} \quad \} \text{ fusion}$$

$$\bullet \text{ distinction between variables and values} \quad \} \text{ vp CCS, App. } \pi\text{-calculus, D}\pi$$

$$\bullet \text{ pattern} - \text{matching} \quad \} \text{ Klaim}$$

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Notations

- The exact syntax of expressions is deliberately omitted
- $\bar{\ }$ denotes tuples of objects, e.g. $\bar{w}$ is a tuple of variables and/or values

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Communication activities

- Services are provided and invoked through communication *endpoints*, written as $p \bullet o$ (i.e. 'partner name' plus 'operation name')
- Receive activities bind neither names nor variables
- Communication is regulated by *pattern-matching*
- Partner names and operation names can be exchanged when communicating (only the 'send capability' is passed over)
- Communication is asynchronous

Syntax of μCOWS^m

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Choice

- $+$ abbreviates binary choice, while empty choice will be denoted by **0**

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Parallel composition

- Permits interleaving executions of activities

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Delimitation

- Only one binding construct: $[u]\, s$ binds u in the scope s
  - free/bound names and variables and closed terms defined accordingly
- Delimitation is used to:
  1. regulate the range of application of substitutions
  2. generate fresh names

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Replication

- Permits implementing persistent services and recursive behaviours

μCOWS^m operational semantics

Labelled transition relation $\xrightarrow{\alpha}$

Label α is generated by the following grammar:

$$\alpha \quad ::= \quad \mathrm{n} \lhd \bar{v} \quad | \quad \mathrm{n} \rhd \bar{w} \quad | \quad \sigma$$

where σ is a *substitution*

i.e. a function from variables to values (written as collections of pairs $x \mapsto v$)

and n denotes endpoints (i.e. $p \bullet o$)

Structural congruence $\equiv$

Standard laws for $\sum$, $|$ and $*$, plus:

- $[u]\,\mathbf{0} \;\equiv\; \mathbf{0}$
- $[u_1]\,[u_2]\,s \;\equiv\; [u_2]\,[u_1]\,s$
- $s_1 \mid [u]\,s_2 \;\equiv\; [u]\,(s_1 \mid s_2)$ if $u \notin \mathrm{fu}(s_1)$

  $\mathrm{fu}(s)$ denotes the set of elements occurring free in s

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μCOWS^m: Invoke/receive activities & Choice

Invoke activities

- Can proceed only if the expressions in the argument can be evaluated
- *Evaluation function* $[\![\_]\!]$: takes closed expressions and returns values

$$\frac{[\![\bar{\epsilon}]\!] = \bar{v}}{\mathrm{n}!\bar{\epsilon} \xrightarrow{\mathrm{n} \lhd \bar{v}} \mathbf{0}}$$

Choice (among receive activities)

- Offers an alternative choice of endpoints
- It is *not* a binder for names and variables (delimitation is used to delimit their scope)

$$\sum_{i=1}^{r} \mathrm{n}_i?\bar{w}_i.s_i \xrightarrow{\mathrm{n}_j \rhd \bar{w}_j} s_j \qquad (1 \leq j \leq r)$$

μCOWS^m: Parallel composition

- Communication takes place when two parallel services perform matching receive and invoke activities

$$\frac{s_1 \xrightarrow{\mathrm{n} \triangleright \bar{w}} s_1' \qquad s_2 \xrightarrow{\mathrm{n} \triangleleft \bar{v}} s_2' \qquad \mathcal{M}(\bar{w}, \bar{v}) = \sigma}{s_1 \mid s_2 \xrightarrow{\sigma} s_1' \mid s_2'}$$

- Execution of parallel services is interleaved

$$\frac{s_1 \xrightarrow{\alpha} s_1'}{s_1 \mid s_2 \xrightarrow{\alpha} s_1' \mid s_2}$$

Matching function

$$\mathcal{M}(x, v) = \{x \mapsto v\} \qquad \mathcal{M}(v, v) = \emptyset \qquad \mathcal{M}(\langle\rangle, \langle\rangle) = \emptyset$$

$$\frac{\mathcal{M}(w_1, v_1) = \sigma_1 \quad \mathcal{M}(\bar{w}_2, \bar{v}_2) = \sigma_2}{\mathcal{M}((w_1, \bar{w}_2), (v_1, \bar{v}_2)) = \sigma_1 \uplus \sigma_2}$$

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μCOWS^m: Delimitation

- $[u]\, s$ behaves like s, except when the transition label α contains u
- When the whole scope of a variable x is determined, and a communication involving x within that scope is taking place the delimitation is removed and the substitution for x is performed

$$\frac{s \xrightarrow{\alpha} s' \quad u \notin \mathrm{u}(\alpha)}{[u]\, s \xrightarrow{\alpha} [u]\, s'} \qquad \frac{s \xrightarrow{\sigma \uplus \{x \mapsto v\}} s'}{[x]\, s \xrightarrow{\sigma} s' \cdot \{x \mapsto v\}}$$

Substitutions (ranged over by σ):

- functions from variables to values (written as collections of pairs $x \mapsto v$)
- $\sigma_1 \uplus \sigma_2$ denotes the union of σ_1 and σ_2 when they have disjoint domains

$\mathrm{u}(\alpha)$ avoids capturing endpoints of actual communications,
it denotes the set of elements occurring in α,

μCOWS^m operational semantics

Labelled transition rules

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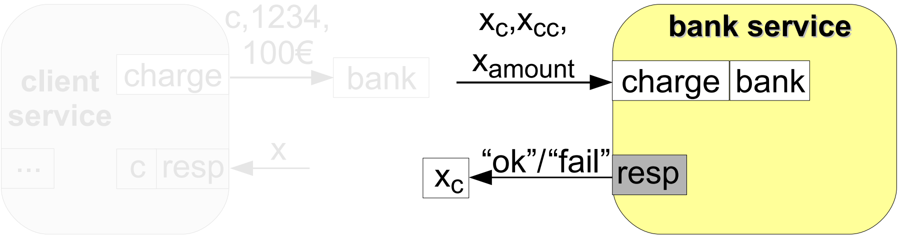
$$\frac{s \equiv \xrightarrow{\alpha} \equiv s'}{s \xrightarrow{\alpha} s'}$$

μCOWS^m: *simple* bank service example



$\mathsf{bank} \bullet \mathsf{charge}!\langle \mathsf{c}, 1234, 100€ \rangle$
$\mid [\mathsf{x}]\, (\mathsf{c} \bullet \mathsf{resp}?\langle \mathsf{x} \rangle.s \mid s')$

$[\mathsf{x_c}, \mathsf{x_{cc}}, \mathsf{x_{amount}}]$
$\mathsf{bank} \bullet \mathsf{charge}?\langle \mathsf{x_c}, \mathsf{x_{cc}}, \mathsf{x_{amount}} \rangle.$
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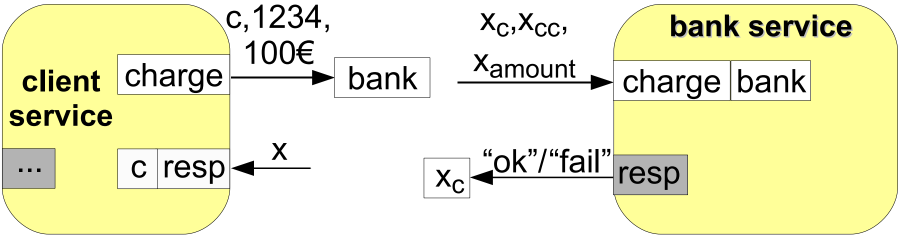

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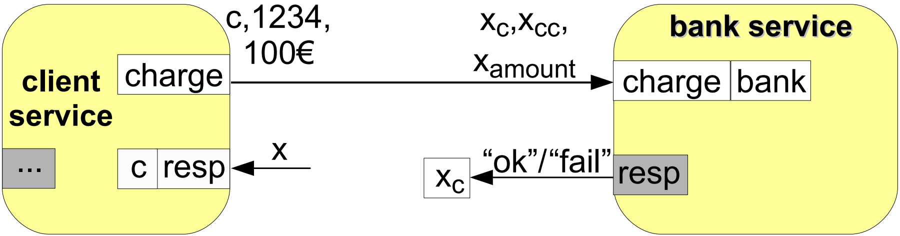
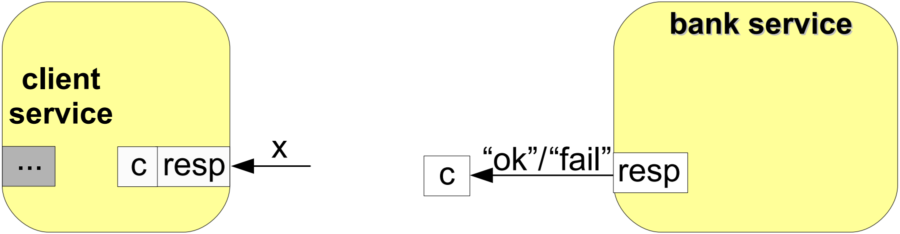
μCOWS^m: *simple* bank service example



$$\mathsf{bank} \bullet \mathsf{charge}!\langle \mathsf{c}, 1234, 100€ \rangle \mid [\mathsf{x}]\,(\mathsf{c} \bullet \mathsf{resp}?\langle \mathsf{x} \rangle.\mathsf{s} \mid \mathsf{s}') \quad \mid \quad [\mathsf{x_c}, \mathsf{x_{cc}}, \mathsf{x_{amount}}]\ \mathsf{bank} \bullet \mathsf{charge}?\langle \mathsf{x_c}, \mathsf{x_{cc}}, \mathsf{x_{amount}} \rangle.\ \mathsf{x_c} \bullet \mathsf{resp}!\langle chk(x_{cc}, x_{amount}) \rangle$$

μCOWS^m: *simple* bank service example



$$[x]\,(c \bullet resp?\langle x\rangle.s \mid s') \qquad\qquad \mid \qquad\qquad c \bullet resp!\langle \mathit{chk}(1234, 100€)\rangle$$

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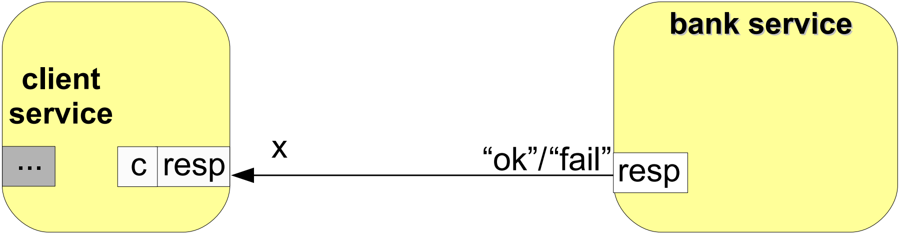
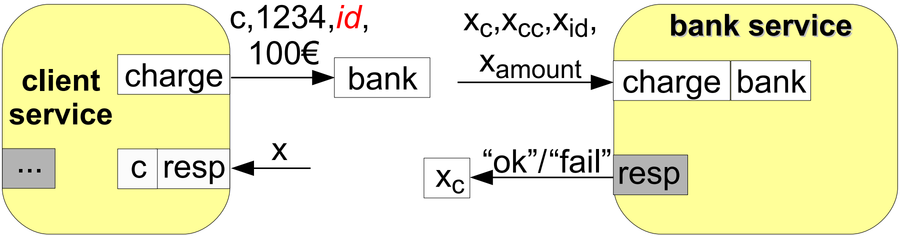


$$[x]\,(c \bullet \mathrm{resp}?\langle x\rangle.s \mid s') \quad \mid \quad c \bullet \mathrm{resp}!\langle \mathit{chk}(1234, 100€)\rangle$$

μCOWS^m: *simple* bank service example

$$(s \mid s') \cdot \{x \mapsto \text{“ok”} / \text{“fail”}\} \qquad \mid \qquad \mathbf{0}$$

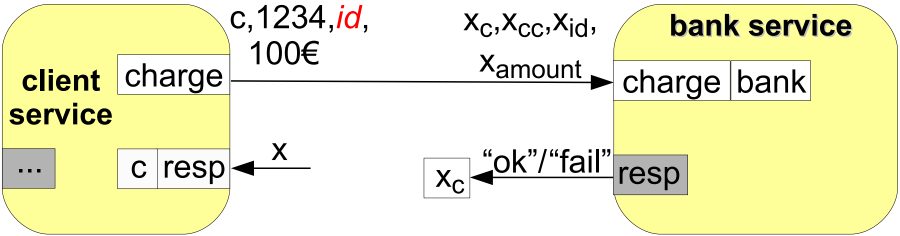
μCOWS^m: communication of private names



$[id]$
$(bank \bullet charge!\langle c, 1234, id, 100€\rangle$
$\mid [x]\,(c \bullet resp?\langle x\rangle.s \mid s')\,)$

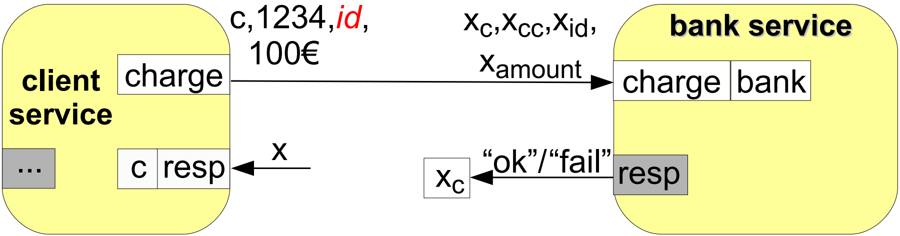
$[x_c, x_{cc}, x_{id}, x_{amount}]$
$bank \bullet charge?\langle x_c, x_{cc}, x_{id}, x_{amount}\rangle.$
$x_c \bullet resp!\langle chk(x_{cc}, x_{id}, x_{amount})\rangle$

μCOWS^m: communication of private names



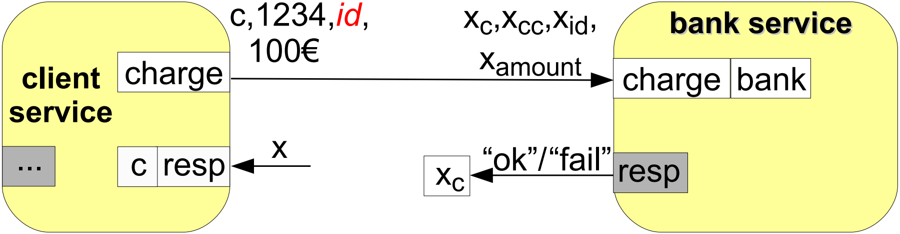
$$[id]\,(bank \bullet charge!\langle c, 1234, id, 100€\rangle \;\; | \;\; [x]\,(c \bullet resp?\langle x\rangle.s \;|\; s')\,) \quad | \quad [x_c, x_{cc}, x_{id}, x_{amount}]\; bank \bullet charge?\langle x_c, x_{cc}, x_{id}, x_{amount}\rangle.\; x_c \bullet resp!\langle \mathit{chk}(x_{cc}, x_{id}, x_{amount})\rangle$$

