Software Engineering and Service-Oriented Systems

– A Calculus for Orchestration of Web Services –

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In co-operation with SENSORIA members, in particular Rosario Pugliese

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. $\texttt{web}\pi$, $\texttt{web}\pi_\infty$, 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

WS-BPEL

- 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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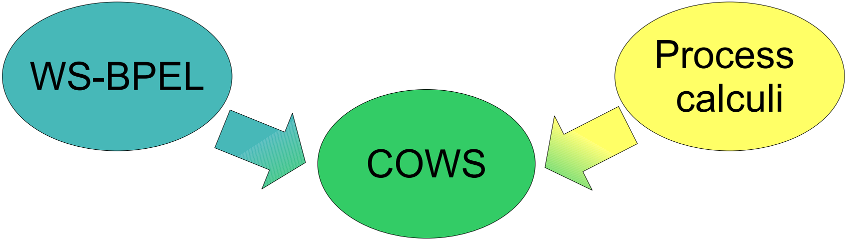

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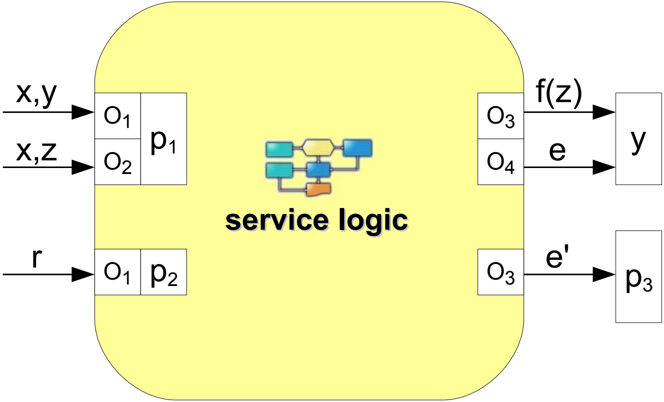
The notion of service in COWS



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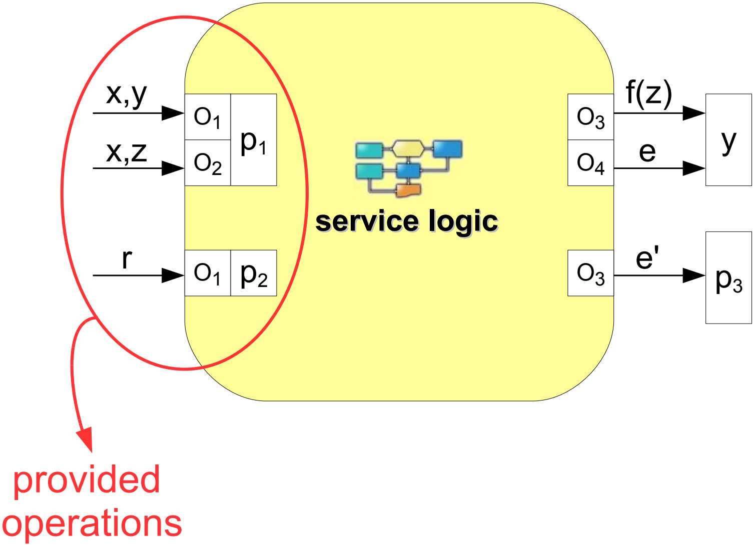

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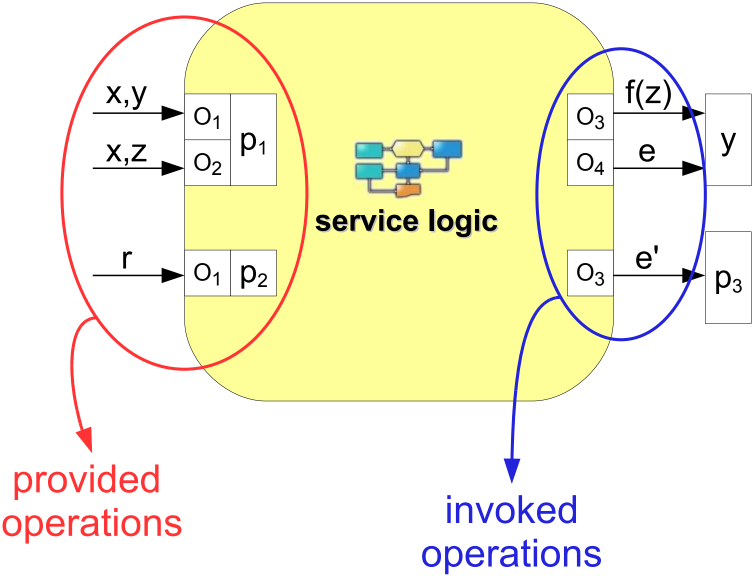

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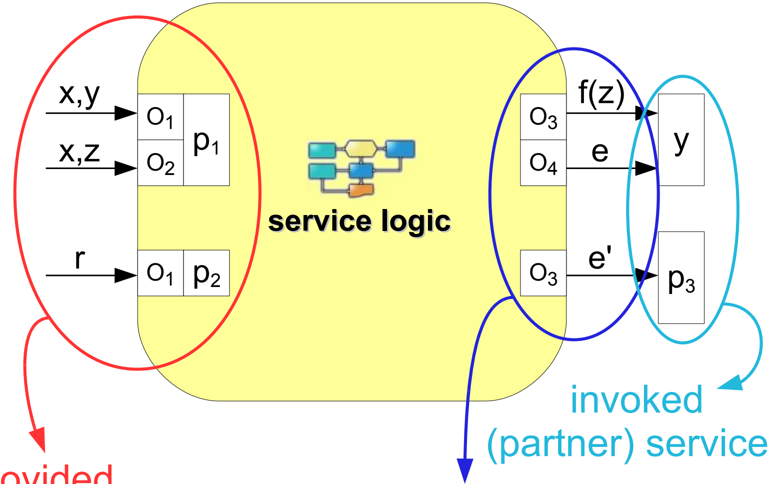

invoked (partner) services

provided operations

invoked operations

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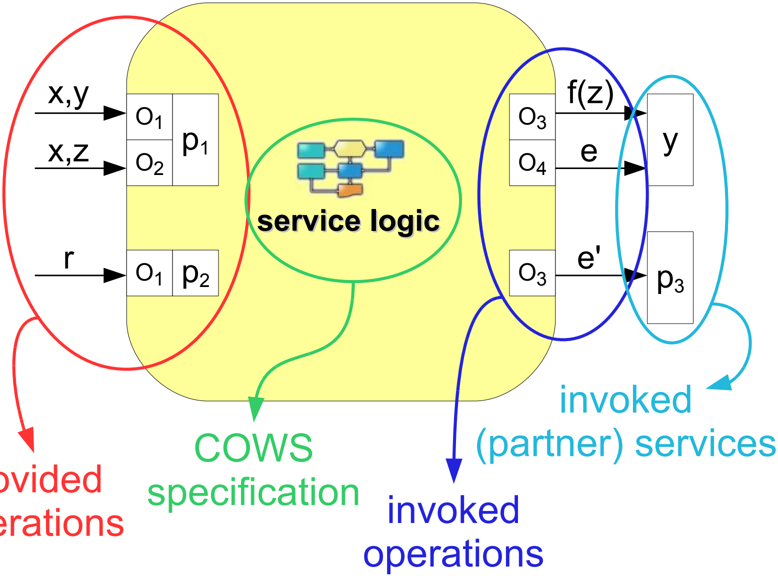

provided operations

COWS specification

invoked operations

invoked (partner) services

COWS in three steps

μCOWS^m (micro COWS minus priority)

Communication activities

- Invoke
- Receive

Control flow activities

- Parallel composition
- Choice
- Replication
- Delimitation

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Termination activities

- Kill activity
- Protection

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μCOWS^m (micro COWS minus priority)

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- Invoke
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Control flow activities

- Parallel composition
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Termination activities

- Kill activity
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Syntax of μCOWS^m

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

(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, ...

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

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

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

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

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Notations

- The exact syntax of expressions is deliberately omitted
- ¯ 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

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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 $u \notin \mathrm{fu}(s_1)$

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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)

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

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

$$\mathcal{M}(x, v) = \{x \mapsto v\} \qquad \mathcal{M}(v, v) = \emptyset \qquad \mathcal{M}(\langle\rangle, \langle\rangle) = \emptyset \qquad \frac{\mathcal{M}(w_1, v_1) = \sigma_1 \quad \mathcal{M}(\bar{w}_2, \bar{v}_2) = \sigma_2}{\mathcal{M}((w_1, \bar{w}_2), (v_1, \bar{v}_2)) = \sigma_1 \uplus \sigma_2}$$

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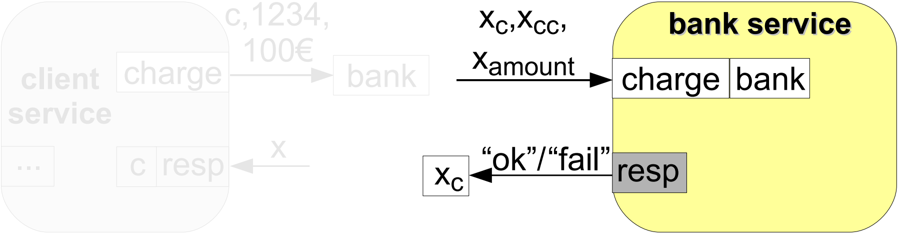
$$\frac{s \equiv \xrightarrow{\alpha} \equiv s'}{s \xrightarrow{\alpha} s'}$$

μCOWS^m: *simple* bank service example



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

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

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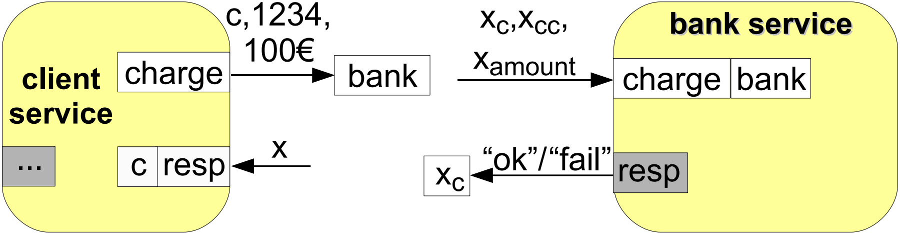

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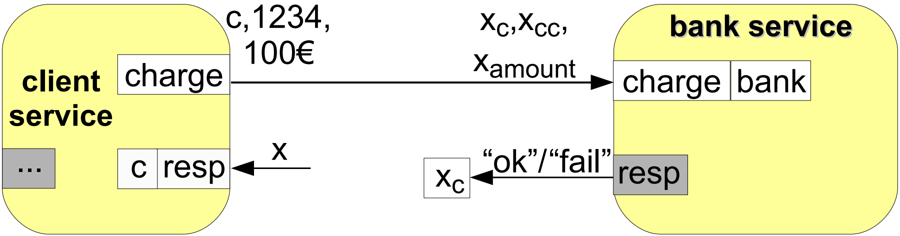
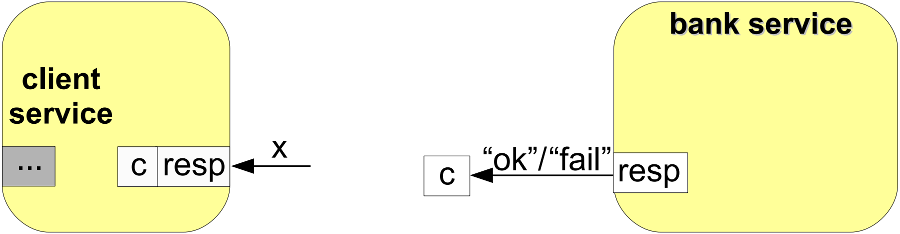


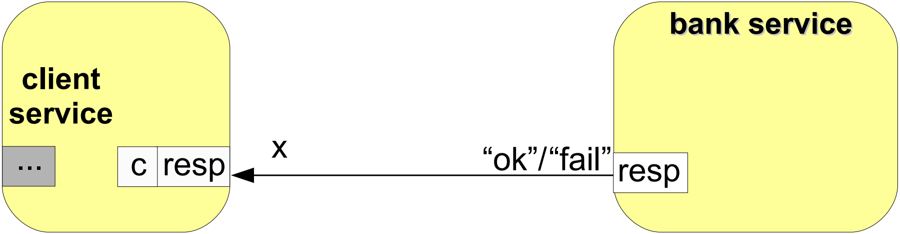
$$\begin{array}{lll} \mathsf{bank} \bullet \mathsf{charge}!\langle \mathsf{c}, 1234, 100€\rangle & & [\mathsf{x_c}, \mathsf{x_{cc}}, \mathsf{x_{amount}}] \\ \mid [\mathsf{x}]\,(\mathsf{c} \bullet \mathsf{resp}?\langle \mathsf{x}\rangle.\mathsf{s} \mid \mathsf{s}') & \mid & \mathsf{bank} \bullet \mathsf{charge}?\langle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

μCOWS^m: *simple* bank service example



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

μCOWS^m: *simple* bank service example

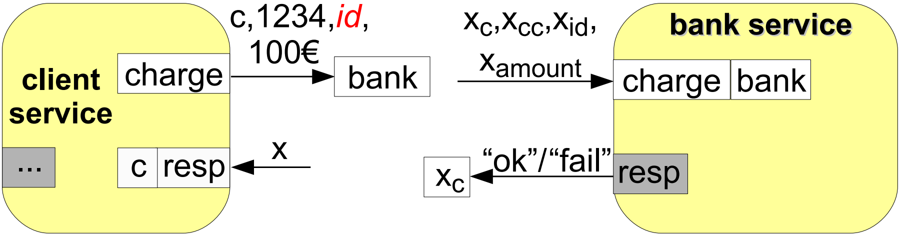


$[x]\,(c \bullet resp?\langle x\rangle.s \mid s') \qquad\qquad \mid \qquad\qquad c \bullet resp!\langle \mathit{chk}(1234, 100€)\rangle$

μCOWS^m: *simple* bank service example

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

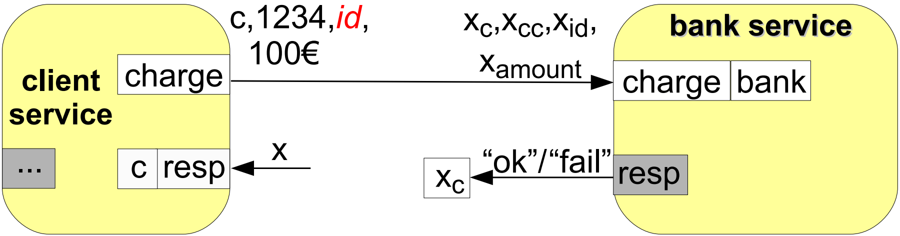
μCOWS^m: communication of private names



[id]
(bank • charge!⟨c, 1234, id, 100€⟩
| [x] (c • resp?⟨x⟩.s | s′))

[x_c, x_{cc}, x_{id}, x_{amount}]
bank • charge?⟨x_c, x_{cc}, x_{id}, x_{amount}⟩.
x_c • resp!⟨$chk(x_{cc}, x_{id}, x_{amount})$⟩

μCOWS^m: communication of private names

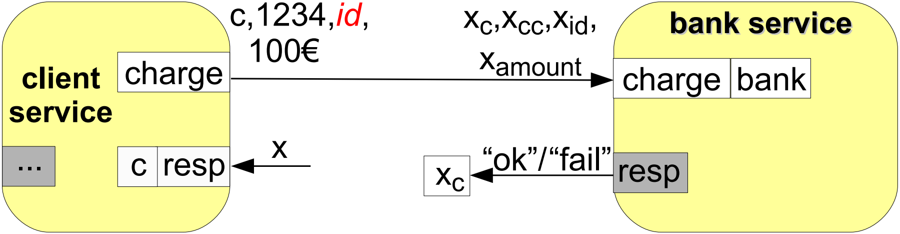


$\color{red}{[id]}$
$\color{red}{(}\mathrm{bank} \bullet \mathrm{charge}!\langle \mathrm{c}, 1234, \color{red}{\mathrm{id}}, 100€\rangle \mid [\mathrm{x}]\,(\mathrm{c} \bullet \mathrm{resp}?\langle \mathrm{x}\rangle.\mathrm{s} \mid \mathrm{s}')\ \color{red}{)}$

$\mid$

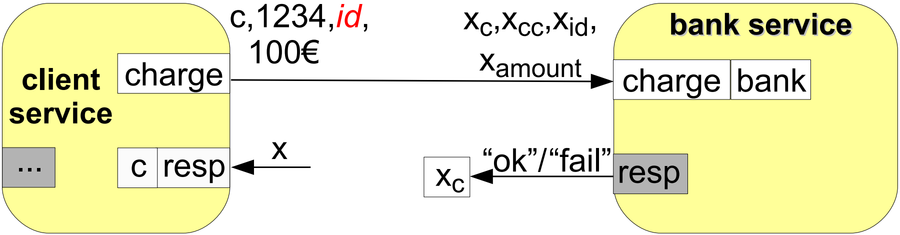
$[\mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{id}}, \mathrm{x_{amount}}]$
$\mathrm{bank} \bullet \mathrm{charge}?\langle \mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{id}}, \mathrm{x_{amount}}\rangle.$
$\mathrm{x_c} \bullet \mathrm{resp}!\langle chk(x_{cc}, x_{id}, x_{amount})\rangle$

μCOWS^m: communication of private names



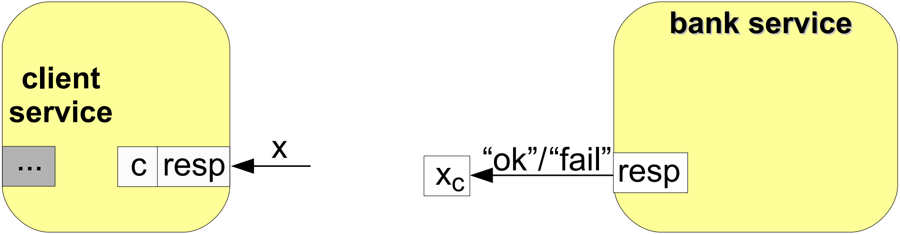
$\equiv$

μCOWS^m: communication of private names



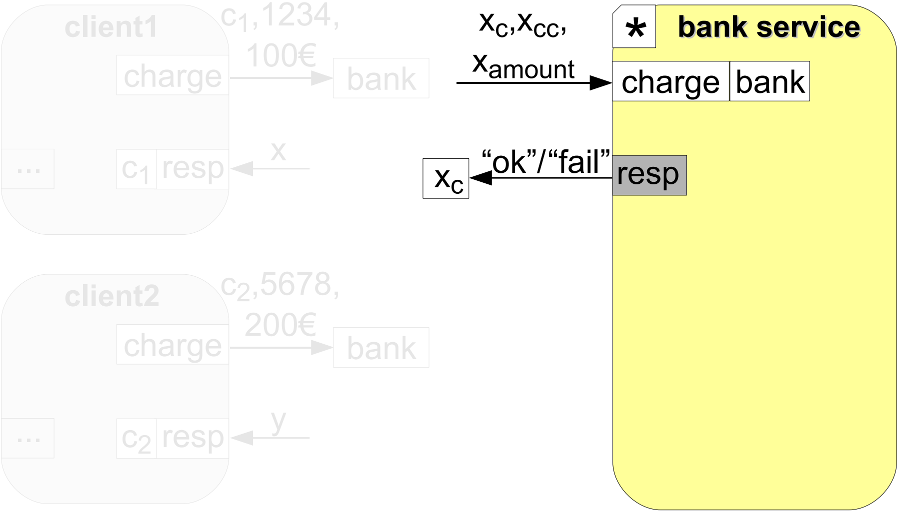
$$[id, x_c, x_{cc}, x_{id}, x_{amount}]\left(\begin{pmatrix} \mathrm{bank} \bullet \mathrm{charge}!\langle c, 1234, id, 100\text{€}\rangle \\ \mid [x]\,(c \bullet \mathrm{resp}?\langle x\rangle.s \mid s') \end{pmatrix} \mid \begin{pmatrix} \mathrm{bank} \bullet \mathrm{charge}?\langle x_c, x_{cc}, x_{id},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

