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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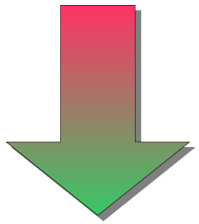

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Approach: rely on Process Calculi

- 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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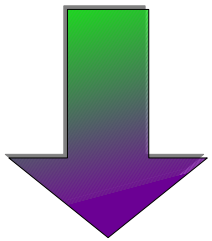

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Process Calculi for SOC

- 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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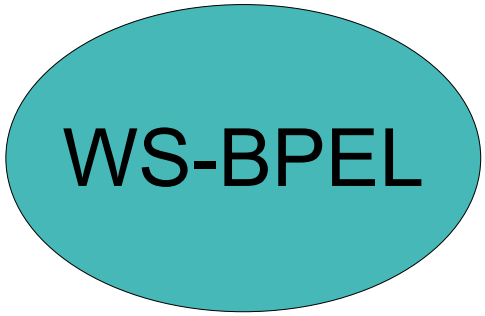
COWS [ESOP'07]

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



- 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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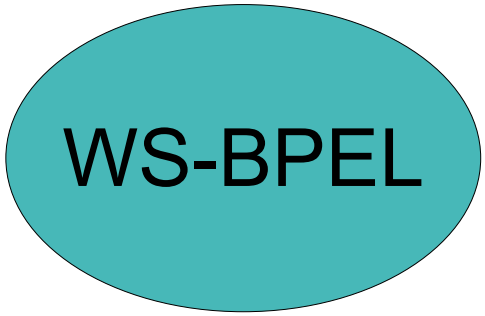

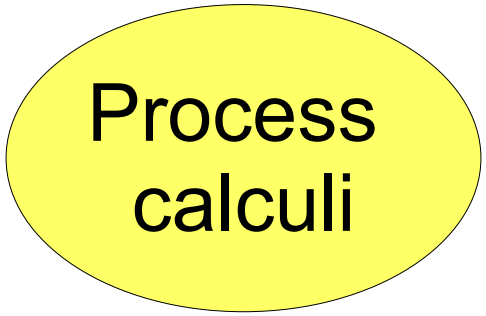

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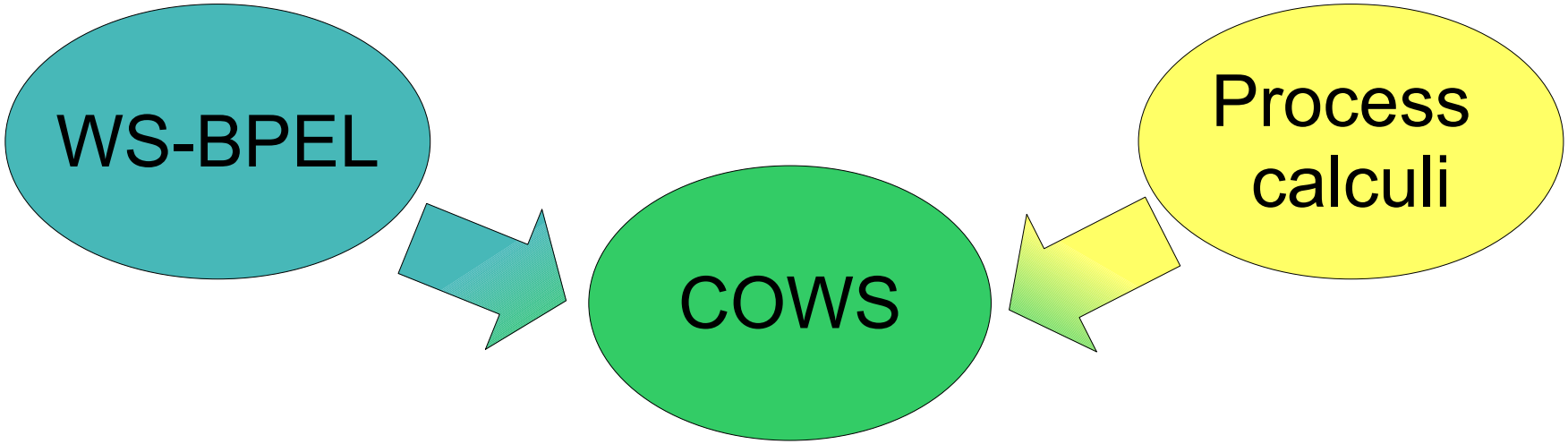

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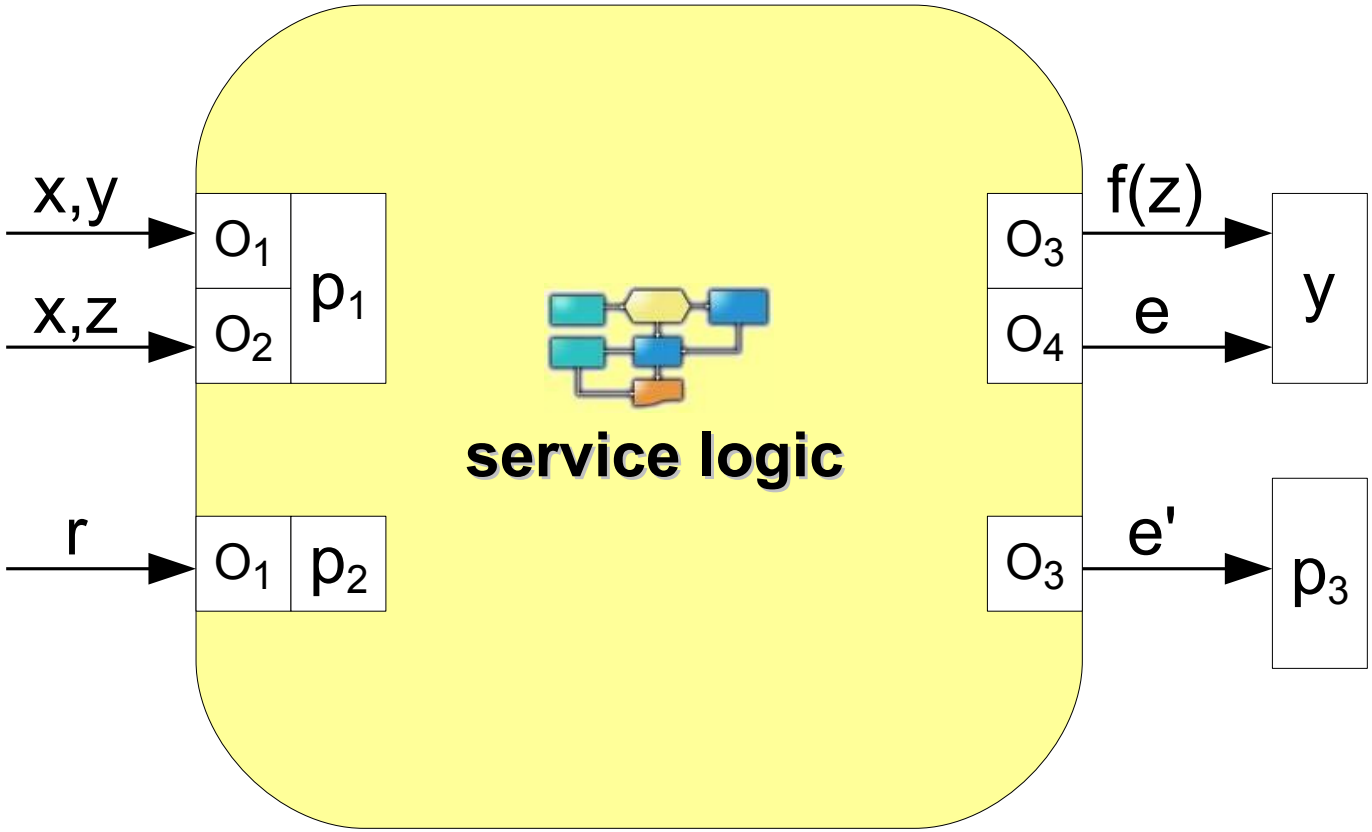

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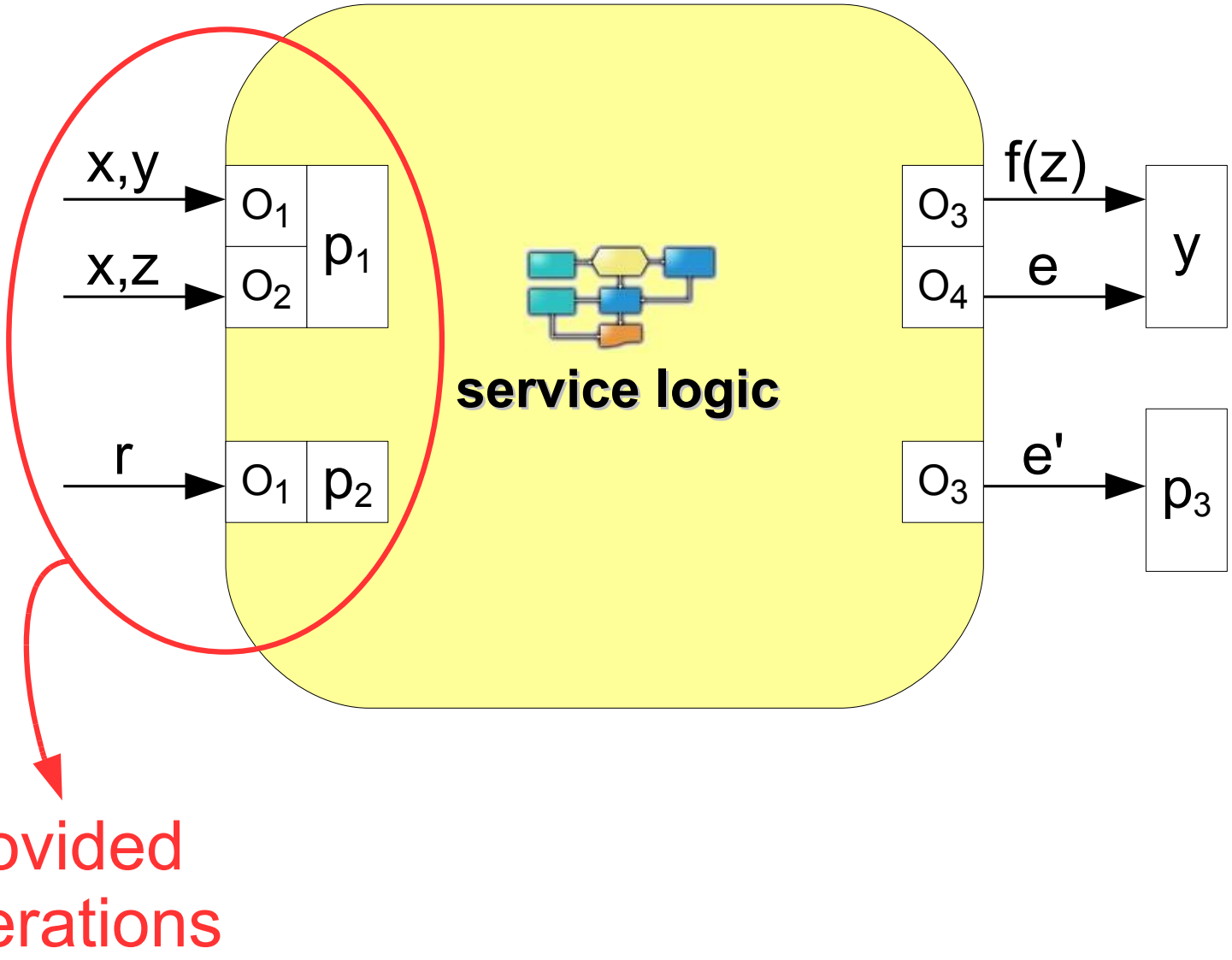

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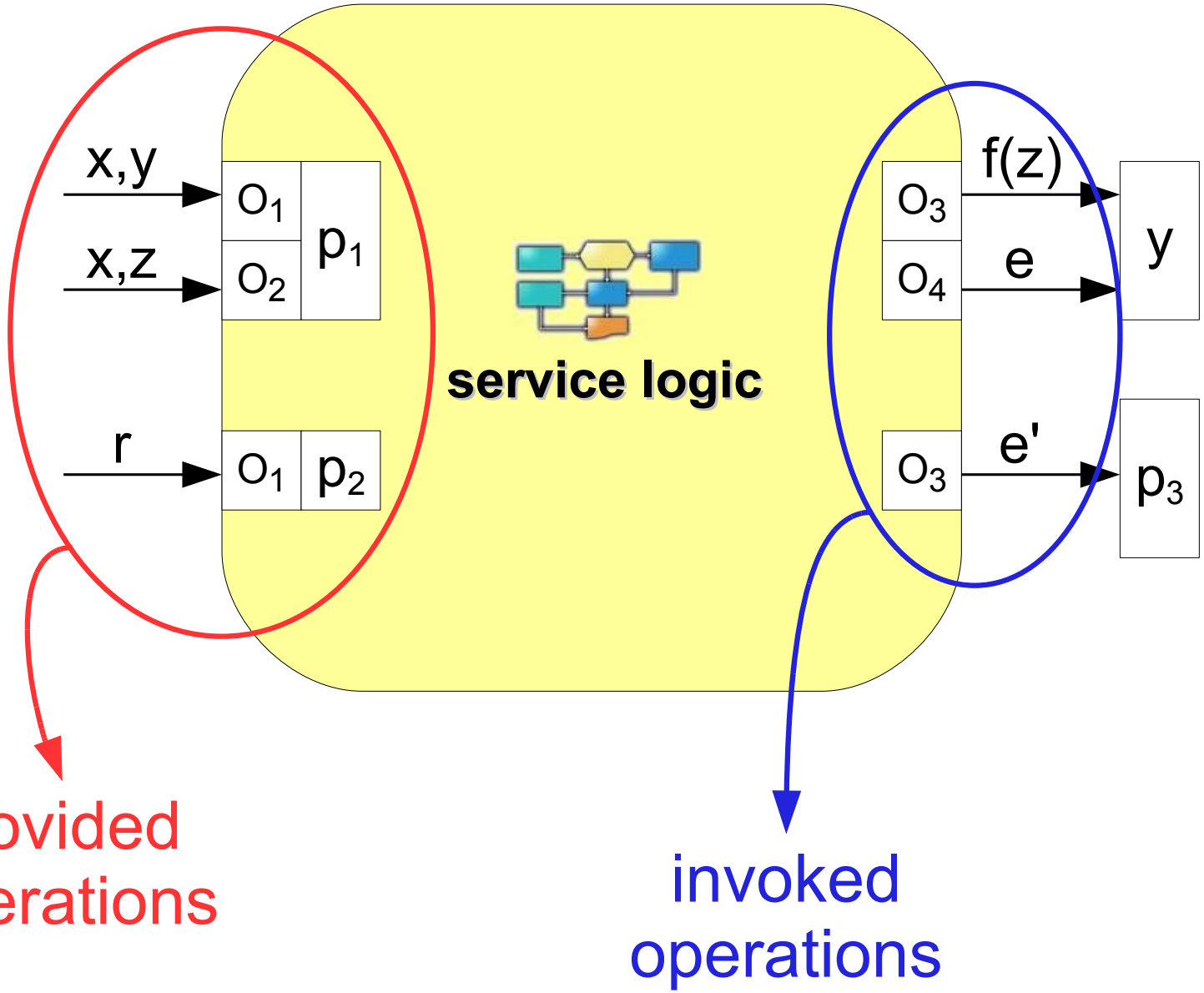

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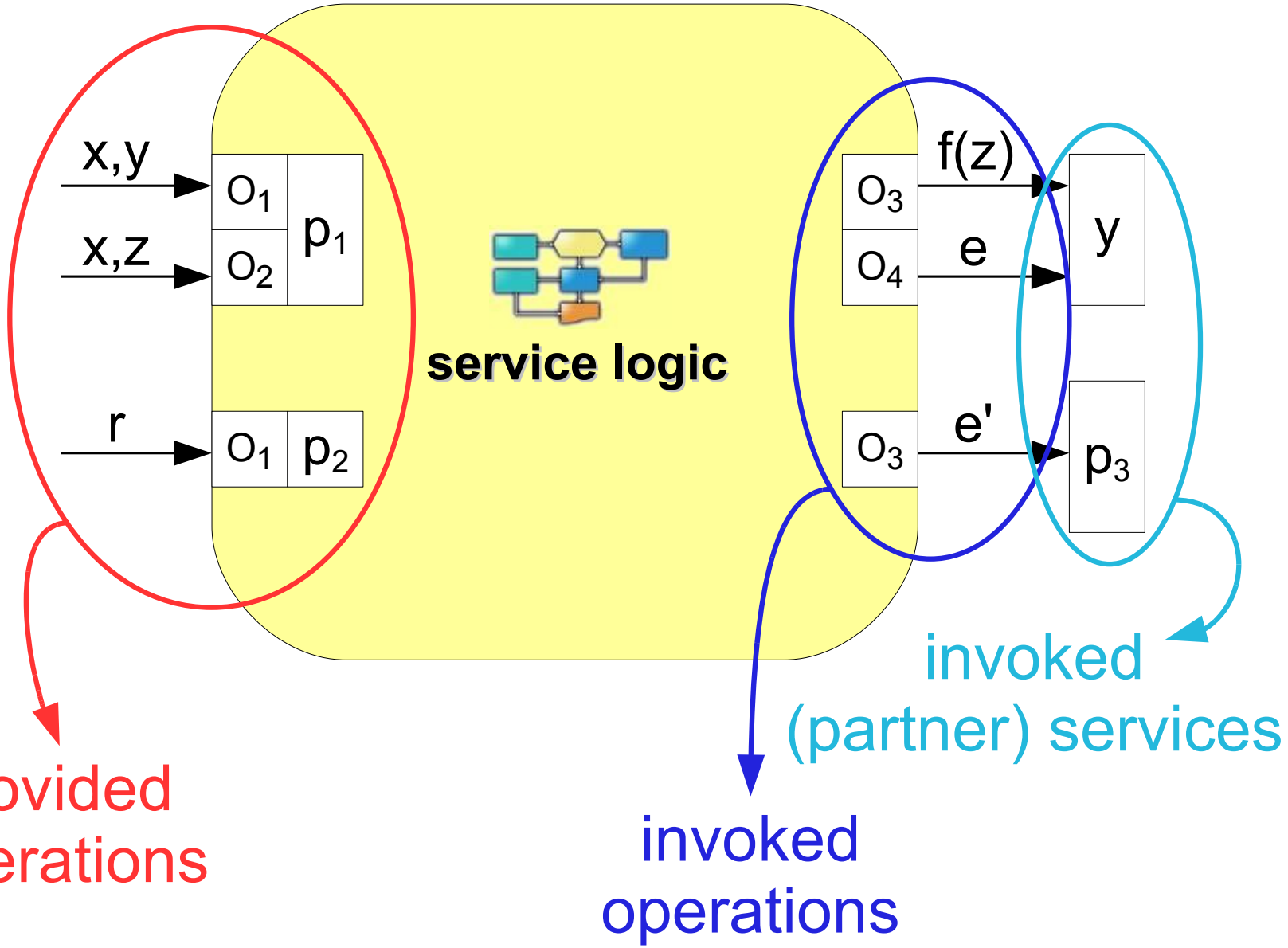