μCOWS^m: communication of private names



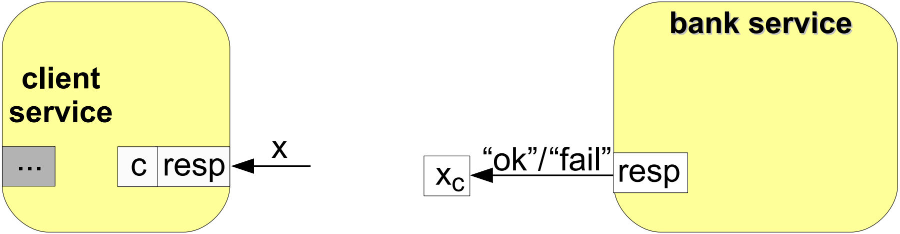
$\equiv$

μCOWS^m: communication of private names



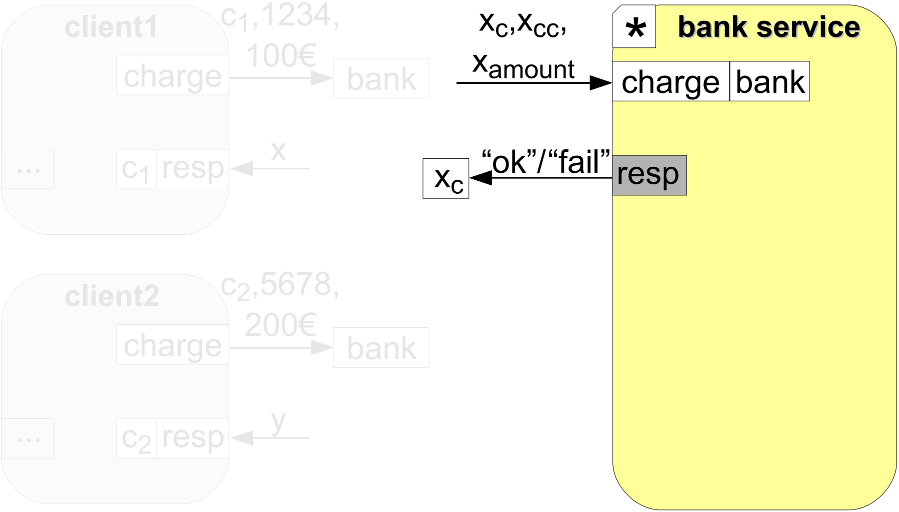
$$[\mathrm{id}, \mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{id}}, \mathrm{x_{amount}}]\left(\begin{pmatrix}\mathrm{bank} \bullet \mathrm{charge}!\langle \mathrm{c}, 1234, \mathrm{id}, 100€\rangle \\ \mid [\mathrm{x}]\,(\mathrm{c} \bullet \mathrm{resp}?\langle \mathrm{x}\rangle.\mathrm{s} \mid \mathrm{s}')\end{pmatrix} \mid \begin{pmatrix}\mathrm{bank} \bullet \mathrm{charge}?\langle \mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{id}}, \mathrm{x_{amount}}\rangle. \\ \mathrm{x_c} \bullet \mathrm{resp}!\langle \mathit{chk}(x_{cc}, x_{id}, x_{amount})\rangle\end{pmatrix}\right)$$

μCOWS^m: communication of private names



$$[\mathrm{id}]$$
$$(\quad [x]\,(c \bullet resp?\langle x\rangle.s \mid s') \quad\mid\quad c \bullet resp!\langle \mathit{chk}(1234, \mathrm{id}, 100€)\rangle \quad)$$

μCOWS^m: *persistent* bank service example



$$* \, [x_c, x_{cc}, x_{amount}] \, \mathrm{bank} \bullet \mathrm{charge}?\langle x_c, x_{cc}, x_{amount}\rangle . x_c \bullet \mathrm{resp}!\langle \mathit{chk}(x_{cc}, x_{amount})\rangle$$

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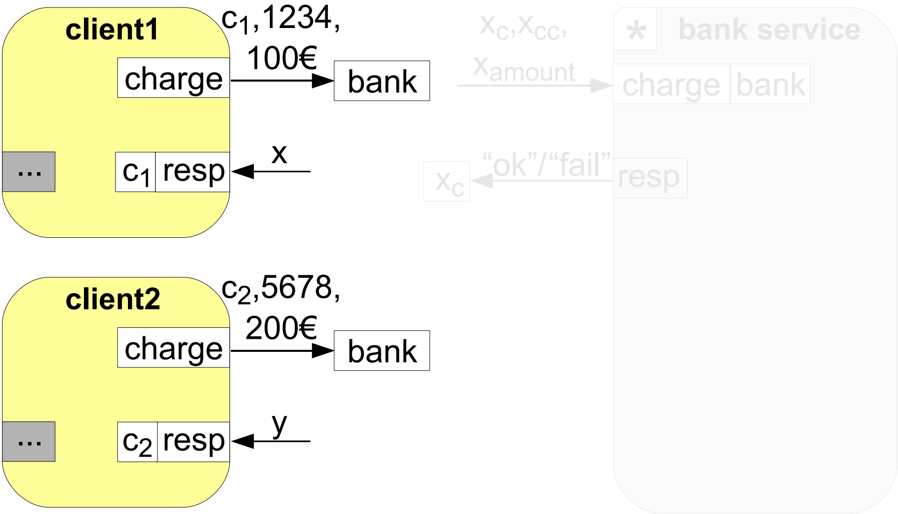
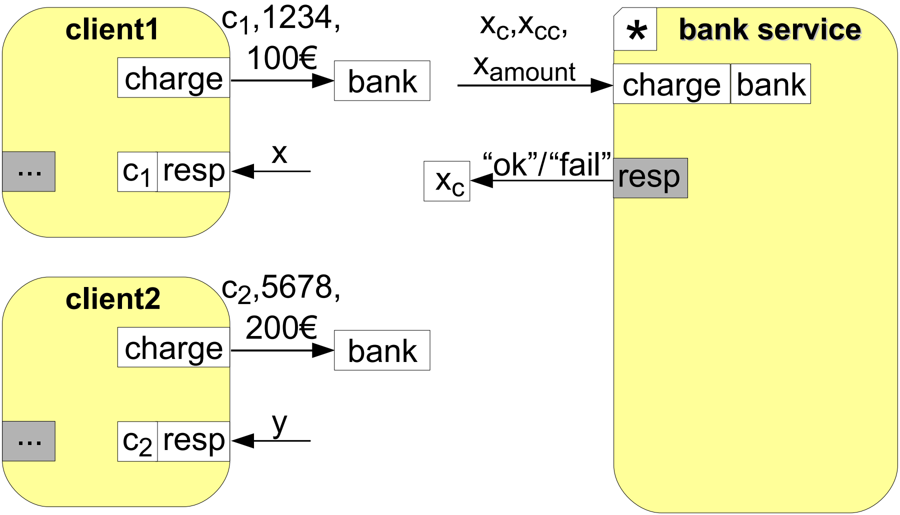


$$\begin{array}{l} \mathsf{bank} \bullet \mathsf{charge}!\langle c_1, 1234, 100€\rangle \mid [x]\, c_1 \bullet \mathsf{resp}?\langle x\rangle.s_1 \\ \mid\ \mathsf{bank} \bullet \mathsf{charge}!\langle c_2, 5678, 200€\rangle \mid [y]\, c_2 \bullet \mathsf{resp}?\langle y\rangle.s_2 \end{array}$$

μCOWS^m: *persistent* bank service example



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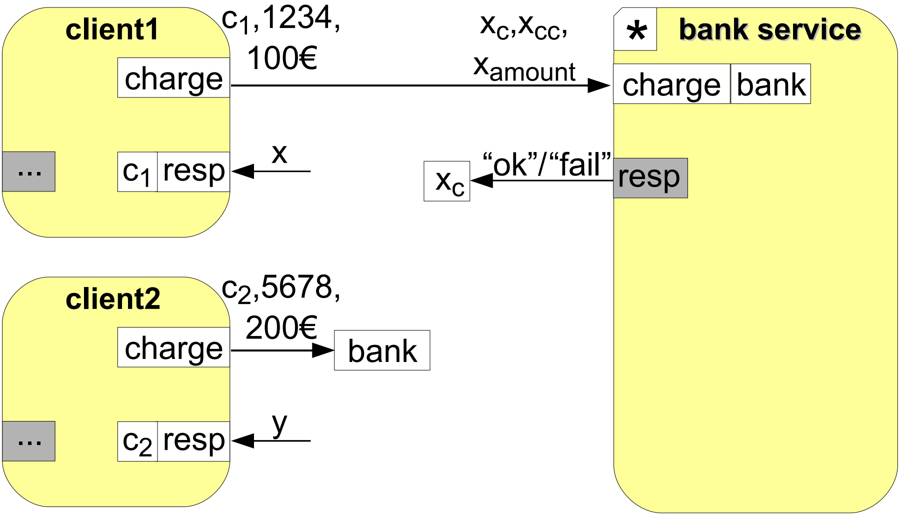

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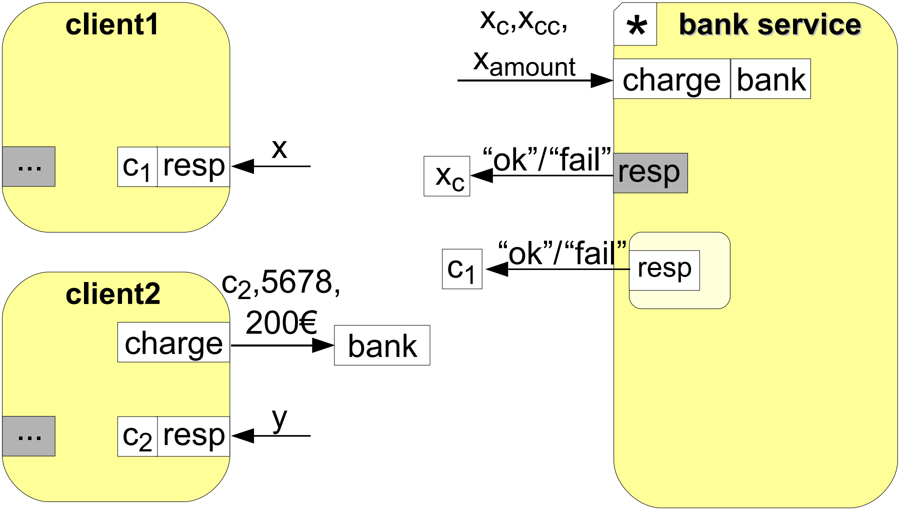

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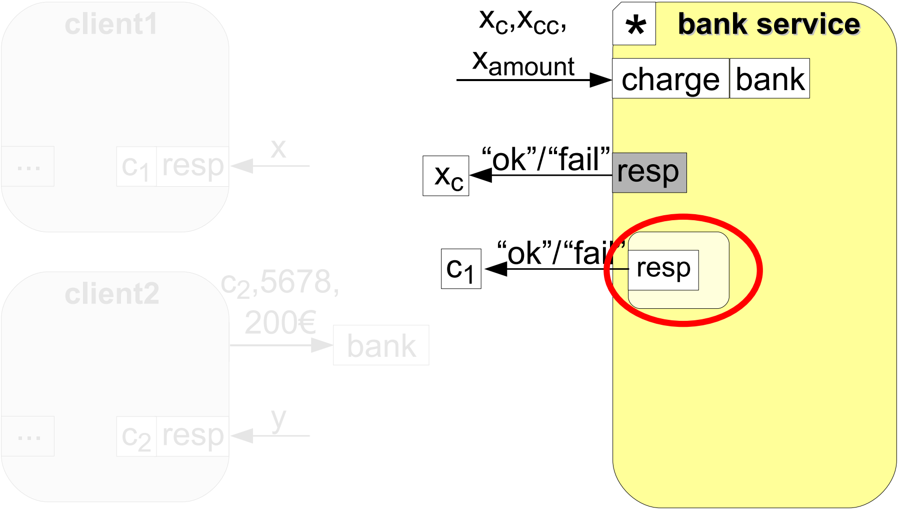

$* \, [x_c, x_{cc}, x_{amount}] \, \mathrm{bank} \bullet \mathrm{charge}?\langle x_c, x_{cc}, x_{amount}\rangle.x_c \bullet \mathrm{resp}!\langle \mathit{chk}(x_{cc}, x_{amount})\rangle$

$\mid \; c_1 \bullet \mathrm{resp}!\langle \mathit{chk}(1234, 100€)\rangle$

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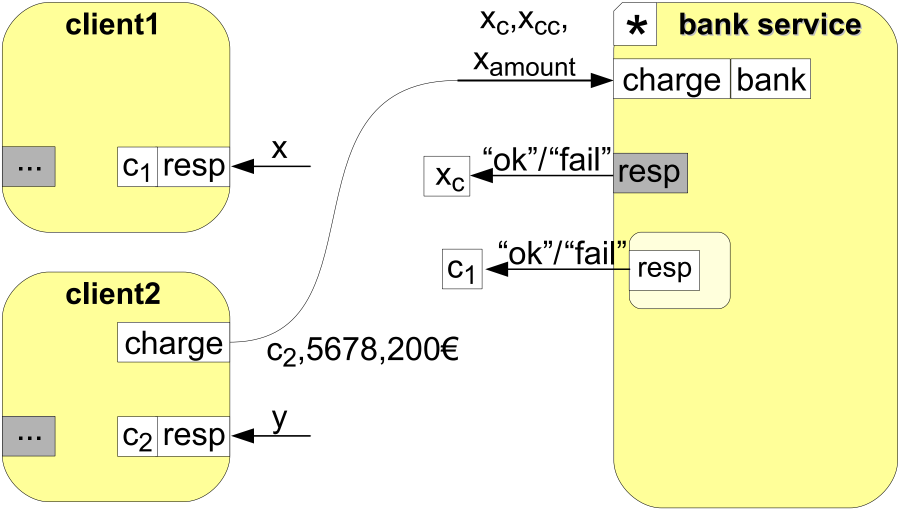

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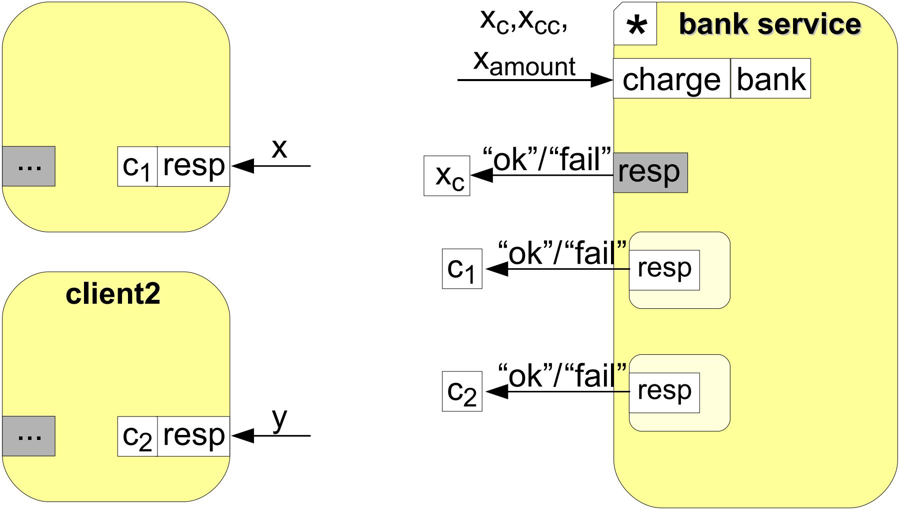

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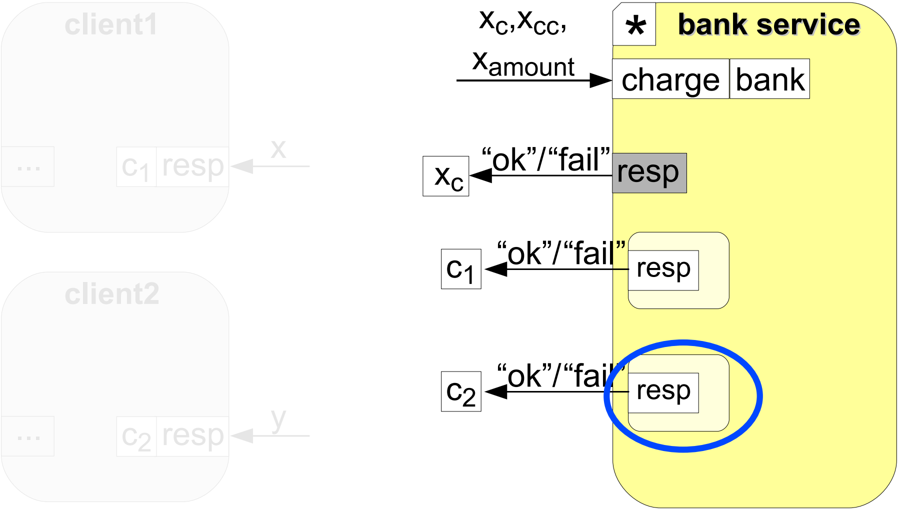
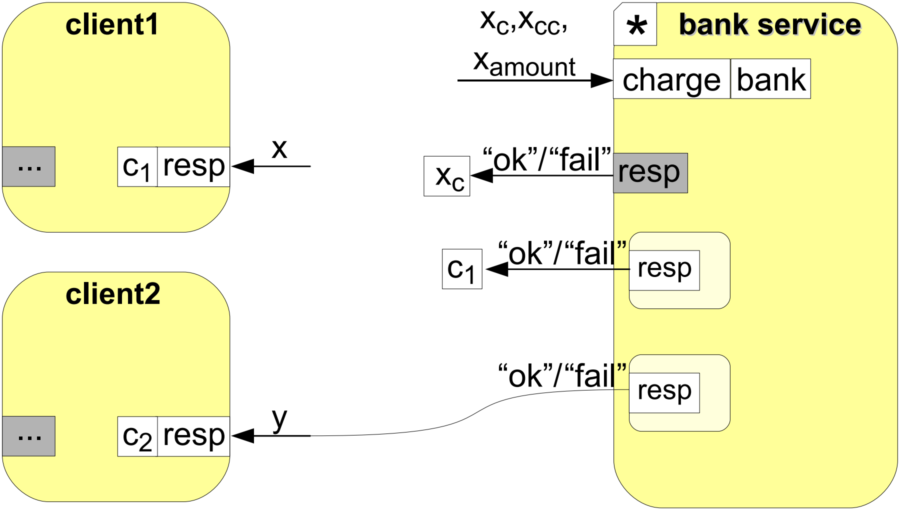