μCOWS^m: communication of private names



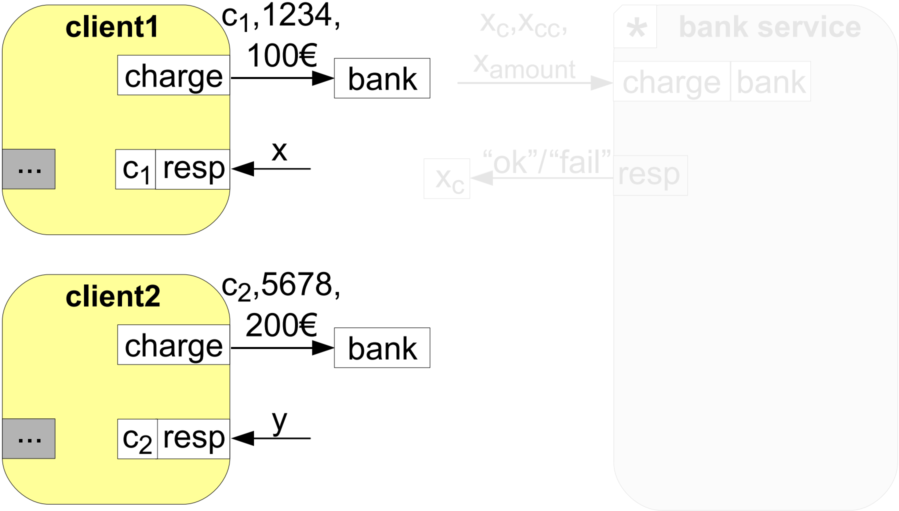
$$[id]\;(\;[x]\,(c \bullet resp?\langle x\rangle.s \mid s') \quad\mid\quad c \bullet resp!\langle chk(1234, id, 100€)\rangle\;)$$

μCOWS^m: *persistent* bank service example



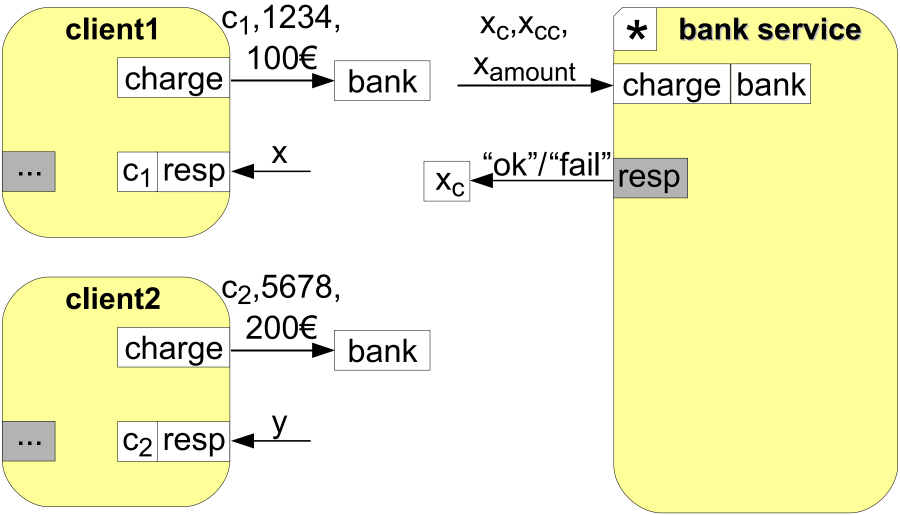
$$* \,[\mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}}]\, \mathrm{bank} \bullet \mathrm{charge}?\langle \mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}}\rangle.\mathrm{x_c} \bullet \mathrm{resp}!\langle chk(x_{cc}, x_{amount})\rangle$$

μCOWS^m: *persistent* bank service example

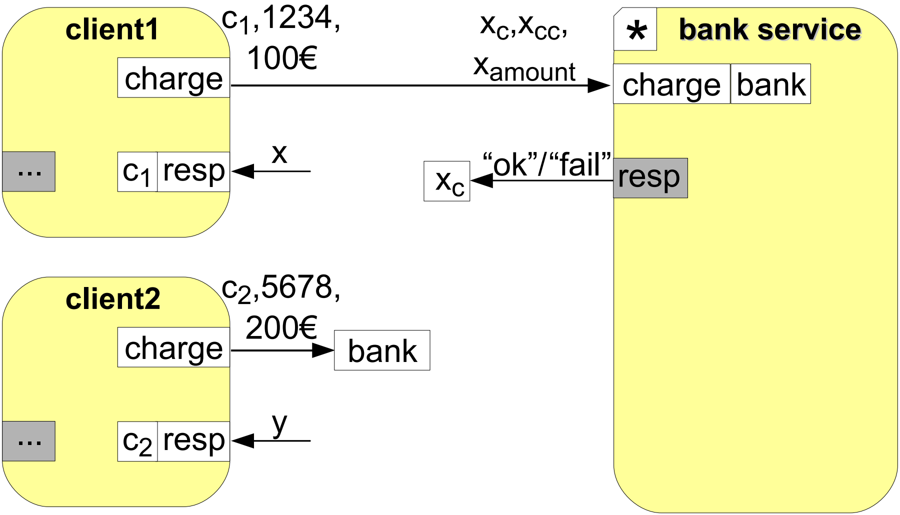


$$\begin{aligned}&\mathrm{bank} \bullet \mathrm{charge}!\langle c_1, 1234, 100€\rangle \mid [x]\, c_1 \bullet \mathrm{resp}?\langle x\rangle.s_1\\ \mid\ &\mathrm{bank} \bullet \mathrm{charge}!\langle c_2, 5678, 200€\rangle \mid [y]\, c_2 \bullet \mathrm{resp}?\langle y\rangle.s_2\end{aligned}$$

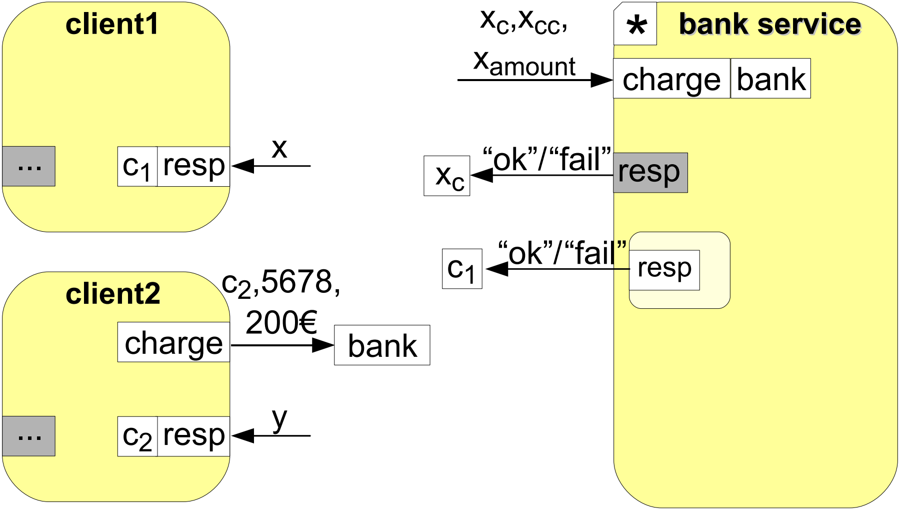
μCOWS^m: *persistent* bank service example



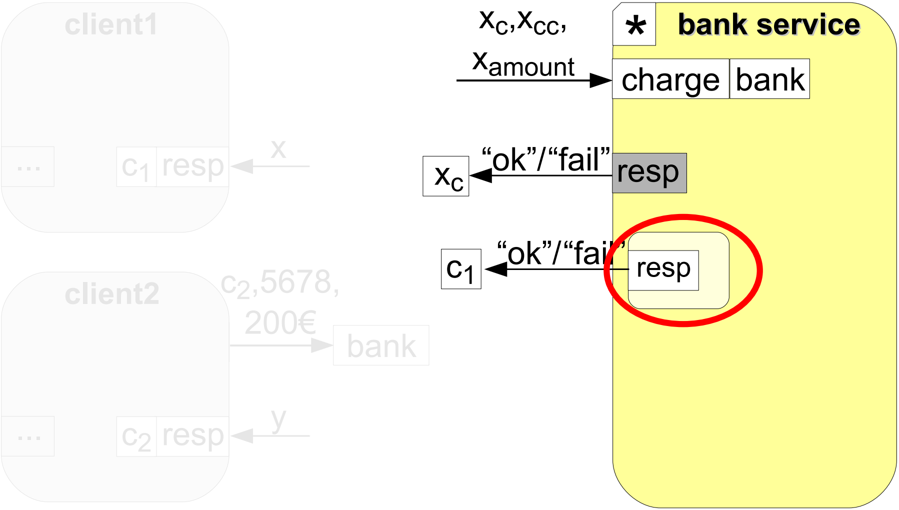
μCOWS^m: *persistent* bank service example



μCOWS^m: *persistent* bank service example



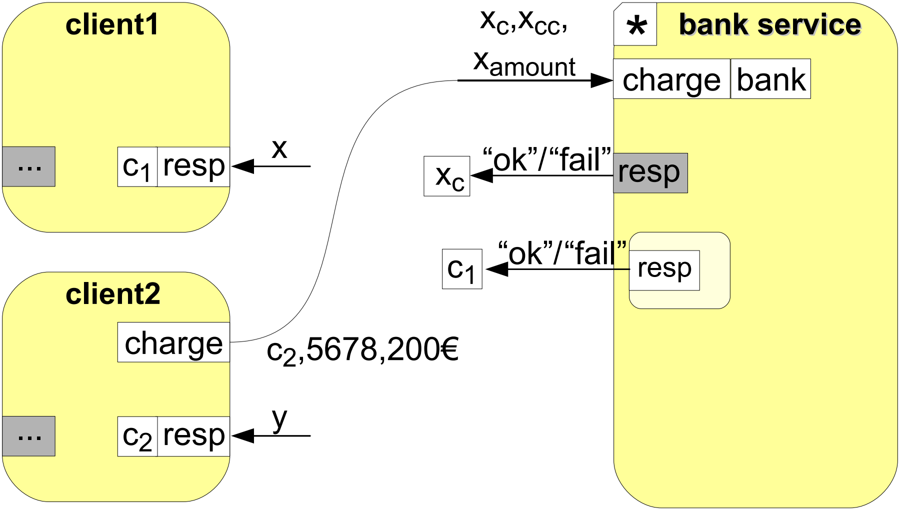
μCOWS^m: *persistent* bank service example



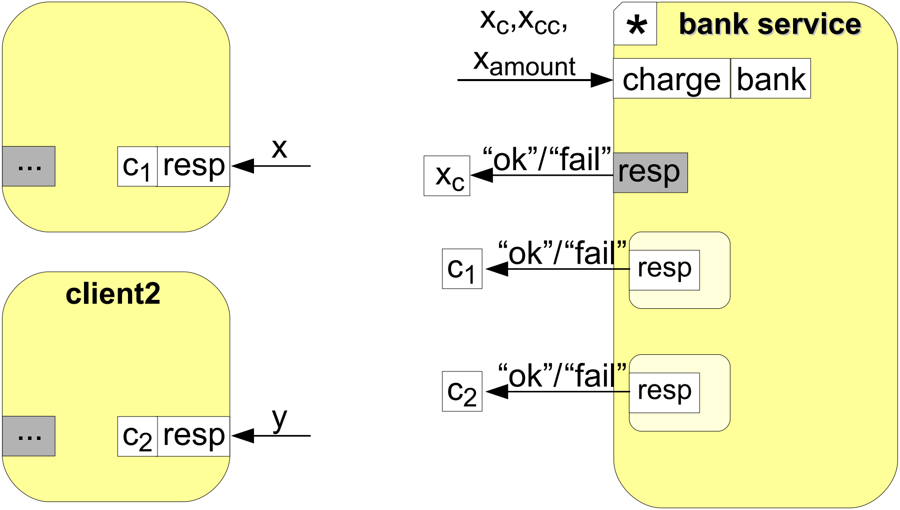
$* [x_c, x_{cc}, x_{amount}]\, \mathrm{bank} \bullet \mathrm{charge}?\langle x_c, x_{cc}, x_{amount}\rangle . x_c \bullet \mathrm{resp}!\langle \mathit{chk}(x_{cc}, x_{amount})\rangle$

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

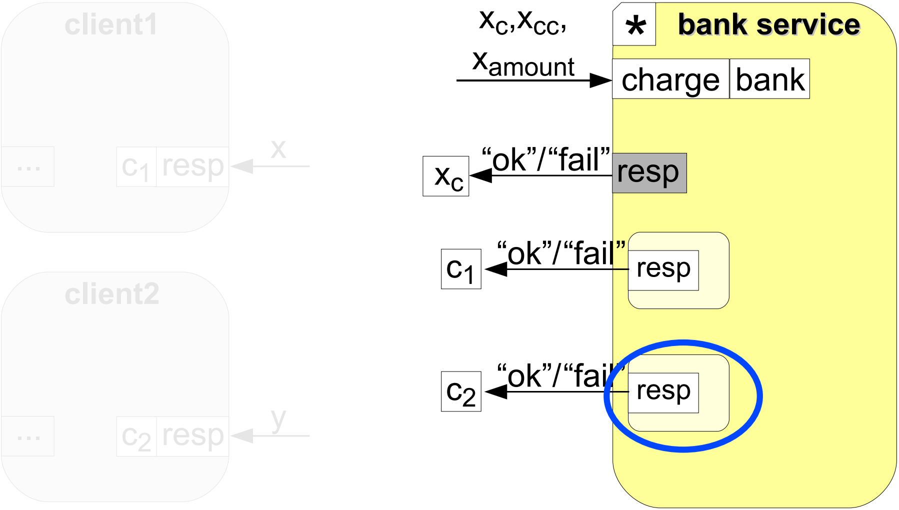
μCOWS^m: *persistent* bank service example



μCOWS^m: *persistent* bank service example



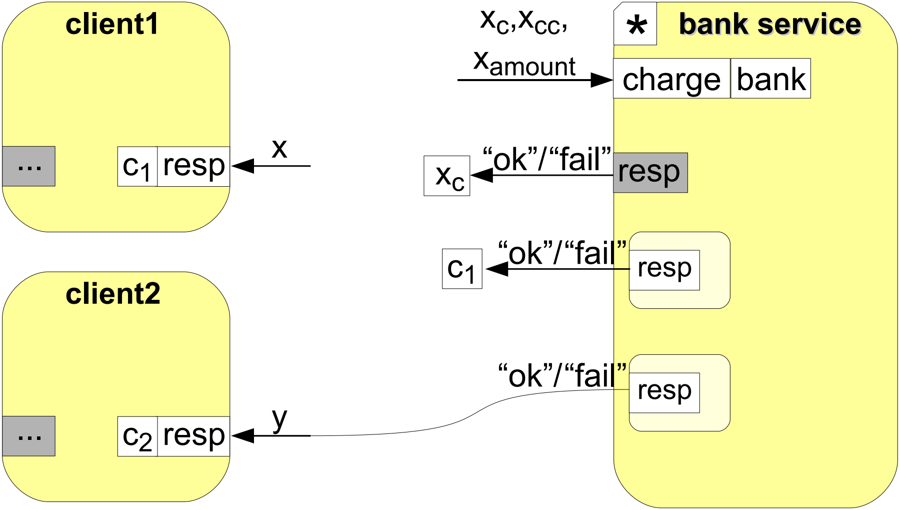
μCOWS^m: *persistent* bank service example



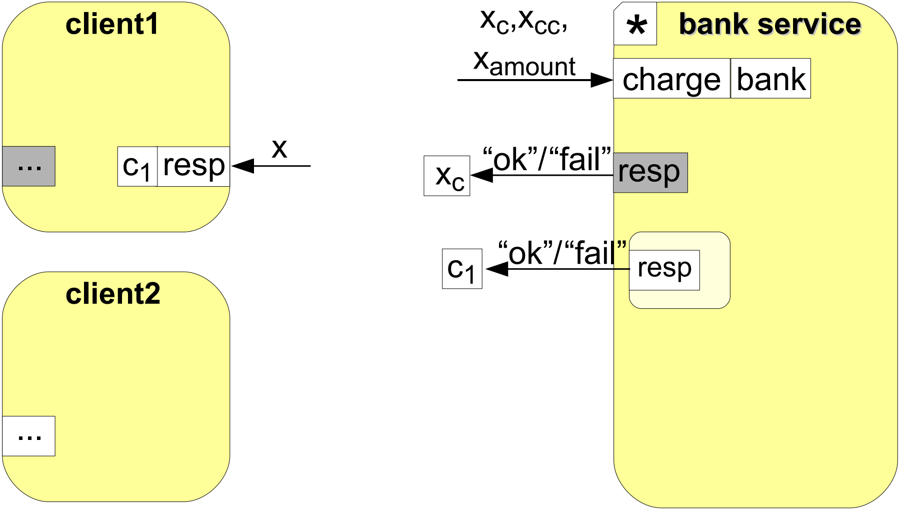
$$* \,[\mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}}]\, \mathrm{bank} \bullet \mathrm{charge}?\langle \mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}}\rangle . \mathrm{x_c} \bullet \mathrm{resp}!\langle chk(x_{cc}, x_{amount})\rangle$$

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

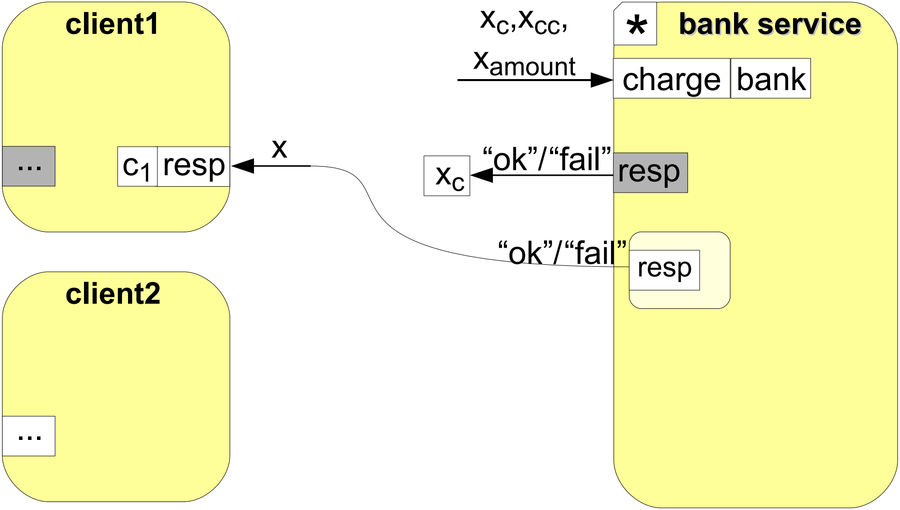
μCOWS^m: *persistent* bank service example