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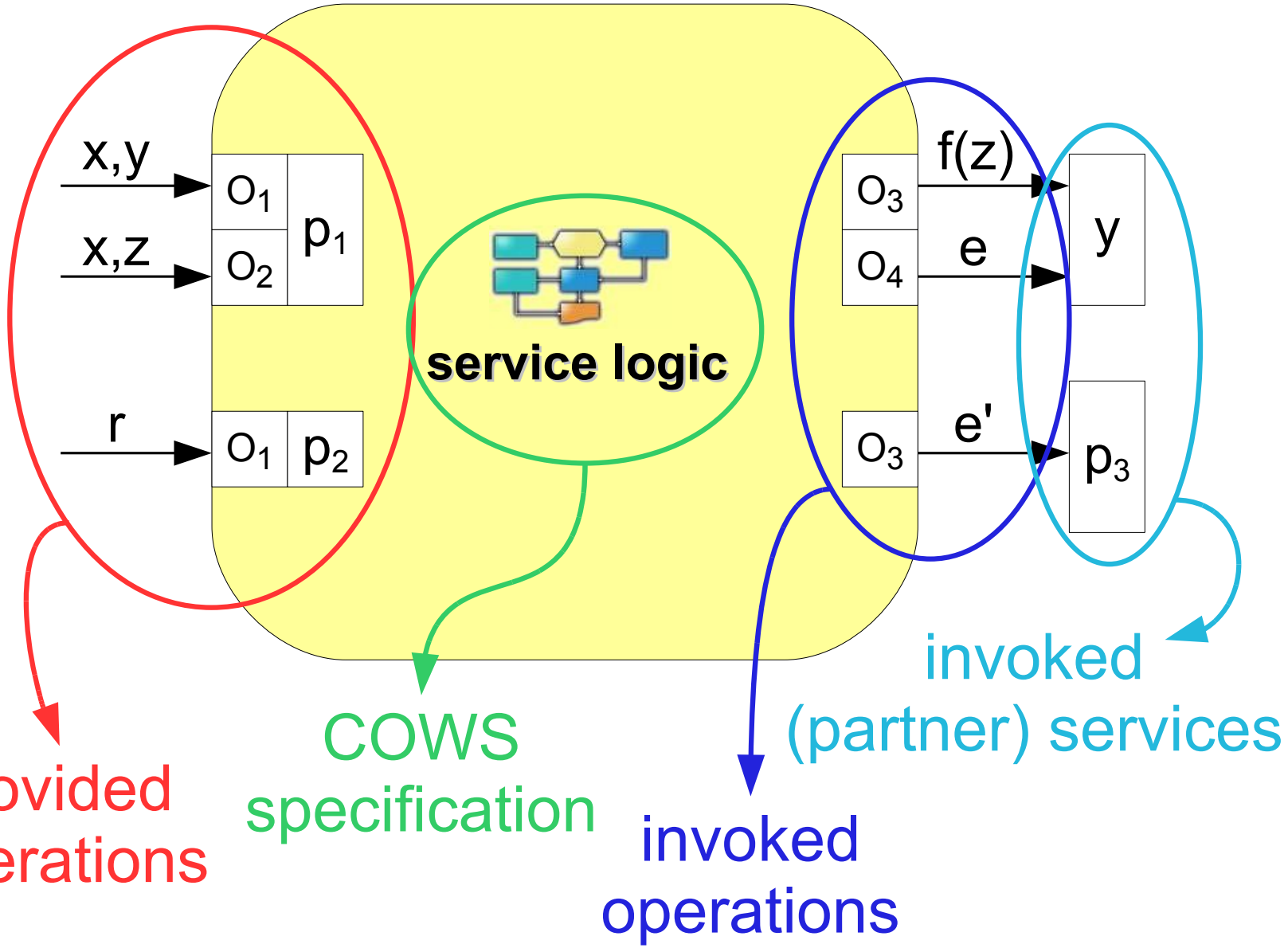

COWS in three steps

μCOWS^m (micro COWS minus priority)

Communication activities

- Invoke
- Receive

Control flow activities

- Parallel composition
- Choice
- Replication
- Delimitation

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- Kill activity
- Protection

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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, ...

- asynchronous and polyadic communication
- input – guarded choice
- polyadic synchronization
- localised channels

} π-calculus

- global scoping (and non – binding input) } fusion
- distinction between variables and values } vp CCS, App. π-calculus, Dπ
- pattern – matching } 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

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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)

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

μCOWS^m: Parallel composition

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

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

- 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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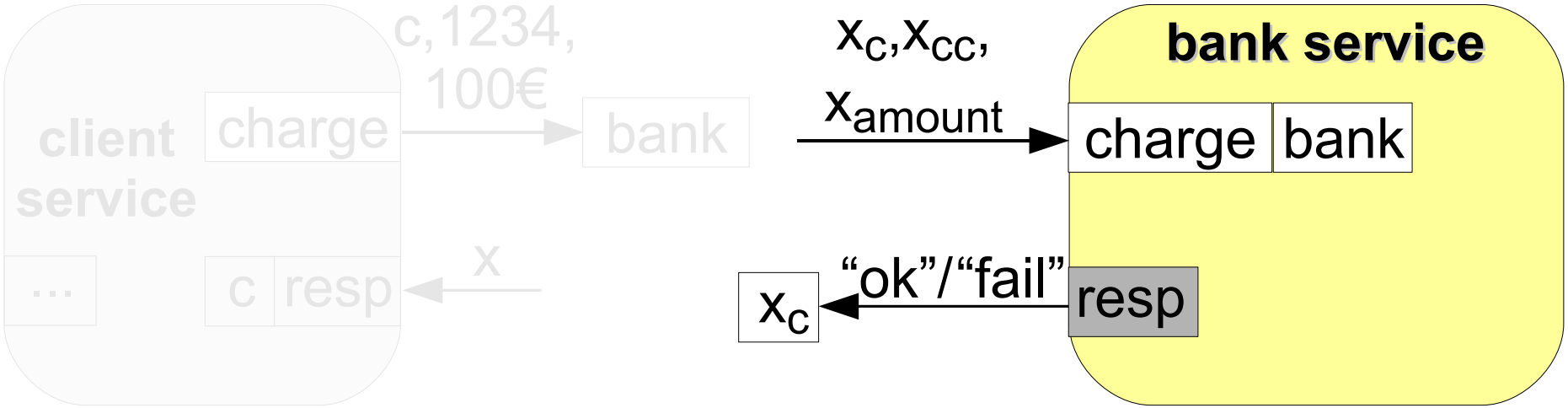
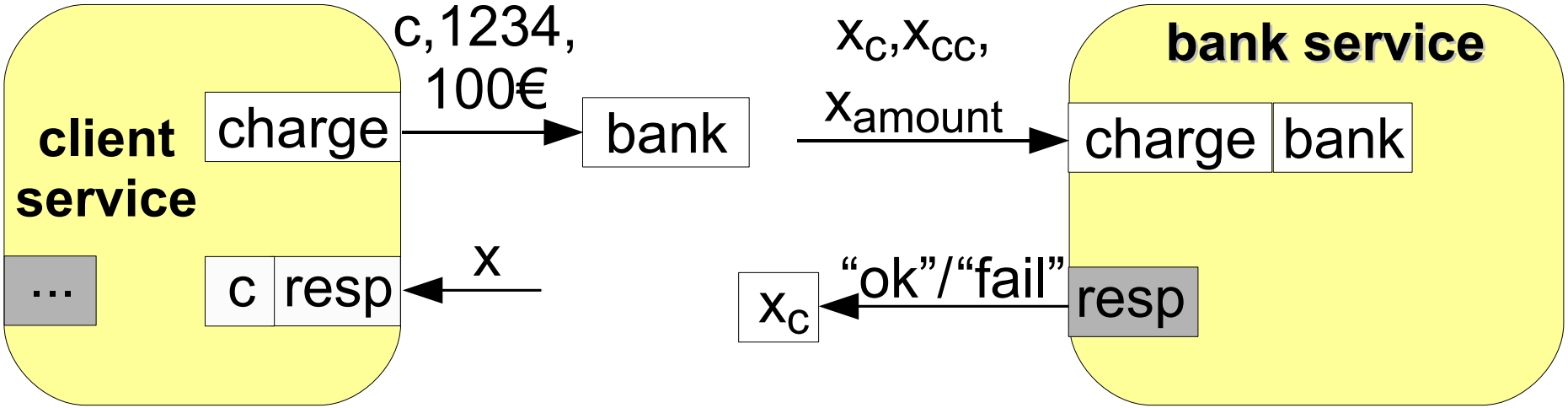
μCOWS^m: *simple* bank service example



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

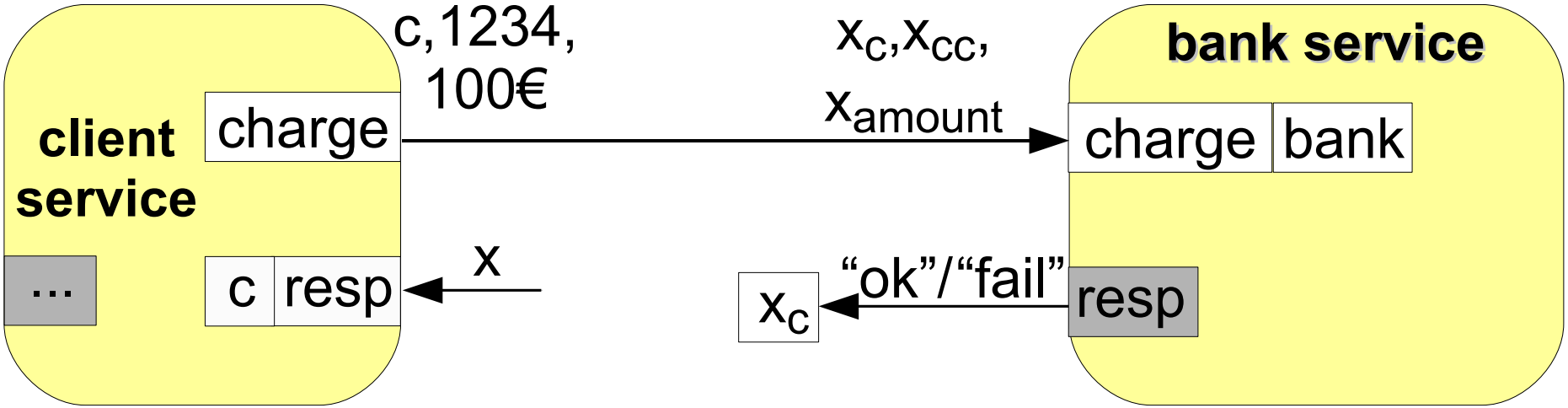
μCOWS^m: *simple* bank service example



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

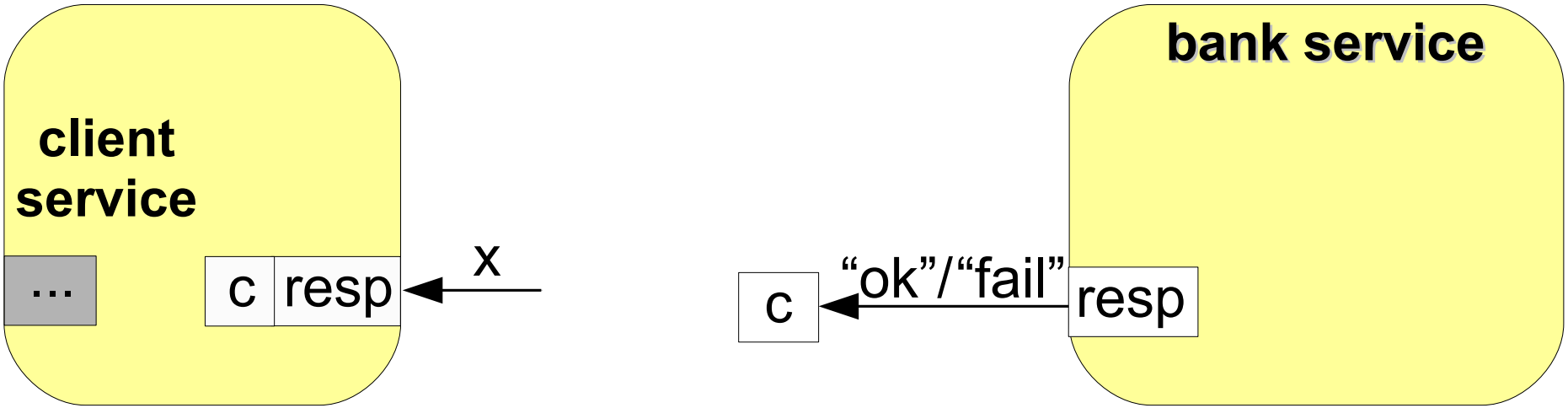
$[x_c, x_{cc}, x_{amount}]$
$\mathsf{bank} \bullet \mathsf{charge}?\langle x_c, x_{cc}, x_{amount}\rangle.$
$x_c \bullet \mathsf{resp}!\langle \mathit{chk}(x_{cc}, x_{amount})\rangle$

μCOWS^m: *simple* bank service example



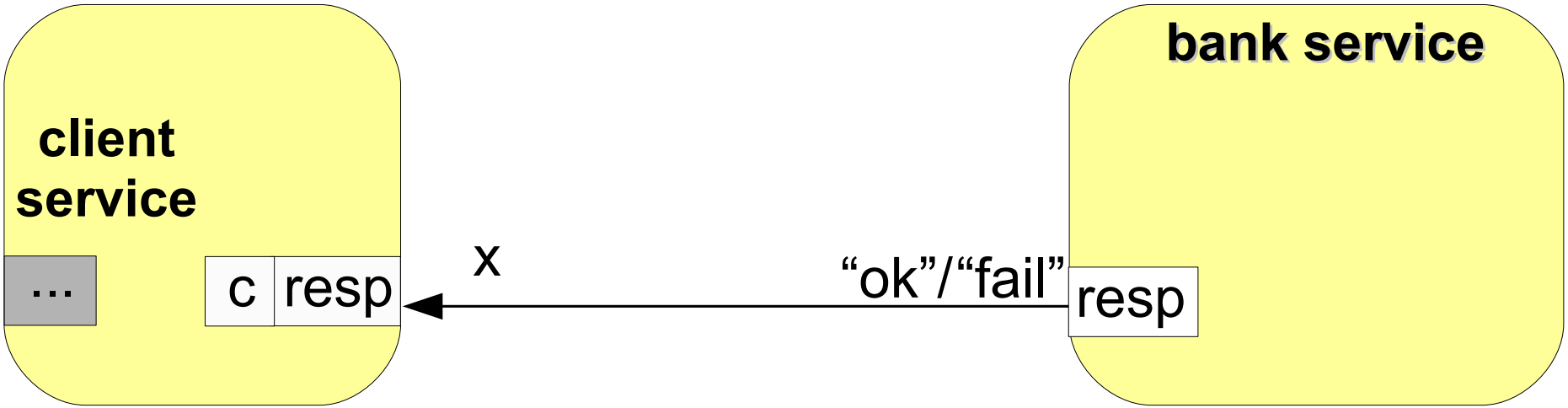
$$\mathsf{bank} \bullet \mathsf{charge}!\langle c, 1234, 100€\rangle \mid [x]\,(c \bullet \mathsf{resp}?\langle x\rangle.s \mid s') \quad \mid \quad [x_c, x_{cc}, x_{amount}]\,\mathsf{bank} \bullet \mathsf{charge}?\langle x_c, x_{cc}, x_{amount}\rangle.\, x_c \bullet \mathsf{resp}!\langle \mathit{chk}(x_{cc},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

μCOWS^m: *simple* bank service example



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

μCOWS^m: *simple* bank service example

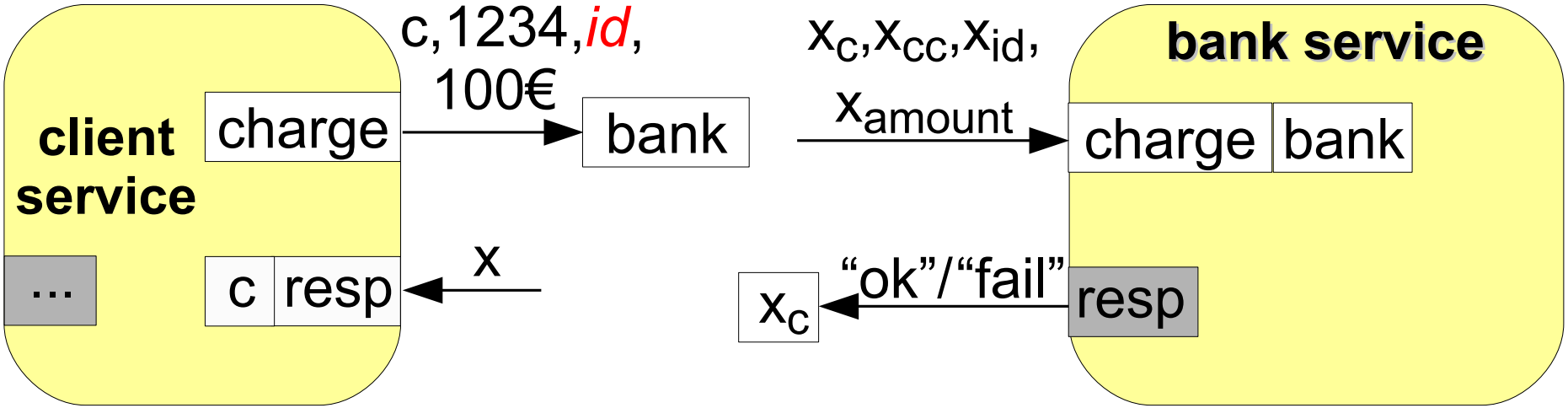


$[x]\,(c \bullet resp?\langle x\rangle.s \mid s') \quad | \quad c \bullet resp!\langle chk(1234, 100€)\rangle$