$* \, [\mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}}] \, \mathrm{bank} \bullet \mathrm{charge}?\langle \mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}} \rangle.\mathrm{x_c} \bullet \mathrm{resp}!\langle chk(x_{cc}, x_{amount}) \rangle$

$| \;\; \mathrm{c_1} \bullet \mathrm{resp}!\langle chk(1234, 100€) \rangle \; | \;\; \mathrm{c_2} \bullet \mathrm{resp}!\langle chk(5678, 200€) \rangle$

μCOWS^m: *persistent* bank service example



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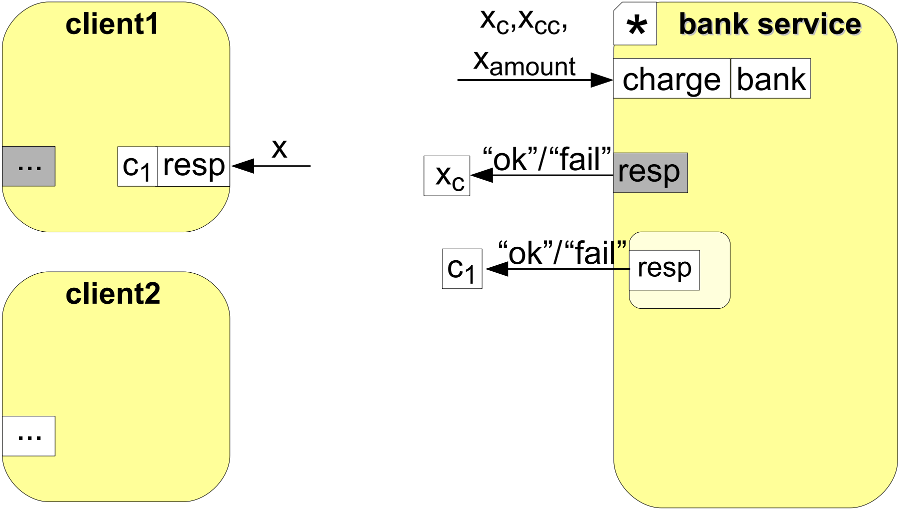

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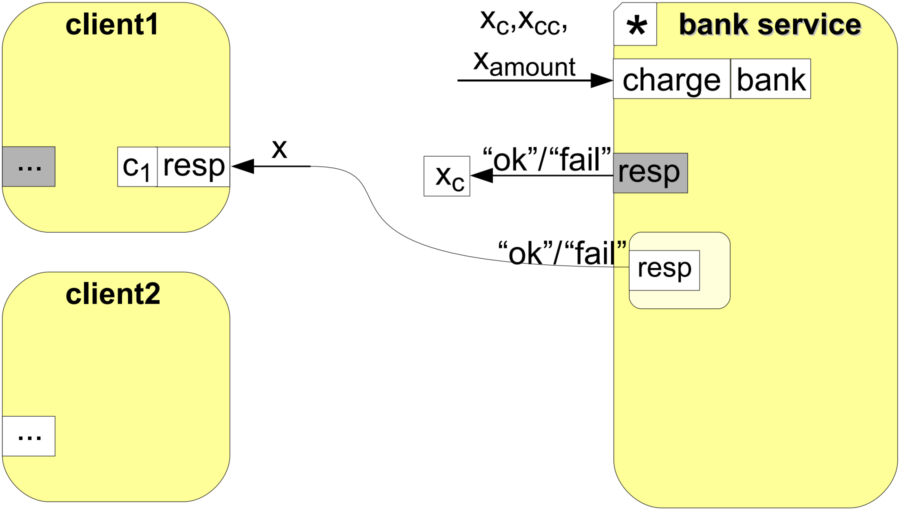

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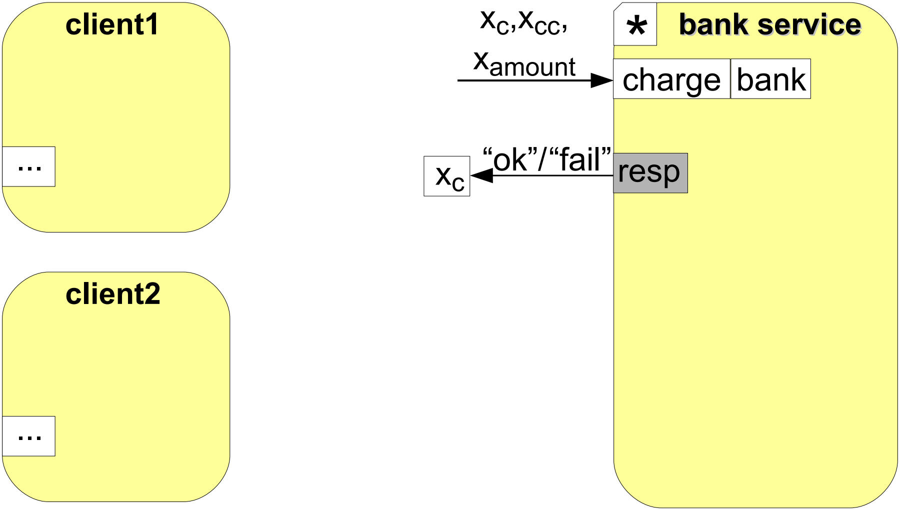
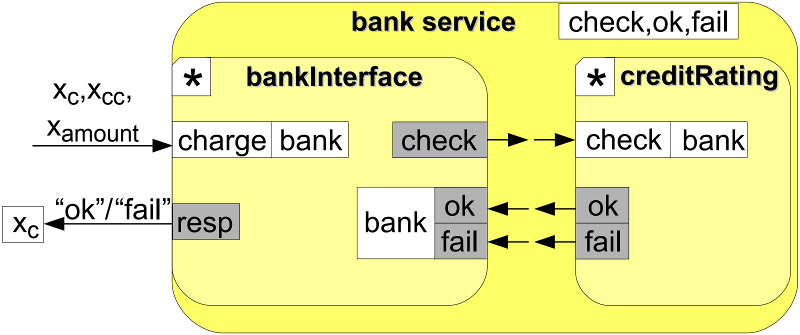
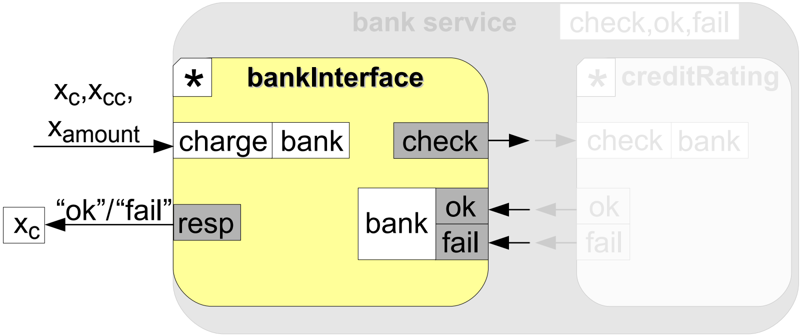


μCOWS^m: *compound* bank service example



$$[check, ok, fail] \,(\, *\, \text{bankInterface} \mid *\, \text{creditRating}\,)$$

μCOWS^m: *compound* bank service example



$$[\text{check}, \text{ok}, \text{fail}]\,(\,*\,\text{bankInterface} \mid *\,\text{creditRating}\,)$$

$$\begin{array}{lll}
\text{bankInterface} & \triangleq & [x_c, x_{cc}, x_{amount}] \\
& & \text{bank} \bullet \text{charge}?\langle x_c, x_{cc}, x_{amount}\rangle. \\
& & (\,\text{bank} \bullet \text{check}!\langle x_{cc}, x_{amount}\rangle \\
& & \;\mid \text{bank} \bullet \text{ok}?\langle x_{cc}\rangle.\, x_c \bullet \text{resp}!\langle \text{"ok"} \rangle \\
& & \quad + \text{bank} \bullet \text{fail}?\langle x_{cc}\rangle.\, x_c \bullet \text{resp}!\langle \text{"fail"} \rangle\,)
\end{array}$$

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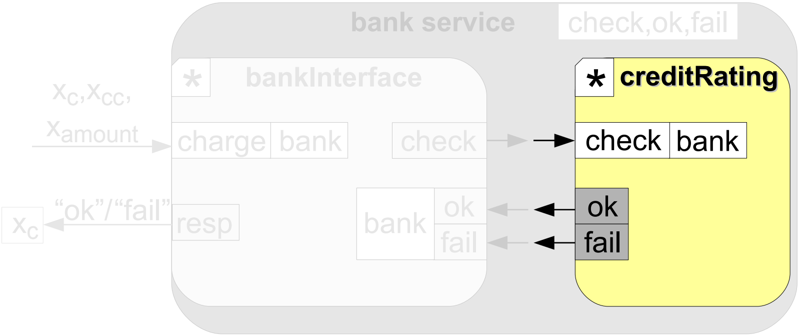

$$[\mathrm{check}, \mathrm{ok}, \mathrm{fail}]\,(\,*\,\mathrm{bankInterface} \mid *\,\mathrm{creditRating}\,)$$

$$\begin{aligned}\mathrm{creditRating} \quad \triangleq \quad & [x_{cc}, x_a] \\ & \mathrm{bank} \bullet \mathrm{check}?\langle x_{cc}, x_a\rangle. \\ & [p, o]\,(\,p \bullet o!\langle\rangle \mid p \bullet o?\langle\rangle.\,\mathrm{bank} \bullet \mathrm{ok}!\langle x_{cc}\rangle \\ & \qquad\qquad\qquad\quad + p \bullet o?\langle\rangle.\,\mathrm{bank} \bullet \mathrm{fail}!\langle x_{cc}\rangle\,)\end{aligned}$$

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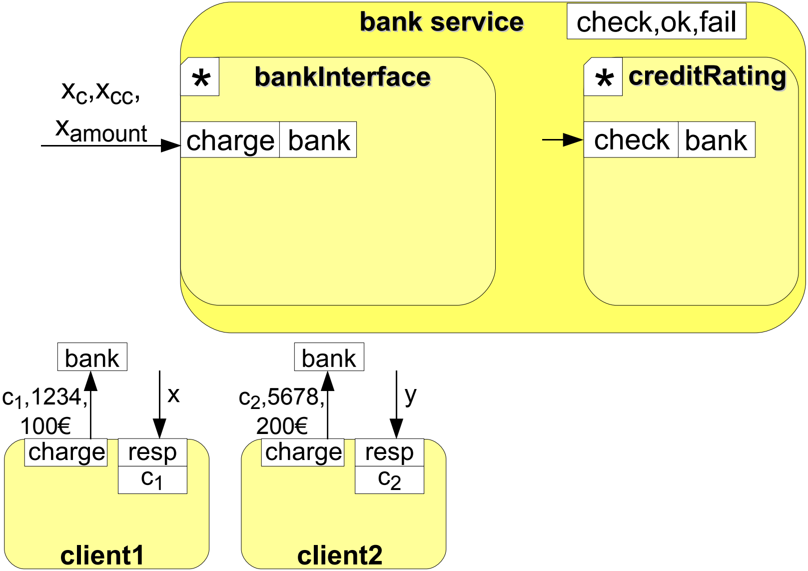

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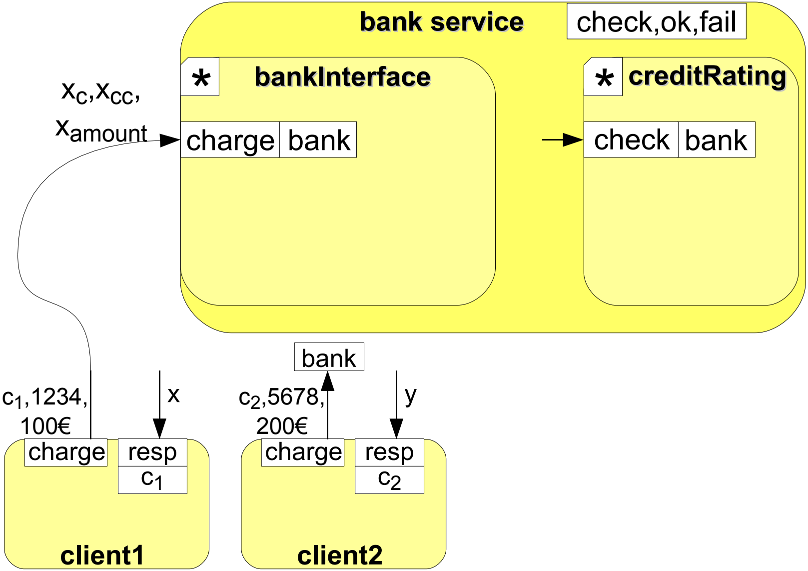

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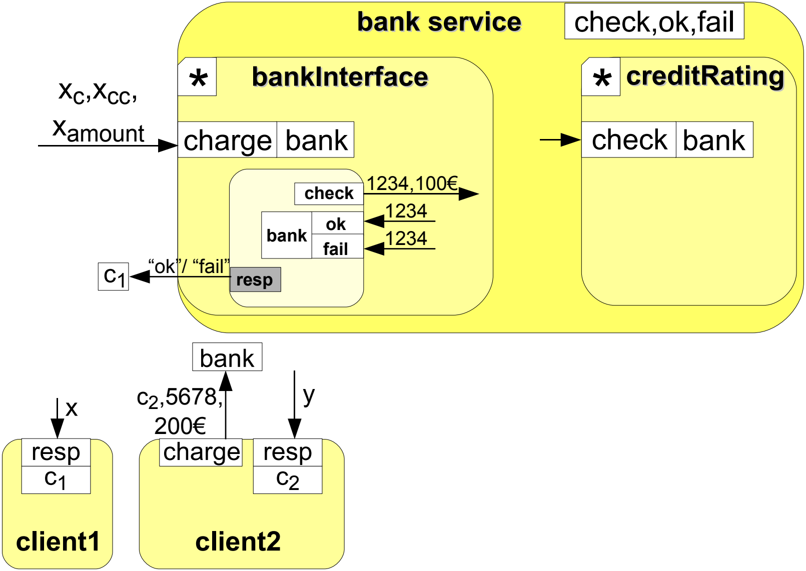

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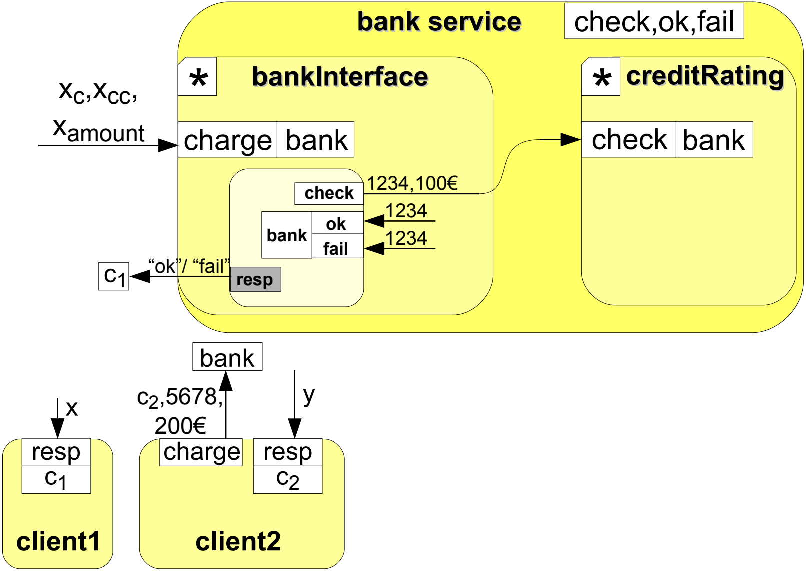