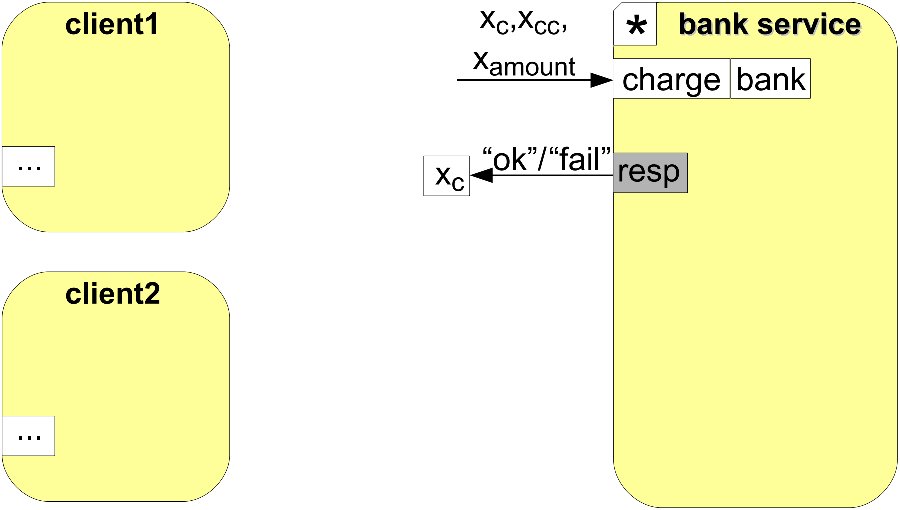
μCOWS^m: *persistent* bank service example



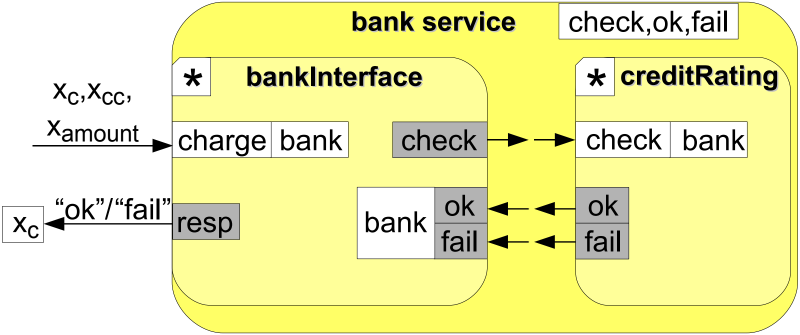
μCOWS^m: *persistent* bank service example



μCOWS^m: *persistent* bank service example

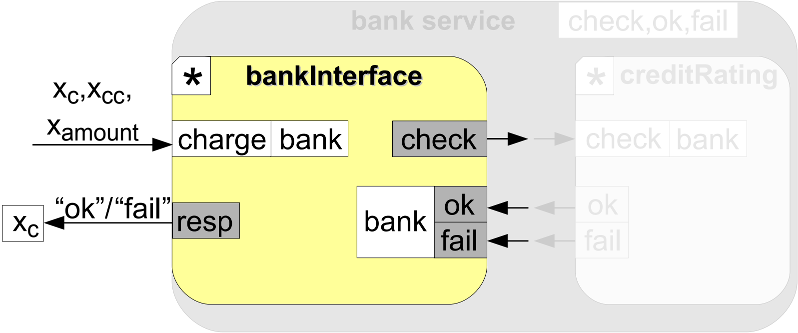


μCOWS^m: *compound* bank service example



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

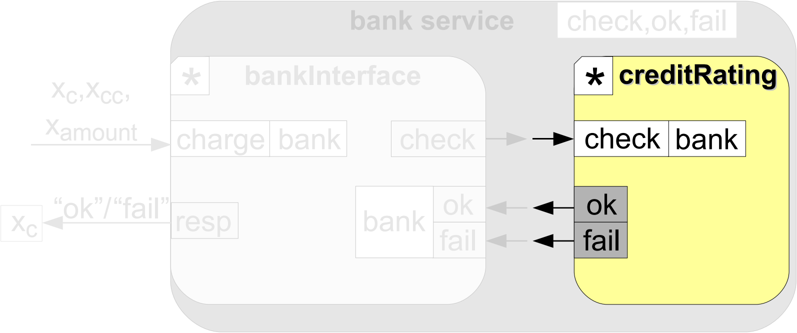
μCOWS^m: *compound* bank service example



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

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

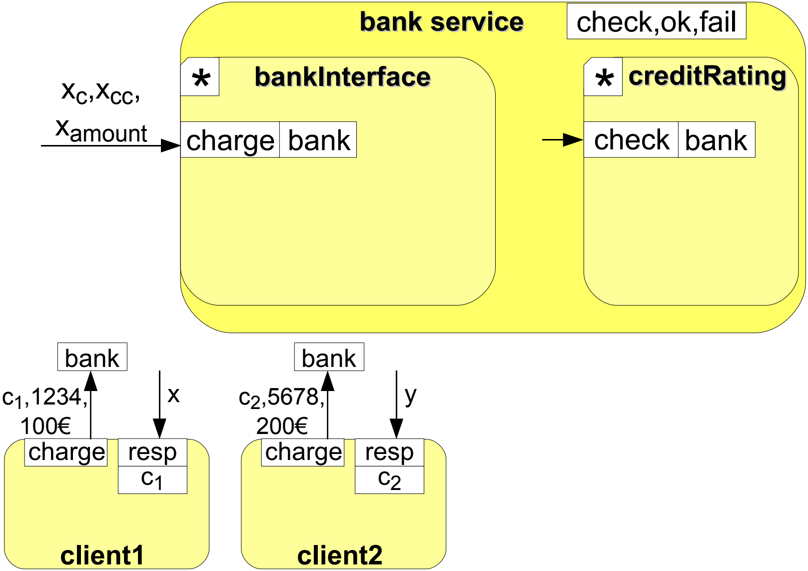
μCOWS^m: *compound* bank service example



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

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

μCOWS^m: *compound* bank service example



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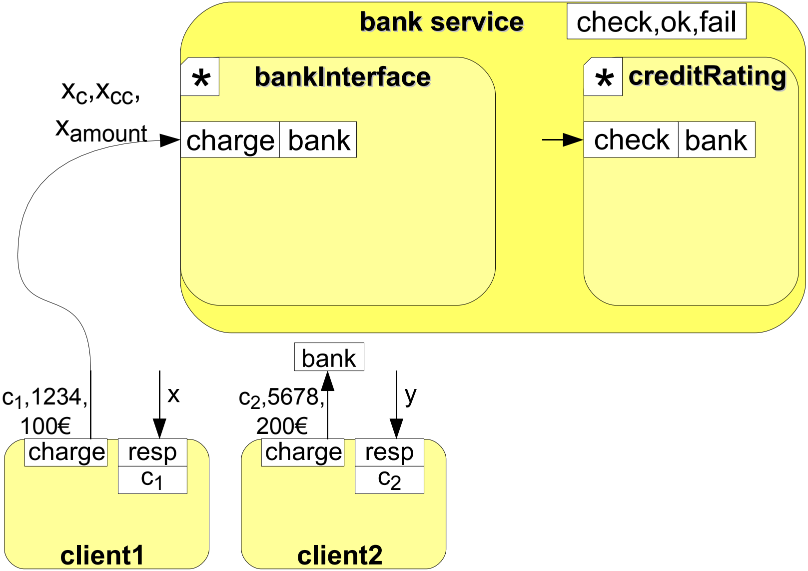

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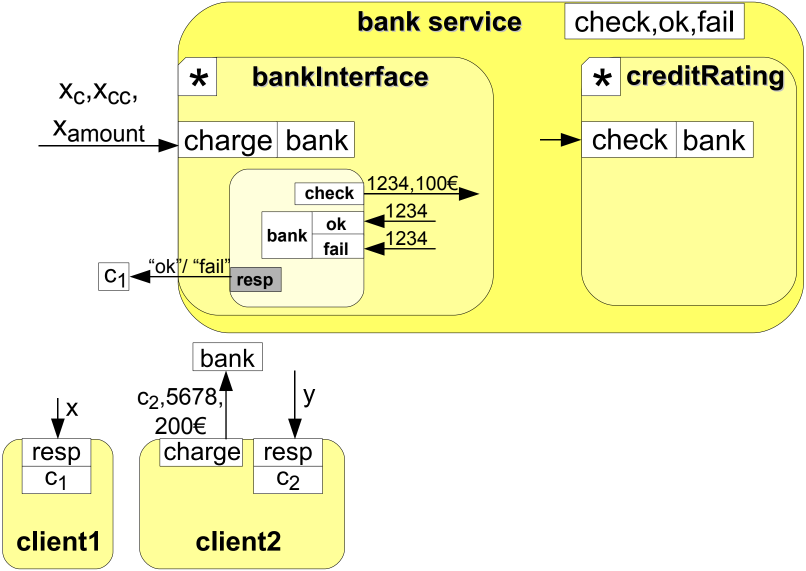
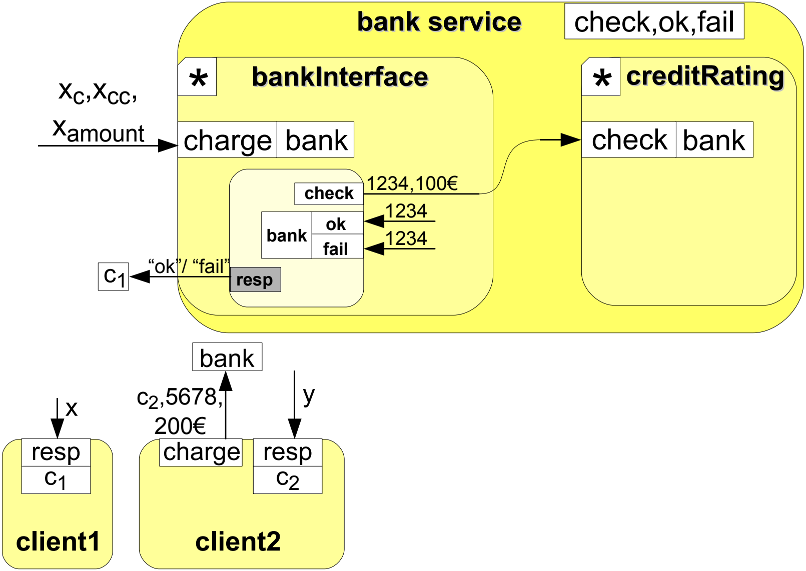
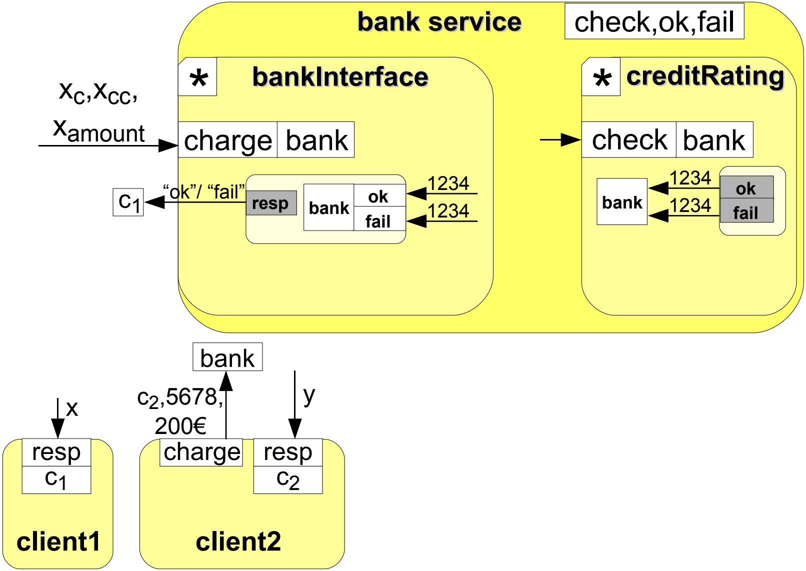


μCOWS^m: *compound* bank service example



μCOWS^m: *compound* bank service example



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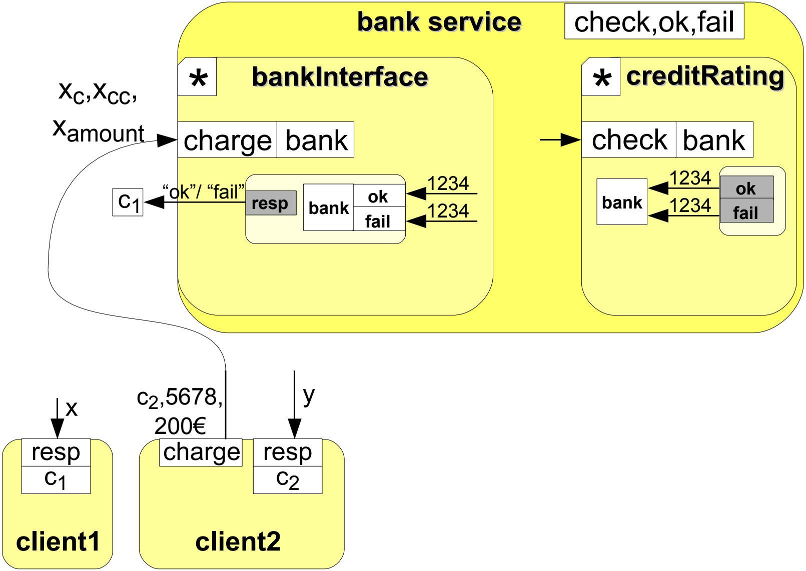

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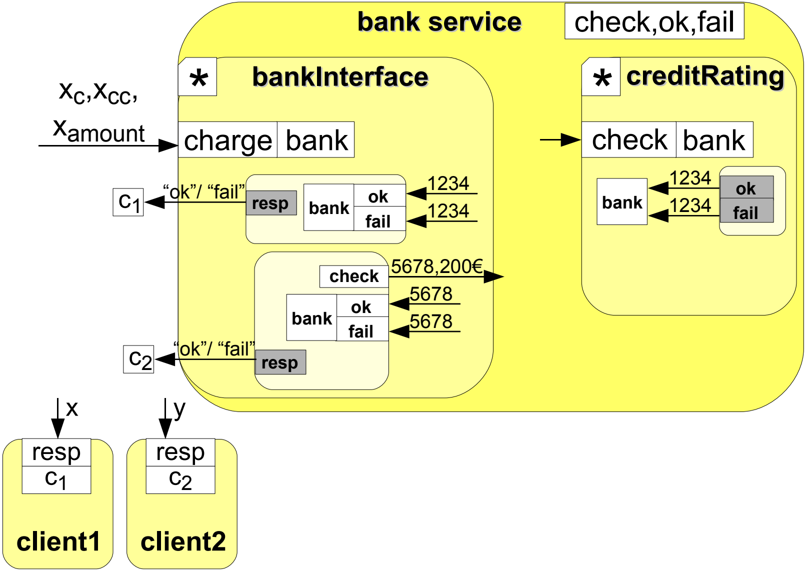
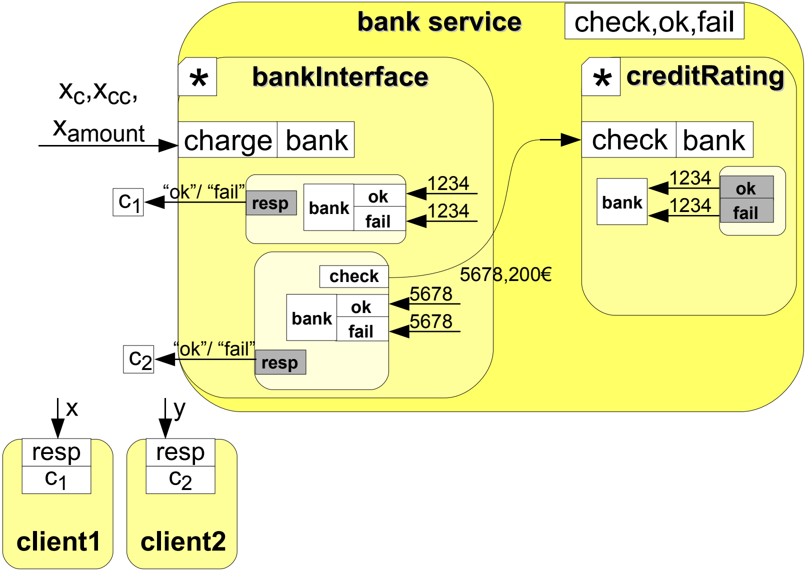


μCOWS^m: *compound* bank service example



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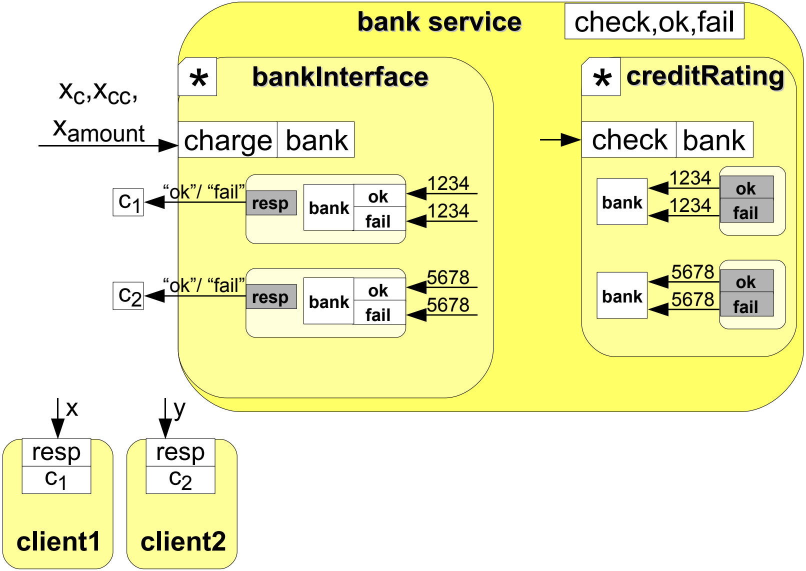