μCOWS^m: *simple* bank service example

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

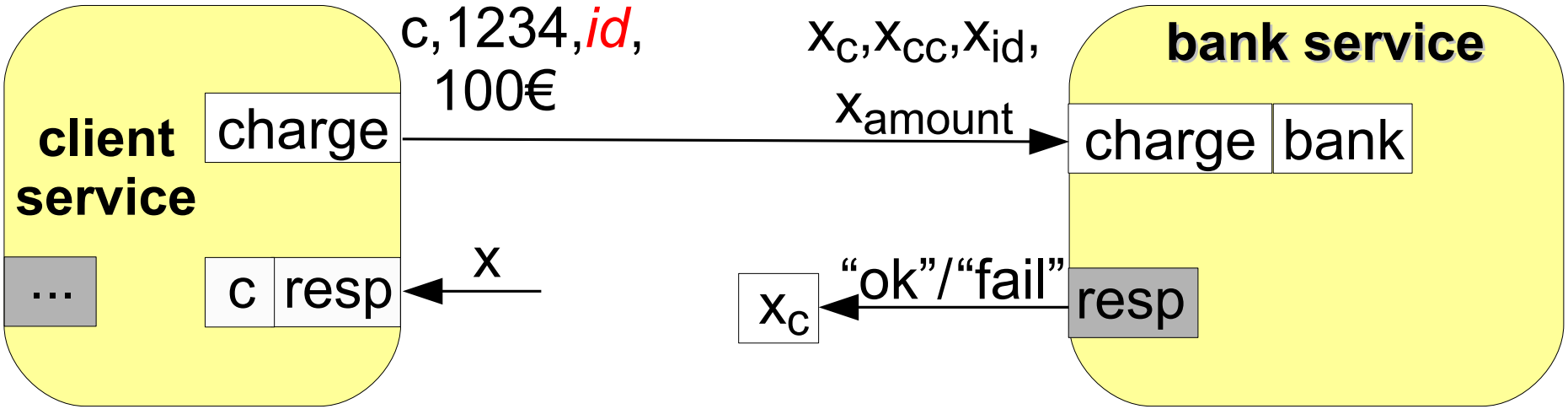
μCOWS^m: communication of private names



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

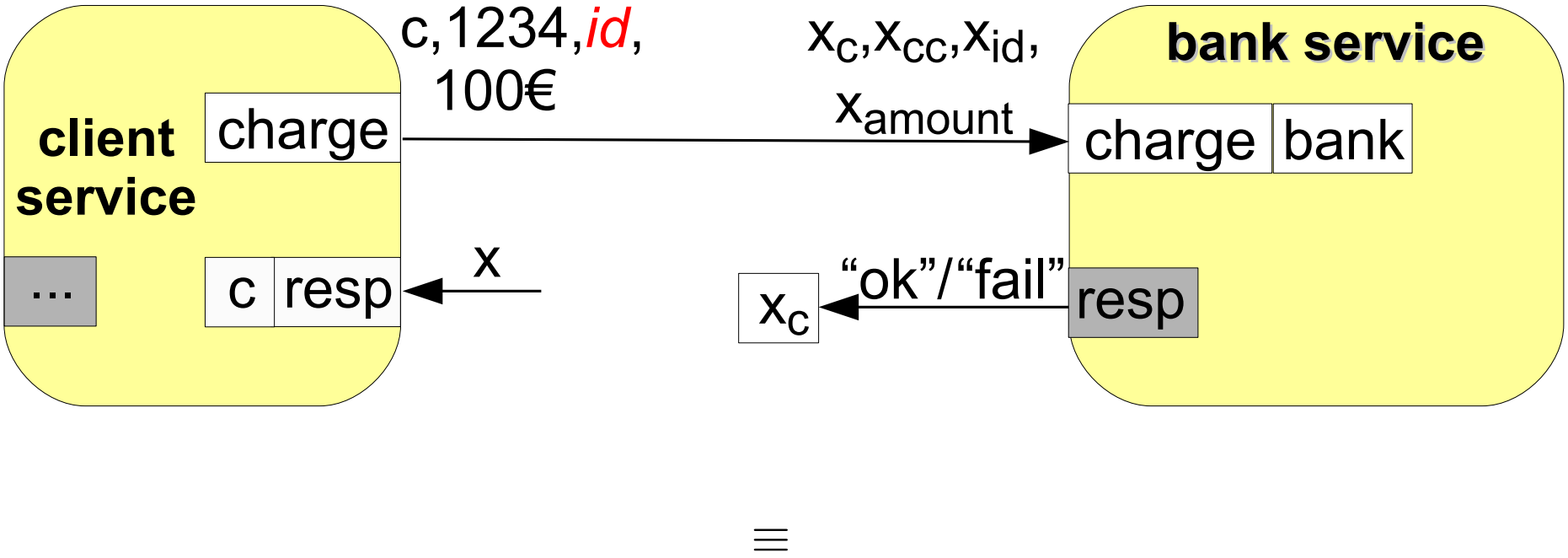
$[x_c, x_{cc}, x_{id}, x_{amount}]$
$bank \bullet charge?\langle x_c, x_{cc}, x_{id}, x_{amount}\rangle.$
$x_c \bullet resp!\langle chk(x_{cc}, x_{id}, x_{amount})\rangle$

μCOWS^m: communication of private names



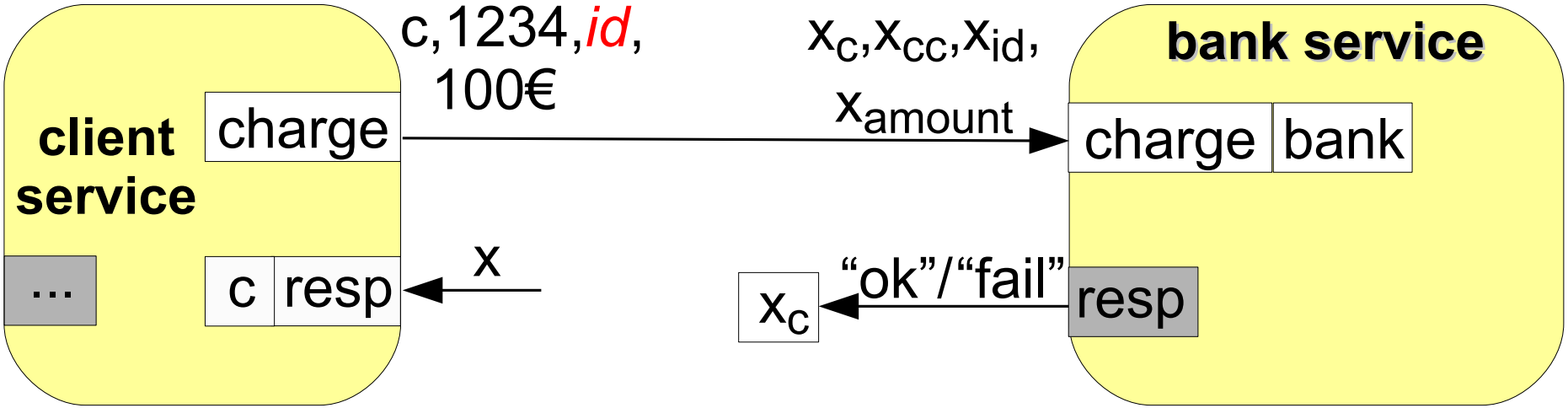
$$[id]\,(bank \bullet charge!\langle c, 1234, id, 100€\rangle \mid [x]\,(c \bullet resp?\langle x\rangle.s \mid s')) \quad \mid \quad [x_c, x_{cc}, x_{id}, x_{amount}]\,bank \bullet charge?\langle x_c, x_{cc}, x_{id}, x_{amount}\rangle.\, x_c \bullet resp!\langle chk(x_{cc}, x_{id}, x_{amount})\rangle$$

μCOWS^m: communication of private names



$\equiv$

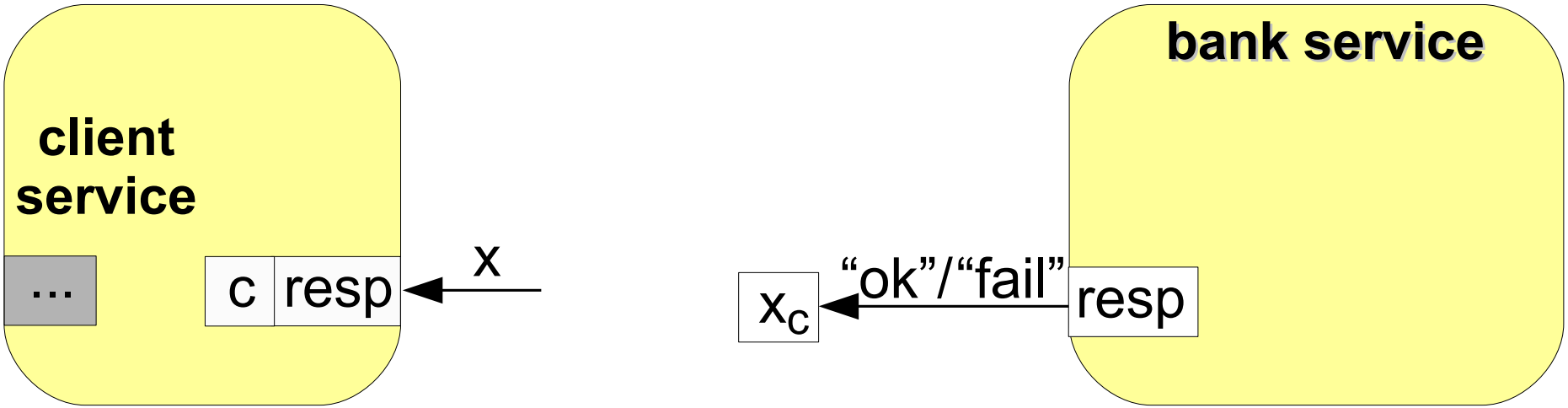
μCOWS^m: communication of private names



$$[id, x_c, x_{cc}, x_{id}, x_{amount}]$$

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

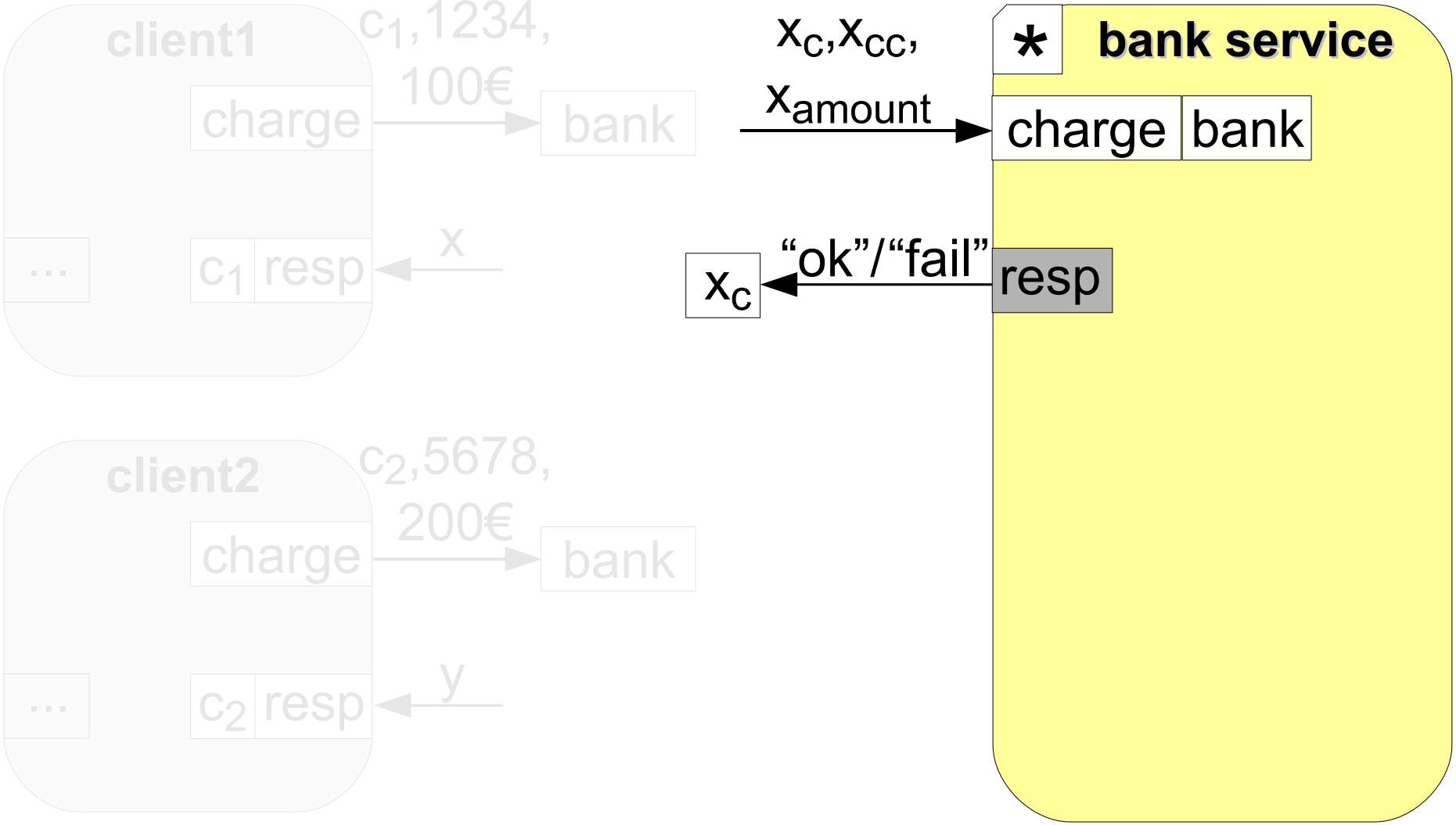
μCOWS^m: communication of private names



[id]

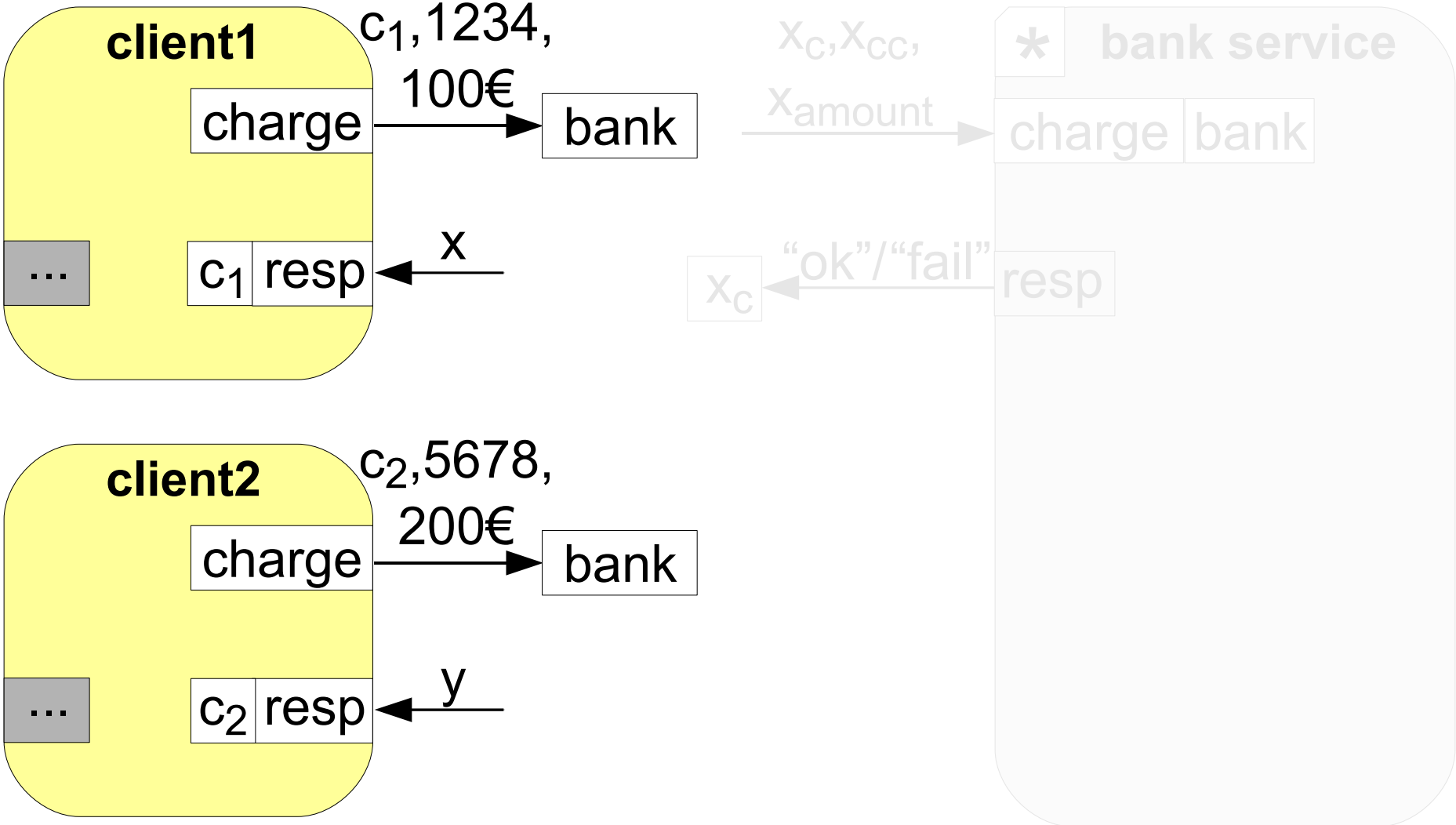
([x] (c • resp?⟨x⟩.s | s′) | c • resp!⟨*chk*(1234, id, 100€)⟩)