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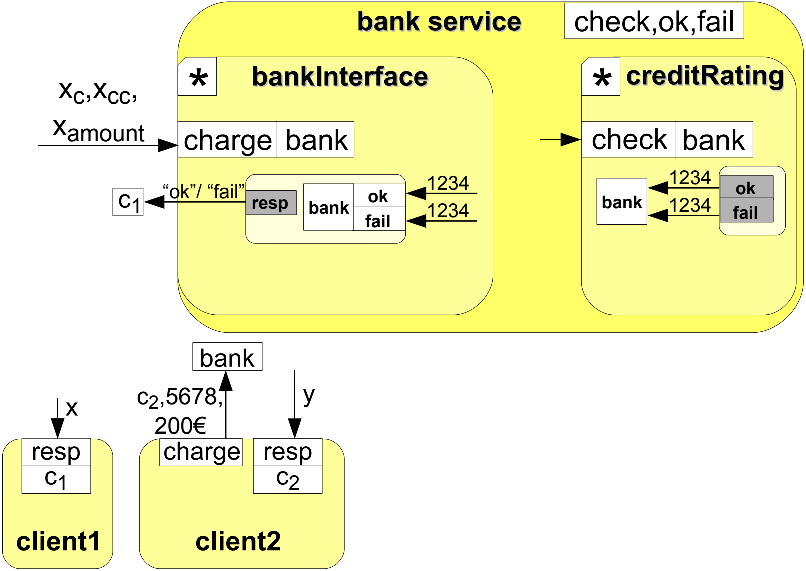

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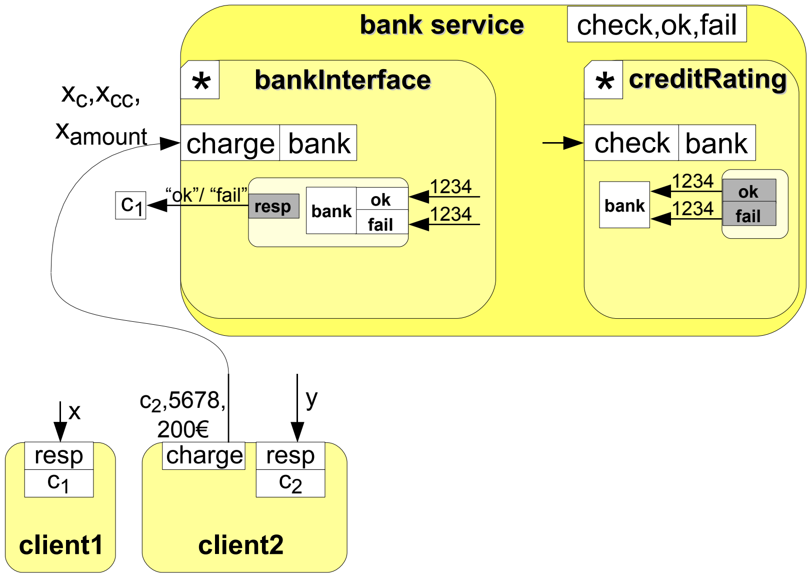

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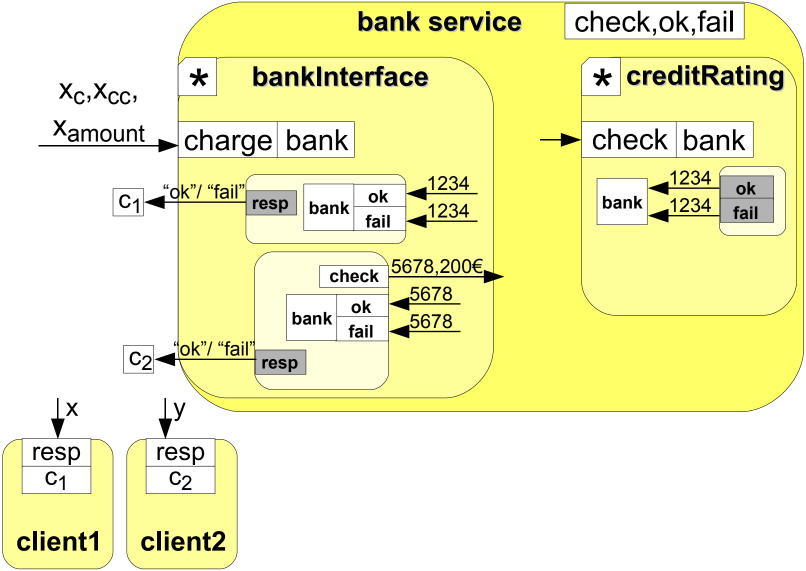

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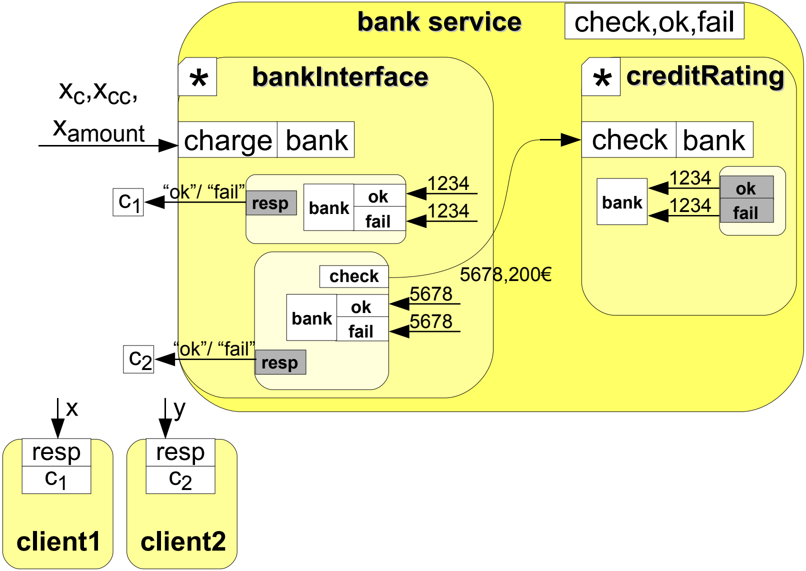

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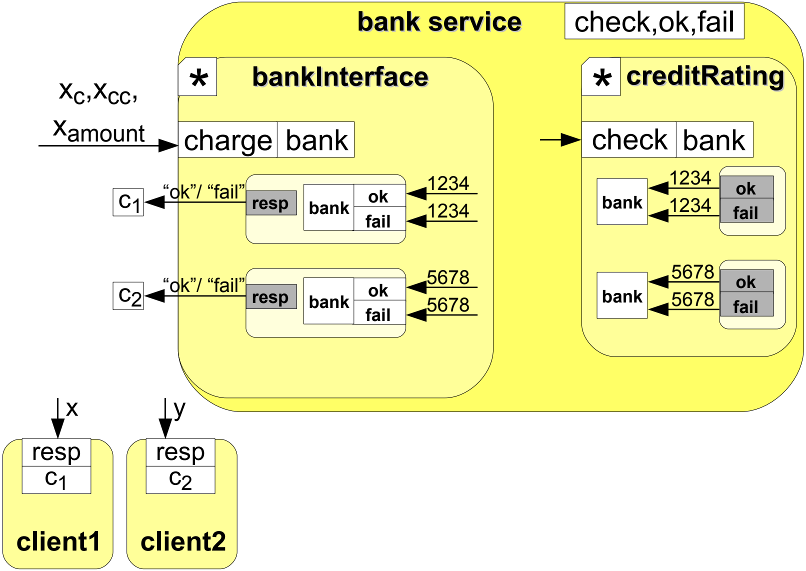

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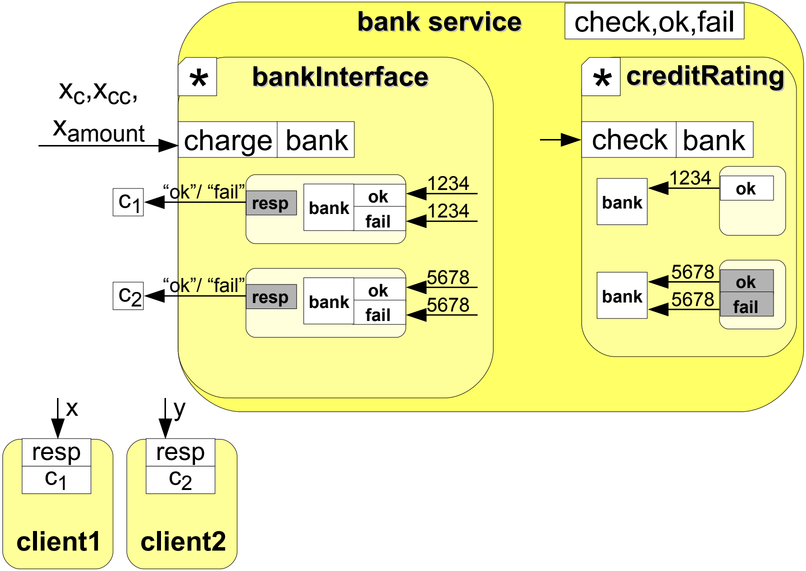

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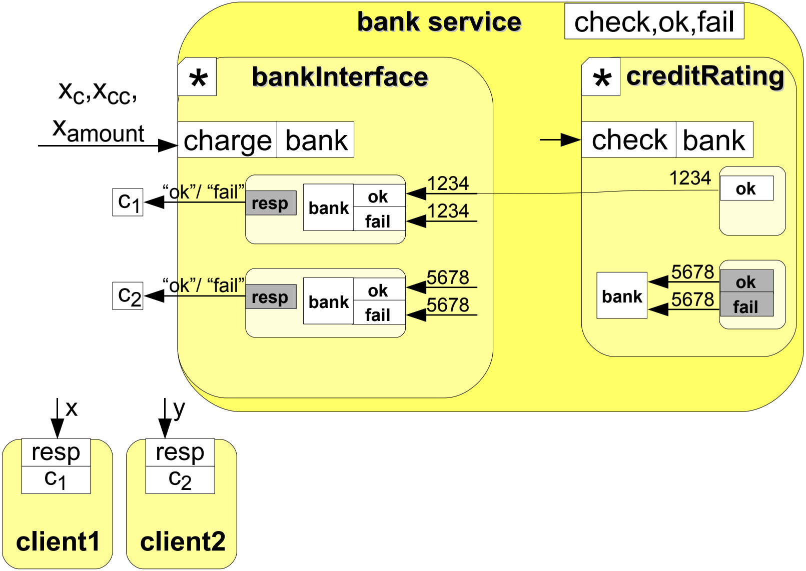

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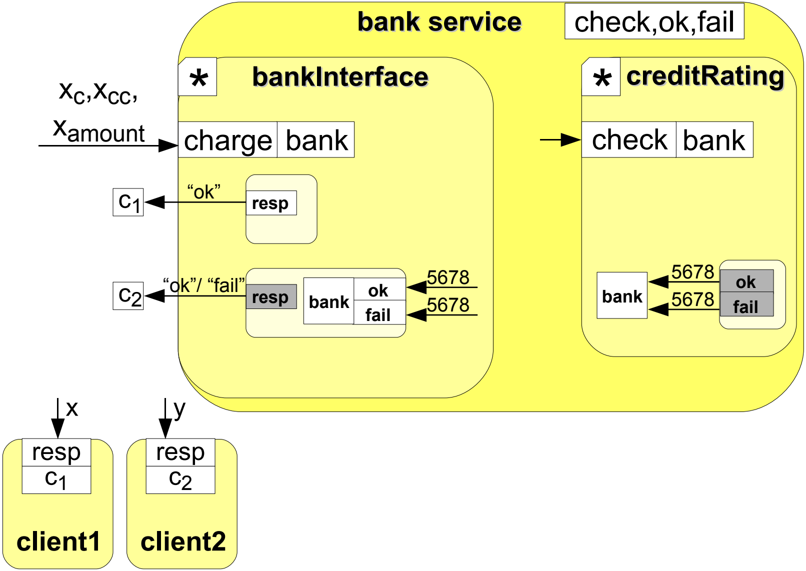

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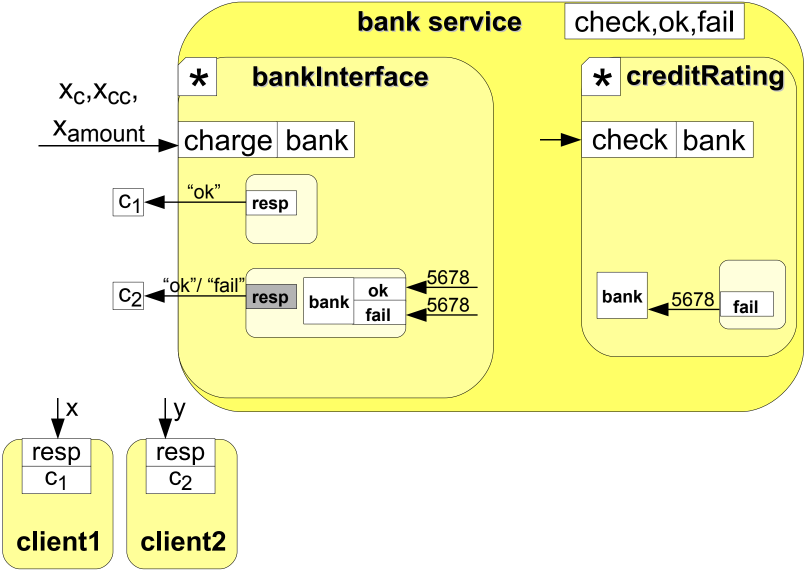

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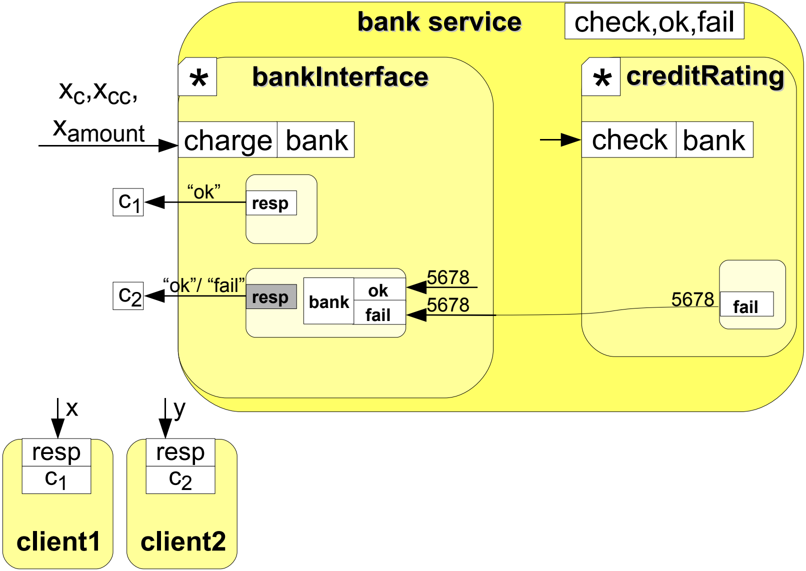

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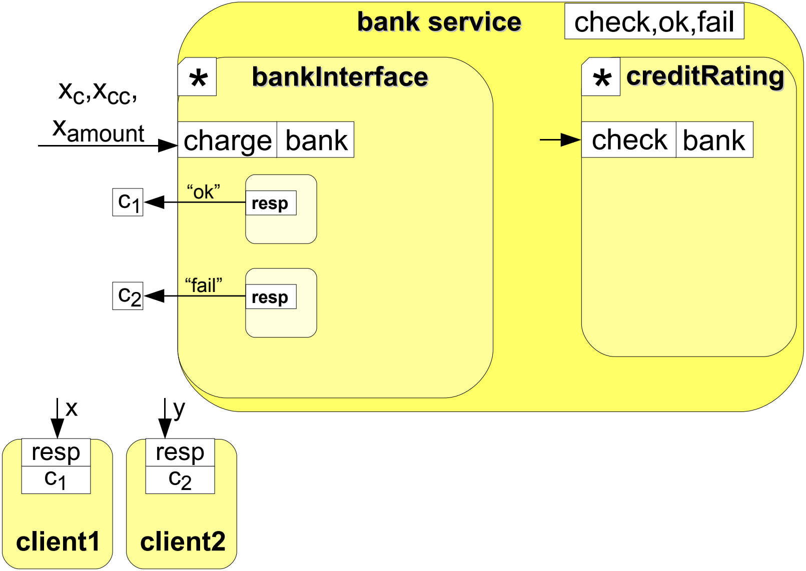