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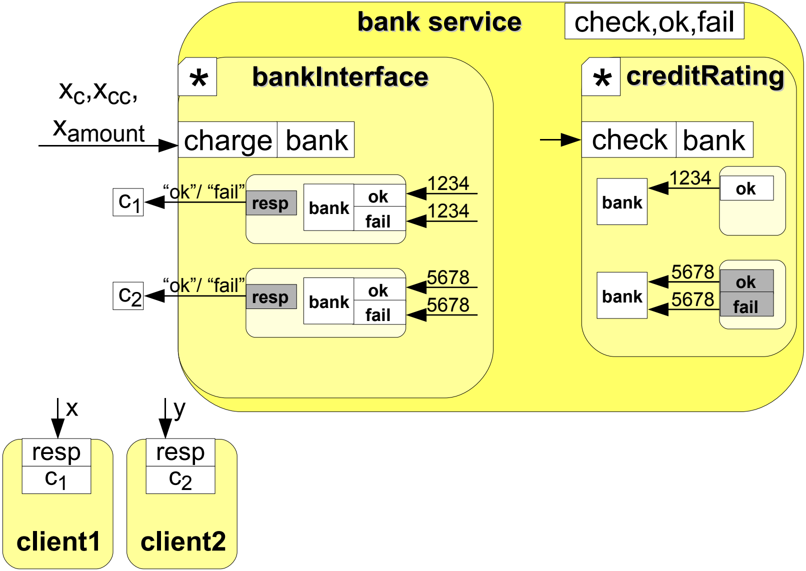


bank service

check,ok,fail

bankInterface

*

$x_c, x_{cc},$

x_{amount}

charge | bank

c_1

"ok"/ "fail"

resp

bank

ok

fail

1234

1234

c_2

"ok"/ "fail"

resp

bank

ok

fail

5678

5678

creditRating

*

check | bank

bank

1234

ok

bank

5678

5678

ok

fail

x

y

resp

c_1

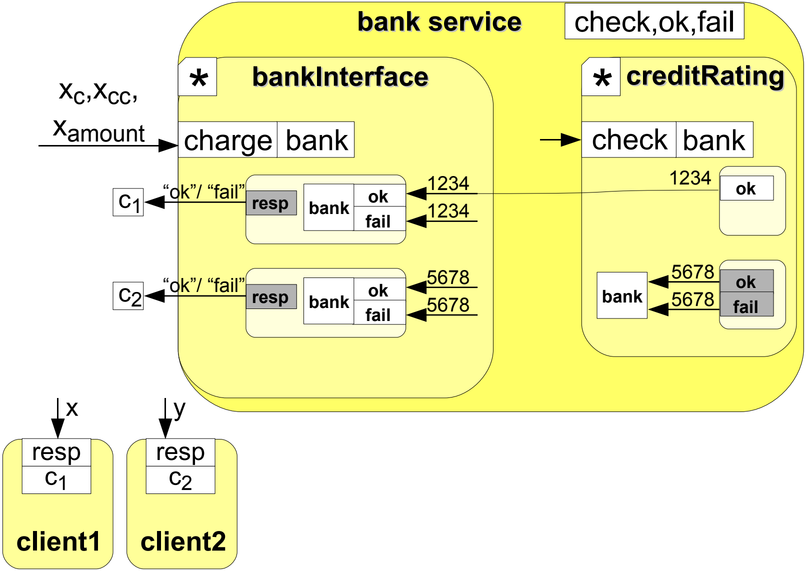
client1

resp

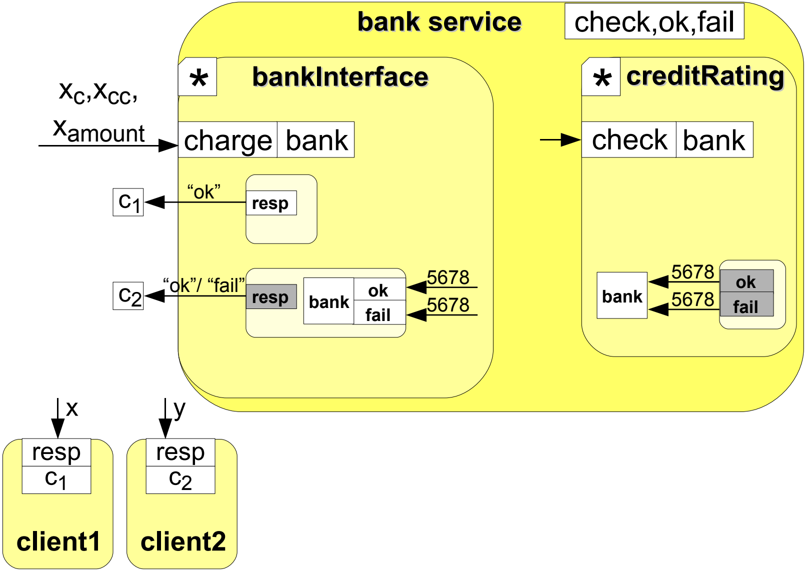
c_2

client2

μCOWS^m: *compound* bank service example



μCOWS^m: *compound* bank service example



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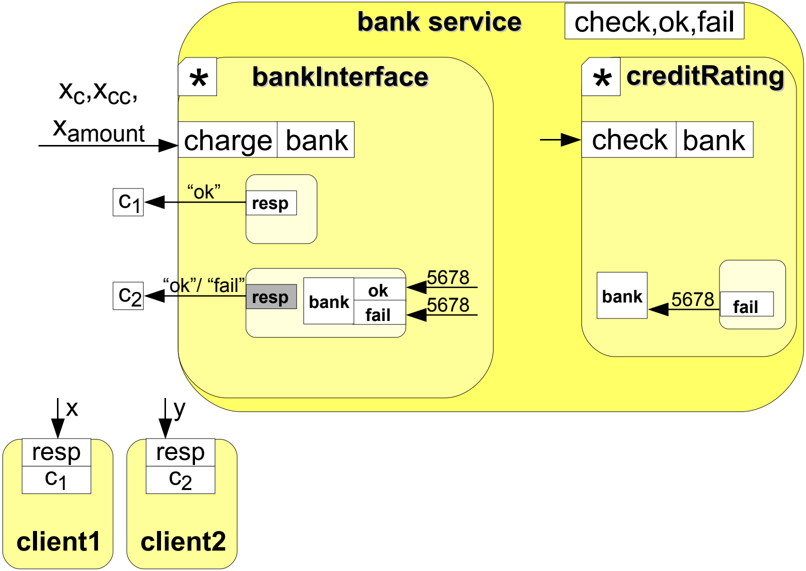

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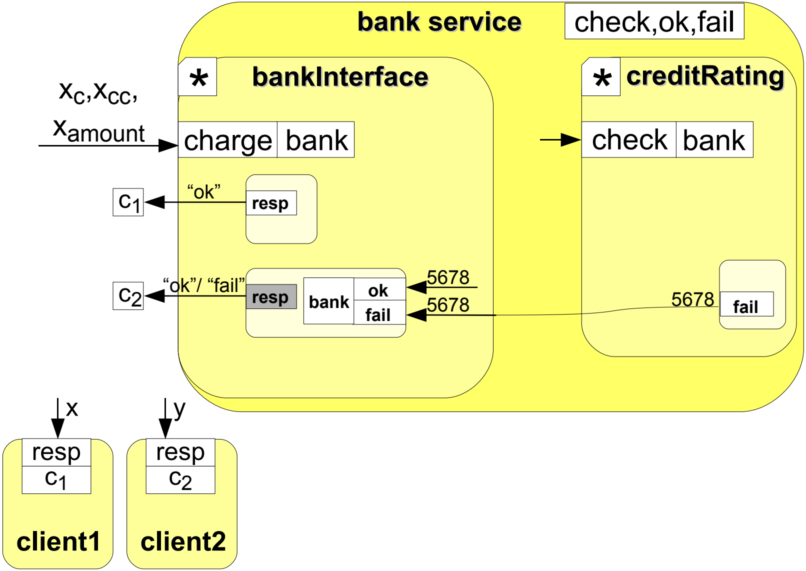

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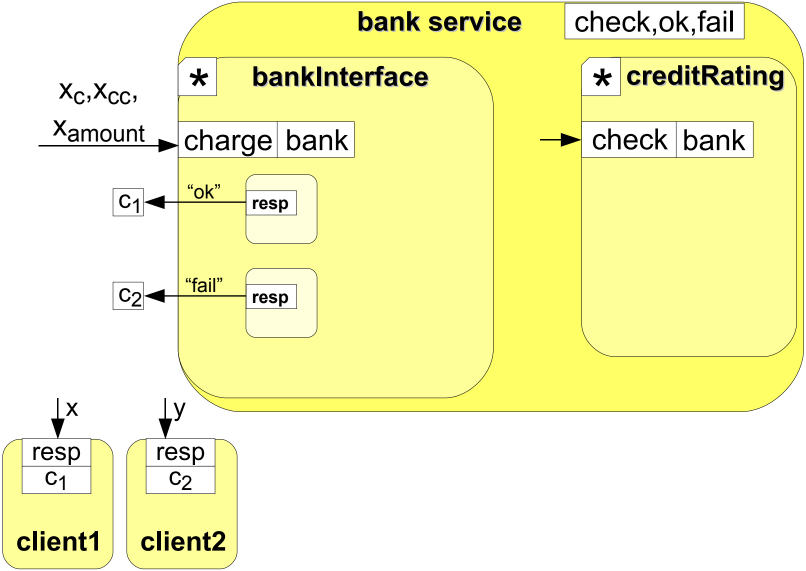

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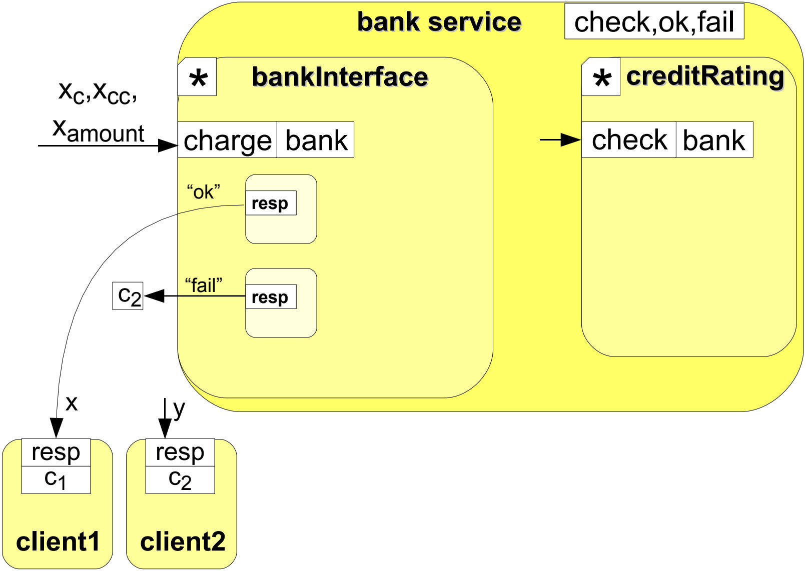

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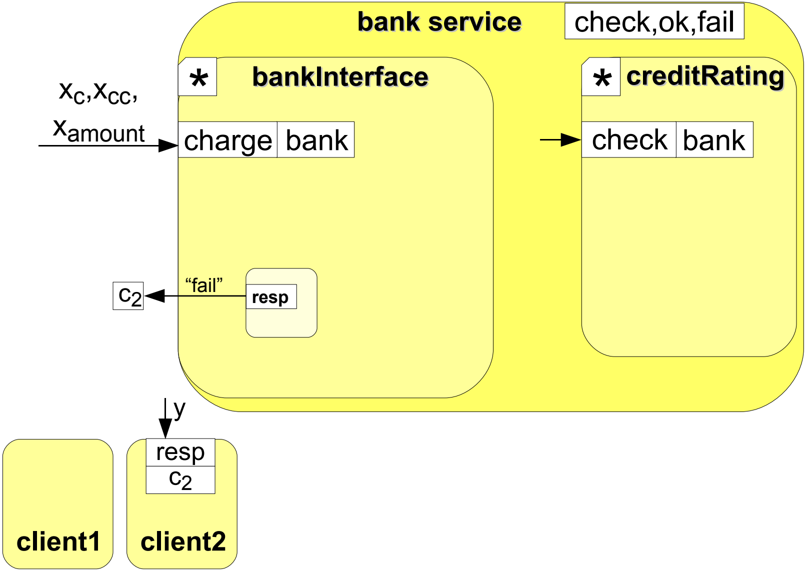

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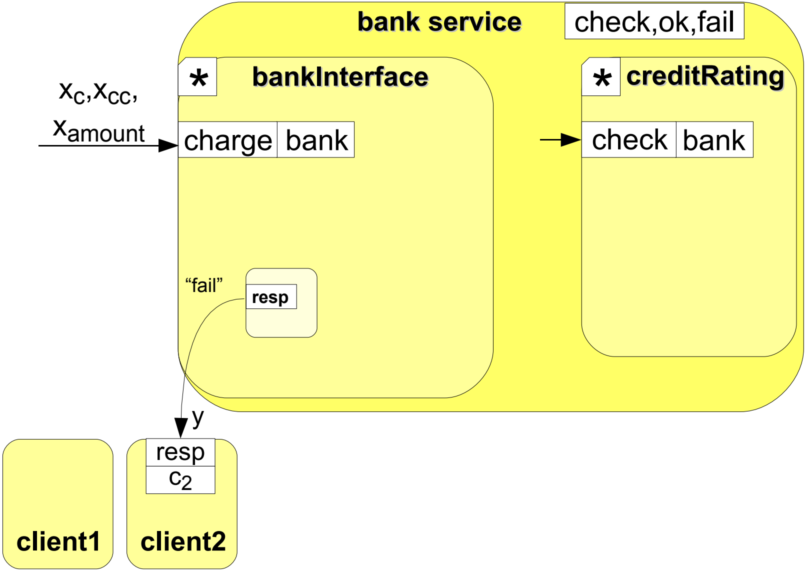

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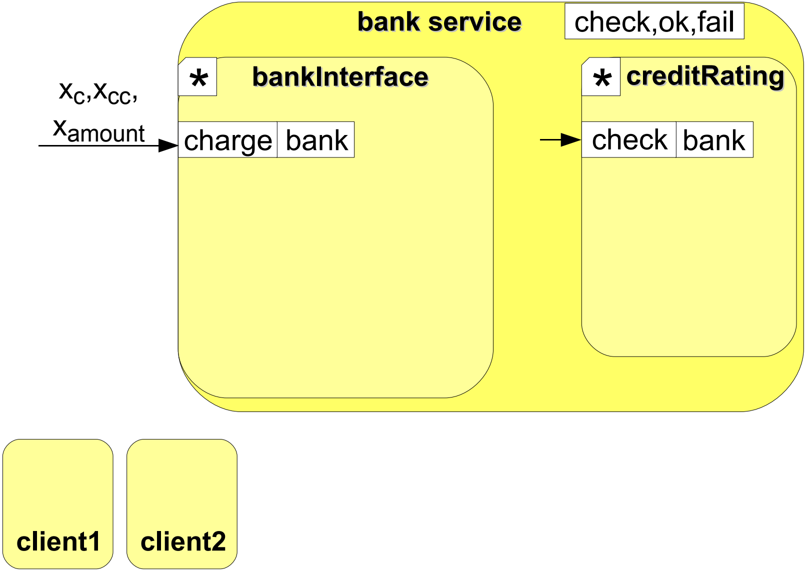

From μCOWS^m to μCOWS

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

μCOWS: why priority in the parallel composition?

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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

μCOWS

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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

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

Conflicting receives predicate

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

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

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

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

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

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

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

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

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

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:

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

μCOWS: Parallel composition with priority

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μCOWS: Parallel composition with priority

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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

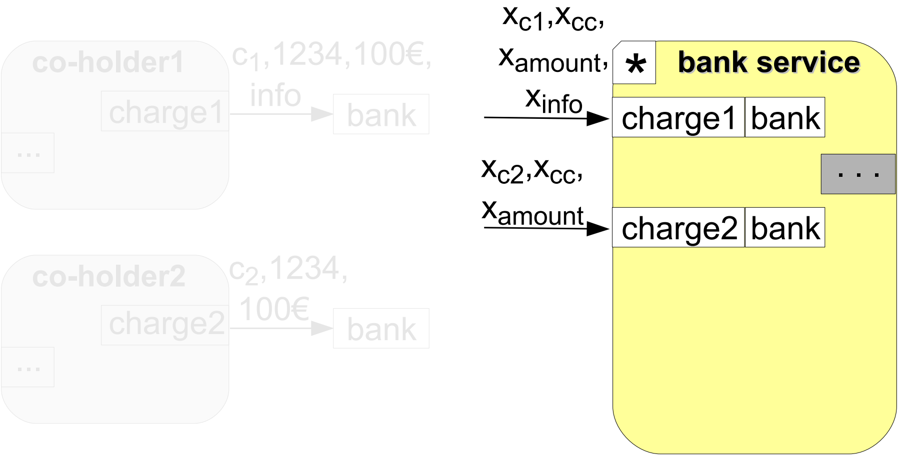
$$\frac{[\![\bar{\epsilon}]\!] = \bar{v}}{\mathrm{n}!\bar{\epsilon} \xrightarrow{\mathrm{n} \lhd \bar{v}} \mathbf{0}} \qquad \frac{1 \le j \le r}{\sum_{i=1}^{r} \mathrm{n}_i?\bar{w}_i.s_i \xrightarrow{\mathrm{n}_j \rhd \bar{w}_j} s_j} \qquad \frac{s \xrightarrow{\alpha} s' \quad u \notin \mathrm{u}(\alpha)}{[u]\,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

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

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

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

μCOWS: *joint account* service example

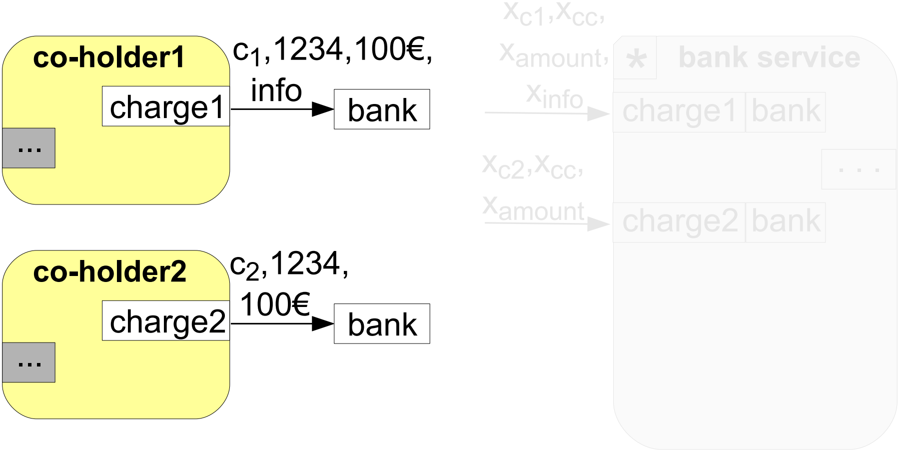


$$* \,[x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}]\,(\,\mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info}\rangle . s_1 \;\mid\; \mathrm{bank} \bullet \mathrm{charge2}?\langle x_{c2}, x_{cc}, x_{amount}\rangle . s_2\,)$$

$$\mid\; (\,\mathrm{bank} \bullet \mathrm{charge1}!\langle c_1, 1234, 100\text{€}, \mathrm{info}\rangle \;\mid\; s_1'\,)$$

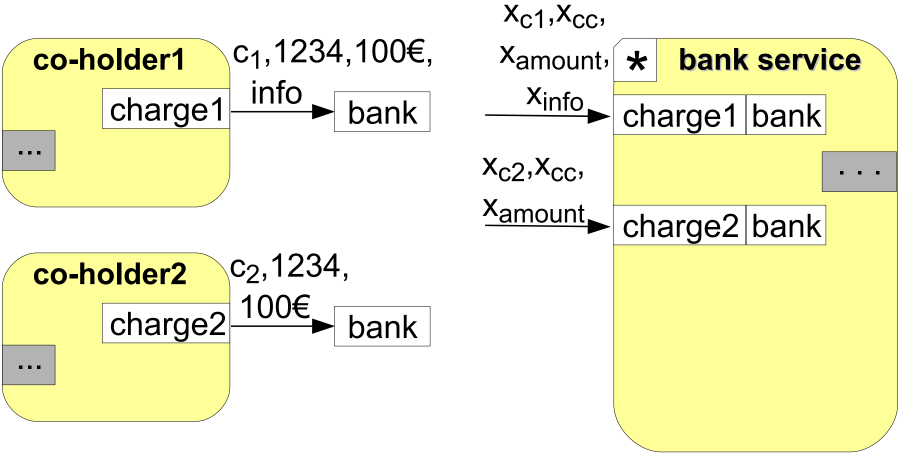
$$\mid\; (\,\mathrm{bank} \bullet \mathrm{charge2}!\langle c_2, 1234, 100\text{€}\rangle \;\mid\; s_2'\,)$$