μCOWS^m: *persistent* bank service example



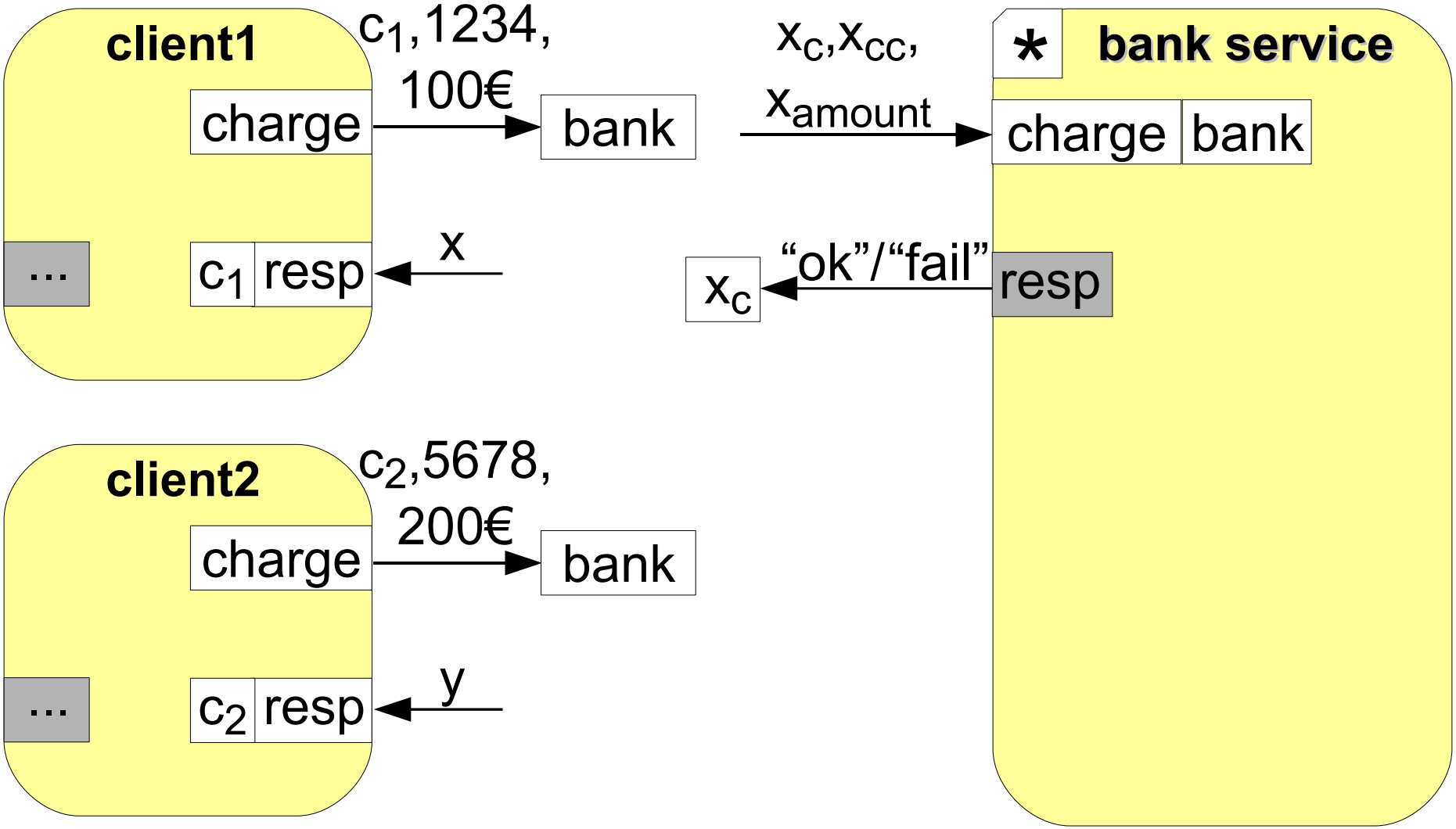
$$*\,[x_c, x_{cc}, x_{amount}]\,\mathsf{bank} \bullet \mathsf{charge}?\langle x_c, x_{cc}, x_{amount}\rangle.x_c \bullet \mathsf{resp}!\langle \mathit{chk}(x_{cc}, x_{amount})\rangle$$

μCOWS^m: *persistent* bank service example

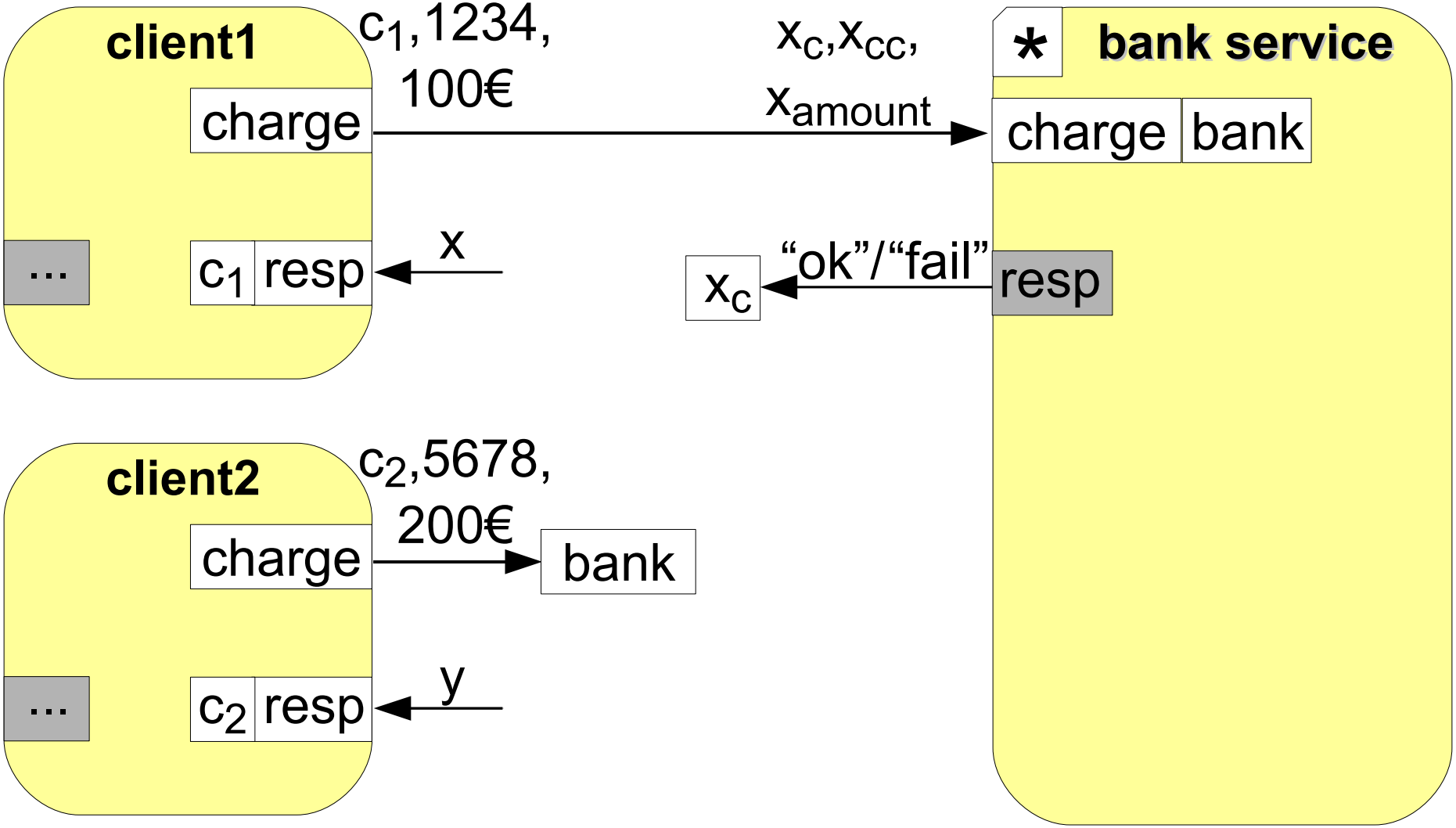


$$\mathrm{bank} \bullet \mathrm{charge}!\langle c_1, 1234, 100€\rangle \mid [x]\, c_1 \bullet \mathrm{resp}?\langle x\rangle.s_1 \mid \mathrm{bank} \bullet \mathrm{charge}!\langle c_2, 5678, 200€\rangle \mid [y]\, c_2 \bullet \mathrm{resp}?\langle y\rangle.s_2$$

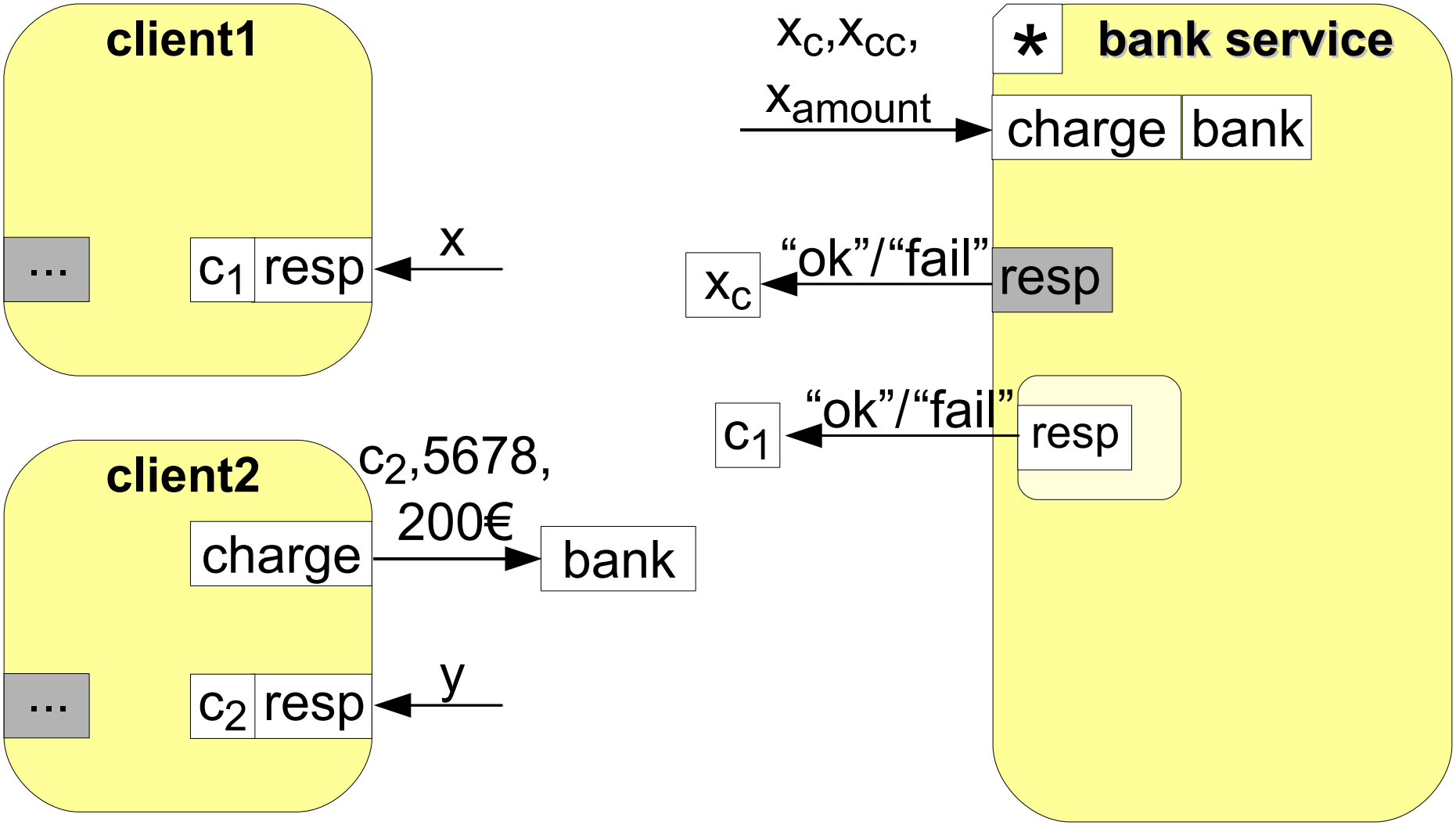
μCOWS^m: *persistent* bank service example



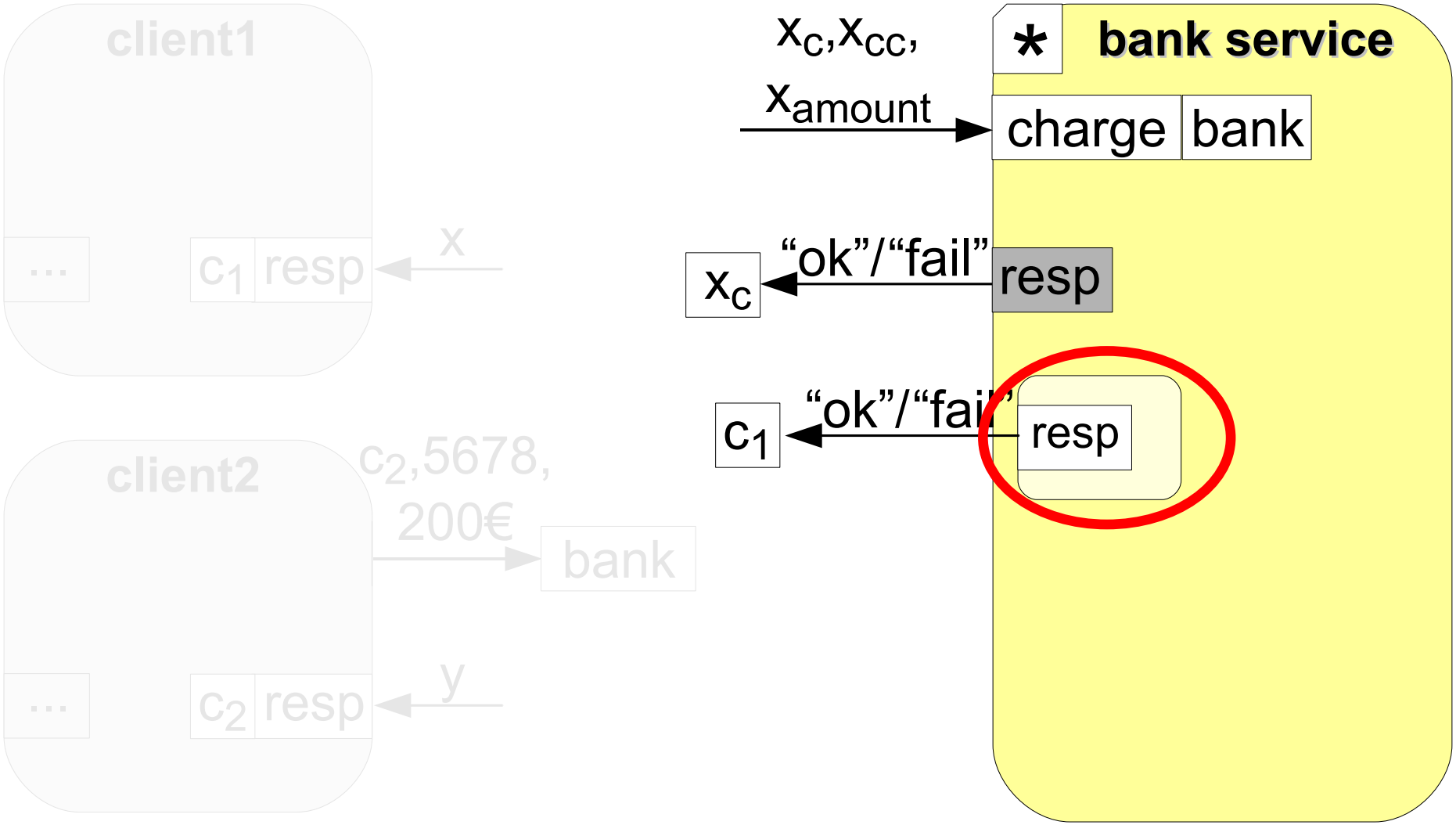
μCOWS^m: *persistent* bank service example