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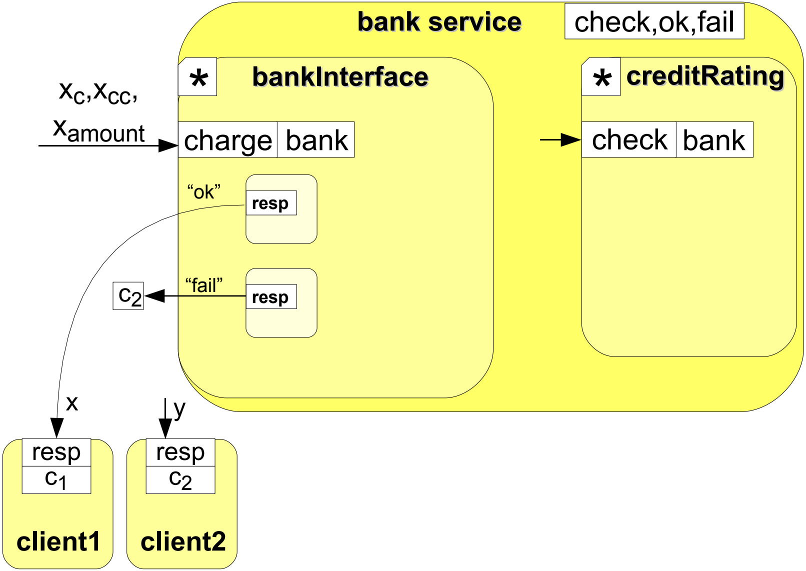

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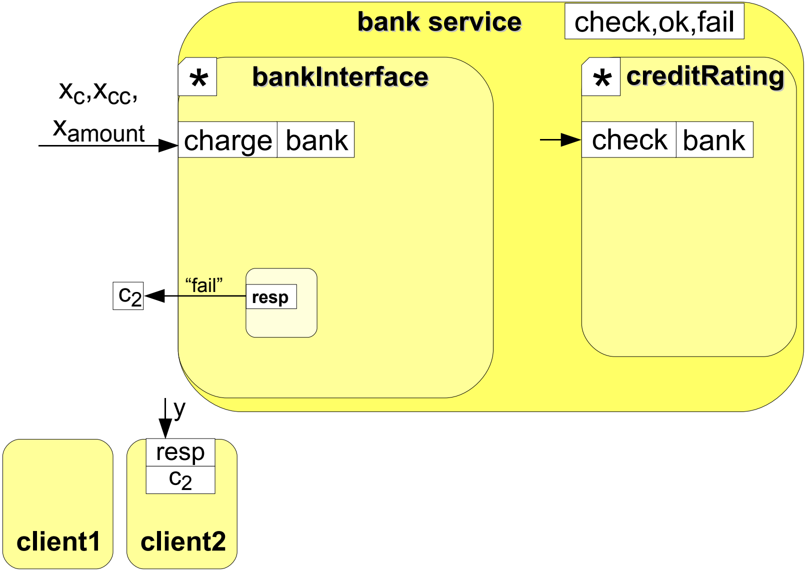

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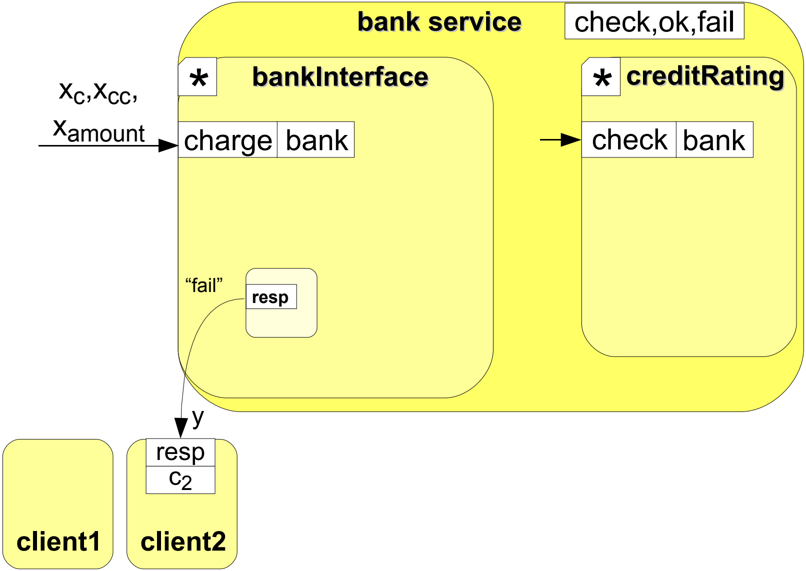

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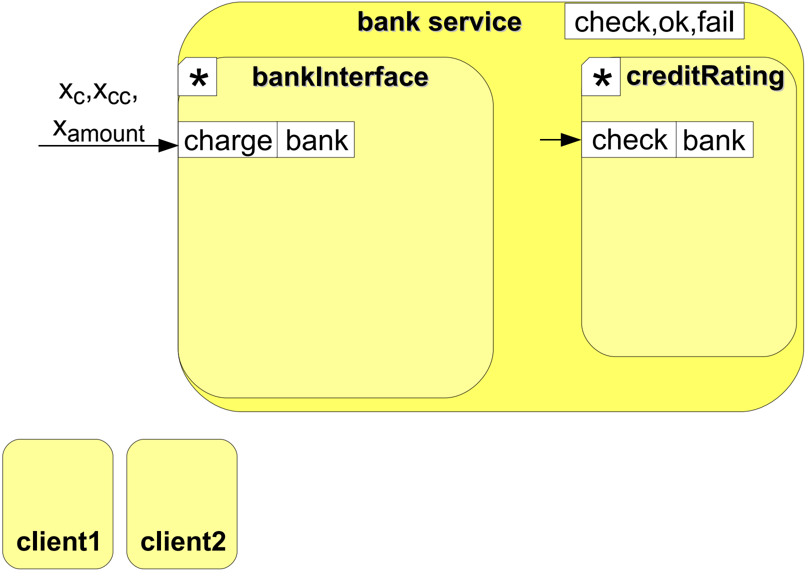

From μCOWS^m to μCOWS

μCOWS^m

From μCOWS^m to μCOWS

μCOWS^m

+

Priority in the parallel composition

From μCOWS^m to μCOWS

μCOWS^m

$+$

Priority in the parallel composition

$=$

μCOWS

μCOWS: why priority in the parallel composition?

1. To deal with *conflicting receives*
   - e.g. in case of multiple start activities
2. Parallel composition with priority can be used (together with pattern-matching) as a *coordination mechanism*
   - e.g. to model default behaviours, transparent session joining, ...

We use a novel combination of *dynamic* priority with *local* pre-emption

dynamic priority: priority values of activities can change as systems evolve

local pre-emption: priorities have a local scope, i.e. prioritised activities can only pre-empt activities in the same scope

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μCOWS

Syntax & structural congruence

μCOWS syntax and the set of laws defining its structural congruence coincide with that of μCOWS^m

Labelled transition relation $\xrightarrow{\alpha}$

Label α is now generated by the following grammar:

$$\alpha \quad ::= \quad \mathrm{n} \lhd \bar{v} \quad | \quad \mathrm{n} \rhd \bar{w} \quad | \quad \mathrm{n}\, \sigma\, \ell\, \bar{v}$$

where ℓ is a natural number

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where ℓ is a natural number

μCOWS: Parallel composition with priority

- Communication takes place when two parallel services perform matching receive and invoke activities
- If more then one matching is possible the receive that needs fewer substitutions is selected to progress

$$\frac{s_1 \xrightarrow{\mathrm{n} \triangleright \bar{w}} s_1' \qquad s_2 \xrightarrow{\mathrm{n} \triangleleft \bar{v}} s_2' \qquad \mathcal{M}(\bar{w}, \bar{v}) = \sigma \qquad \mathrm{noConf}(s_1 \mid s_2, \mathrm{n}, \bar{v}, |\sigma|)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\ \sigma\ |\sigma|\ \bar{v}} s_1' \mid s_2'}$$

Conflicting receives predicate

$\mathrm{noConf}(s, \mathrm{n}, \bar{v}, \ell)$ checks existence of potential communication conflicts, i.e. the ability of s of performing a receive activity matching $\bar{v}$ over the endpoint n that generates a substitution with fewer pairs than ℓ

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$$\frac{s_1 \xrightarrow{\mathrm{n} \triangleright \bar{w}} s_1' \qquad s_2 \xrightarrow{\mathrm{n} \triangleleft \bar{v}} s_2' \qquad \mathcal{M}(\bar{w}, \bar{v}) = \sigma \qquad \mathrm{noConf}(s_1 \mid s_2, \mathrm{n}, \bar{v}, |\sigma|)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\ \sigma\ |\sigma|\ \bar{v}} s_1' \mid s_2'}$$

Conflicting receives predicate

$\mathrm{noConf}(s, \mathrm{n}, \bar{v}, \ell)$ checks existence of potential communication conflicts, i.e. the ability of s of performing a receive activity matching $\bar{v}$ over the endpoint n that generates a substitution with fewer pairs than ℓ

μCOWS: Parallel composition with priority

- Communication takes place when two parallel services perform matching receive and invoke activities
- If more then one matching is possible the receive that needs fewer substitutions is selected to progress

$$\frac{s_1 \xrightarrow{\mathrm{n} \rhd \bar{w}} s_1' \qquad s_2 \xrightarrow{\mathrm{n} \lhd \bar{v}} s_2' \qquad \mathcal{M}(\bar{w}, \bar{v}) = \sigma \qquad \mathrm{noConf}(s_1 \mid s_2, \mathrm{n}, \bar{v}, |\sigma|)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\,\sigma\,|\sigma|\,\bar{v}} s_1' \mid s_2'}$$

Conflicting receives predicate (inductive definition, part 1/2)

$$\mathrm{noConf}(\mathbf{kill}(k), \mathrm{n}, \bar{v}, \ell) = \mathrm{noConf}(\mathrm{u}!\bar{\epsilon}, \mathrm{n}, \bar{v}, \ell) = \textbf{true}$$

$$\mathrm{noConf}(\textstyle\sum_{i=1}^{r} \mathrm{n}_i?\bar{w}_i.s_i, \mathrm{n}, \bar{v}, \ell) = \begin{cases} \textbf{false} & \text{if } \exists\, i \,.\, \mathrm{n}_i = \mathrm{n} \wedge |\mathcal{M}(\bar{w}_i, \bar{v})| < \ell \\ \textbf{true} & \text{otherwise} \end{cases}$$

μCOWS: Parallel composition with priority

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$$\frac{s_1 \xrightarrow{\mathrm{n} \rhd \bar{w}} s_1' \qquad s_2 \xrightarrow{\mathrm{n} \lhd \bar{v}} s_2' \qquad \mathcal{M}(\bar{w}, \bar{v}) = \sigma \qquad \mathrm{noConf}(s_1 \mid s_2, \mathrm{n}, \bar{v}, |\sigma|)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\,\sigma\,|\sigma|\,\bar{v}} s_1' \mid s_2'}$$

Conflicting receives predicate (inductive definition, part 2/2)

$$\mathrm{noConf}(s \mid s', \mathrm{n}, \bar{v}, \ell) = \mathrm{noConf}(s, \mathrm{n}, \bar{v}, \ell) \wedge \mathrm{noConf}(s', \mathrm{n}, \bar{v}, \ell)$$

$$\mathrm{noConf}([u]\, s, \mathrm{n}, \bar{v}, \ell) = \begin{cases} \mathrm{noConf}(s, \mathrm{n}, \bar{v}, \ell) & \text{if } u \notin \mathrm{n} \\ \textbf{true} & \text{otherwise} \end{cases}$$

$$\mathrm{noConf}(\{|s|\}, \mathrm{n}, \bar{v}, \ell) = \mathrm{noConf}(*\, s, \mathrm{n}, \bar{v}, \ell) = \mathrm{noConf}(s, \mathrm{n}, \bar{v}, \ell)$$

μCOWS: Parallel composition with priority

- Execution of parallel services is interleaved, when no communication is involved:

$$\frac{s_1 \xrightarrow{\alpha} s_1' \qquad \alpha \neq \mathrm{n}\,\sigma\,\ell\,\bar{v}}{s_1 \mid s_2 \xrightarrow{\alpha} s_1' \mid s_2}$$

- In case of communications, the receive activity with greater priority progresses:

$$\frac{s_1 \xrightarrow{\mathrm{n}\,\sigma\,\ell\,\bar{v}} s_1' \qquad \mathrm{noConf}(s_2, \mathrm{n}, \bar{v}, \ell)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\,\sigma\,\ell\,\bar{v}} s_1' \mid s_2}$$

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μCOWS: Delimitation

- Rules for delimitation are tailored to deal with labels $\mathrm{n}\,\sigma\,\ell\,\bar{v}$

$$\frac{s \xrightarrow{\mathrm{n}\ \sigma \uplus \{x \mapsto v\}\ \ell\ \bar{v}} s'}{[x]\, s \xrightarrow{\mathrm{n}\ \sigma\ \ell\ \bar{v}} s' \cdot \{x \mapsto v\}} \qquad \frac{s \xrightarrow{\alpha} s' \quad u \notin \mathrm{u}(\alpha)}{[u]\, s \xrightarrow{\alpha} [u]\, s'}$$

where

- $\mathrm{u}(\alpha)$ is extended with $\mathrm{u}(\mathrm{n}\,\sigma\,\ell\,\bar{v}) = \mathrm{u}(\sigma)$

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  where

  - $\mathrm{u}(\alpha)$ is extended with $\mathrm{u}(\mathrm{n}\,\sigma\,\ell\,\bar{v}) = \mathrm{u}(\sigma)$

μCOWS operational semantics

Labelled transition rules

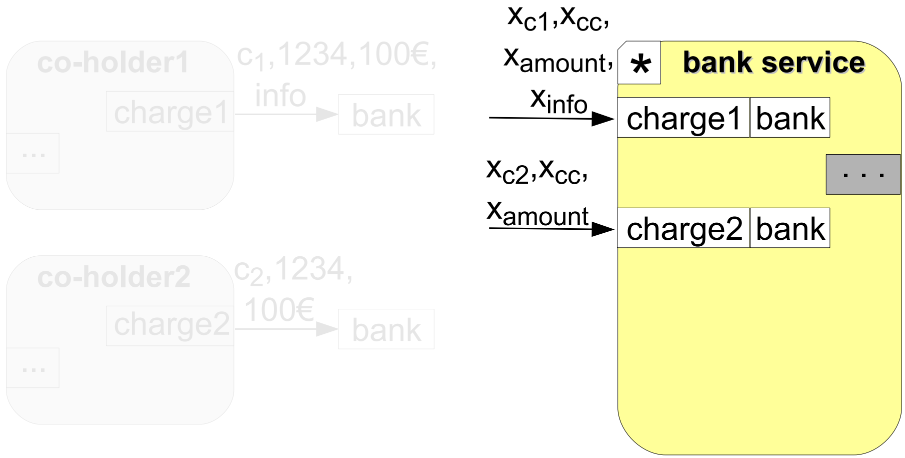
$$\frac{[\![\bar{\epsilon}]\!] = \bar{v}}{\mathrm{n}!\bar{\epsilon} \xrightarrow{\mathrm{n} \lhd \bar{v}} \mathbf{0}} \qquad \frac{1 \leq j \leq r}{\sum_{i=1}^{r} \mathrm{n}_i?\bar{w}_i.s_i \xrightarrow{\mathrm{n}_j \rhd \bar{w}_j} s_j} \qquad \frac{s \xrightarrow{\alpha} s' \quad u \notin \mathrm{u}(\alpha)}{[u]\, s \xrightarrow{\alpha} [u]\, s'} \qquad \frac{s \equiv \xrightarrow{\alpha} \equiv s'}{s \xrightarrow{\alpha} s'}$$

$$\frac{s_1 \xrightarrow{\mathrm{n} \rhd \bar{w}} s_1' \quad s_2 \xrightarrow{\mathrm{n} \lhd \bar{v}} s_2' \quad \mathcal{M}(\bar{w}, \bar{v}) = \sigma \quad \mathrm{noConf}(s_1 \mid s_2, \mathrm{n}, \bar{v}, |\sigma|)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\, \sigma\, |\sigma|\, \bar{v}} s_1' \mid s_2'}$$

$$\frac{s_1 \xrightarrow{\alpha} s_1' \qquad \alpha \neq \mathrm{n}\, \sigma\, \ell\, \bar{v}}{s_1 \mid s_2 \xrightarrow{\alpha} s_1' \mid s_2} \qquad \frac{s_1 \xrightarrow{\mathrm{n}\, \sigma\, \ell\, \bar{v}} s_1' \qquad \mathrm{noConf}(s_2, \mathrm{n}, \bar{v}, \ell)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\, \sigma\, \ell\, \bar{v}} s_1' \mid s_2}$$