μCOWS: *joint account* service example



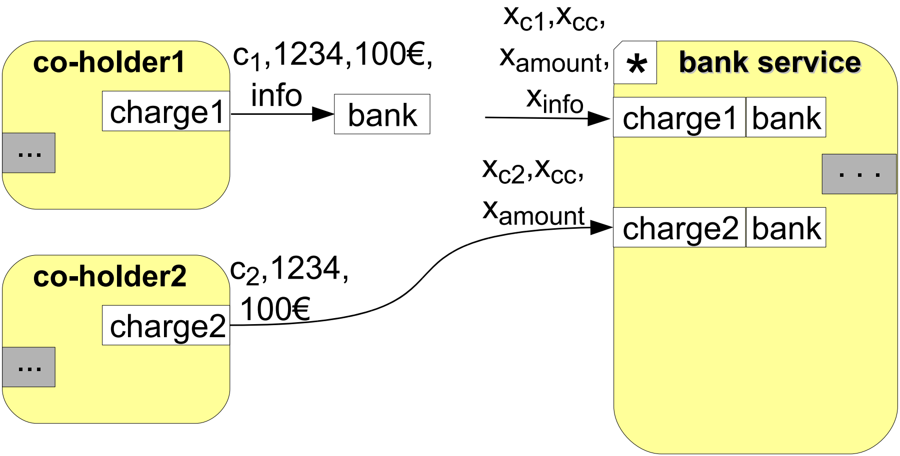
$$
\begin{aligned}
& * \; [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] \, (\mathrm{bank} \bullet \mathrm{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info} \rangle . s_1 \\
& \qquad \mid \mathrm{bank} \bullet \mathrm{charge2}?\langle x_{c2}, x_{cc}, x_{amount} \rangle . s_2 \,) \\
\mid \; & (\mathrm{bank} \bullet \mathrm{charge1}!\langle c_1, 1234, 100\text{€}, \mathrm{info} \rangle \mid s'_1 \,) \\
\mid \; & (\mathrm{bank} \bullet \mathrm{charge2}!\langle c_2, 1234, 100\text{€} \rangle \mid s'_2 \,)
\end{aligned}
$$

μCOWS: *joint account* service example



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

μCOWS: *joint account* service example



co-holder1

charge1

...

c_1,1234,100€, info

bank

x_{c1},x_{cc}, x_{amount}, x_{info}

*

bank service

charge1 bank

. . .

x_{c2},x_{cc}, x_{amount}

charge2 bank

co-holder2

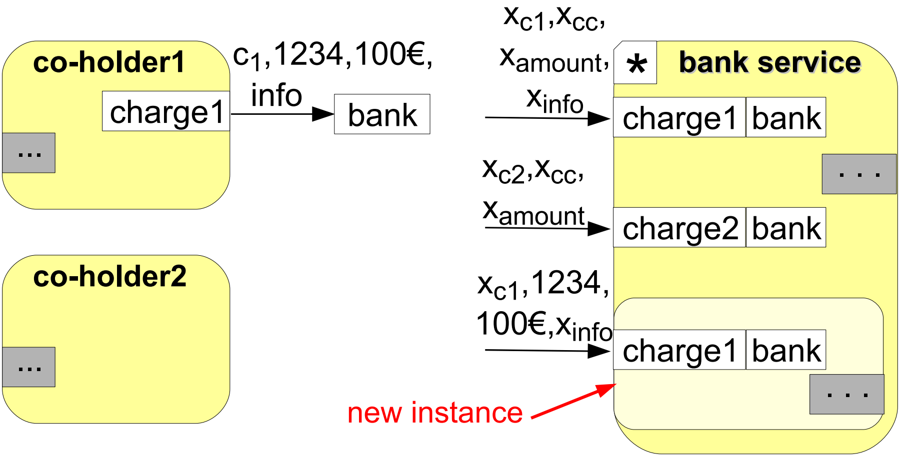
charge2

...

c_2,1234, 100€

$$\begin{aligned}
&* \, [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] \, (\, \text{bank} \bullet \text{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info} \rangle . s_1 \\
&\qquad\qquad\qquad\qquad\qquad \mid \; \text{bank} \bullet \text{charge2}?\langle x_{c2}, x_{cc}, x_{amount} \rangle . s_2 \,) \\
&\mid \; (\, \text{bank} \bullet \text{charge1}!\langle c_1, 1234, 100\text{€}, \text{info} \rangle \;\mid\; s'_1 \,) \\
&\mid \; (\, \text{bank} \bullet \text{charge2}!\langle c_2, 1234, 100\text{€} \rangle \;\mid\; s'_2 \,)
\end{aligned}$$

μCOWS: *joint account* service example



co-holder1

charge1

c_1,1234,100€, info

bank

...

co-holder2

...

x_{c1},x_{cc}, x_{amount}, x_{info}

$*$

bank service

charge1 bank

. . .

x_{c2},x_{cc}, x_{amount}

charge2 bank

x_{c1},1234, 100€,x_{info}

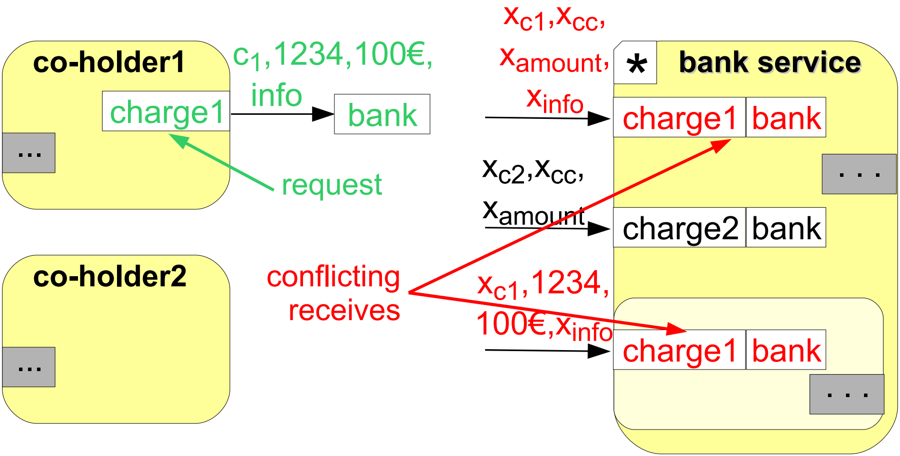
charge1 bank

. . .

new instance

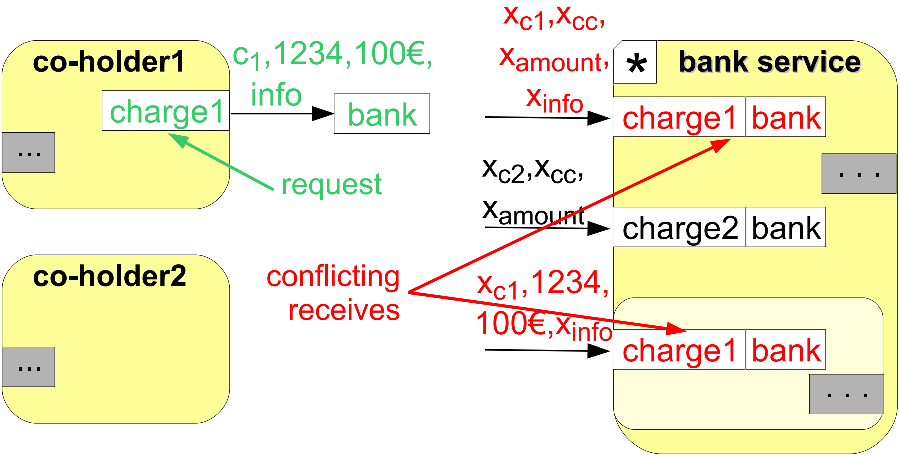
$$\begin{aligned}
&* \,[x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}]\, (\,\mathsf{bank} \bullet \mathsf{charge1}?\langle x_{c1}, x_{cc}, x_{amount}, x_{info}\rangle . s_1 \\
&\qquad\qquad\qquad\qquad \mid \mathsf{bank} \bullet \mathsf{charge2}?\langle x_{c2}, x_{cc}, x_{amount}\rangle . s_2\,) \\
&\mid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

μCOWS: *joint account* service example



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

μCOWS: *joint account* service example

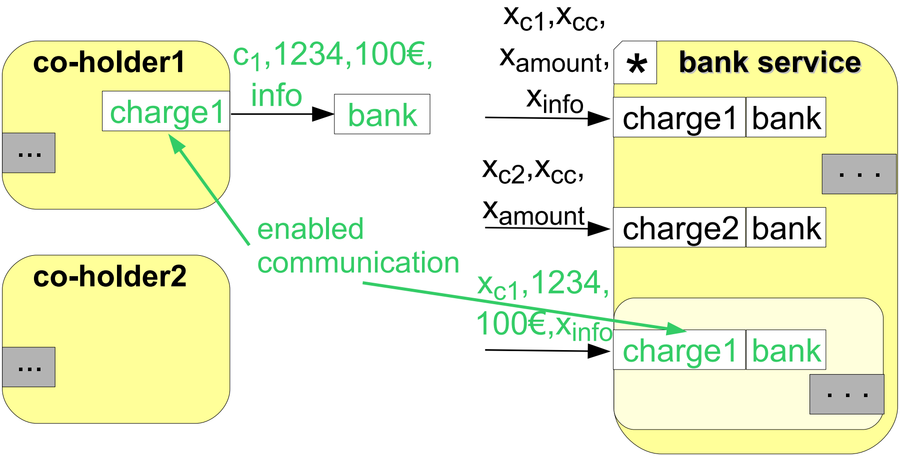


Multiple start activities

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

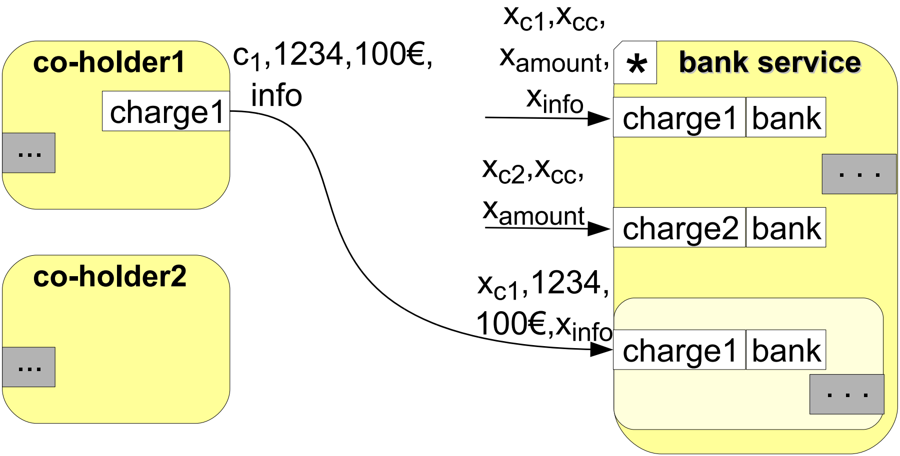
- the first incoming message triggers creation of a service instance
- subsequent messages are delivered to the created instance

μCOWS: *joint account* service example



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

μCOWS: *joint account* service example



co-holder1

charge1

...

c_1,1234,100€, info

co-holder2

...

x_{c1},x_{cc}, x_{amount}, x_{info}

*****

bank service

charge1 bank

. . .

x_{c2},x_{cc}, x_{amount}

charge2 bank

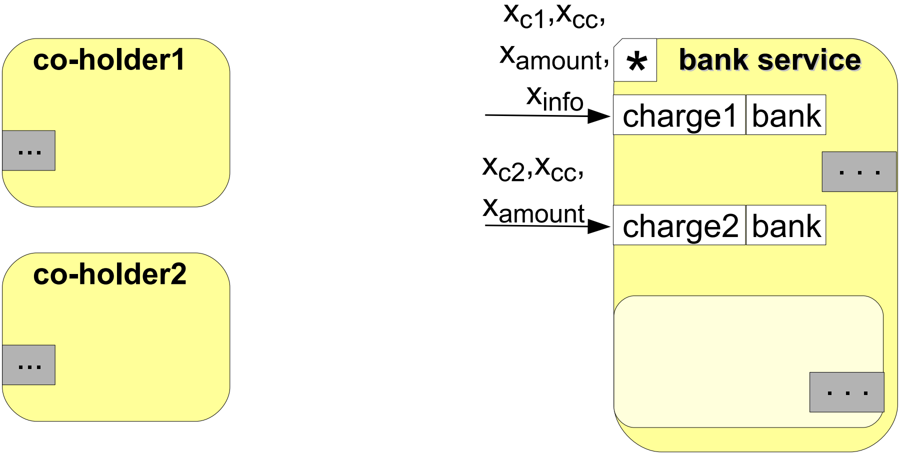
x_{c1},1234, 100€,x_{info}

charge1 bank

. . .

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

μCOWS: *joint account* service example



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

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

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

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

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

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

Parallel with priority as a coordination mechanism

‘Blind date’ session joining

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& \quad \mathit{master} \bullet \mathit{join}?\langle x_{game}, x_{player1}\rangle. \\
& \quad \mathit{master} \bullet \mathit{join}?\langle x_{game}, x_{player2}\rangle. \\
& \quad \mathit{master} \bullet \mathit{join}?\langle x_{game}, x_{player3}\rangle. \\
& \quad \mathit{master} \bullet \mathit{join}?\langle x_{game}, x_{player4}\rangle. \\
& \qquad [\mathit{matchId}]\,(\, x_{player1} \bullet \mathit{start}!\langle \mathit{matchId}\rangle \\
& \qquad\qquad\quad \mid x_{player2} \bullet \mathit{start}!\langle \mathit{matchId}\rangle \\
& \qquad\qquad\quad \mid x_{player3} \bullet \mathit{start}!\langle \mathit{matchId}\rangle \\
& \qquad\qquad\quad \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

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

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

(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

- $\{\!|\mathbf{0}|\!\} \;\equiv\; \mathbf{0} \qquad \{\!|\,\{\!|s|\!\}\,|\!\} \;\equiv\; \{\!|s|\!\} \qquad \{\!|[e]\,s|\!\} \;\equiv\; [e]\,\{\!|s|\!\}$
- $s_1 \mid [e]\,s_2 \;\equiv\; [e]\,(s_1 \mid s_2) \quad \mathrm{if}\ e \notin \mathrm{fe}(s_1) \cup \mathrm{fk}(s_2)$
  - $\mathrm{fe}(s)$ 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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$$\frac{s \xrightarrow{\alpha} s' \quad e \notin \mathrm{e}(\alpha) \quad \alpha \neq k, \dagger \quad \mathrm{noKill}(s, e)}{[e]\, s \xrightarrow{\alpha} [e]\, s'}$$

Predicate $\mathrm{noKill}(s, e)$ (part 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 $e \neq k$

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

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

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

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

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

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

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

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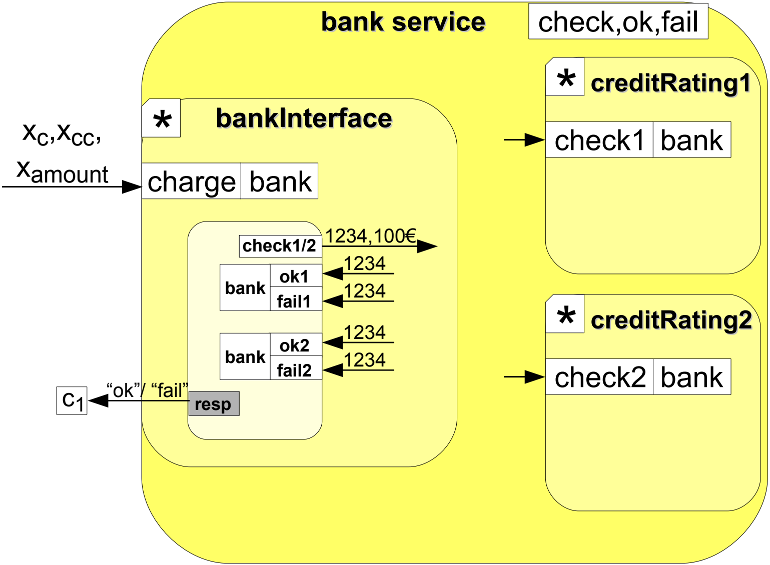
COWS: *multi rating* bank service example



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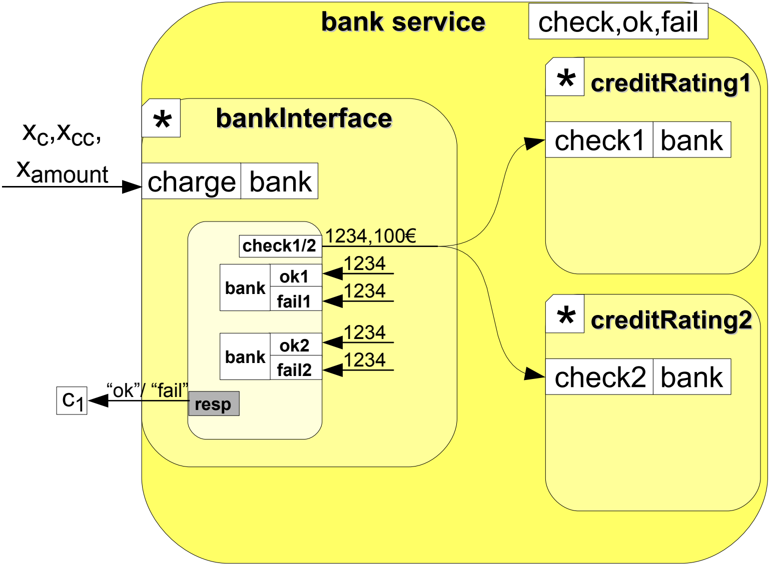

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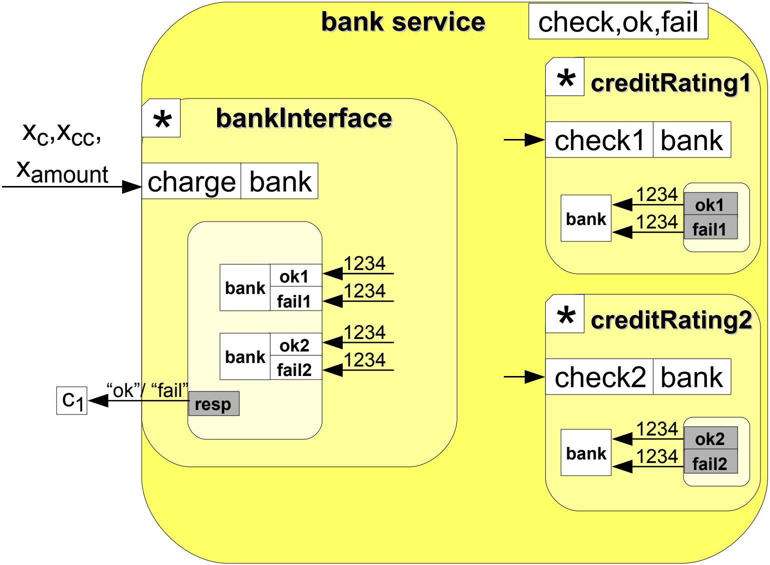

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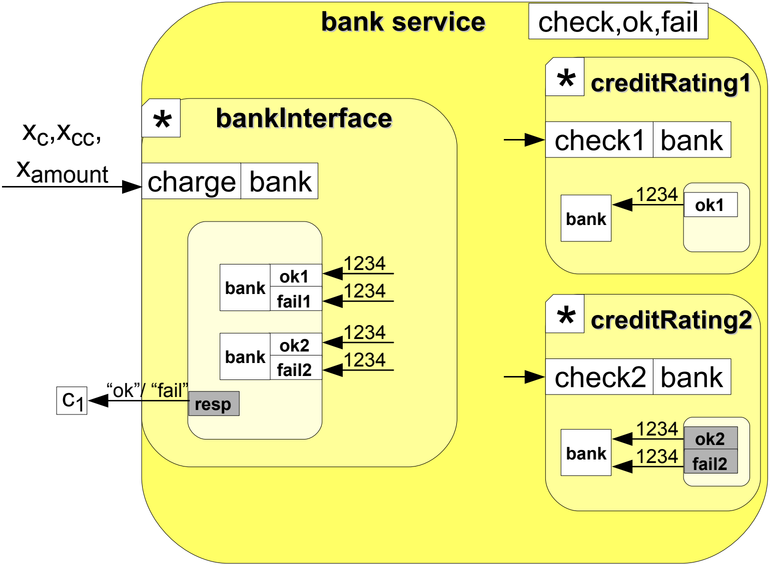