μCOWS^m: *persistent* bank service example

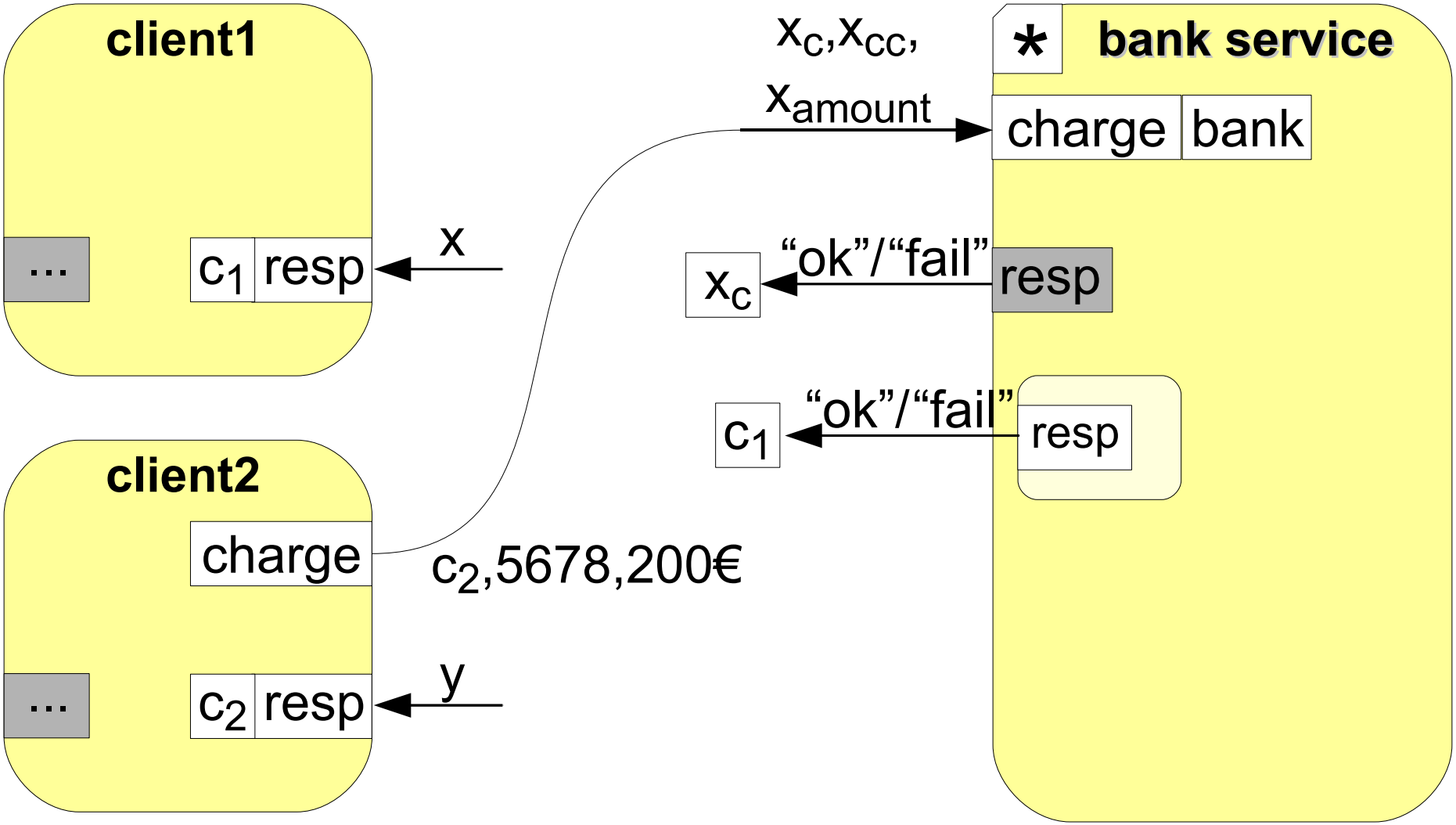


μCOWS^m: *persistent* bank service example

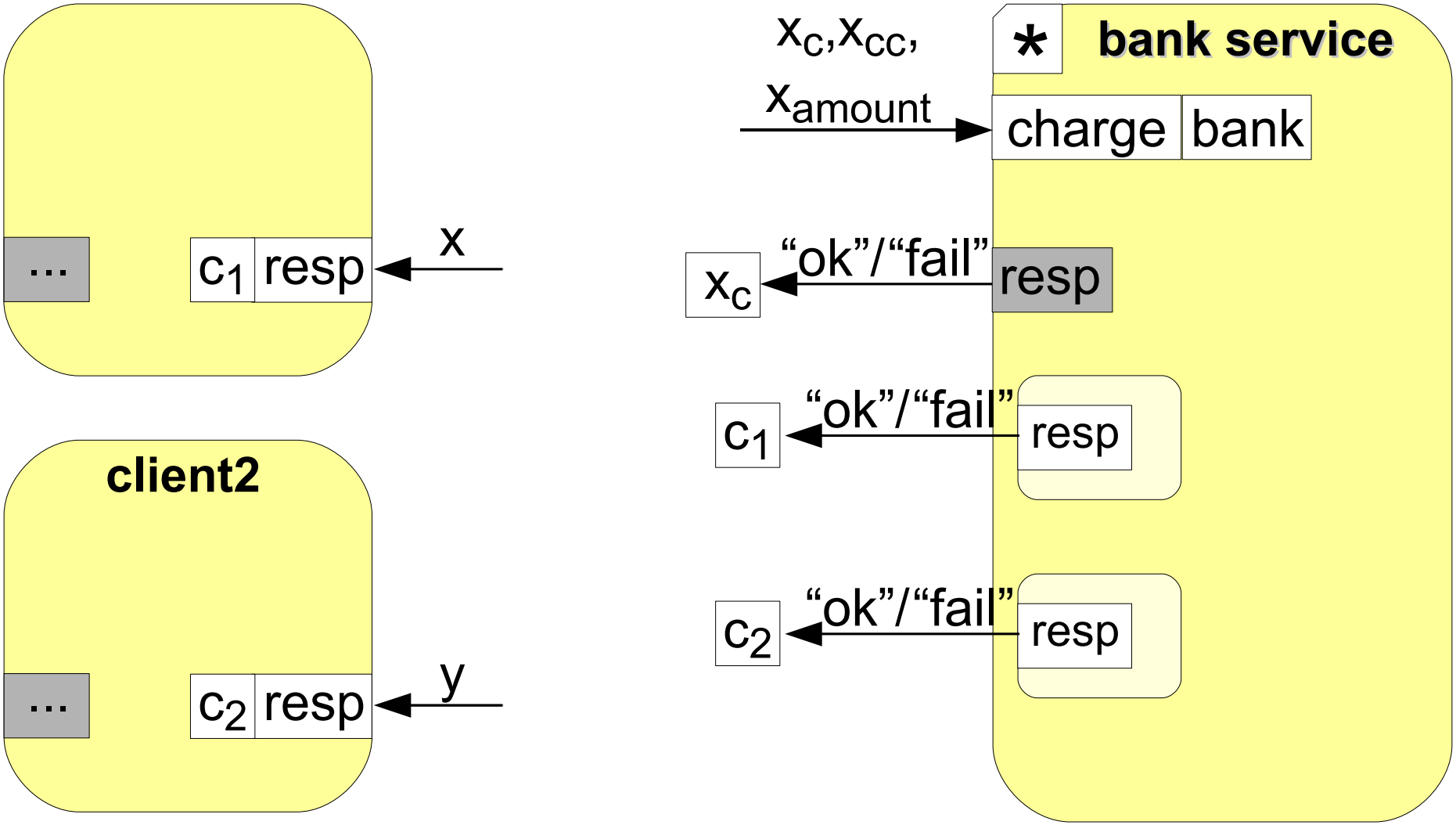


$$* [x_c, x_{cc}, x_{amount}]\, bank \bullet charge?\langle x_c, x_{cc}, x_{amount}\rangle.x_c \bullet resp!\langle chk(x_{cc}, x_{amount})\rangle$$
$$\mid\ c_1 \bullet resp!\langle chk(1234, 100€)\rangle$$

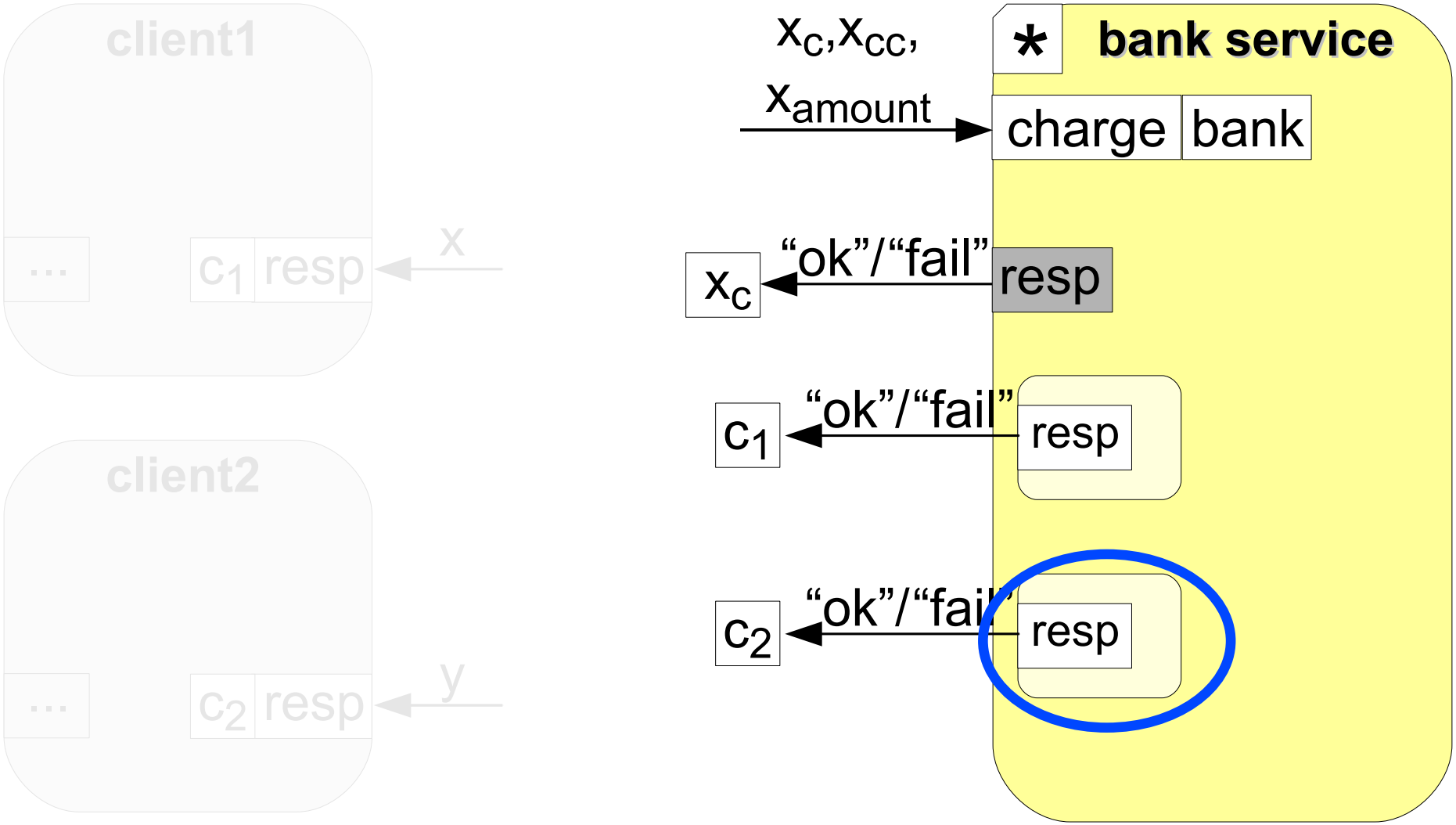
μCOWS^m: *persistent* bank service example



μCOWS^m: *persistent* bank service example

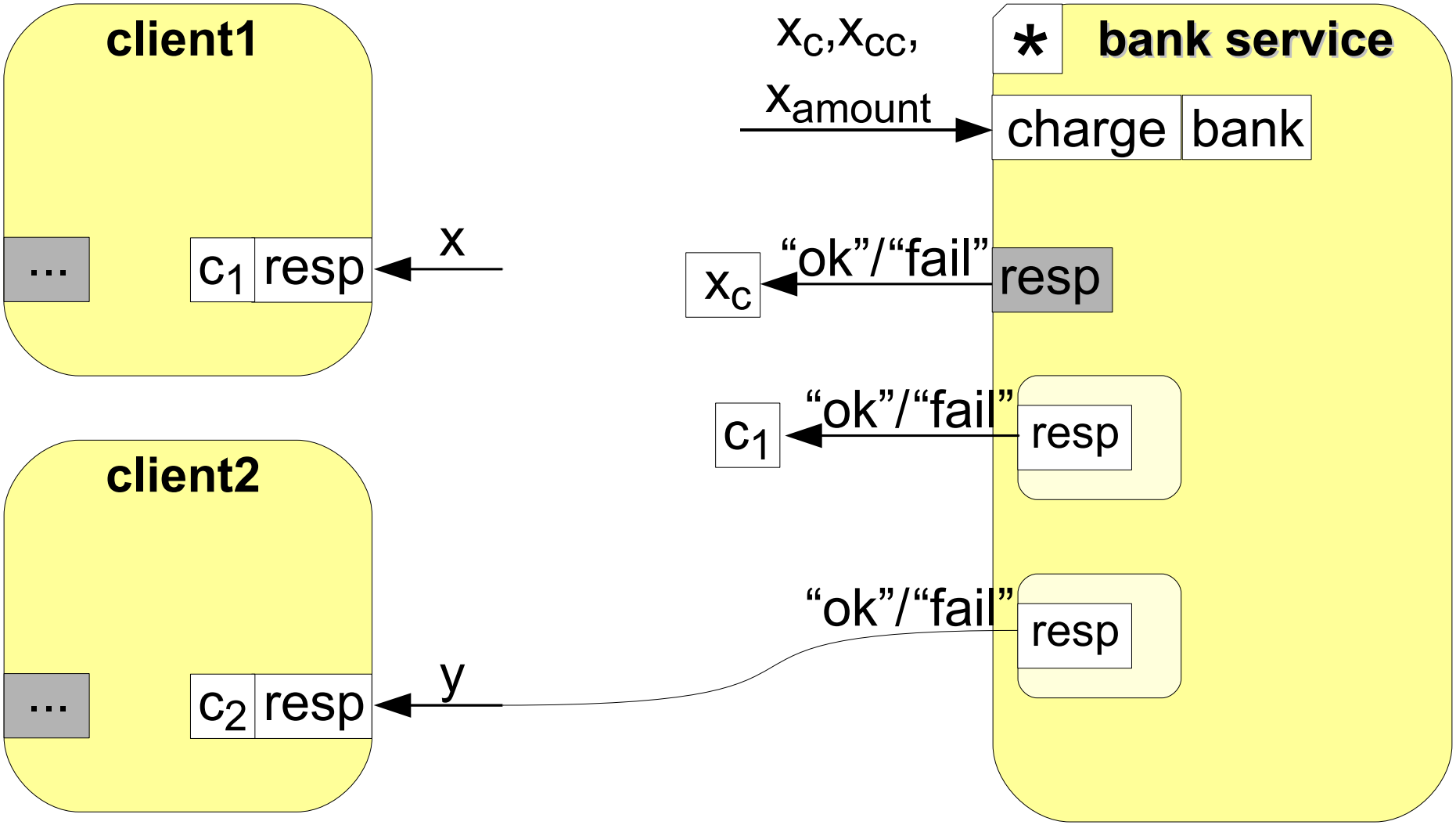


μCOWS^m: *persistent* bank service example

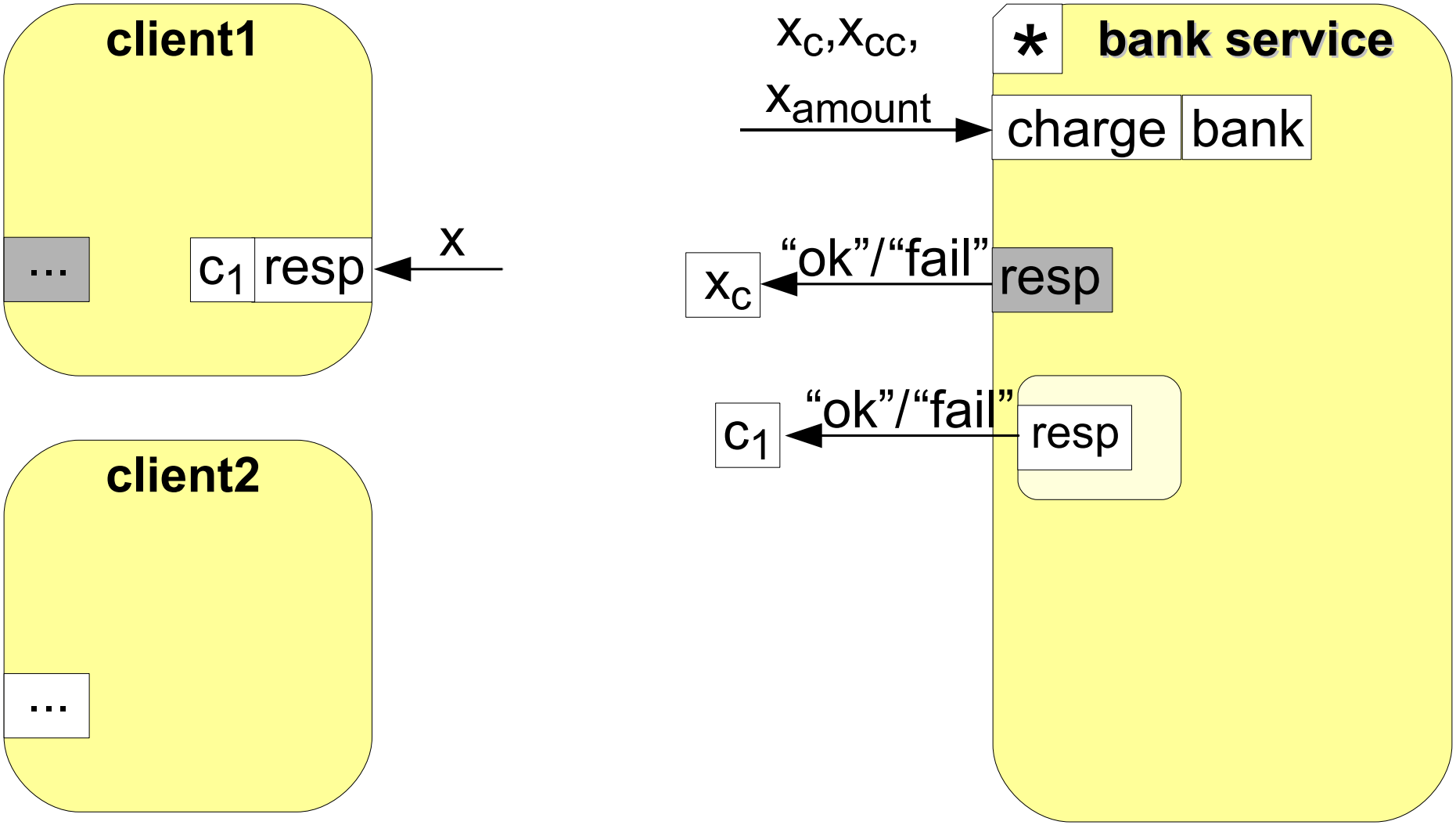


$$*\,[x_c, x_{cc}, x_{amount}]\,\mathsf{bank} \bullet \mathsf{charge}?\langle x_c, x_{cc}, x_{amount}\rangle.x_c \bullet \mathsf{resp}!\langle \mathit{chk}(x_{cc}, x_{amount})\rangle$$
$$\mid\ c_1 \bullet \mathsf{resp}!\langle \mathit{chk}(1234, 100€)\rangle \mid\ c_2 \bullet \mathsf{resp}!\langle \mathit{chk}(5678, 200€)\rangle$$