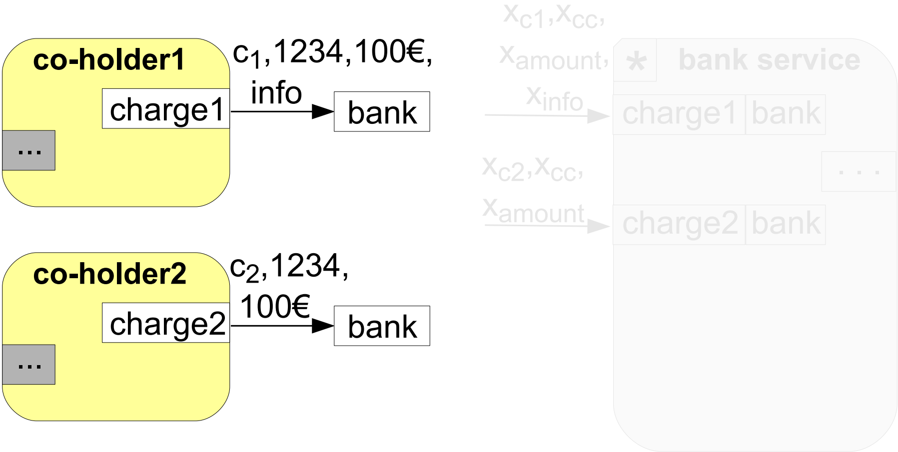
$$\frac{s \xrightarrow{\mathrm{n}\, \sigma \uplus \{x \mapsto v\}\, \ell\, \bar{v}} s'}{[x]\, s \xrightarrow{\mathrm{n}\, \sigma\, \ell\, \bar{v}} s' \cdot \{x \mapsto v\}}$$

μCOWS: *joint account* service example



$$
\begin{aligned}
* \,[x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}]\; (\, & \mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info}\rangle.s_1 \\
\mid\; & \mathrm{bank} \bullet \mathrm{charge2}?\langle x_{c2}, x_{cc}, x_{amount}\rangle.s_2\,) \\
\mid\; (\, \mathrm{bank} \bullet \mathrm{charge1}!\langle c_1, 1234, 100€, \mathrm{info}\rangle \mid s_1' \,) & \\
\mid\; (\, \mathrm{bank} \bullet \mathrm{charge2}!\langle c_2, 1234, 100€\rangle \mid s_2' \,) &
\end{aligned}
$$

μCOWS: *joint account* service example

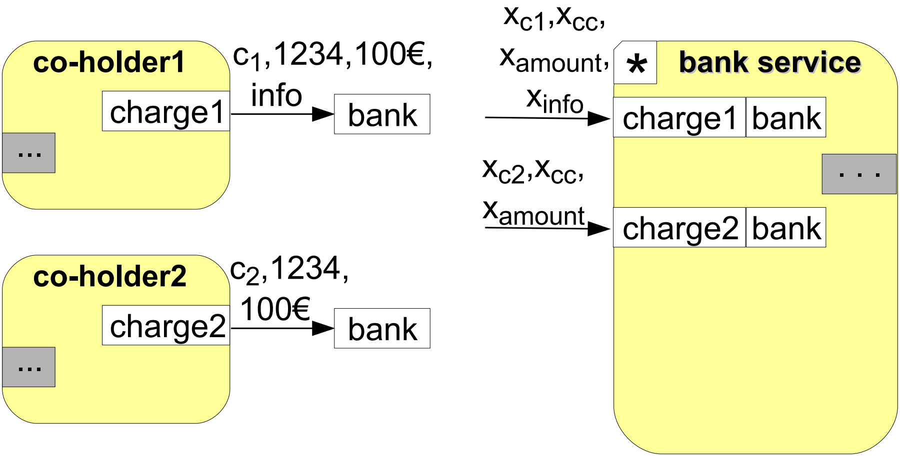


$$* \; [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] \, (\mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info} \rangle . s_1 \; | \; \mathrm{bank} \bullet \mathrm{charge2}?\langle x_{c2}, x_{cc}, x_{amount} \rangle . s_2 \,)$$

$$| \; (\mathrm{bank} \bullet \mathrm{charge1}!\langle c_1, 1234, 100€, \mathrm{info} \rangle \; | \; s'_1 \,)$$

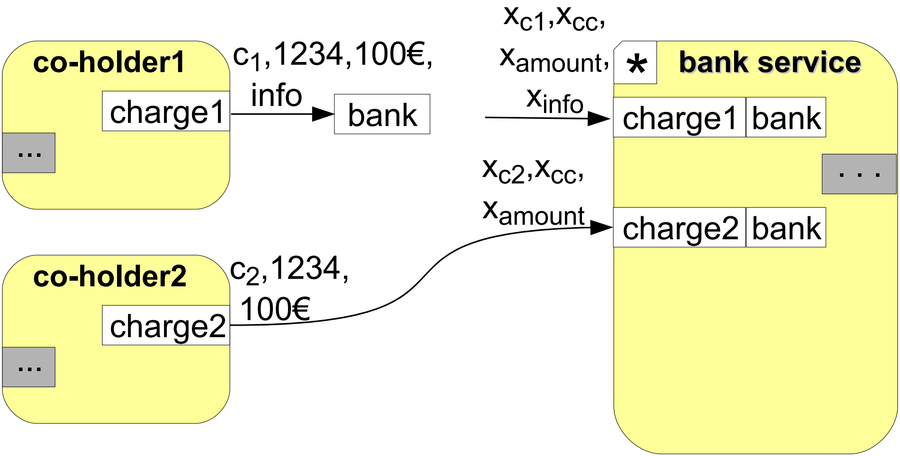
$$| \; (\mathrm{bank} \bullet \mathrm{charge2}!\langle c_2, 1234, 100€ \rangle \; | \; s'_2 \,)$$

μCOWS: *joint account* service example



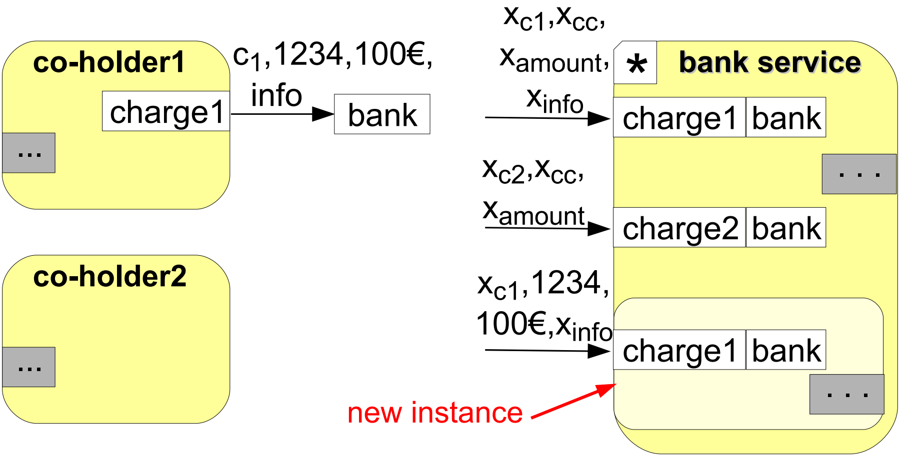
$$
\begin{array}{l}
* \, [\mathrm{x}_{c1}, \mathrm{x}_{c2}, \mathrm{x}_{cc}, \mathrm{x}_{amount}, \mathrm{x}_{info}] \, (\, \mathrm{bank} \bullet \mathrm{charge1} ? \langle \mathrm{x}_{c1}, \mathrm{x}_{cc}, \mathrm{x}_{amount}, \mathrm{x}_{info} \rangle . s_1 \\
\qquad\qquad\qquad\qquad\qquad\quad \mid \, \mathrm{bank} \bullet \mathrm{charge2} ? \langle \mathrm{x}_{c2}, \mathrm{x}_{cc}, \mathrm{x}_{amount} \rangle . s_2 \,) \\
\mid \, (\, \mathrm{bank} \bullet \mathrm{charge1} ! \langle \mathrm{c}_1, 1234, 100€, \mathrm{info} \rangle \mid s_1' \,) \\
\mid \, (\, \mathrm{bank} \bullet \mathrm{charge2} ! \langle \mathrm{c}_2, 1234, 100€ \rangle \mid s_2' \,)
\end{array}
$$

μCOWS: *joint account* service example



$$
\begin{array}{l}
* \, [\mathrm{x_{c1}}, \mathrm{x_{c2}}, \mathrm{x_{cc}}, \mathrm{x_{amount}}, \mathrm{x_{info}}] \, (\, \mathrm{bank} \bullet \mathrm{charge1} ? \langle \mathrm{x_{c1}}, \mathrm{x_{cc}}, \mathrm{x_{amount}}, \mathrm{x_{info}} \rangle . s_1 \\
\qquad\qquad\qquad\qquad\qquad \mid \, \mathrm{bank} \bullet \mathrm{charge2} ? \langle \mathrm{x_{c2}}, \mathrm{x_{cc}}, \mathrm{x_{amount}} \rangle . s_2 \,) \\
\mid \; (\, \mathrm{bank} \bullet \mathrm{charge1} ! \langle \mathrm{c_1}, 1234, 100€, \mathrm{info} \rangle \mid s_1' \,) \\
\mid \; (\, \mathrm{bank} \bullet \mathrm{charge2} ! \langle \mathrm{c_2}, 1234, 100€ \rangle \mid s_2' \,)
\end{array}
$$

μCOWS: *joint account* service example



$$
\begin{array}{l}
* \, [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] \, (\mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info} \rangle . s_1 \\
\qquad\qquad\qquad\qquad \mid \; \mathrm{bank} \bullet \mathrm{charge2}?\langle x_{c2}, x_{cc}, x_{amount} \rangle . s_2 \,) \\
\mid \; (\mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, 1234, 100€, x_{info} \rangle . s_1 \; \mid \; s_2 \,) \cdot \{ \cdots \mapsto \cdots \} \\
\mid \; (\mathrm{bank} \bullet \mathrm{charge1}!\langle c_1, 1234, 100€, \mathrm{info} \rangle \; \mid \; s'_1 \,) \; \mid \; (\, s'_2 \,)
\end{array}
$$

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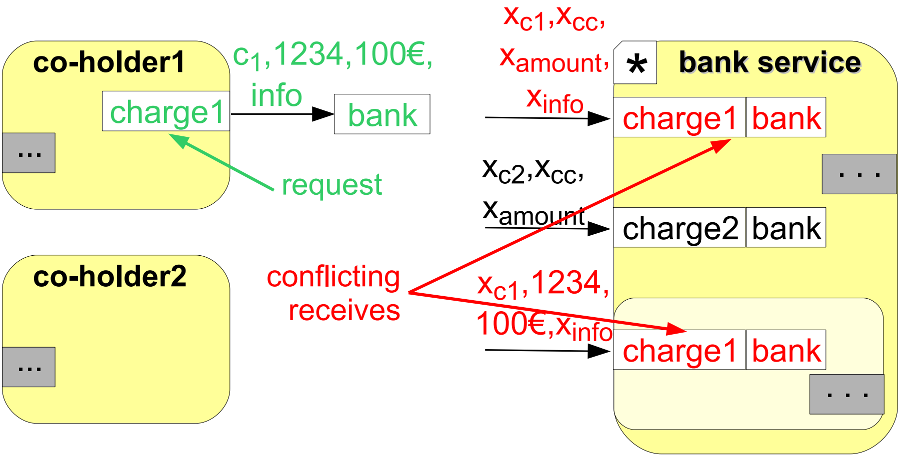
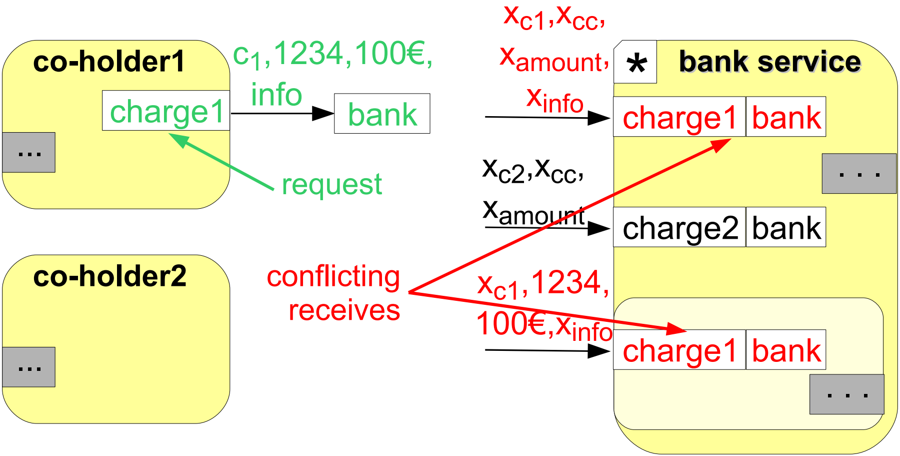


$$
\begin{array}{l}
* \, [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] \, (\, bank \bullet charge1?\langle x_{c1}, x_{cc}, x_{amount}, x_{info} \rangle . s_1 \\
\qquad\qquad\qquad\qquad\qquad \mid \; bank \bullet charge2?\langle x_{c2}, x_{cc}, x_{amount} \rangle . s_2 \,) \\
\mid \; (\, bank \bullet charge1?\langle x_{c1}, 1234, 100€, x_{info} \rangle . s_1 \; \mid \; s_2 \,) \cdot \{ \cdots \mapsto \cdots \} \\
\mid \; (\, bank \bullet charge1!\langle c_1, 1234, 100€, info \rangle \; \mid \; s'_1 \,) \; \mid \; (\, s'_2 \,)
\end{array}
$$

μCOWS: *joint account* service example

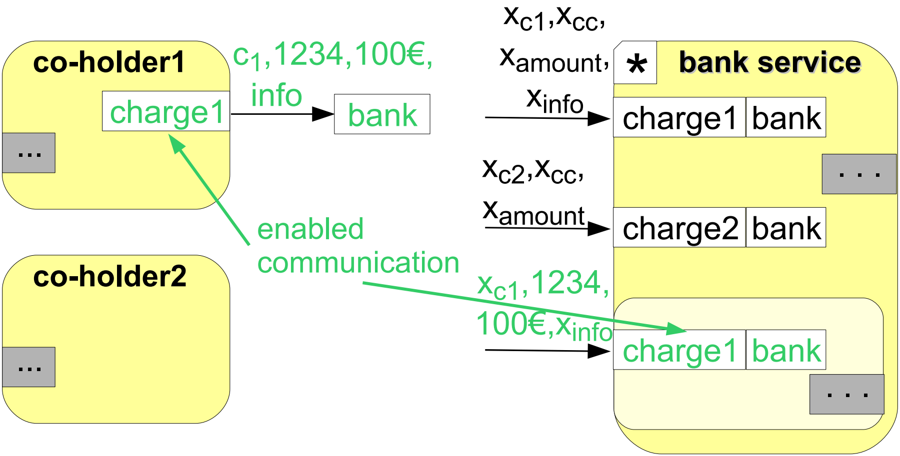


Multiple start activities

The service can receive multiple messages in a statically unpredictable order s.t.