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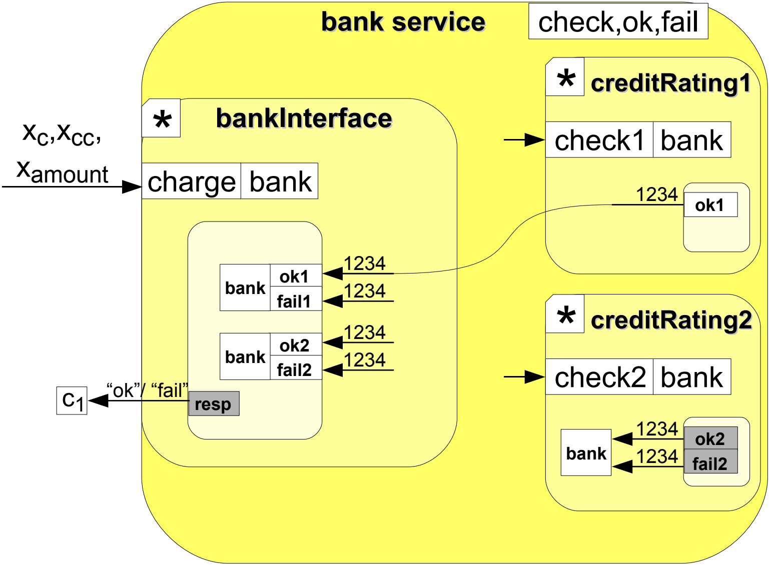

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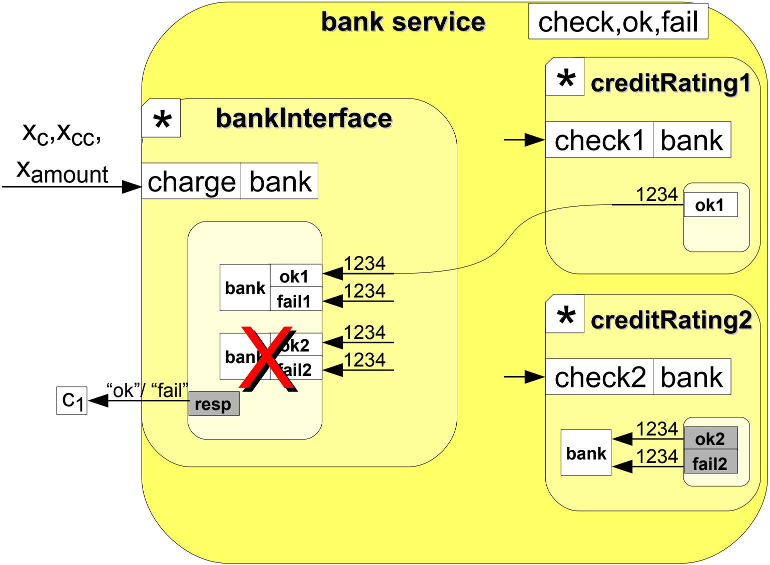

COWS: *multi rating* bank service example

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

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

COWS: peculiar examples

Protected kill activity

- Execution of a kill activity within a protection block

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

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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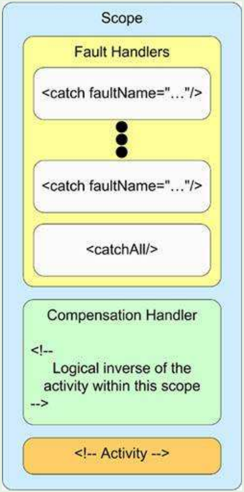
COWS: fault and compensation handling

Scope



Scope

Fault Handlers

<catch faultName="..."/>

<catch faultName="..."/>

<catchAll/>

Compensation Handler

<!--
Logical inverse of the activity within this scope
-->

<!-- Activity -->

COWS: fault and compensation handling

Syntax for compensation

$$\begin{array}{lll} s ::= & \ldots & (\textit{services}) \\ \mid & \textbf{throw}(\phi) & (\textit{fault generator}) \\ \mid & \textbf{compensate}(i) & (\textit{compensate}) \\ \mid & [s : \textbf{catch}(\phi_1)\{s_1\} : \ldots : \textbf{catch}(\phi_n)\{s_n\} : s_c]_i & (\textit{scope}) \end{array}$$

- **throw**(ϕ): rises a fault signal ϕ that triggers execution of s if a construct **catch**(ϕ)$\{s\}$ exists within the same scope
- **compensate**(i): invokes a compensation handler of an inner scope i that has already completed normally (i.e. without faulting)
- $[s : \textbf{catch}(\phi_1)\{s_1\} : \ldots : \textbf{catch}(\phi_n)\{s_n\} : s_c]_i$: is uniquely identified by i and groups together a service s (the normal behaviour), an optional list of fault handlers, and a compensation handler s_c

COWS: fault and compensation handling

Encoding

$$
\begin{aligned}
\langle\!\langle [s : \textbf{catch}(\phi_1)\{s_1\} : \ldots : \textbf{catch}(\phi_n)\{s_n\} : s_c]_i \rangle\!\rangle_k \ = \ & [\phi_1, \ldots, \phi_n]\ (\ \langle\!\langle \textbf{catch}(\phi_1)\{s_1\} \rangle\!\rangle_k \mid \ \ldots \ \mid \langle\!\langle \textbf{catch}(\phi_n)\{s_n\} \rangle\!\rangle_k \\
& \mid [k_i]\ \langle\!\langle s \rangle\!\rangle_{k_i}\ ;\ (\ x_{done} \bullet o_{done}!\langle\rangle \mid [k']\ \{\!|\mathtt{undo}?\langle i \rangle.\langle\!\langle s_c \rangle\!\rangle_{k'} |\!\}\ )\ )
\end{aligned}
$$

$$\langle\!\langle \textbf{catch}(\phi)\{s\} \rangle\!\rangle_k \ = \ \mathtt{throw}?\langle\phi\rangle.[k']\ \langle\!\langle s \rangle\!\rangle_{k'}$$

$$\langle\!\langle \textbf{compensate}(i) \rangle\!\rangle_k \ = \ \mathtt{undo}!\langle i \rangle \mid x_{done} \bullet o_{done}!\langle\rangle$$

$$\langle\!\langle \textbf{throw}(\phi) \rangle\!\rangle_k \ = \ \{\!|\mathtt{throw}!\langle\phi\rangle|\!\}\ \mid \textbf{kill}(k)$$

- s_c is installed when the normal behaviour s successfully completes, but it is activated only when signal $\mathtt{undo}!\langle i \rangle$ occurs
- Whenever a fault ϕ occurs, a signal $\mathtt{throw}!\langle\phi\rangle$ triggers execution of the corresponding fault handler (if any), while installed compensation handlers are protected from killing by means of $\{\!|\_|\!\}$
- ‘;’ denotes sequential composition, that can be easily encoded in COWS alike in CCS

COWS: fault and compensation handling

Encoding

$$\begin{aligned}\langle\!\langle [s : \mathbf{catch}(\phi_1)\{s_1\} : \ldots : \mathbf{catch}(\phi_n)\{s_n\} : s_c]_i \rangle\!\rangle_k \; = \;& [\phi_1, \ldots, \phi_n]\;(\,\langle\!\langle \mathbf{catch}(\phi_1)\{s_1\}\rangle\!\rangle_k \mid \ldots \mid \langle\!\langle \mathbf{catch}(\phi_n)\{s_n\}\rangle\!\rangle_k \\ & \mid [k_i]\,\langle\!\langle s \rangle\!\rangle_{k_i}\,;(\,x_{done} \bullet o_{done}!\langle\rangle \mid [k']\,\{\!|\,\texttt{undo?}\langle i\rangle.\langle\!\langle s_c\rangle\!\rangle_{k'}\,|\!\}\,)\,)\end{aligned}$$

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& \mid [k_i] \, \langle\!\langle s \rangle\!\rangle_{k_i} \, ; (\, x_{done} \bullet o_{done}!\langle\rangle \mid [k'] \, \{\!|\mathtt{undo}?\langle i \rangle . \langle\!\langle s_c \rangle\!\rangle_{k'} |\!\} \,)\,)
\end{aligned}
$$

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COWS: fault and compensation handling

Encoding

$$\begin{aligned}\langle\!\langle [s : \textbf{catch}(\phi_1)\{s_1\} : \ldots : \textbf{catch}(\phi_n)\{s_n\} : s_c]_i \rangle\!\rangle_k \;=\;& [\phi_1,\ldots,\phi_n]\,(\,\langle\!\langle \textbf{catch}(\phi_1)\{s_1\}\rangle\!\rangle_k \mid \;\ldots\; \mid \langle\!\langle \textbf{catch}(\phi_n)\{s_n\}\rangle\!\rangle_k \\ & \mid [k_i]\,\langle\!\langle s\rangle\!\rangle_{k_i} \,;\, (\,x_{done}\bullet o_{done}!\langle\rangle \mid [k']\,\{\!|\texttt{undo}?\langle i\rangle.\langle\!\langle s_c\rangle\!\rangle_{k'}|\!\}\,)\,)\end{aligned}$$

$$\langle\!\langle \textbf{catch}(\phi)\{s\}\rangle\!\rangle_k = \texttt{throw}?\langle\phi\rangle.[k']\,\langle\!\langle s\rangle\!\rangle_{k'}$$

$$\langle\!\langle \textbf{compensate}(i)\rangle\!\rangle_k = \texttt{undo}!\langle i\rangle \mid x_{done}\bullet o_{done}!\langle\rangle$$

$$\langle\!\langle \textbf{throw}(\phi)\rangle\!\rangle_k = \{\!|\texttt{throw}!\langle\phi\rangle|\!\} \mid \textbf{kill}(k)$$

- s_c is installed when the normal behaviour s successfully completes, but it is activated only when signal $\texttt{undo}!\langle i\rangle$ occurs
- Whenever a fault ϕ occurs, a signal $\texttt{throw}!\langle\phi\rangle$ triggers execution of the corresponding fault handler (if any), while installed compensation handlers are protected from killing by means of $\{\!|\_|\!\}$
- ‘;’ denotes sequential composition, that can be easily encoded in COWS alike in CCS

Considerations on COWS expressiveness

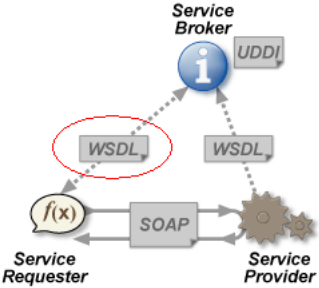
- Encoding other calculi
  - π-calculus, Localized π-calculus (Lπ), . . .
  - SCC (Session Centered Calculus)
  - Orc
  - WS-CALCULUS
  - B*lite* (a lightweight version of WS-BPEL)
- COWS (like other calculi equipped with priority) is not encodable into mainstream calculi (e.g. CCS and π-calculus) [EXPRESS'10]
- 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]

QoS specifications and SLA negotiations

- We have demonstrated so far that COWS can model service specification, orchestration, reconfiguration, and execution
- Now, we focus on other important phases of the life cycle of service-oriented applications
- We want now to show that service publication, discovery and SLA negotiation can be naturally modelled in COWS
- We exploit ‘constraints’ and operations on them

Discovery and Negotiation

- In a SOA, requesters should be able to *discover* functionalities



- Service descriptions should include both functional and non-functional aspects (*Quality of Service*, QoS)
- Dynamic service discovery can rely on a negotiation mechanism
  - negotiation allows two or more parties to reach a joint agreement about cost and quality of a service
  - the outcome is a contract, called *Service Level Agreement* (SLA)

Dealing with QoS and SLA in COWS

- COWS syntax and semantics are parametrically defined w.r.t.:
  - the set of manipulable values
  - the syntax of expressions
  - the definition of the pattern-matching function

- We appropriately specialize these parameters
  - expressions also include *constraints* and *constraint multisets*
  - additional rules tailor pattern-matching to operations on constraints

- The specialized language combines basic features of *name-passing calculi* and of *concurrent constraint programming*
  - SLA requirements are constraints that can be dynamically generated and composed
  - At the end of the negotiation process, if the resulting set of constraints is consistent then it represents the reached agreement

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A credit card issue scenario

client

needs a credit card

bank

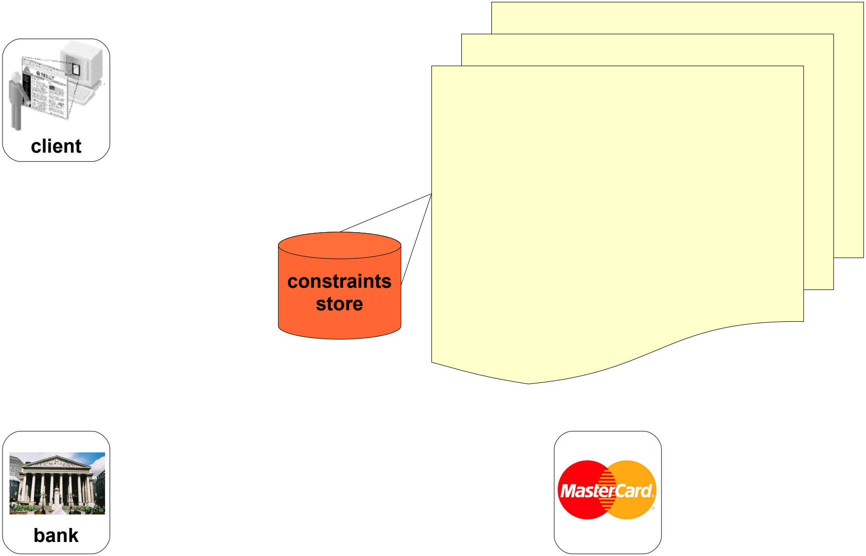
offers different credit cards varying in cost x year and cost x operation

provide credit card services to banks

constraints store

allows clients, banks and credit card associations to execute the negotiation process

A credit card issue scenario: negotiation with MC



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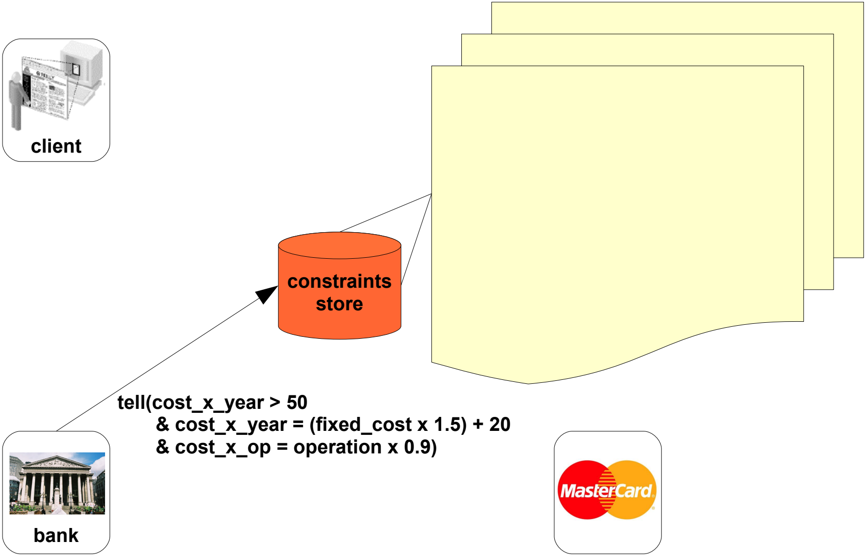
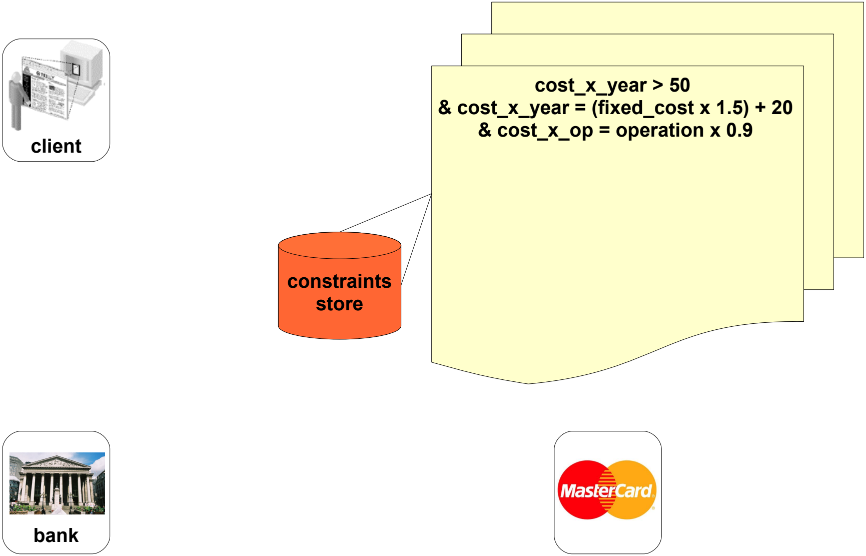


```
tell(cost_x_year > 50
      & cost_x_year = (fixed_cost x 1.5) + 20
      & cost_x_op = operation x 0.9)
```