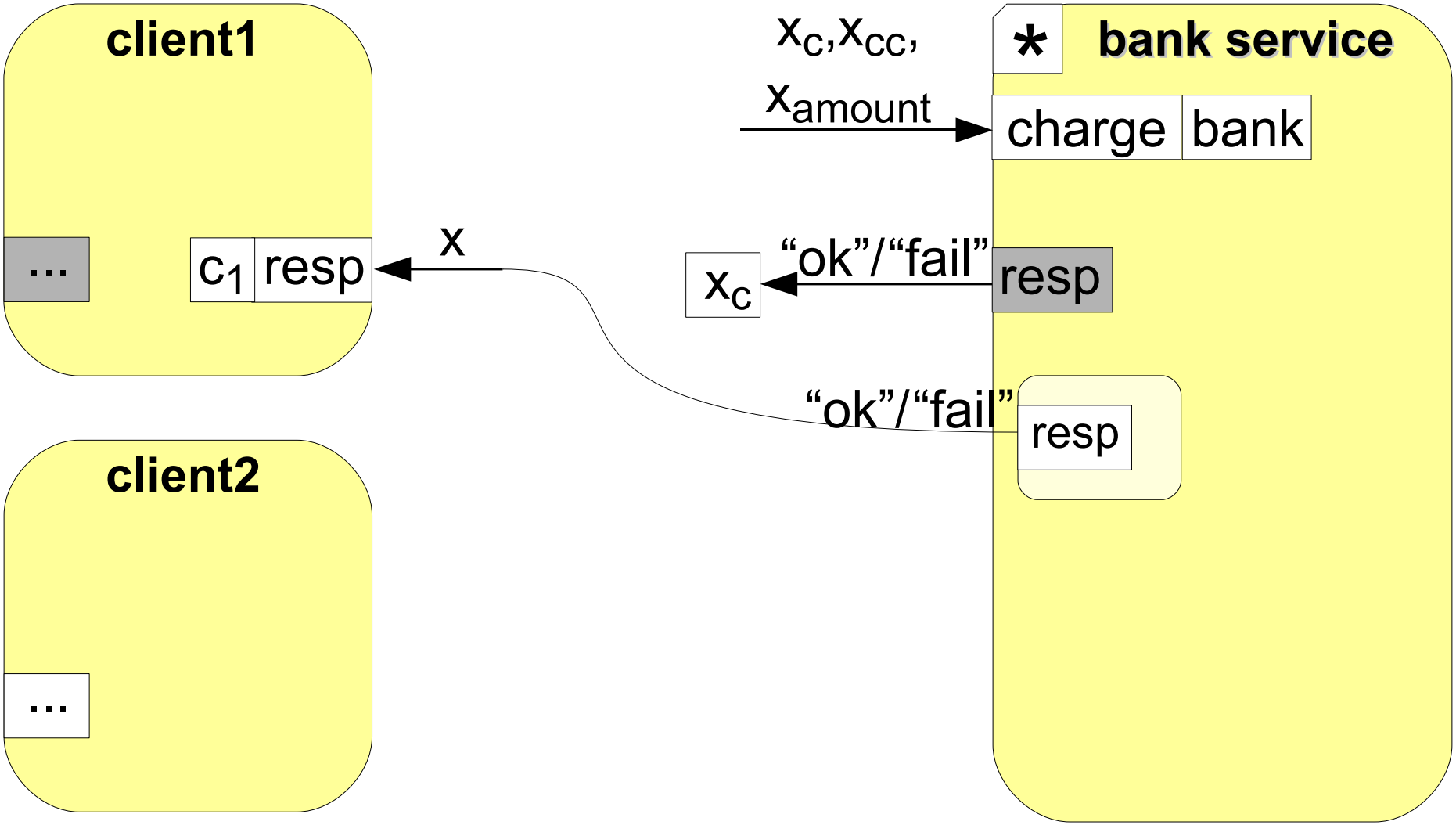
μCOWS^m: *persistent* bank service example



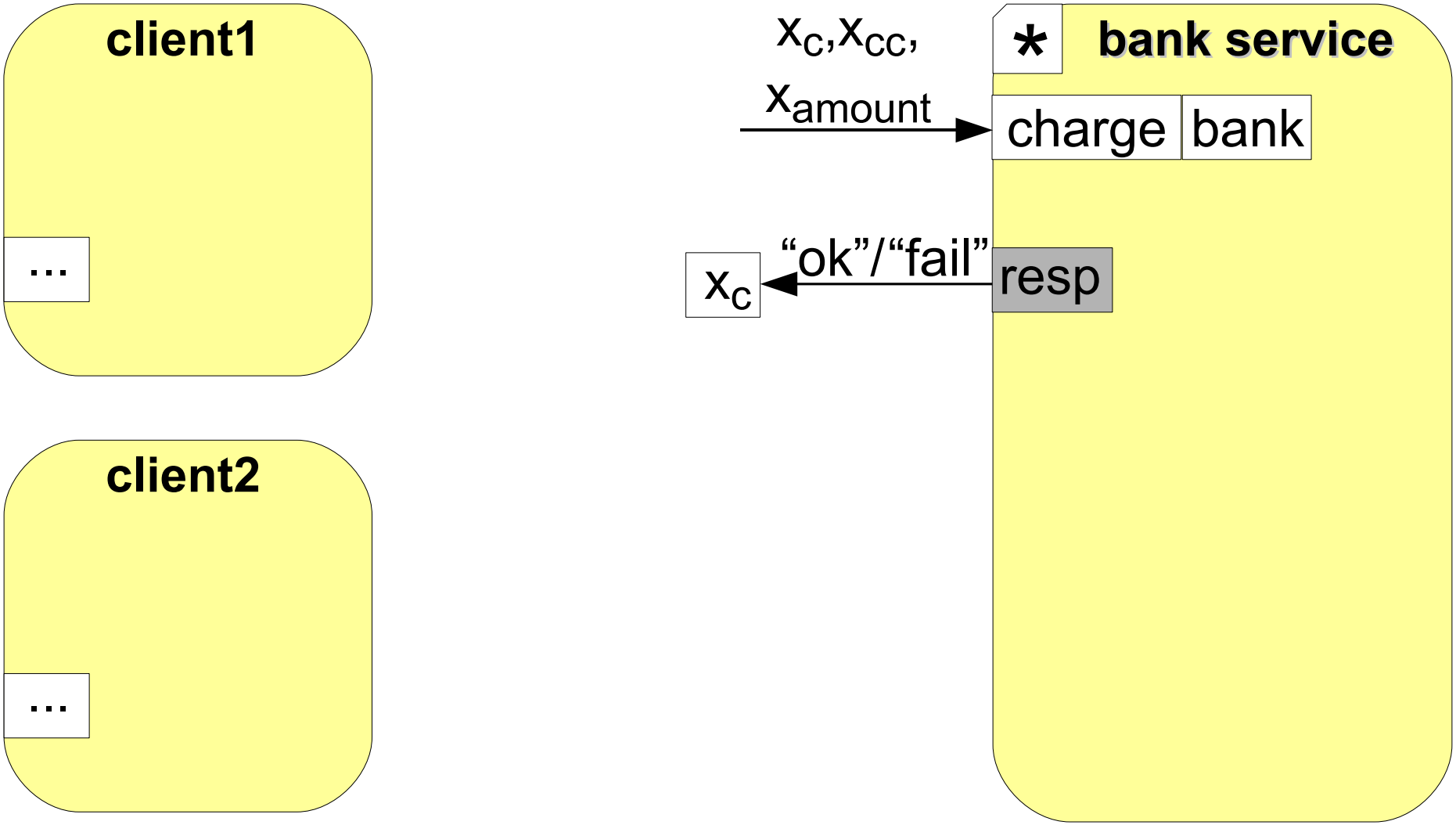
μCOWS^m: *persistent* bank service example



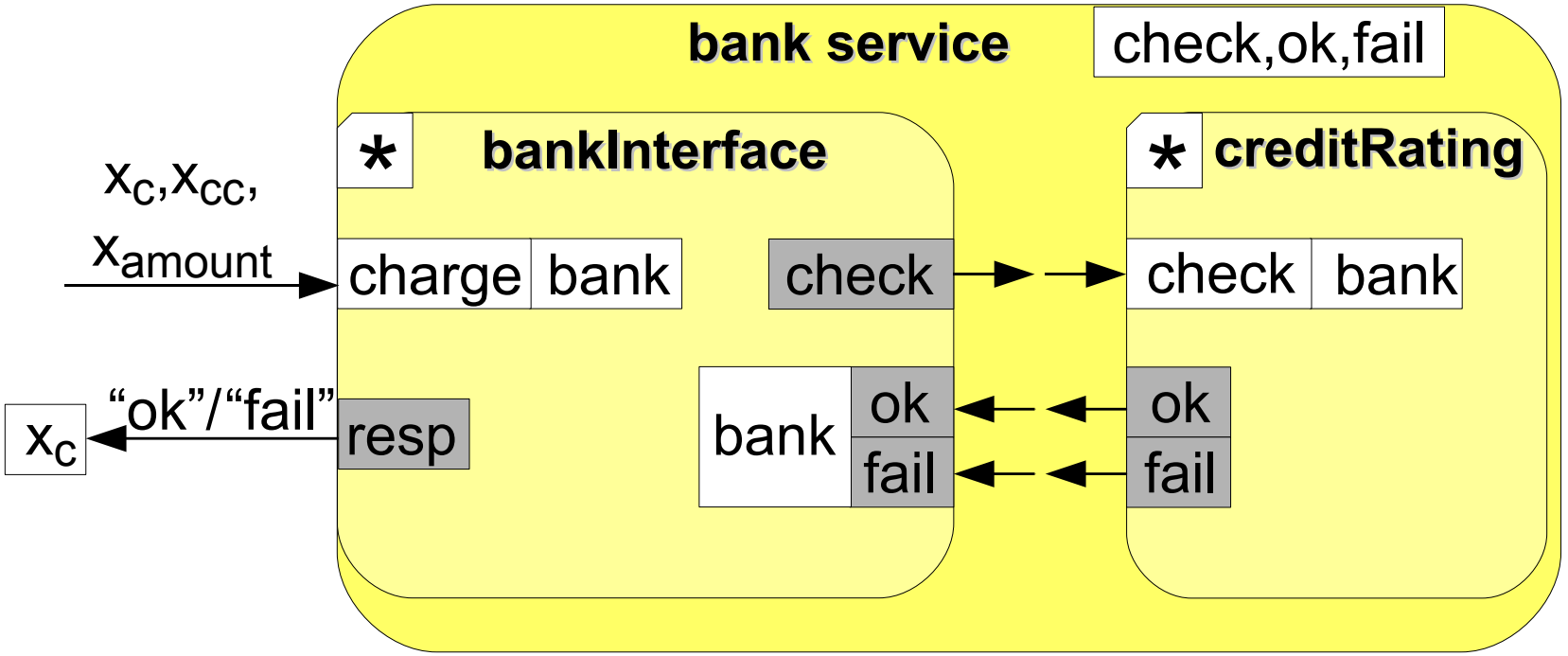
μCOWS^m: *persistent* bank service example



μCOWS^m: *persistent* bank service example

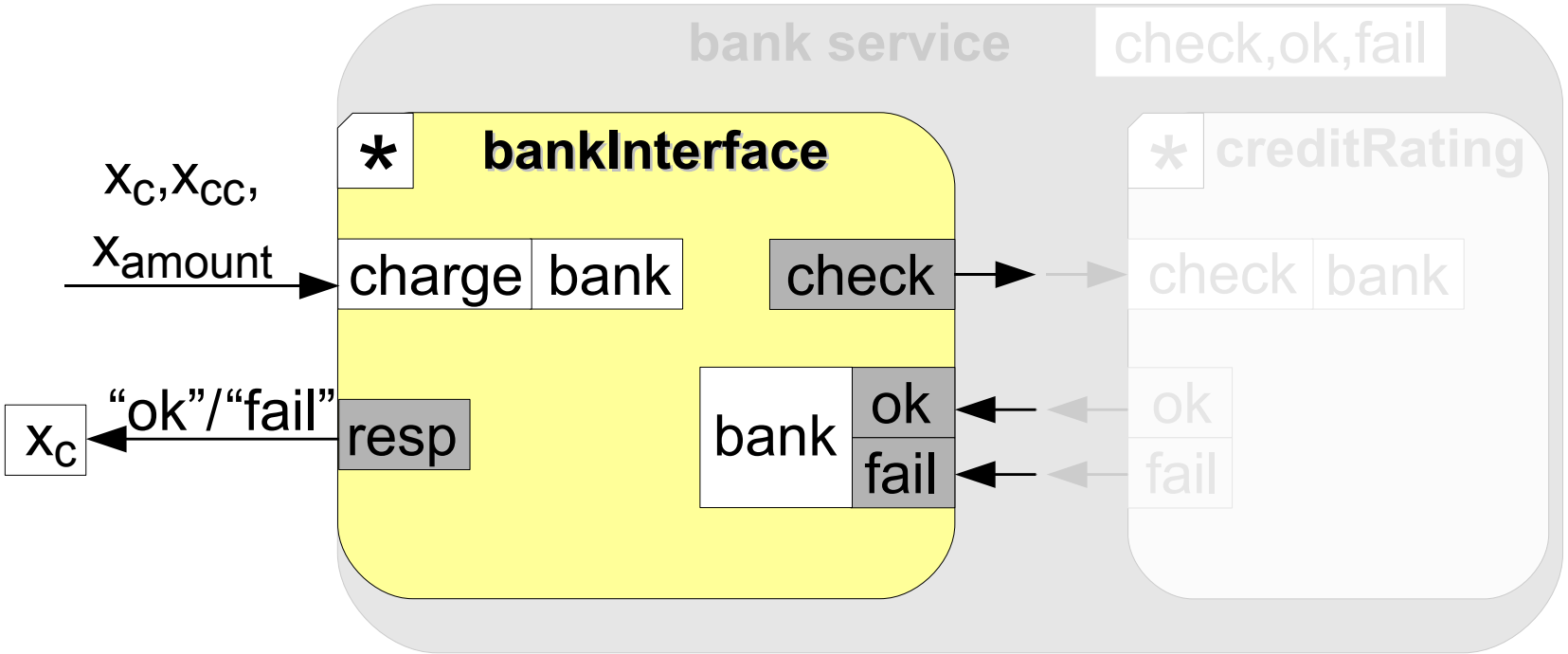


μCOWS^m: *compound* bank service example



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

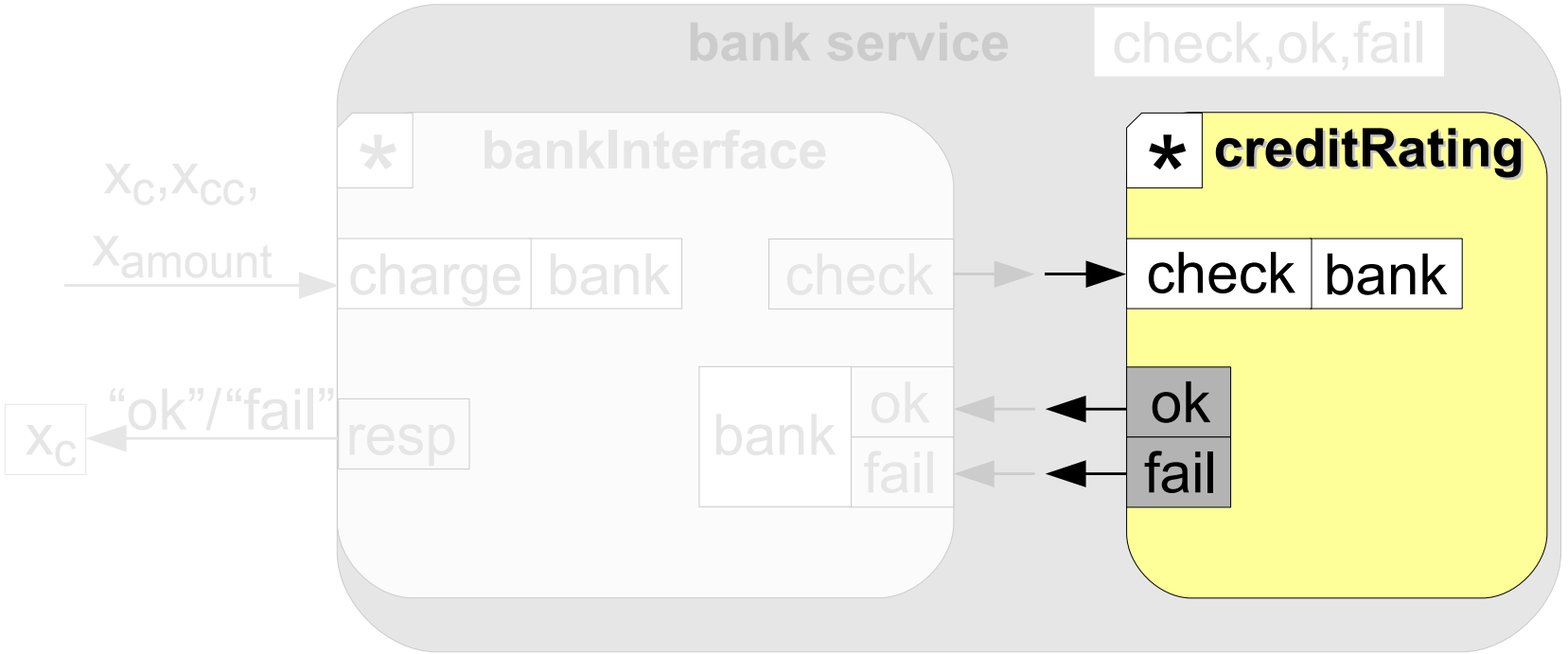
μCOWS^m: *compound* bank service example