- the first incoming message triggers creation of a service instance
- subsequent messages are delivered to the created instance

μCOWS: *joint account* service example



$$
\begin{array}{l}
* \, [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] \, (\, \mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info}\rangle.s_1 \\
\qquad\qquad\qquad\qquad\qquad \mid \; \mathrm{bank} \bullet \mathrm{charge2}?\langle x_{c2}, x_{cc}, x_{amount}\rangle.s_2 \,) \\
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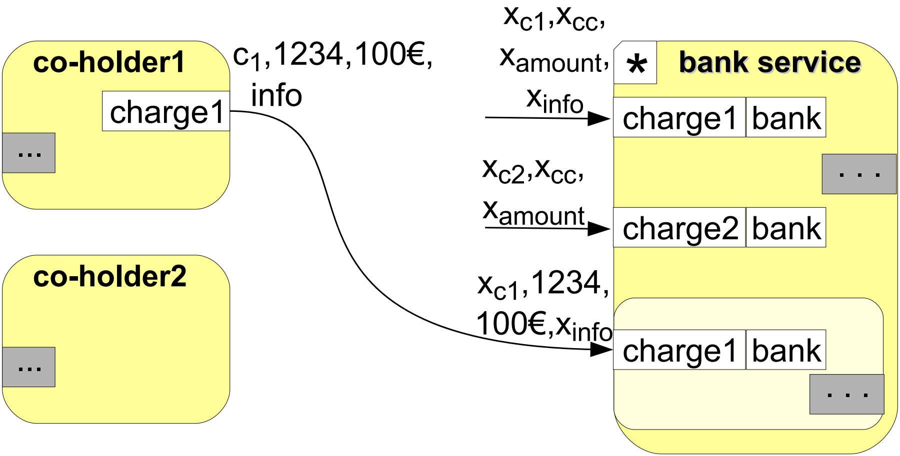
\mid \; (\, \mathrm{bank} \bullet \mathrm{charge1}!\langle c_1, 1234, 100€, \mathrm{info}\rangle \;\mid\; s'_1 \,) \;\mid\; (\, s'_2 \,)
\end{array}
$$

μCOWS: *joint account* service example



$$
\begin{array}{l}
* \, [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] \, (\, \mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info} \rangle . s_1 \\
\qquad\qquad\qquad\qquad\qquad \mid \ \mathrm{bank} \bullet \mathrm{charge2}?\langle x_{c2}, x_{cc}, x_{amount} \rangle . s_2 \,) \\
\mid \ (\, \mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, 1234, 100€, x_{info} \rangle . s_1 \ \mid \ s_2 \,) \cdot \{ \cdots \mapsto \cdots \} \\
\mid \ (\, \mathrm{bank} \bullet \mathrm{charge1}!\langle c_1, 1234, 100€, \mathrm{info} \rangle \ \mid \ s'_1 \,) \ \mid \ (\, s'_2 \,)
\end{array}
$$

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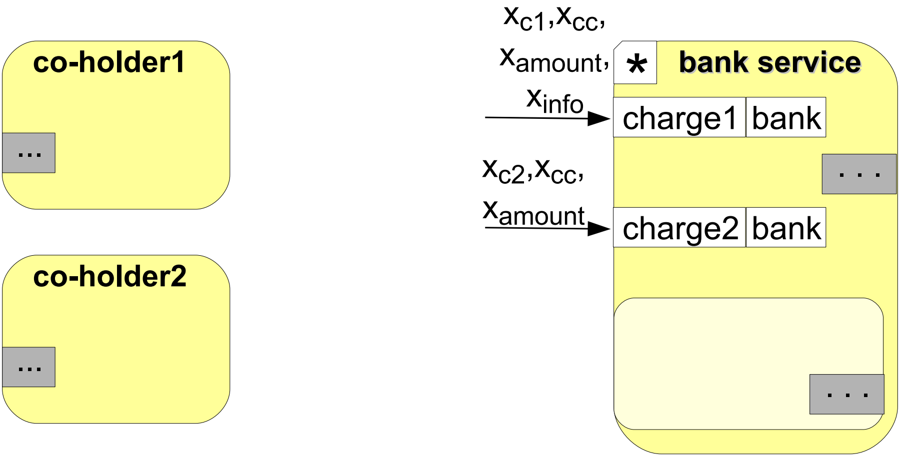

$$
\begin{aligned}
* \, [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] \, (& \, \mathsf{bank} \bullet \mathsf{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info} \rangle . s_1 \\
& \mid \mathsf{bank} \bullet \mathsf{charge2}?\langle x_{c2}, x_{cc}, x_{amount} \rangle . s_2 \,) \\
\mid \; (\, s_1 \mid s_2 \,) \cdot \{ \cdots \mapsto \cdots \} & \\
\mid \; (\, s'_1 \,) \mid (\, s'_2 \,) &
\end{aligned}
$$

Parallel with priority as a coordination mechanism

Default behaviour

Consider a service providing mathematical functionalities
e.g. sum of two integers between 0 and 5

$$
\begin{aligned}
*\,[x,y,z]\,(\,& \mathit{math} \bullet \mathit{sum}?\langle x,y,z\rangle.\, x \bullet \mathit{resp}!\langle \mathit{error}\rangle \\
& + \ \mathit{math} \bullet \mathit{sum}?\langle x,0,0\rangle.\, x \bullet \mathit{resp}!\langle 0\rangle \\
& + \ \mathit{math} \bullet \mathit{sum}?\langle x,0,1\rangle.\, x \bullet \mathit{resp}!\langle 1\rangle \\
& + \ \ldots + \ \mathit{math} \bullet \mathit{sum}?\langle x,5,5\rangle.\, x \bullet \mathit{resp}!\langle 10\rangle\ )
\end{aligned}
$$

In case the two values are not admissible, i.e. they are not integers between 0 and 5, the service replies with the string *error*

Parallel with priority as a coordination mechanism

‘Only the first time’ behaviour

Consider a service that has a certain behaviour at the first correct invocation and a different behaviour at any incorrect or further invocation
(useful, e.g., for compensation handling à la WS-BPEL)

$$\begin{array}{l} p \bullet comp?\langle scopeName \rangle . \langle \text{compensation of } scopeName \rangle \\ \mid \; *\, [x]\, p \bullet comp?\langle x \rangle . \langle \text{do nothing} \rangle \end{array}$$

Parallel with priority as a coordination mechanism

'Blind date' session joining

Consider a service capable of arranging matches of 4-players online games

$$
\begin{aligned}
\mathit{masterServ} \triangleq\ * \,[x_{game}, x_{player1}, x_{player2}, x_{player3}, x_{player4}]\ & \\
& \mathit{master} \bullet \mathit{join}?\langle x_{game}, x_{player1}\rangle. \\
& \mathit{master} \bullet \mathit{join}?\langle x_{game}, x_{player2}\rangle. \\
& \mathit{master} \bullet \mathit{join}?\langle x_{game}, x_{player3}\rangle. \\
& \mathit{master} \bullet \mathit{join}?\langle x_{game}, x_{player4}\rangle. \\
& \quad [\mathit{matchId}]\,(\, x_{player1} \bullet \mathit{start}!\langle \mathit{matchId}\rangle \\
& \qquad\qquad\qquad \mid x_{player2} \bullet \mathit{start}!\langle \mathit{matchId}\rangle \\
& \qquad\qquad\qquad \mid x_{player3} \bullet \mathit{start}!\langle \mathit{matchId}\rangle \\
& \qquad\qquad\qquad \mid x_{player4} \bullet \mathit{start}!\langle \mathit{matchId}\rangle\,)
\end{aligned}
$$

$$\mathit{Player}_i \triangleq \mathit{master} \bullet \mathit{join}!\langle \mathit{poker}, p_i\rangle \mid [x_{id}]\, p_i \bullet \mathit{start}?\langle x_{id}\rangle.\ \langle \text{rest of } \mathit{Player}_i\rangle$$

$$\mathit{Player}_j \triangleq \mathit{master} \bullet \mathit{join}!\langle \mathit{bridge}, p_j\rangle \mid [x_{id}]\, p_j \bullet \mathit{start}?\langle x_{id}\rangle.\ \langle \text{rest of } \mathit{Player}_j\rangle$$

It could be hard to render this behaviour with other process calculi

Parallel with priority as a coordination mechanism

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& \textit{master} \bullet \textit{join}?\langle x_{game}, x_{player2}\rangle.\\
& \textit{master} \bullet \textit{join}?\langle x_{game}, x_{player3}\rangle.\\
& \textit{master} \bullet \textit{join}?\langle x_{game}, x_{player4}\rangle.\\
& \quad [\textit{matchId}]\,(\, x_{player1} \bullet \textit{start}!\langle \textit{matchId}\rangle\\
& \quad\quad \mid x_{player2} \bullet \textit{start}!\langle \textit{matchId}\rangle\\
& \quad\quad \mid x_{player3} \bullet \textit{start}!\langle \textit{matchId}\rangle\\
& \quad\quad \mid x_{player4} \bullet \textit{start}!\langle \textit{matchId}\rangle\,)
\end{aligned}
$$

$$\textit{Player}_i \triangleq \textit{master} \bullet \textit{join}!\langle \textit{poker}, p_i\rangle \mid [x_{id}]\, p_i \bullet \textit{start}?\langle x_{id}\rangle.\,\langle \text{rest of } \textit{Player}_i\rangle$$

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It could be hard to render this behaviour with other process calculi

From μCOWS to COWS

μCOWS

From μCOWS to COWS

μCOWS

+

Termination activities

From μCOWS to COWS

μCOWS

+

Termination activities

=

COWS

COWS: why termination activities?

1. To handle *faults* and enable *compensation*

2. Termination activities can be used as *orchestration mechanisms*
   - E.g. to model the asymmetric parallel composition of Orc (i.e. the *pruning* construct, that prunes threads selectively)

Syntax of COWS

$s ::=$		(services)
	$\mathbf{kill}(k)$	(kill)
$\mid$	$u \bullet u' ! \bar{\epsilon}$	(invoke)
$\mid$	$\sum_{i=0}^{r} g_i . s_i$	(receive-guarded choice)
$\mid$	$s \mid s$	(parallel composition)
$\mid$	$\{\mid s \mid\}$	(protection)
$\mid$	$[e]\, s$	(delimitation)
$\mid$	$* s$	(replication)
$g ::=$		(guards)
	$p \bullet o ? \bar{w}$	(receive)

(notations)
k: (killer) labels
ϵ: *expressions*
x: *variables*
v: *values*
n, p, o: *names*
u: *variables* | *names*
w: *variables* | *values*
e: *labels* | *variables* | *names*

- Killer labels cannot occur within expressions
  $\Rightarrow$ they are not (communicable) values
- Only one binding construct: $[e]\, s$ binds e in the scope s
  - free/bound *elements* (i.e. names/variables/labels) defined accordingly

COWS operational semantics

Additional structural congruence laws

- $\{\!|\mathbf{0}|\!\} \;\equiv\; \mathbf{0} \qquad \{\!|\, \{\!|s|\!\}\, |\!\} \;\equiv\; \{\!|s|\!\} \qquad \{\!|[e]\,s|\!\} \;\equiv\; [e]\,\{\!|s|\!\}$
- $s_1 \mid [e]\,s_2 \;\equiv\; [e]\,(s_1 \mid s_2) \quad \text{if } e \notin \mathrm{fe}(s_1) \cup \mathrm{fk}(s_2)$
  - $\mathrm{fe}(s)$ denotes the set of elements occurring free in s
  - $\mathrm{fk}(s)$ denotes the set of free killer labels in s
  - thus, differently from names/variables, the scope of killer labels cannot be extended

Labelled transition relation $\xrightarrow{\alpha}$

Label α is now generated by the following grammar:

$$\alpha \;::=\; \mathrm{n} \lhd \bar{v} \;\mid\; \mathrm{n} \rhd \bar{w} \;\mid\; \mathrm{n}\,\sigma\,\ell\,\bar{v} \;\mid\; k \;\mid\; \dagger$$

COWS: Kill activity

- Activity **kill**(k) forces termination of all unprotected parallel activities inside an enclosing $[k]$, that stops the killing effect

$$\mathbf{kill}(k) \xrightarrow{k} \mathbf{0} \qquad \frac{s_1 \xrightarrow{k} s_1'}{s_1 \mid s_2 \xrightarrow{k} s_1' \mid \mathrm{halt}(s_2)} \qquad \frac{s \xrightarrow{k} s'}{[k]\, s \xrightarrow{\dagger} [k]\, s'}$$

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Function $\mathrm{halt}(s)$

returns the service obtained by only retaining the protected activities inside s

$$\mathrm{halt}(\mathbf{kill}(k)) \;=\; \mathrm{halt}(\mathtt{u}!\bar{\epsilon}) \;=\; \mathrm{halt}(\textstyle\sum_{i=0}^{r} \mathtt{n}_i?\bar{w}_i.s_i) \;=\; \mathbf{0}$$

$$\mathrm{halt}(s_1 \mid s_2) = \mathrm{halt}(s_1) \mid \mathrm{halt}(s_2) \qquad \mathrm{halt}(\{\!|s|\!\}) = \{\!|s|\!\}$$

$$\mathrm{halt}([e]\, s) = [e]\, \mathrm{halt}(s) \qquad \mathrm{halt}(*\, s) = *\, \mathrm{halt}(s)$$

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- Kill activities are executed *eagerly*

$$\frac{s \xrightarrow{k} s' \quad k \neq e}{[e]\, s \xrightarrow{k} [e]\, s'} \qquad \frac{s \xrightarrow{\dagger} s'}{[e]\, s \xrightarrow{\dagger} [e]\, s'}$$

$$\frac{s \xrightarrow{\alpha} s' \quad e \notin \mathrm{e}(\alpha) \quad \alpha \neq k, \dagger \quad \mathrm{noKill}(s, e)}{[e]\, s \xrightarrow{\alpha} [e]\, s'}$$

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Predicate $\mathrm{noKill}(s, e)$ (part 1/2)

checks the ability of s of immediately performing a kill activity

$$\mathrm{noKill}(s, e) = \textbf{true} \quad \text{if } \mathrm{fk}(e) = \emptyset \qquad \mathrm{noKill}(\textbf{kill}(k'), k) = \textbf{true} \quad \text{if } k \neq k'$$

$$\mathrm{noKill}(\textbf{kill}(k), k) = \textbf{false} \qquad \mathrm{noKill}(\mathrm{u}!\bar{\epsilon}, k) = \mathrm{noKill}(\textstyle\sum_{i=0}^{r} \mathrm{n}_i?\bar{w}_i.s_i, k) = \textbf{true}$$

COWS: Kill activity

- Activity **kill**(k) forces termination of all unprotected parallel activities inside an enclosing $[k]$, that stops the killing effect
- Kill activities are executed *eagerly*

$$\frac{s \xrightarrow{k} s' \quad k \neq e}{[e]\, s \xrightarrow{k} [e]\, s'} \qquad \frac{s \xrightarrow{\dagger} s'}{[e]\, s \xrightarrow{\dagger} [e]\, s'}$$

$$\frac{s \xrightarrow{\alpha} s' \quad e \notin \mathrm{e}(\alpha) \quad \alpha \neq k, \dagger \quad \mathrm{noKill}(s, e)}{[e]\, s \xrightarrow{\alpha} [e]\, s'}$$

Predicate $\mathrm{noKill}(s, e)$ (part 2/2)

checks the ability of s of immediately performing a kill activity

$\mathrm{noKill}(s \mid s', k) = \mathrm{noKill}(s, k) \wedge \mathrm{noKill}(s', k) \quad \mathrm{noKill}([e]\, s, k) = \mathrm{noKill}(s, k)$ if $e \neq k$

$\mathrm{noKill}([k]\, s, k) = \textbf{true} \qquad \mathrm{noKill}(\{|s|\}, k) = \mathrm{noKill}(*\, s, k) = \mathrm{noKill}(s, k)$

COWS: Kill activity

- Activity **kill**(k) forces termination of all unprotected parallel activities inside an enclosing $[k]$, that stops the killing effect
- Kill activities are executed *eagerly*
- $\{\!|\cdot|\!\}$ protects activities from the effect of a forced termination

$$\frac{s \xrightarrow{\alpha} s'}{\{\!|s|\!\} \xrightarrow{\alpha} \{\!|s'|\!\}}$$