A credit card issue scenario: negotiation with MC



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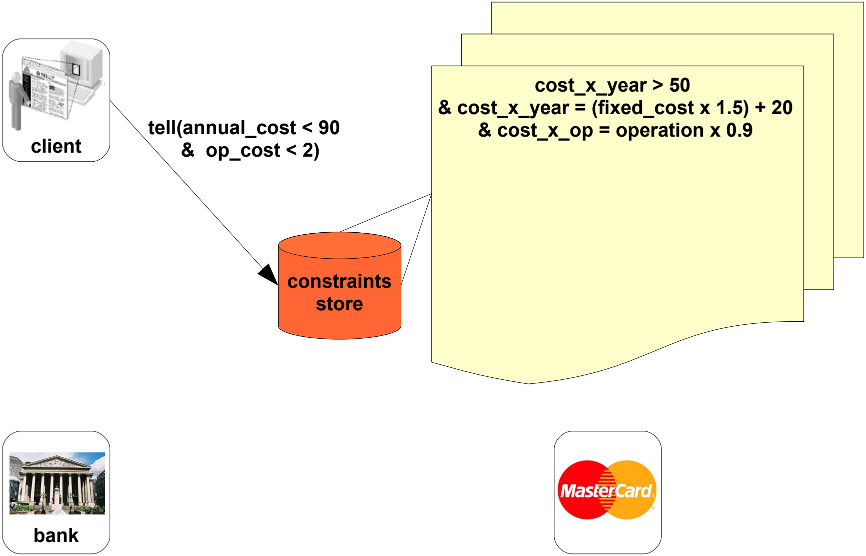


client

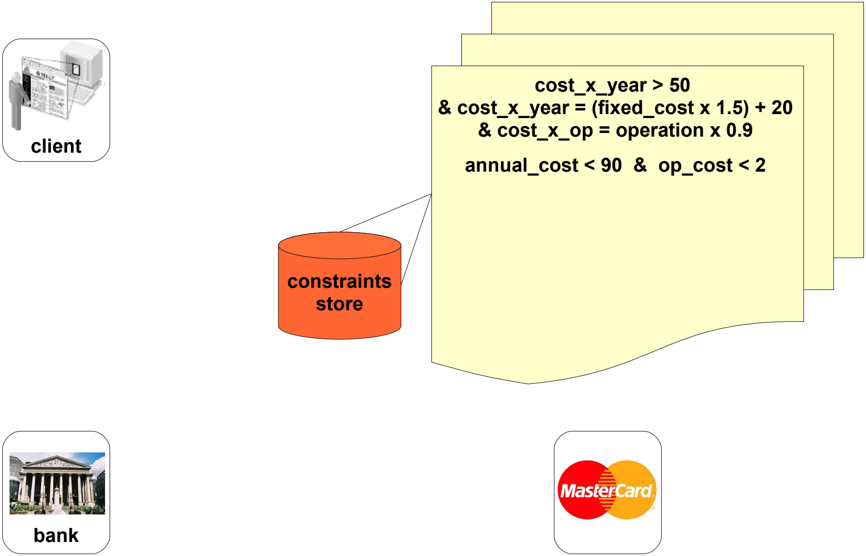
tell(annual_cost < 90
& op_cost < 2)

constraints store

cost_x_year > 50
& cost_x_year = (fixed_cost x 1.5) + 20
& cost_x_op = operation x 0.9

bank

A credit card issue scenario: negotiation with MC



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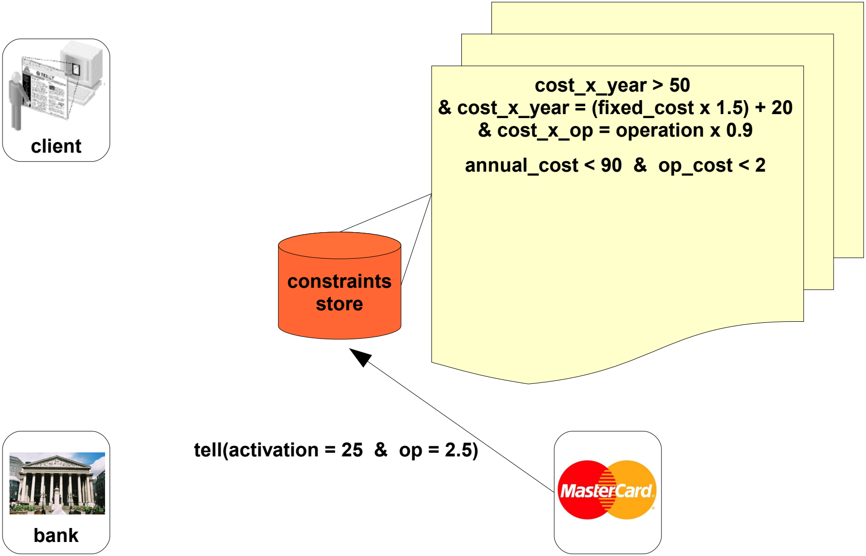


client

constraints store

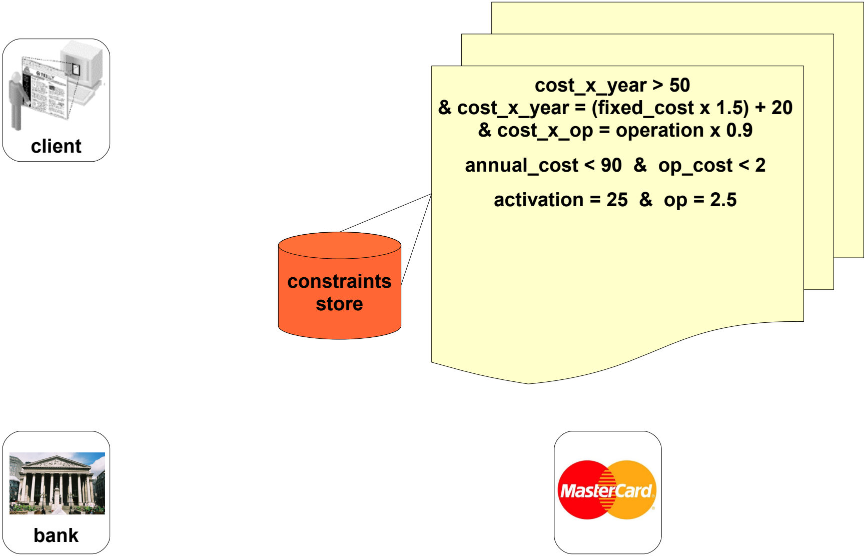
cost_x_year > 50
& cost_x_year = (fixed_cost x 1.5) + 20
& cost_x_op = operation x 0.9

annual_cost < 90 & op_cost < 2

tell(activation = 25 & op = 2.5)

bank

A credit card issue scenario: negotiation with MC



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bank

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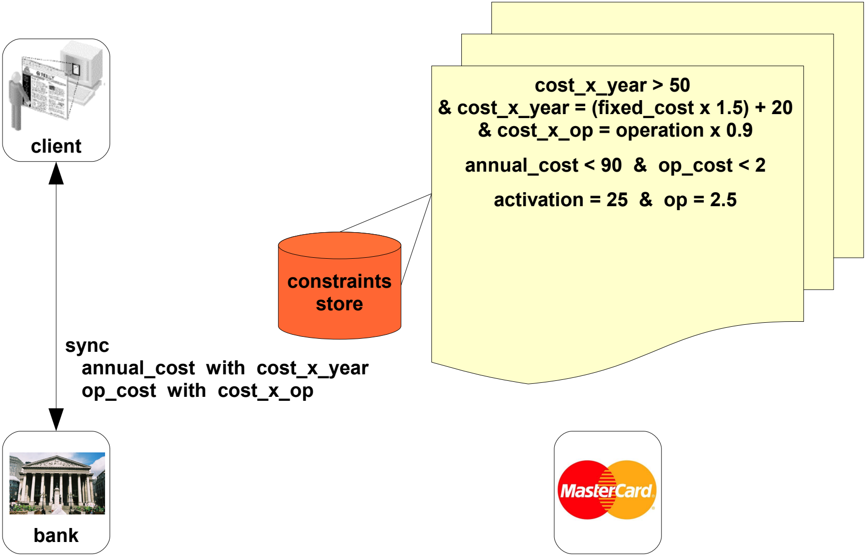

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constraints store

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& cost_x_year = (fixed_cost x 1.5) + 20
& cost_x_op = operation x 0.9

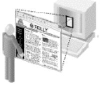
annual_cost < 90 & op_cost < 2

activation = 25 & op = 2.5

sync
annual_cost with cost_x_year
op_cost with cost_x_op

bank

A credit card issue scenario: negotiation with MC



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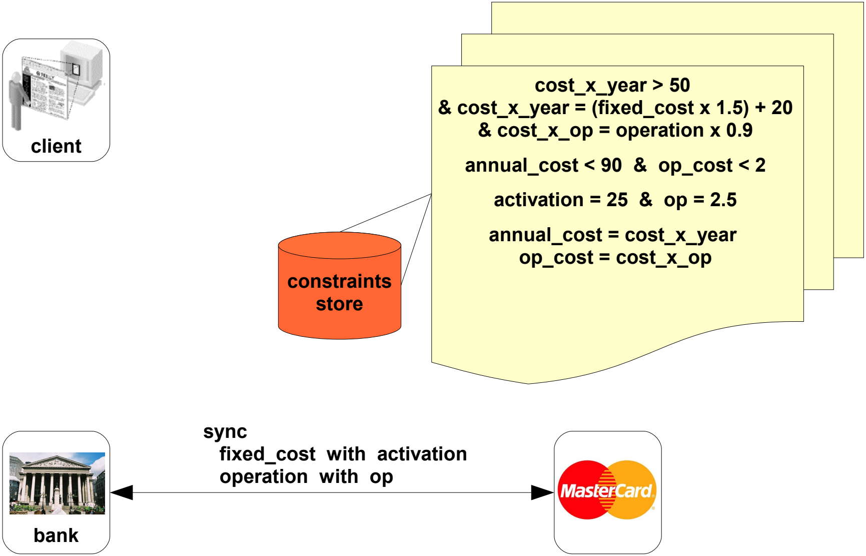
activation = 25 & op = 2.5

annual_cost = cost_x_year
op_cost = cost_x_op

bank

MasterCard

A credit card issue scenario: negotiation with MC



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annual_cost < 90 & op_cost < 2

activation = 25 & op = 2.5

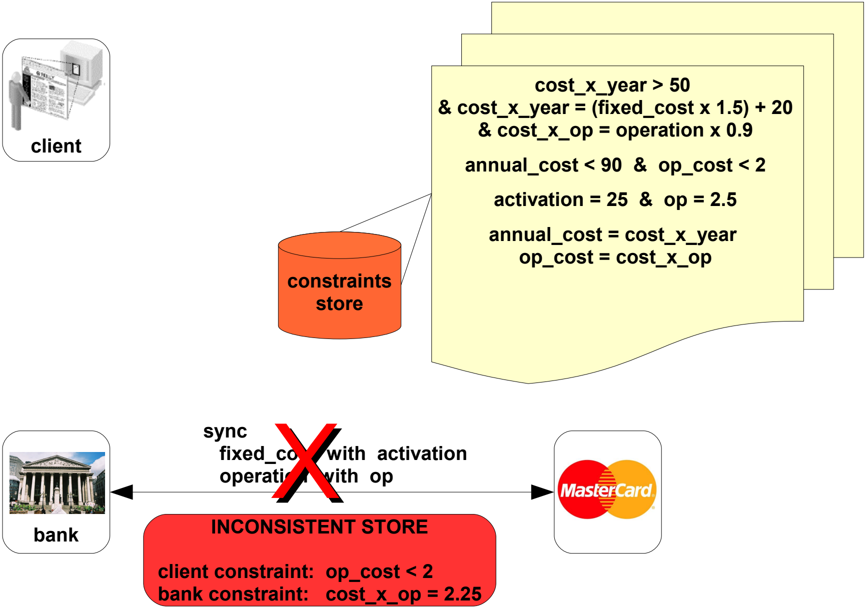
annual_cost = cost_x_year
op_cost = cost_x_op

constraints store

sync
fixed_cost with activation
operation with op

bank

A credit card issue scenario: negotiation with MC



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constraints store

bank

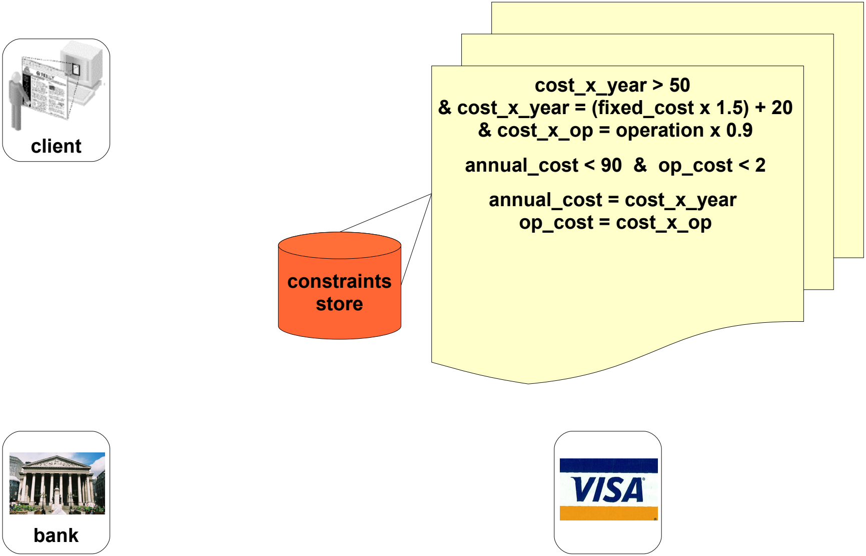
sync
fixed_co with activation
operati with op

MasterCard

INCONSISTENT STORE

client constraint: op_cost < 2
bank constraint: cost_x_op = 2.25

A credit card issue scenario: negotiation with VISA



cost_x_year > 50
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annual_cost = cost_x_year
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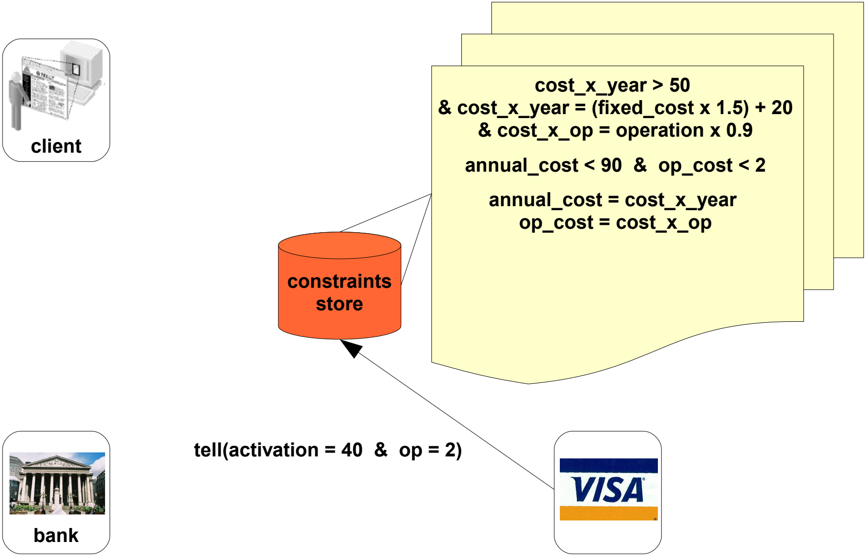
A credit card issue scenario: negotiation with VISA



client

cost_x_year > 50
& cost_x_year = (fixed_cost x 1.5) + 20
& cost_x_op = operation x 0.9

annual_cost < 90 & op_cost < 2

annual_cost = cost_x_year
op_cost = cost_x_op

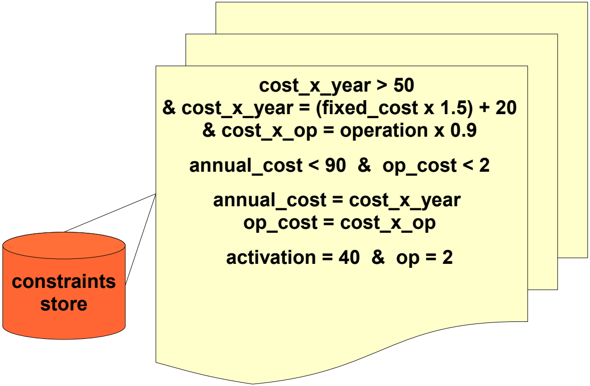
constraints store

tell(activation = 40 & op = 2)

bank

A credit card issue scenario: negotiation with VISA

client



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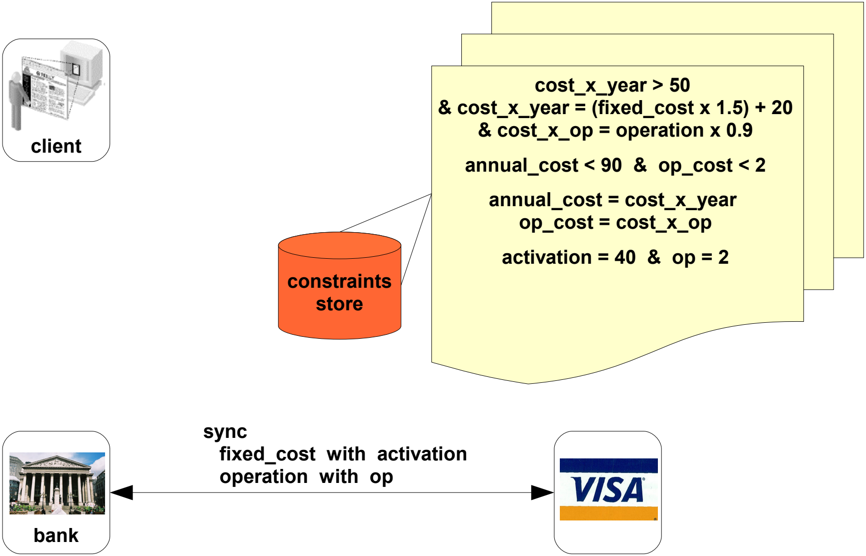
activation = 40 & op = 2

bank

VISA

A credit card issue scenario: negotiation with VISA



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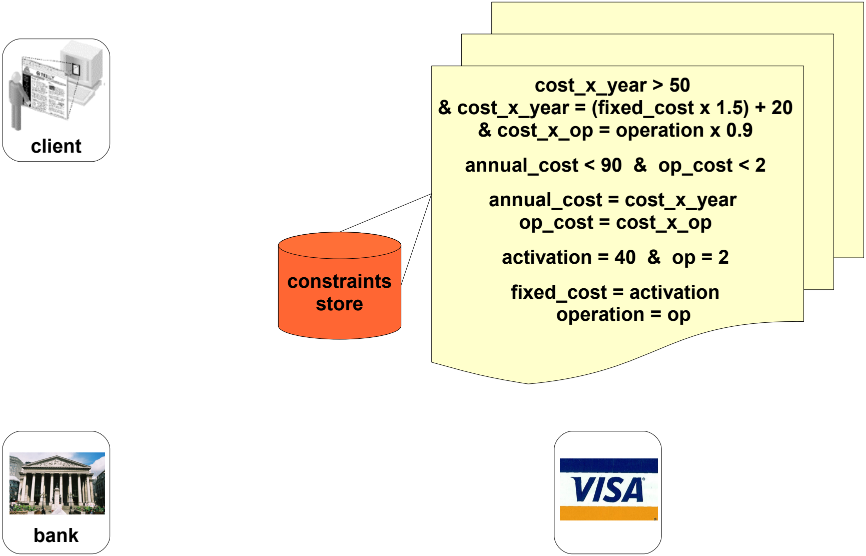
sync
fixed_cost with activation
operation with op

bank

A credit card issue scenario: negotiation with VISA



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operation = op

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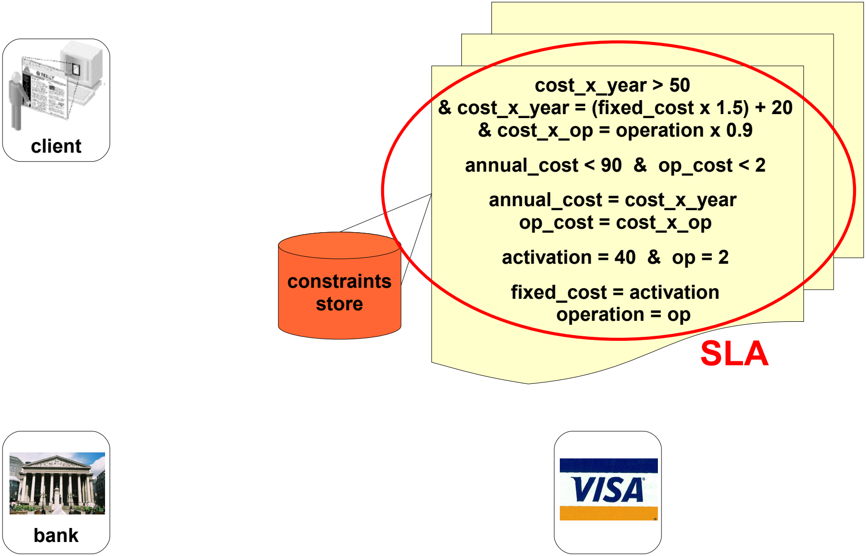