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

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

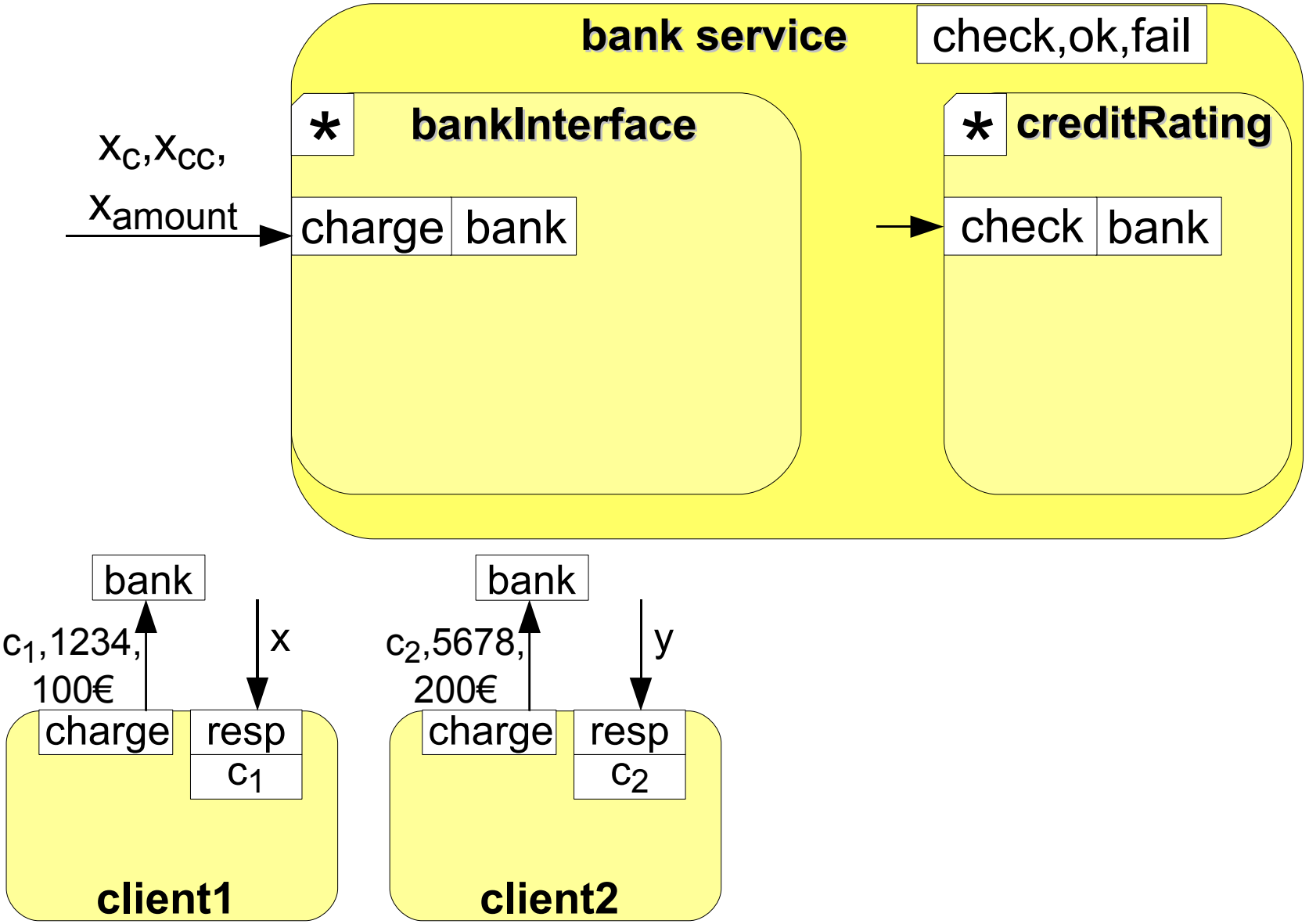
μCOWS^m: *compound* bank service example



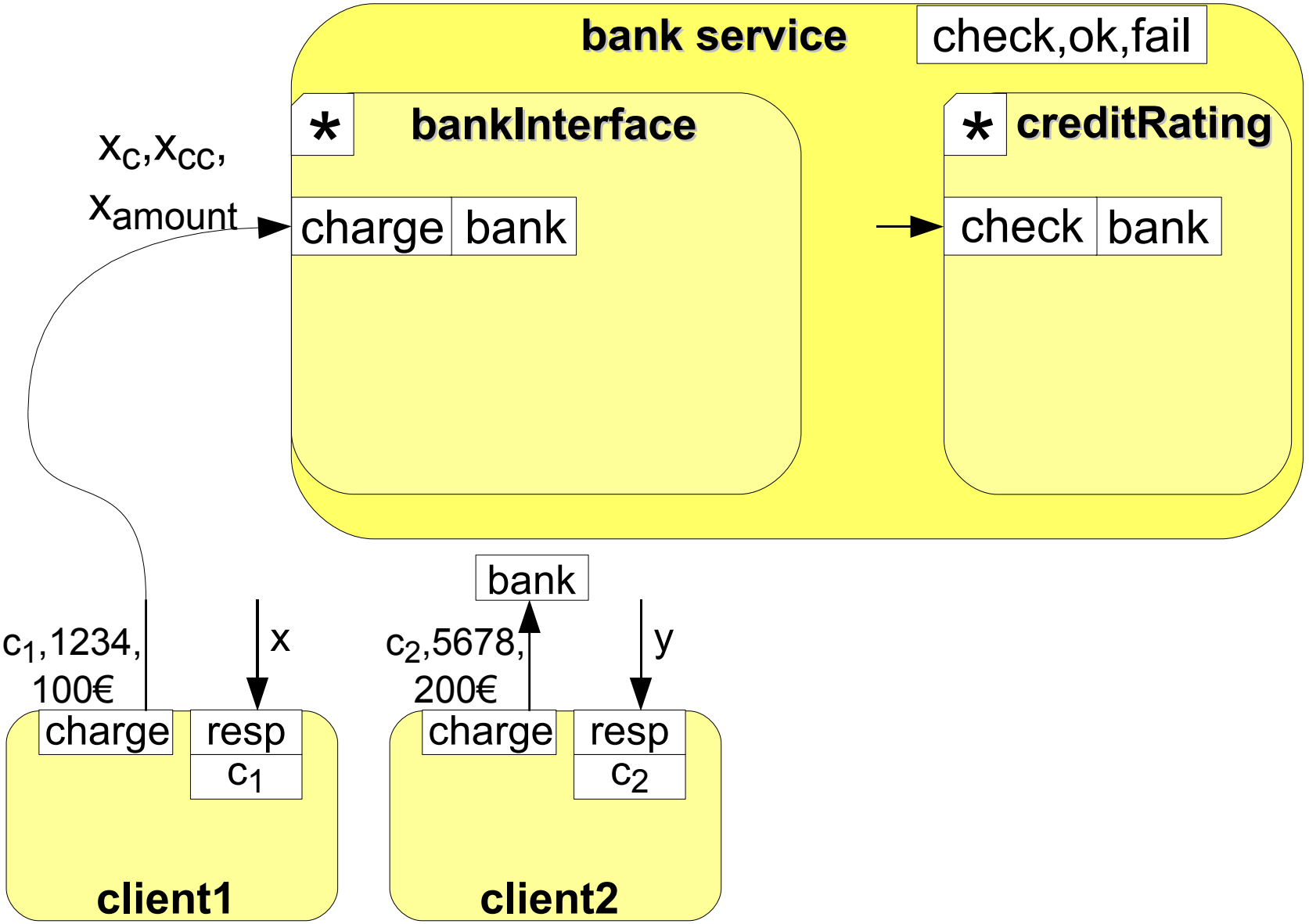
$$[\text{check}, \text{ok}, \text{fail}]\ (\ *\,\text{bankInterface} \mid *\,\text{creditRating}\ )$$

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

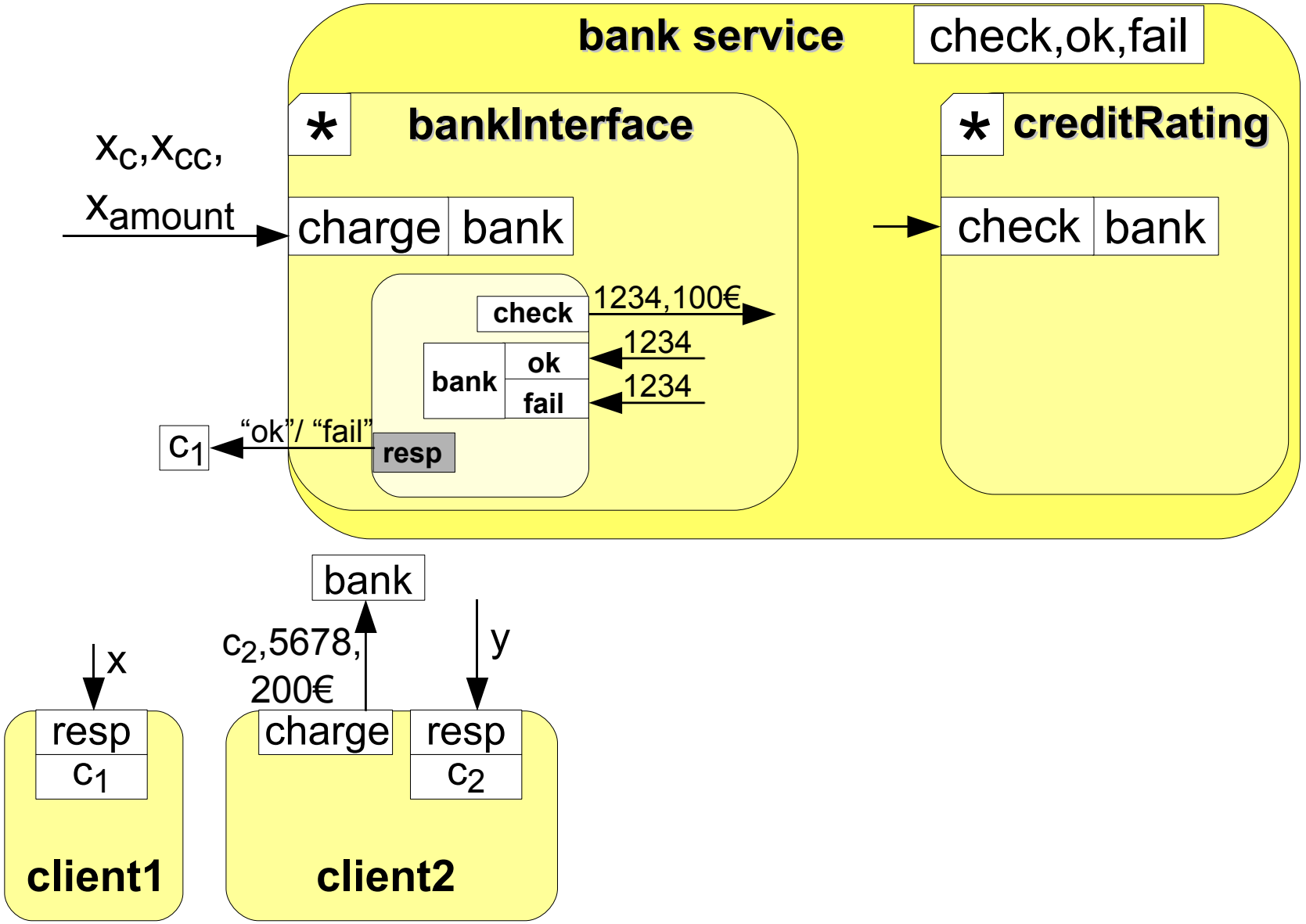
μCOWS^m: *compound* bank service example



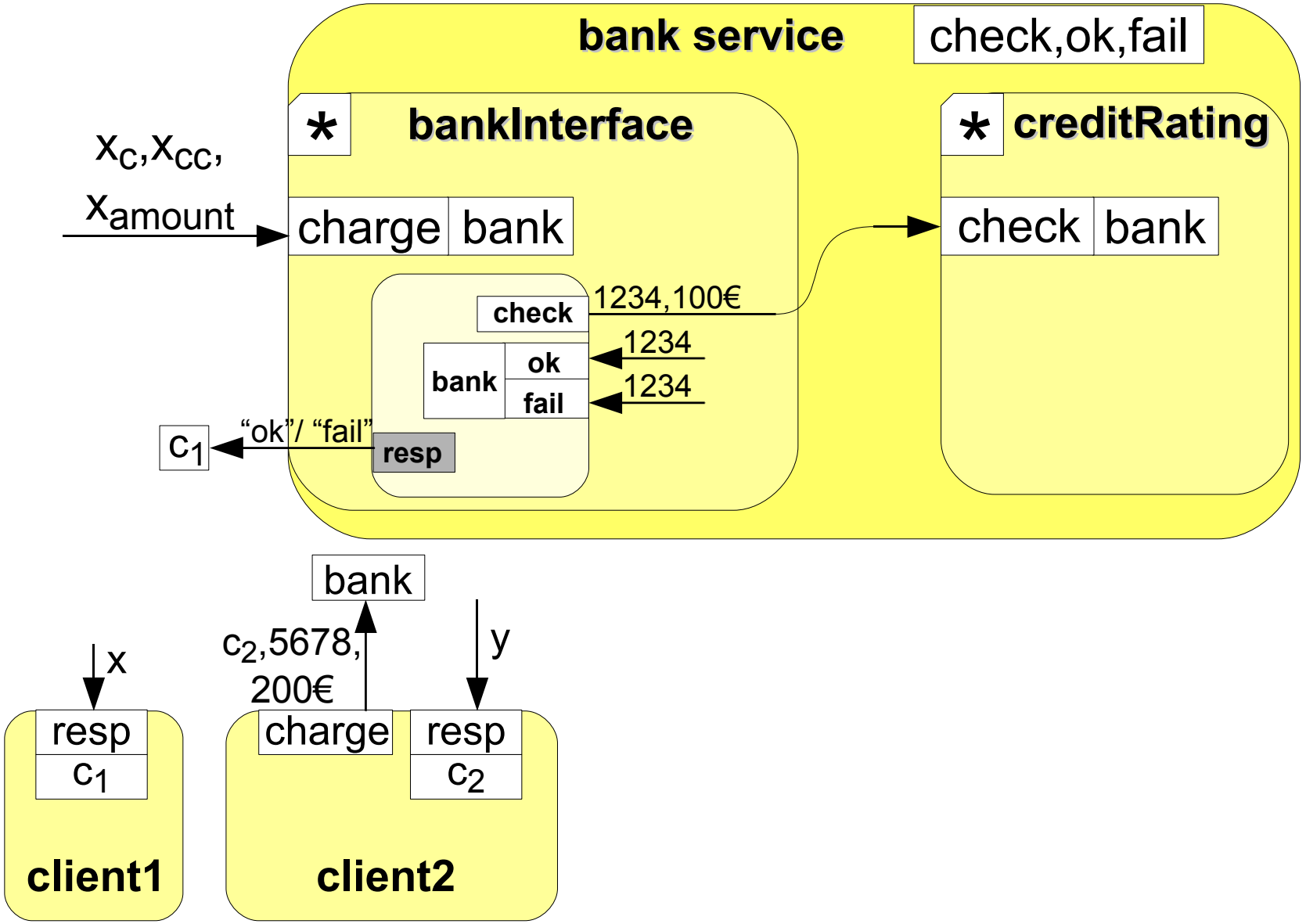
μCOWS^m: *compound* bank service example



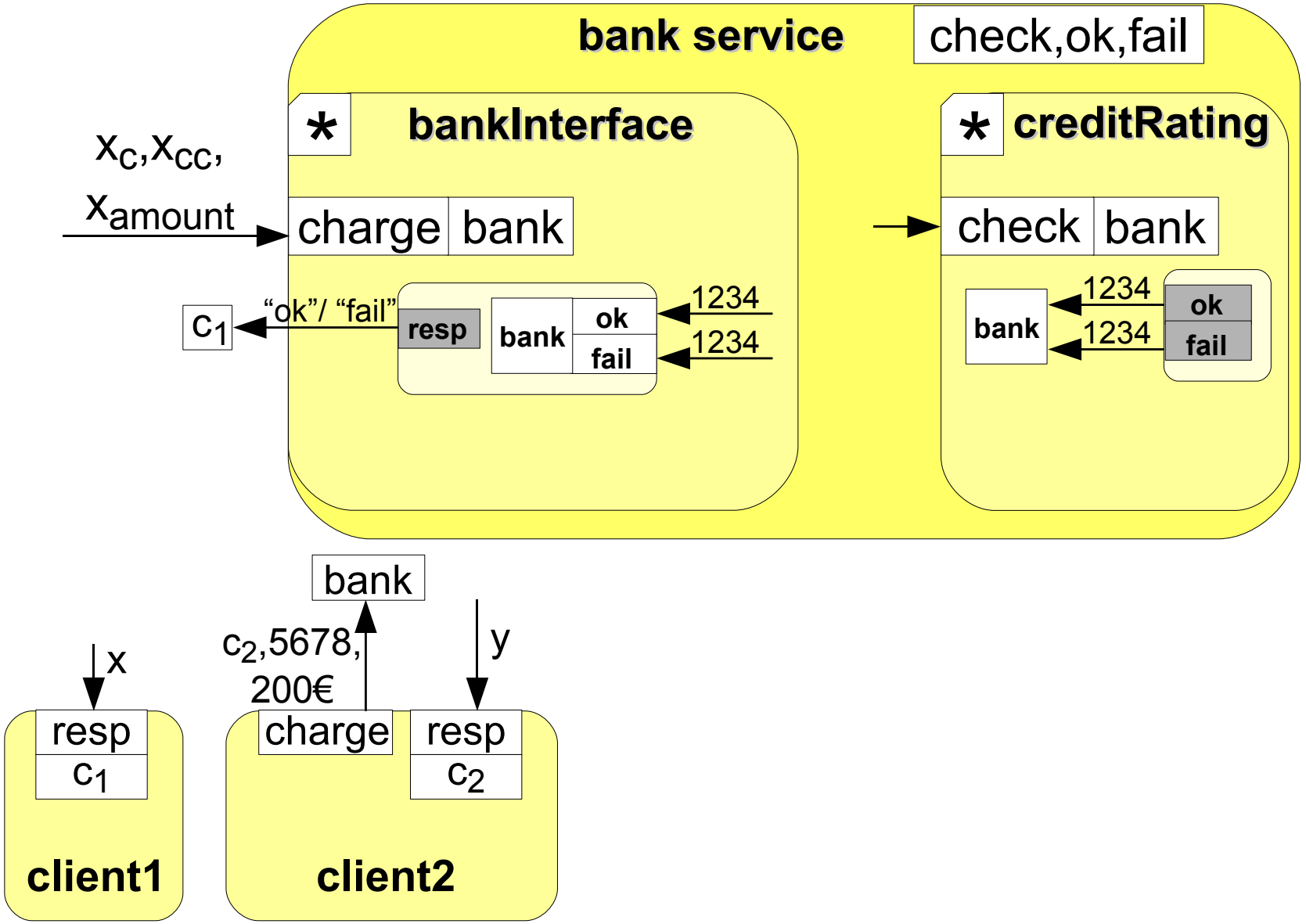
μCOWS^m: *compound* bank service example