COWS operational semantics: labelled transition rules

$$\frac{[\![\bar{\epsilon}]\!] = \bar{v}}{\mathrm{n}!\bar{\epsilon} \xrightarrow{\mathrm{n} \lhd \bar{v}} \mathbf{0}} \qquad \frac{1 \leq j \leq r}{\sum_{i=1}^{r} \mathrm{n}_i?\bar{w}_i.s_i \xrightarrow{\mathrm{n}_j \rhd \bar{w}_j} s_j} \qquad \frac{s \equiv \xrightarrow{\alpha} \equiv s'}{s \xrightarrow{\alpha} s'}$$

$$\frac{s_1 \xrightarrow{\mathrm{n} \rhd \bar{w}} s_1' \quad s_2 \xrightarrow{\mathrm{n} \lhd \bar{v}} s_2' \quad \mathcal{M}(\bar{w}, \bar{v}) = \sigma \quad \mathrm{noConf}(s_1 \mid s_2, \mathrm{n}, \bar{v}, |\sigma|)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\, \sigma\, |\sigma|\, \bar{v}} s_1' \mid s_2'}$$

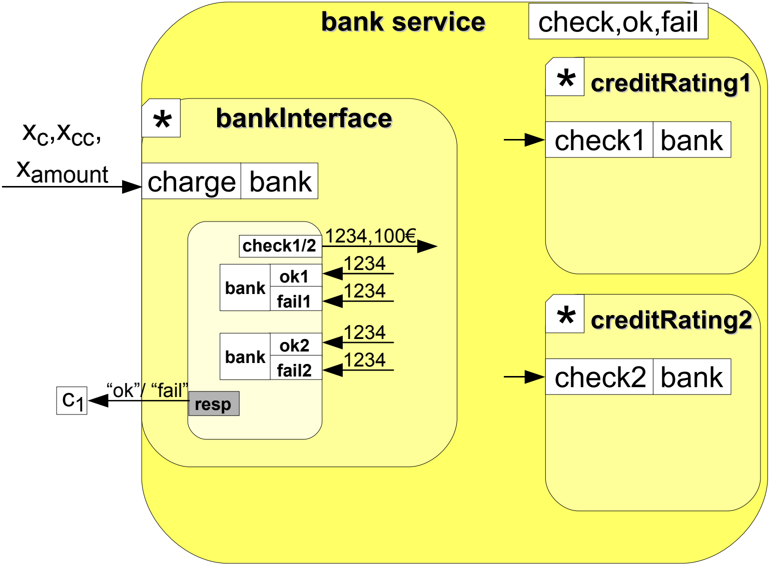
$$\frac{s \xrightarrow{\mathrm{n}\, \sigma \uplus \{x \mapsto v\}\, \ell\, \bar{v}} s'}{[x]\, s \xrightarrow{\mathrm{n}\, \sigma\, \ell\, \bar{v}} s' \cdot \{x \mapsto v\}} \qquad \frac{s_1 \xrightarrow{\mathrm{n}\, \sigma\, \ell\, \bar{v}} s_1' \quad \mathrm{noConf}(s_2, \mathrm{n}, \bar{v}, \ell)}{s_1 \mid s_2 \xrightarrow{\mathrm{n}\, \sigma\, \ell\, \bar{v}} s_1' \mid s_2}$$

$$\mathbf{kill}(k) \xrightarrow{k} \mathbf{0} \qquad \frac{s \xrightarrow{\alpha} s'}{\{\!|s|\!\} \xrightarrow{\alpha} \{\!|s'|\!\}} \qquad \frac{s_1 \xrightarrow{\alpha} s_1' \quad \alpha \neq k, \mathrm{n}\, \sigma\, \ell\, \bar{v}}{s_1 \mid s_2 \xrightarrow{\alpha} s_1' \mid s_2}$$

$$\frac{s \xrightarrow{k} s'}{[k]\, s \xrightarrow{\dagger} [k]\, s'} \qquad \frac{s \xrightarrow{k} s' \quad k \neq e}{[e]\, s \xrightarrow{k} [e]\, s'} \qquad \frac{s_1 \xrightarrow{k} s_1'}{s_1 \mid s_2 \xrightarrow{k} s_1' \mid \mathrm{halt}(s_2)}$$

$$\frac{s \xrightarrow{\dagger} s'}{[e]\, s \xrightarrow{\dagger} [e]\, s'} \qquad \frac{s \xrightarrow{\alpha} s' \quad e \notin \mathrm{e}(\alpha) \quad \alpha \neq k, \dagger \quad \mathrm{noKill}(s, e)}{[e]\, s \xrightarrow{\alpha} [e]\, s'}$$

COWS: *multi rating* bank service example



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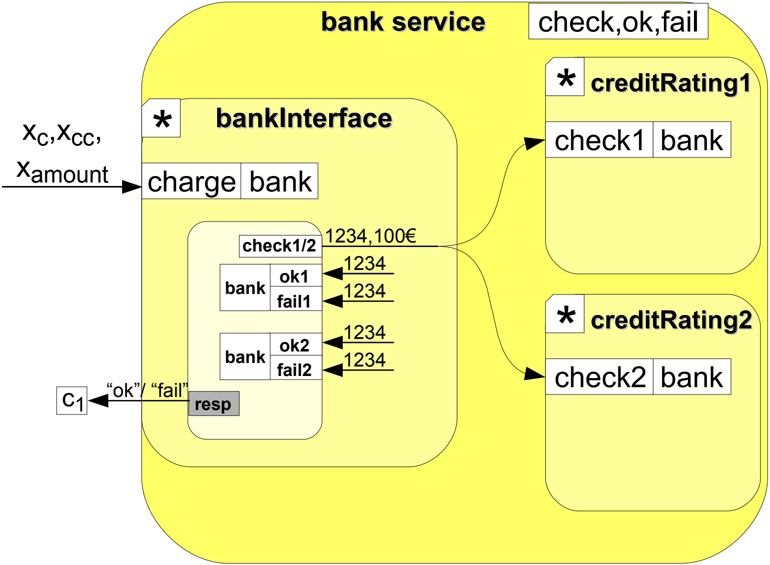

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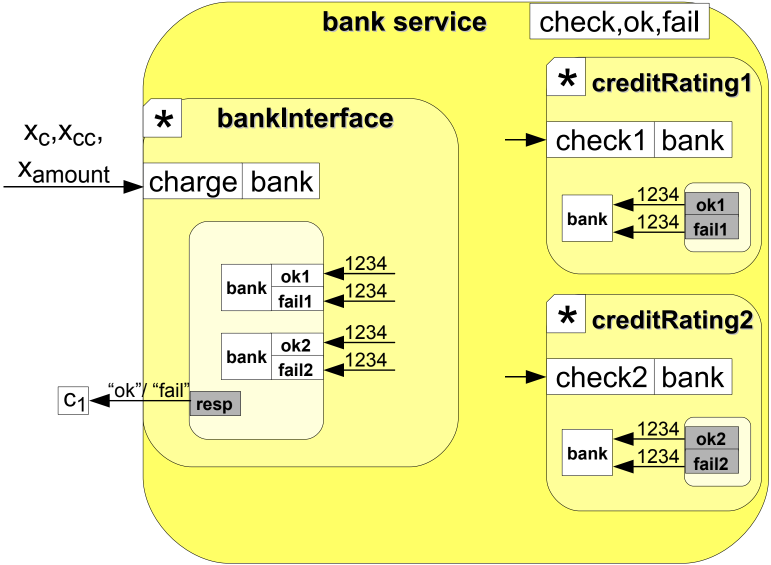

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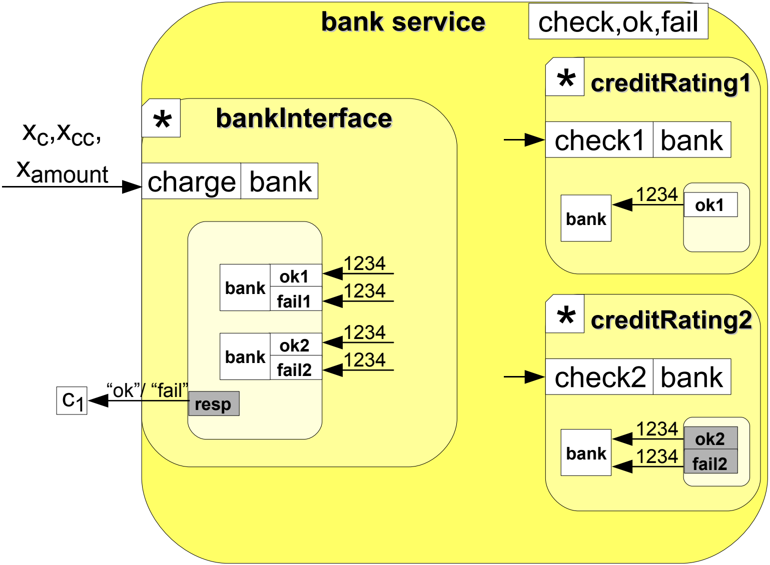

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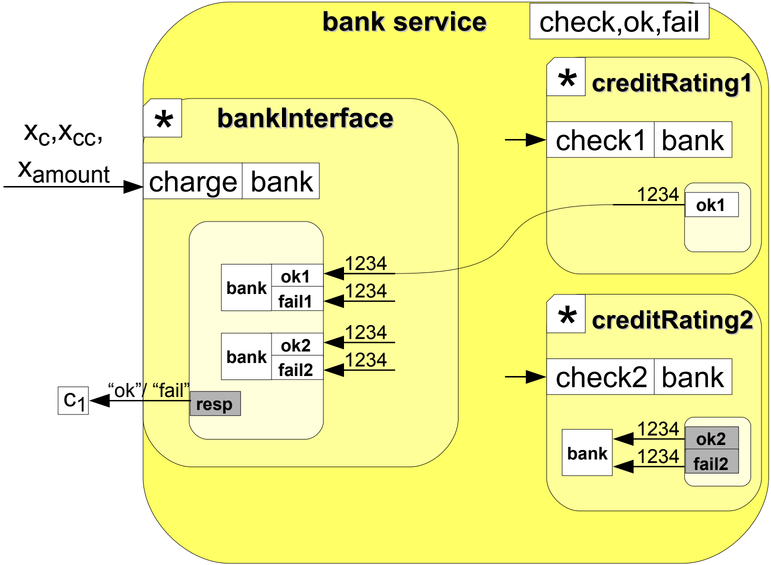

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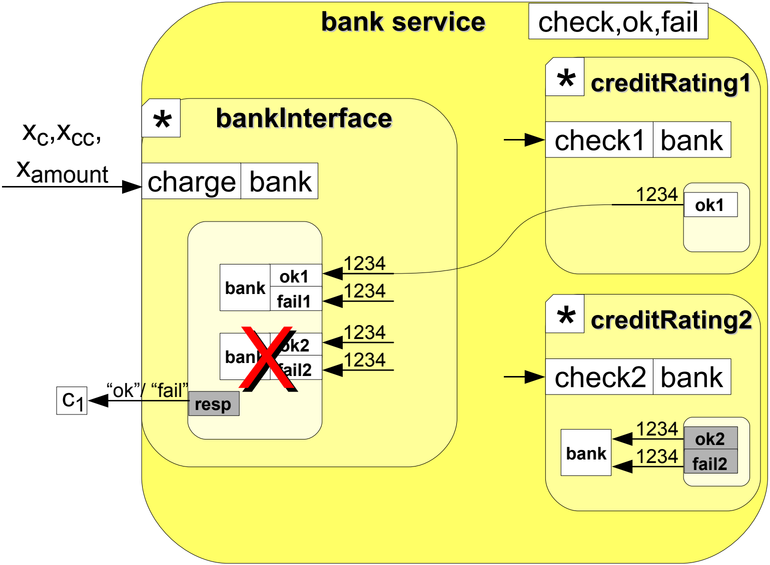

COWS: *multi rating* bank service example

$$[\mathrm{check1}, \mathrm{check2}, \mathrm{ok1}, \mathrm{ok2}, \mathrm{fail1}, \mathrm{fail2}]$$
$$(\, * \,\mathrm{bankInterface} \mid * \,\mathrm{creditRating1} \mid * \,\mathrm{creditRating2}\,)$$

$$
\begin{array}{l}
\mathrm{bankInterface} \;\triangleq \\
\quad [\mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}}] \\
\quad \mathrm{bank} \bullet \mathrm{charge}?\langle \mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}} \rangle. \\
\quad (\, \mathrm{bank} \bullet \mathrm{check1}!\langle \mathrm{x_{cc}}, \mathrm{x_{amount}} \rangle \mid \mathrm{bank} \bullet \mathrm{check2}!\langle \mathrm{x_{cc}}, \mathrm{x_{amount}} \rangle \\
\quad\;\; \mid [k]\,(\, \mathrm{bank} \bullet \mathrm{ok1}?\langle \mathrm{x_{cc}} \rangle.\,(\, \mathbf{kill}(k) \mid \{\!|\, \mathrm{x_c} \bullet \mathrm{resp}!\langle \text{“ok”} \rangle \,|\!\}\,) \\
\qquad\qquad\quad + \mathrm{bank} \bullet \mathrm{fail1}?\langle \mathrm{x_{cc}} \rangle.\, s_1 \\
\qquad\qquad \mid \mathrm{bank} \bullet \mathrm{ok2}?\langle \mathrm{x_{cc}} \rangle.\,(\, \mathbf{kill}(k) \mid \{\!|\, \mathrm{x_c} \bullet \mathrm{resp}!\langle \text{“ok”} \rangle \,|\!\}\,) \\
\qquad\qquad\quad + \mathrm{bank} \bullet \mathrm{fail2}?\langle \mathrm{x_{cc}} \rangle.\, s_2 \,)\,)
\end{array}
$$

COWS: peculiar examples

Protected kill activity

- Execution of a kill activity within a protection block

$$[k]\,(\{\!|s_1 \mid \{\!|s_2|\!\} \mid \mathbf{kill}(k)|\!\} \mid s_3) \mid s_4 \xrightarrow{\dagger} [k]\,\{\!|s_2|\!\} \mid s_4$$

For simplicity, assume that $\mathrm{halt}(s_1) = \mathrm{halt}(s_3) = \mathbf{0}$

- **kill**(k) terminates all parallel services inside delimitation $[k]$ (i.e. s_1 and s_3), except those that are protected at the same nesting level of the kill activity (i.e. s_2)

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COWS: peculiar examples

Interplay between communication and kill activity

$$p \bullet o!\langle n \rangle \mid [k]\,([x]\,p \bullet o?\langle x \rangle.s \mid \mathbf{kill}(k)) \xrightarrow{\dagger} p \bullet o!\langle n \rangle \mid [k]\,[x]\,\mathbf{0}$$

- Kill activities can break communication
- This is the only possible evolution (kills are executed *eagerly*)
- Communication can be guaranteed by protecting the receive

$$p \bullet o!\langle n \rangle \mid [k]\,([x]\,\{\!|p \bullet o?\langle x \rangle.s|\!\} \mid \mathbf{kill}(k)) \xrightarrow{\dagger}$$

$$p \bullet o!\langle n \rangle \mid [k]\,([x]\,\{\!|p \bullet o?\langle x \rangle.s|\!\}) \xrightarrow{p \bullet o\,\emptyset\,1\,\langle n \rangle} [k]\,\{\!|s \cdot \{x \mapsto n\}|\!\}$$

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COWS expressiveness

Considerations on COWS expressiveness

- Encoding other calculi
  - π-calculus, Localized π-calculus (Lπ), ...
  - SCC (Session Centered Calculus)
  - Orc
  - WS-CALCULUS
  - B*lite* (a lightweight version of WS-BPEL)
- COWS (like other calculi equipped with priority) is not encodable into mainstream calculi (e.g. CCS and π-calculus) [EXPRESS'10]
- Modelling imperative and orchestration constructs
  - Assignment, conditional choice, sequential composition,...
  - WS-BPEL flow graphs, fault and compensation handlers
  - QoS requirement specifications and SLA negotiations [WWV'07]
  - Timed orchestration constructs [ICTAC'07]

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