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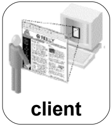
annual_cost = cost_x_year
op_cost = cost_x_op

activation = 40 & op = 2

fixed_cost = activation
operation = op

A credit card issue scenario: COWS specification



$[\mathtt{annual\_cost}, \mathtt{op\_cost}]$
$\mathtt{tell}(\mathtt{annual\_cost} < 90 \wedge \mathtt{op\_cost} < 2).$
$\mathsf{bank} \bullet \mathsf{sync}!\langle \mathtt{annual\_cost}, \mathtt{op\_cost} \rangle$

$[\mathtt{cost\_x\_year}, \mathtt{cost\_x\_op}, \mathtt{fixed\_cost}, \mathtt{operation}]$
$\mathtt{tell}(\mathtt{cost\_x\_year} > 50$
$\quad \wedge\ \mathtt{cost\_x\_year} = (\mathtt{fixed\_cost} \times 1.5) + 20$
$\quad \wedge\ \mathtt{cost\_x\_op} = \mathtt{operation} \times 0.9).$
$\mathsf{bank} \bullet \mathsf{sync}?\langle \mathtt{cost\_x\_year}, \mathtt{cost\_x\_op} \rangle.$
$\mathsf{visa} \bullet \mathsf{sync}!\langle \mathtt{fixed\_cost}, \mathtt{operation} \rangle$

$[\mathtt{activation}, \mathtt{op}]$
$\mathtt{tell}(\mathtt{activation} = 40 \wedge \mathtt{op} = 2).$
$\mathsf{visa} \bullet \mathsf{sync}?\langle \mathtt{activation}, \mathtt{op} \rangle$

Using COWS for concurrent constraint programming

- A shared store of constraints provides partial information about possible values of variables

The shared store

$$store_C \;\triangleq\; [\hat{n}]\,(\,\hat{n}!\langle C\rangle \mid *\,[x]\,\hat{n}?\langle x\rangle.(\,p_s\bullet o_{get}!\langle x\rangle \mid [y]\,p_s\bullet o_{set}?\langle y\rangle.\hat{n}!\langle y\rangle\,)\,)$$

- Services can act on the store by performing operations

Add/remove constraints to/from the store

$$\langle\!\langle \texttt{tell}\ c.s\rangle\!\rangle = [\hat{n}]\,(\,\hat{n}!\langle c\rangle \mid [y]\,\hat{n}?\langle y\rangle.[x]\,p_s\bullet o_{get}?\langle\langle y,x\rangle\rangle.(\{\!|\,p_s\bullet o_{set}!\langle x \uplus \{y\}\rangle\,|\!\} \mid \langle\!\langle s\rangle\!\rangle)\,)$$

$$\langle\!\langle \texttt{retract}\ c.s\rangle\!\rangle = [\hat{n}]\,(\,\hat{n}!\langle c\rangle \mid [y]\,\hat{n}?\langle y\rangle.[x]\,p_s\bullet o_{get}?\langle x\rangle.(\{\!|\,p_s\bullet o_{set}!\langle x - y\rangle\,|\!\} \mid \langle\!\langle s\rangle\!\rangle)\,)$$

Check entailment/consistency of a constraint by/with the store

$$\langle\!\langle \texttt{ask}\ c.s\rangle\!\rangle = [\hat{n}]\,(\,\hat{n}!\langle c^{\vdash}\rangle \mid [y]\,\hat{n}?\langle y\rangle.[x]\,p_s\bullet o_{get}?\langle\langle y,x\rangle\rangle.(\{\!|\,p_s\bullet o_{set}!\langle x\rangle\,|\!\} \mid \langle\!\langle s\rangle\!\rangle)\,)$$

$$\langle\!\langle \texttt{check}\ c.s\rangle\!\rangle = [\hat{n}]\,(\,\hat{n}!\langle c\rangle \mid [y]\,\hat{n}?\langle y\rangle.[x]\,p_s\bullet o_{get}?\langle\langle y,x\rangle\rangle.(\{\!|\,p_s\bullet o_{set}!\langle x\rangle\,|\!\} \mid \langle\!\langle s\rangle\!\rangle)\,)$$

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- 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]

Dealing with timed orchestration constructs

- *Timed activities* are frequently exploited in service orchestration for dealing with service transactions or with message losses
  - A service could wait a callback message for a certain amount of time after which, if no callback has been received, it invokes another operation or throws a fault

- Timed activities can be exploited to allow services not to get stuck forever waiting on a receive

- It is not known to what extent timed computation can be reduced to untimed forms of computation

- C◷WS extends COWS with timed orchestration constructs

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C◷WS: a timed extension of COWS

COWS (Calculus for Orchestration of Web Services)

μCOWS

- Communication activities
- Parallel composition
- Replication
- Choice
- Delimitation

Termination constructs

- Kill activity
- Protection

C🕘WS: a timed extension of COWS

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Timed constructs

- Wait activity
- Pick activity

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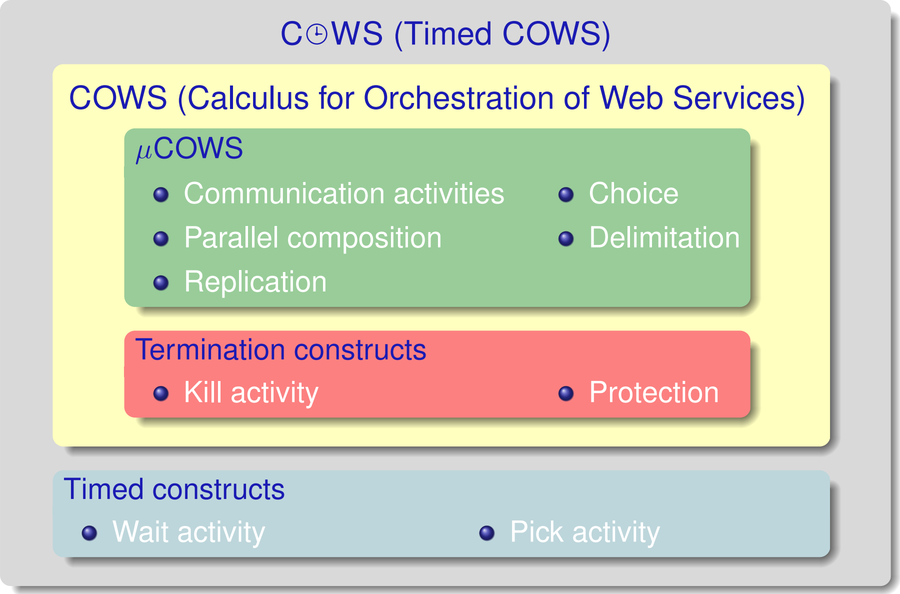

C🕒WS (Timed COWS)

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Syntax of C🕒WS

$$\begin{array}{lll}
s ::= & & \text{(services)} \\
 & \mathbf{kill}(k) & \text{(kill)} \\
 \mid & u \bullet u'!\bar{e} & \text{(invoke)} \\
 \mid & \sum_{i=0}^{r} g_i . s_i & \text{(choice/pick)} \\
 \mid & s \mid s & \text{(parallel composition)} \\
 \mid & \{\!| s |\!\} & \text{(protection)} \\
 \mid & [e]\, s & \text{(delimitation)} \\
 \mid & * \, s & \text{(replication)} \\
 & & \\
g ::= p \bullet o?\bar{w} & \mid \ \text{🕒}_{e} & \text{(guards)}
\end{array}$$

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

- *Time intervals* δ are positive numbers
- The *wait activity* 🕒_{e} specifies the time interval, whose value is given by evaluation of e, the executing service has to wait for
- Time elapsing cannot make a choice within a *pick* activity $\sum$, while the occurrence of a timeout can

C🕘WS operational semantics

COWS operational semantics rules

+

$$\mathbf{0} \xrightarrow{\delta} \mathbf{0} \qquad * s \xrightarrow{\delta} * s \qquad u \bullet u'!\bar{e} \xrightarrow{\delta} u \bullet u'!\bar{e}$$

$$\frac{s \xrightarrow{\delta} s'}{\{|s|\} \xrightarrow{\delta} \{|s'|\}} \qquad \frac{s \xrightarrow{\delta} s'}{[e]\, s \xrightarrow{\delta} [e]\, s'} \qquad p \bullet o?\bar{w}.s \xrightarrow{\delta} p \bullet o?\bar{w}.s$$

$$\text{🕘}_{0}.s \xrightarrow{\dagger} s \qquad \frac{[\![e]\!] \neq \delta'}{\text{🕘}_{e}.s \xrightarrow{\delta} \text{🕘}_{e}.s} \qquad \frac{\delta \leqslant [\![e]\!]}{\text{🕘}_{e}.s \xrightarrow{\delta} \text{🕘}_{[\![e-\delta]\!]}.s}$$

$$\frac{g_1 \xrightarrow{\delta} g_1' \qquad g_2 \xrightarrow{\delta} g_2'}{g_1 + g_2 \xrightarrow{\delta} g_1' + g_2'} \qquad \frac{s_1 \xrightarrow{\delta} s_1' \qquad s_2 \xrightarrow{\delta} s_2'}{s_1 \mid s_2 \xrightarrow{\delta} s_1' \mid s_2'}$$

C🕒WS: bank service with timeout

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

$$\begin{array}{lcl}
\mathrm{bankTimedInterface} & \triangleq & [x_c, x_{cc}, x_{amount}] \\
 & & \mathrm{bank} \bullet \mathrm{charge}?\langle x_c, x_{cc}, x_{amount}\rangle . \\
 & & (\,\mathrm{bank} \bullet \mathrm{check}!\langle x_{cc}, x_{amount}\rangle \\
 & & \quad \mid \mathrm{bank} \bullet \mathrm{ok}?\langle x_{cc}\rangle .\, x_c \bullet \mathrm{resp}!\langle \text{“ok”} \rangle \\
 & & \qquad + \mathrm{bank} \bullet \mathrm{fail}?\langle x_{cc}\rangle .\, x_c \bullet \mathrm{resp}!\langle \text{“fail”} \rangle \\
 & & \qquad + \text{🕒}_{120} .\, x_c \bullet \mathrm{resp}!\langle \text{“timeout”} \rangle \,)
\end{array}$$

The bank service guarantees a response within two minutes

C🕒WS: bank service with timeout

$$
\begin{array}{lcl}
\mathrm{bank} \bullet \mathrm{charge}!\langle \mathrm{c}, 1234, 100\text{€}\rangle & & [\mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}}] \\
\mid [\mathrm{x}]\,(\mathrm{c} \bullet \mathrm{resp}?\langle \mathrm{x}\rangle.\mathrm{s} \mid \mathrm{s}') & \mid & \mathrm{bank} \bullet \mathrm{charge}?\langle \mathrm{x_c}, \mathrm{x_{cc}}, \mathrm{x_{amount}}\rangle. \\
 & & (\,\mathrm{bank} \bullet \mathrm{check}!\langle \mathrm{x_{cc}}, \mathrm{x_{amount}}\rangle \\
 & & \;\mid \mathrm{bank} \bullet \mathrm{ok}?\langle \mathrm{x_{cc}}\rangle.\, \mathrm{x_c} \bullet \mathrm{resp}!\langle \text{“ok”} \rangle \\
 & & \quad + \mathrm{bank} \bullet \mathrm{fail}?\langle \mathrm{x_{cc}}\rangle.\, \mathrm{x_c} \bullet \mathrm{resp}!\langle \text{“fail”} \rangle \\
 & & \quad + \text{🕒}_{120}.\, \mathrm{x_c} \bullet \mathrm{resp}!\langle \text{“timeout”} \rangle\,)
\end{array}
$$

C🕒WS: bank service with timeout

$$\begin{array}{lcl}
\mathrm{bank} \bullet \mathrm{charge}!\langle c, 1234, 100€\rangle & & [x_c, x_{cc}, x_{amount}] \\
\mid [x]\,(c \bullet \mathrm{resp}?\langle x\rangle.s \mid s') & \mid & \mathrm{bank} \bullet \mathrm{charge}?\langle x_c, x_{cc}, x_{amount}\rangle. \\
 & & (\,\mathrm{bank} \bullet \mathrm{check}!\langle x_{cc}, x_{amount}\rangle \\
 & & \;\mid \mathrm{bank} \bullet \mathrm{ok}?\langle x_{cc}\rangle.\, x_c \bullet \mathrm{resp}!\langle \text{“ok”}\rangle \\
 & & \quad + \mathrm{bank} \bullet \mathrm{fail}?\langle x_{cc}\rangle.\, x_c \bullet \mathrm{resp}!\langle \text{“fail”}\rangle \\
 & & \quad + \text{🕒}_{120}.\, x_c \bullet \mathrm{resp}!\langle \text{“timeout”}\rangle\,)
\end{array}$$

The client sends its request to the bank service …

C🕒WS: bank service with timeout

$$\begin{array}{lll}
[x]\,(\mathrm{c} \bullet \mathrm{resp}?\langle \mathrm{x}\rangle.\mathrm{s} \mid \mathrm{s}') & \quad\mid\quad & \mathrm{bank} \bullet \mathrm{check}!\langle 1234, 100\text{€}\rangle \\
 & & \;\mid \mathrm{bank} \bullet \mathrm{ok}?\langle 1234\rangle.\, \mathrm{c} \bullet \mathrm{resp}!\langle \text{“ok”}\rangle \\
 & & \quad + \mathrm{bank} \bullet \mathrm{fail}?\langle 1234\rangle.\, \mathrm{c} \bullet \mathrm{resp}!\langle \text{“fail”}\rangle \\
 & & \quad + \text{🕒}_{120}.\, \mathrm{c} \bullet \mathrm{resp}!\langle \text{“timeout”}\rangle
\end{array}$$

C🕒WS: bank service with timeout

$$
\begin{array}{lcl}
[\mathrm{x}]\,(\mathrm{c} \bullet \mathrm{resp}?\langle \mathrm{x} \rangle.\mathrm{s} \mid \mathrm{s}') & \mid & \mathrm{bank} \bullet \mathrm{check}!\langle 1234, 100\text{€} \rangle \\
 & & \quad \mid \mathrm{bank} \bullet \mathrm{ok}?\langle 1234 \rangle .\, \mathrm{c} \bullet \mathrm{resp}!\langle \text{“ok”} \rangle \\
 & & \qquad + \mathrm{bank} \bullet \mathrm{fail}?\langle 1234 \rangle .\, \mathrm{c} \bullet \mathrm{resp}!\langle \text{“fail”} \rangle \\
 & & \qquad + \text{🕒}_{120} .\, \mathrm{c} \bullet \mathrm{resp}!\langle \text{“timeout”} \rangle
\end{array}
$$

The credit rating service is unavailable and a first minute elapses . . .

C🕒WS: bank service with timeout

$$
\begin{array}{lcl}
[x]\,(c \bullet resp?\langle x \rangle.s \mid s') & \mid & bank \bullet check!\langle 1234, 100\text{€} \rangle \\
 & & \quad \mid bank \bullet ok?\langle 1234 \rangle .\, c \bullet resp!\langle \text{“ok”} \rangle \\
 & & \qquad + \, bank \bullet fail?\langle 1234 \rangle .\, c \bullet resp!\langle \text{“fail”} \rangle \\
 & & \qquad + \, \text{🕒}_{60} .\, c \bullet resp!\langle \text{“timeout”} \rangle
\end{array}
$$

C🕒WS: bank service with timeout

$$
\begin{array}{lll}
[x]\,(c \bullet resp?\langle x\rangle.s \mid s') & \mid & bank \bullet check!\langle 1234, 100€\rangle \\
 & & \quad \mid bank \bullet ok?\langle 1234\rangle.\, c \bullet resp!\langle \text{“ok”}\rangle \\
 & & \qquad + bank \bullet fail?\langle 1234\rangle.\, c \bullet resp!\langle \text{“fail”}\rangle \\
 & & \qquad + \text{🕒}_{60}.\, c \bullet resp!\langle \text{“timeout”}\rangle
\end{array}
$$

The last minute elapses …

C🕒WS: bank service with timeout

$$
\begin{array}{lcl}
[\mathrm{x}]\,(\mathrm{c}\bullet\mathrm{resp}?\langle \mathrm{x}\rangle.\mathrm{s} \mid \mathrm{s}') & \mid & \mathrm{bank}\bullet\mathrm{check}!\langle 1234, 100€\rangle \\
 & & \quad\mid \mathrm{bank}\bullet\mathrm{ok}?\langle 1234\rangle.\,\mathrm{c}\bullet\mathrm{resp}!\langle\text{“ok”}\rangle \\
 & & \qquad + \mathrm{bank}\bullet\mathrm{fail}?\langle 1234\rangle.\,\mathrm{c}\bullet\mathrm{resp}!\langle\text{“fail”}\rangle \\
 & & \qquad + \text{🕒}_{0}.\,\mathrm{c}\bullet\mathrm{resp}!\langle\text{“timeout”}\rangle
\end{array}
$$

C🕒WS: bank service with timeout

$$
\begin{array}{lcl}
[\mathsf{x}]\,(\mathsf{c}\bullet\mathsf{resp}?\langle\mathsf{x}\rangle.\mathsf{s} \mid \mathsf{s}') & \quad\mid\quad & \mathsf{bank}\bullet\mathsf{check}!\langle 1234, 100\text{€}\rangle \\
 & & \quad\mid \mathsf{bank}\bullet\mathsf{ok}?\langle 1234\rangle.\,\mathsf{c}\bullet\mathsf{resp}!\langle\text{“ok”}\rangle \\
 & & \qquad + \mathsf{bank}\bullet\mathsf{fail}?\langle 1234\rangle.\,\mathsf{c}\bullet\mathsf{resp}!\langle\text{“fail”}\rangle \\
 & & \qquad + \text{🕒}_{0}.\,\mathsf{c}\bullet\mathsf{resp}!\langle\text{“timeout”}\rangle
\end{array}
$$

The timeout expires . . .

this way the receives along bank • ok and bank • fail are discarded

C🕒WS: bank service with timeout

$$
\begin{array}{lcl}
[\mathrm{x}]\,(\mathrm{c}\bullet\mathrm{resp}?\langle\mathrm{x}\rangle.\mathrm{s} \mid \mathrm{s}') & \mid & \mathrm{bank}\bullet\mathrm{check}!\langle 1234, 100€\rangle \\
 & & \quad \mid \mathrm{c}\bullet\mathrm{resp}!\langle\,\text{“timeout”}\,\rangle
\end{array}
$$

C🕒WS: bank service with timeout

$$[x]\,(\mathsf{c} \bullet \mathsf{resp}?\langle \mathsf{x}\rangle.\mathsf{s} \mid \mathsf{s}') \qquad \mid \qquad \begin{array}{l}\mathsf{bank} \bullet \mathsf{check}!\langle 1234, 100€\rangle \\ \mid \mathsf{c} \bullet \mathsf{resp}!\langle \text{“timeout”} \rangle\end{array}$$

The client is notified that the time is expired . . .

so he can try to contact again the bank or call an assistance service

Service engines

- Time passes synchronously for all services in parallel
  - all services run on a same service *engine*
  - the services share the same clock and can be tightly coupled
- Existing SOC systems are loosely coupled
  - usually deployed on top of distributed systems that offer only weak guarantees on the upper bound of inter-location clock drift

Example: client & compound bank service

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

- client and bank are loosely coupled and can be deployed on different engines
- The subservices bankInterface and creditRating are tightly coupled and must be colocated
- We introduce explicitly the notions of *service engine* and of *deployment* of services on engines

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

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

Service engines

- C⌚WS is extended by introducing the category of *engines*

$$\mathbb{E} ::= 0 \mid \{s\} \mid [n]\mathbb{E} \mid \mathbb{E} \mid \mathbb{E}$$

- Communication can take place *intra-engine* or *inter-engine*
- Passing of time is modelled
  - *synchronously* for services deployed on the same service engine
  - *asynchronously* among different engines

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