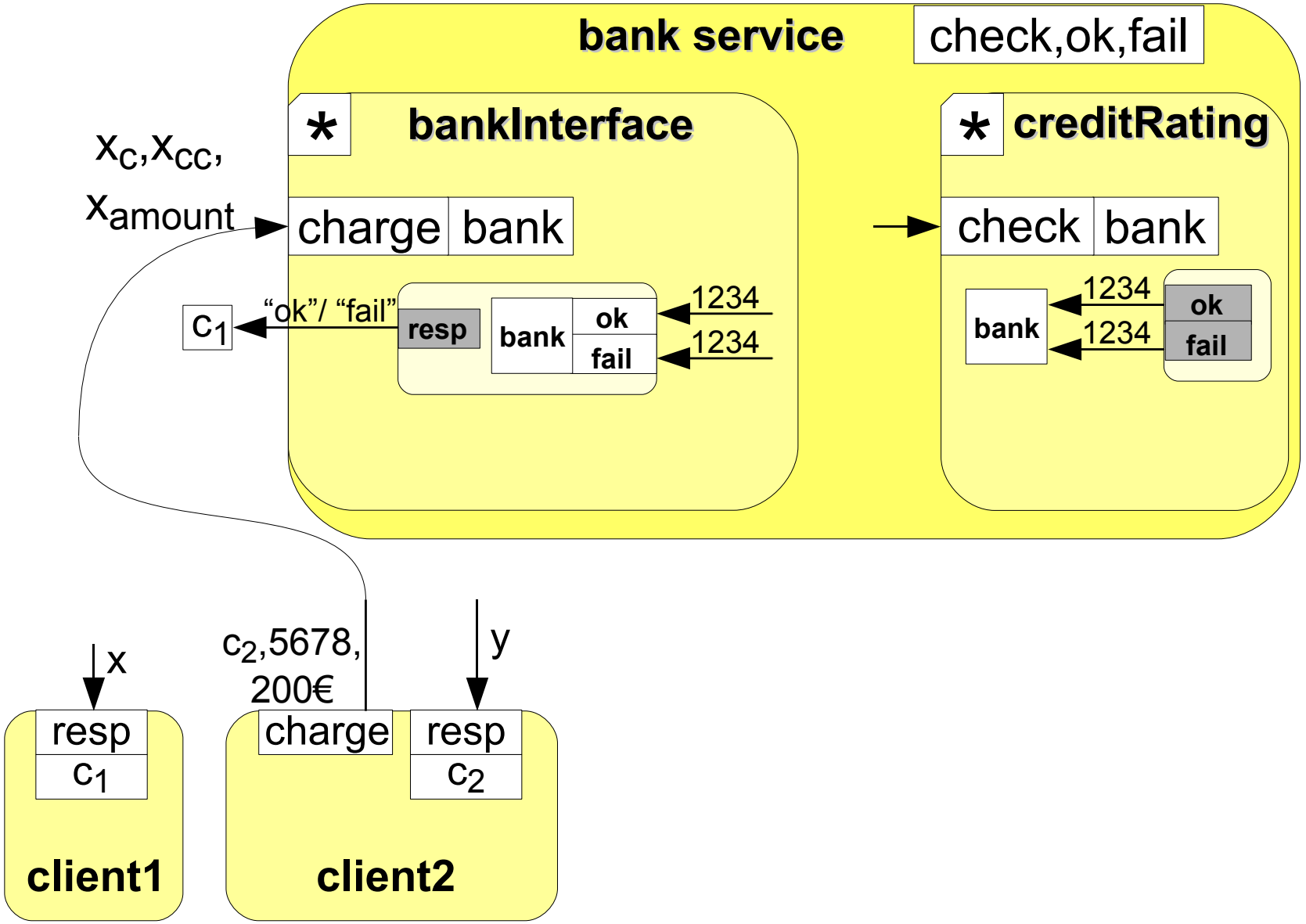
μCOWS^m: *compound* bank service example



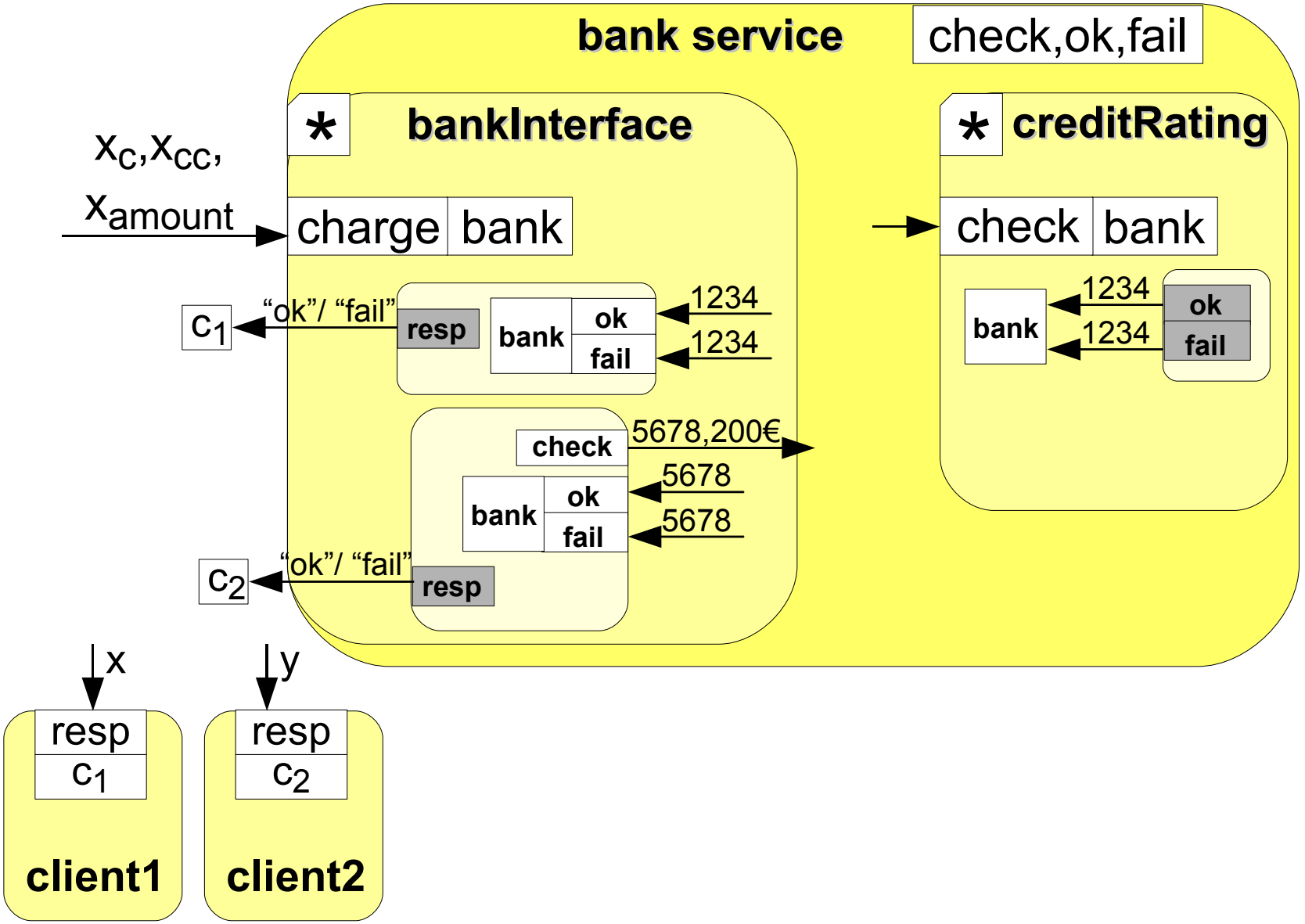
μCOWS^m: *compound* bank service example



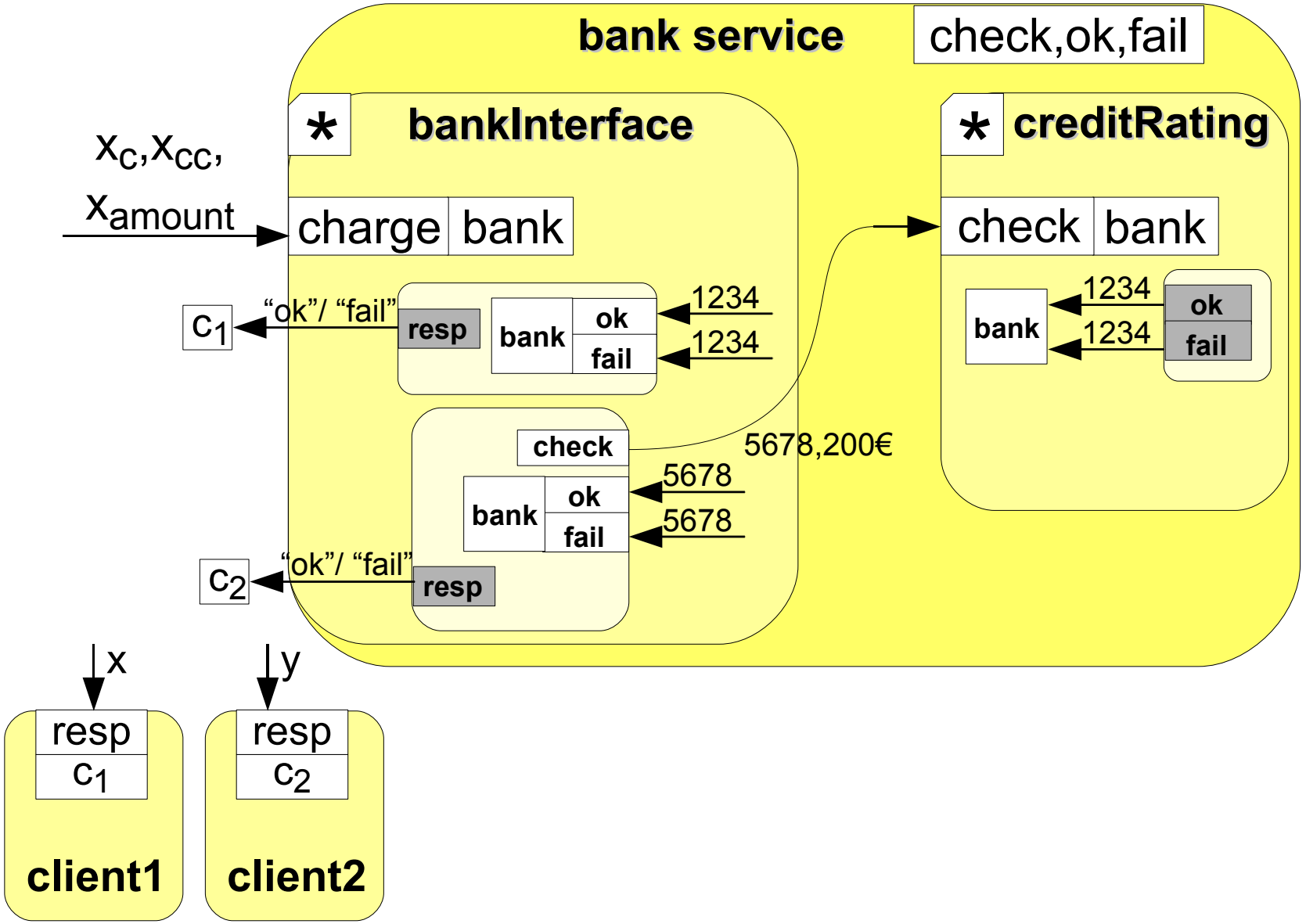
μCOWS^m: *compound* bank service example



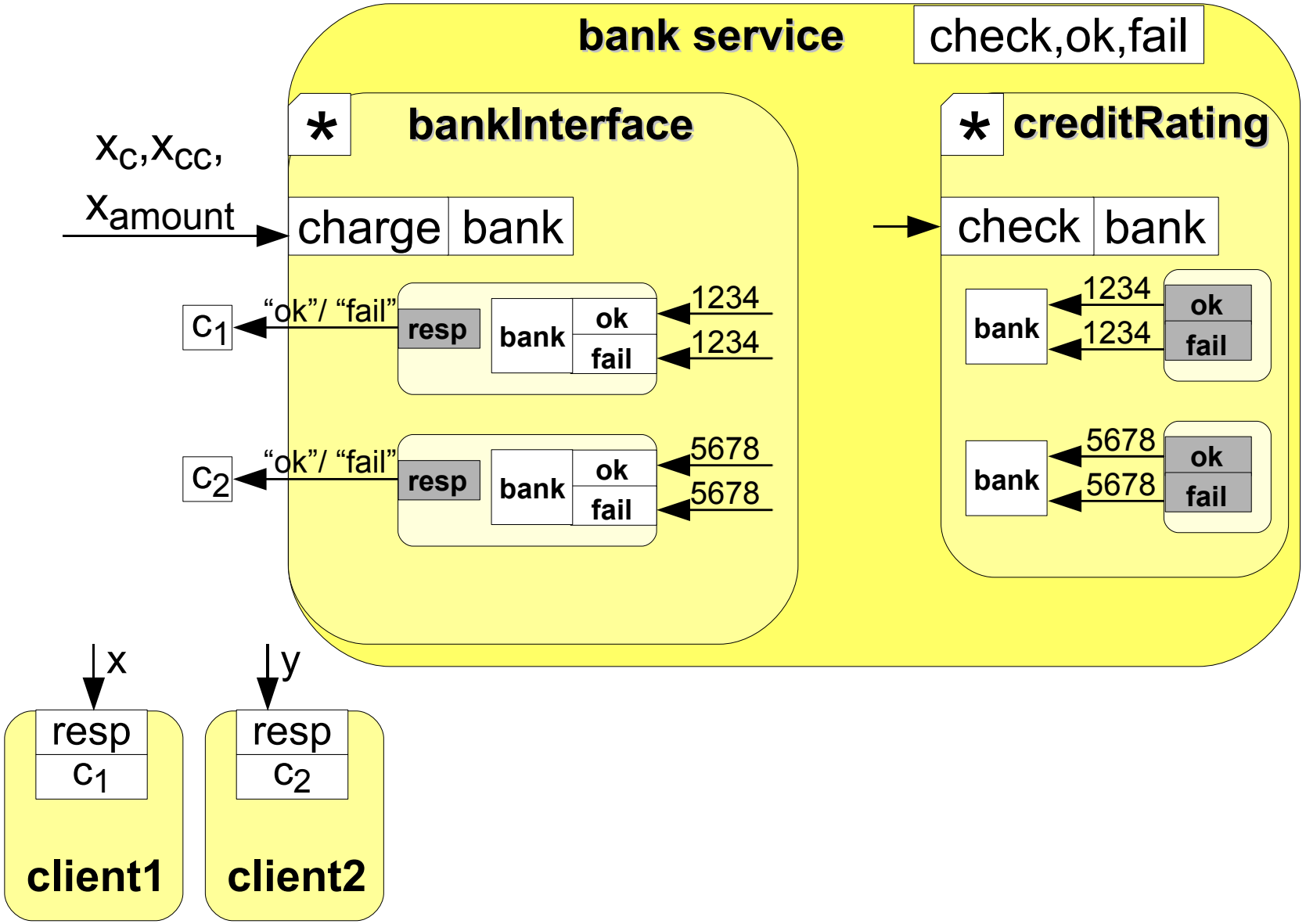
μCOWS^m: *compound* bank service example



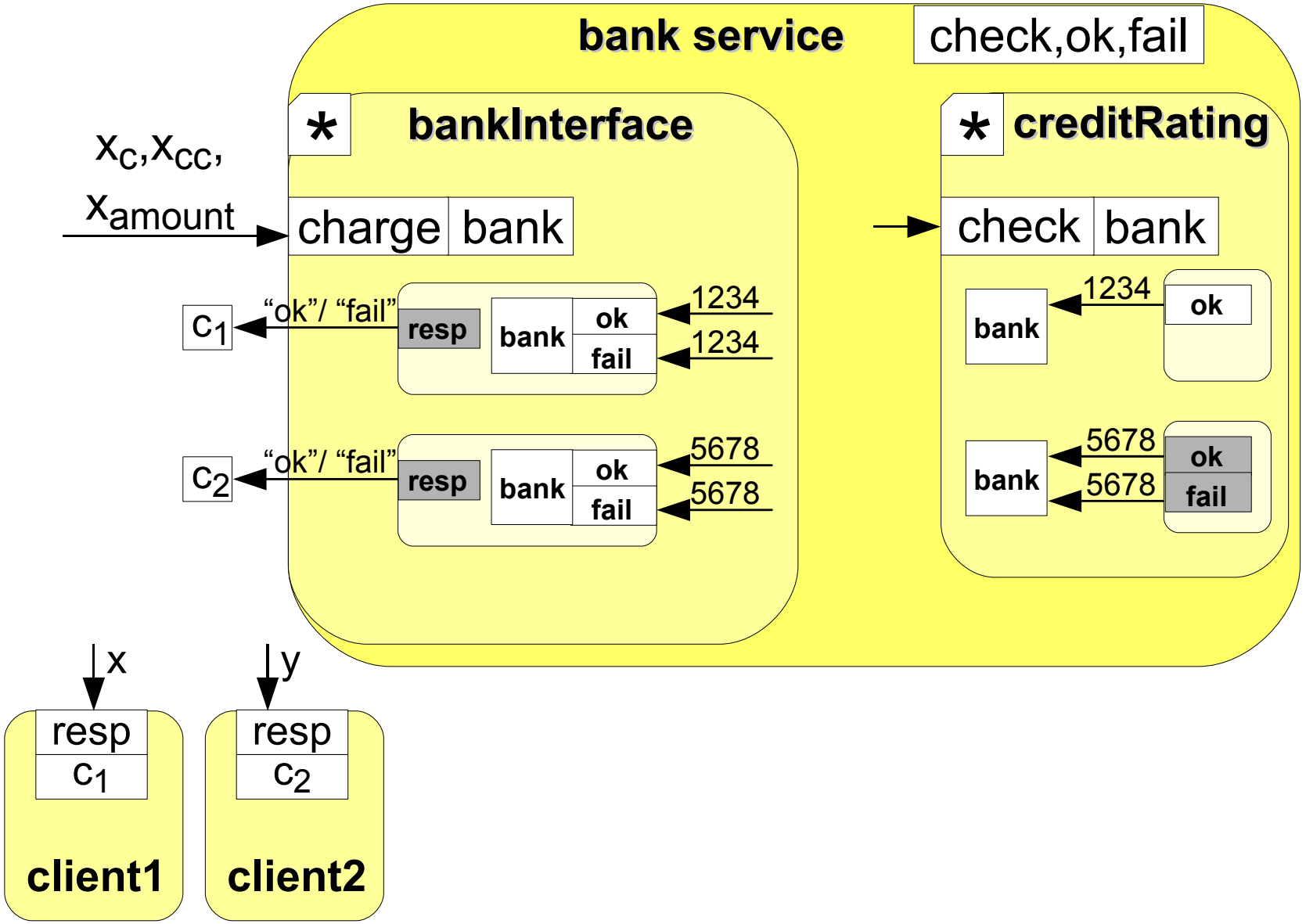
μCOWS^m: *compound* bank service example



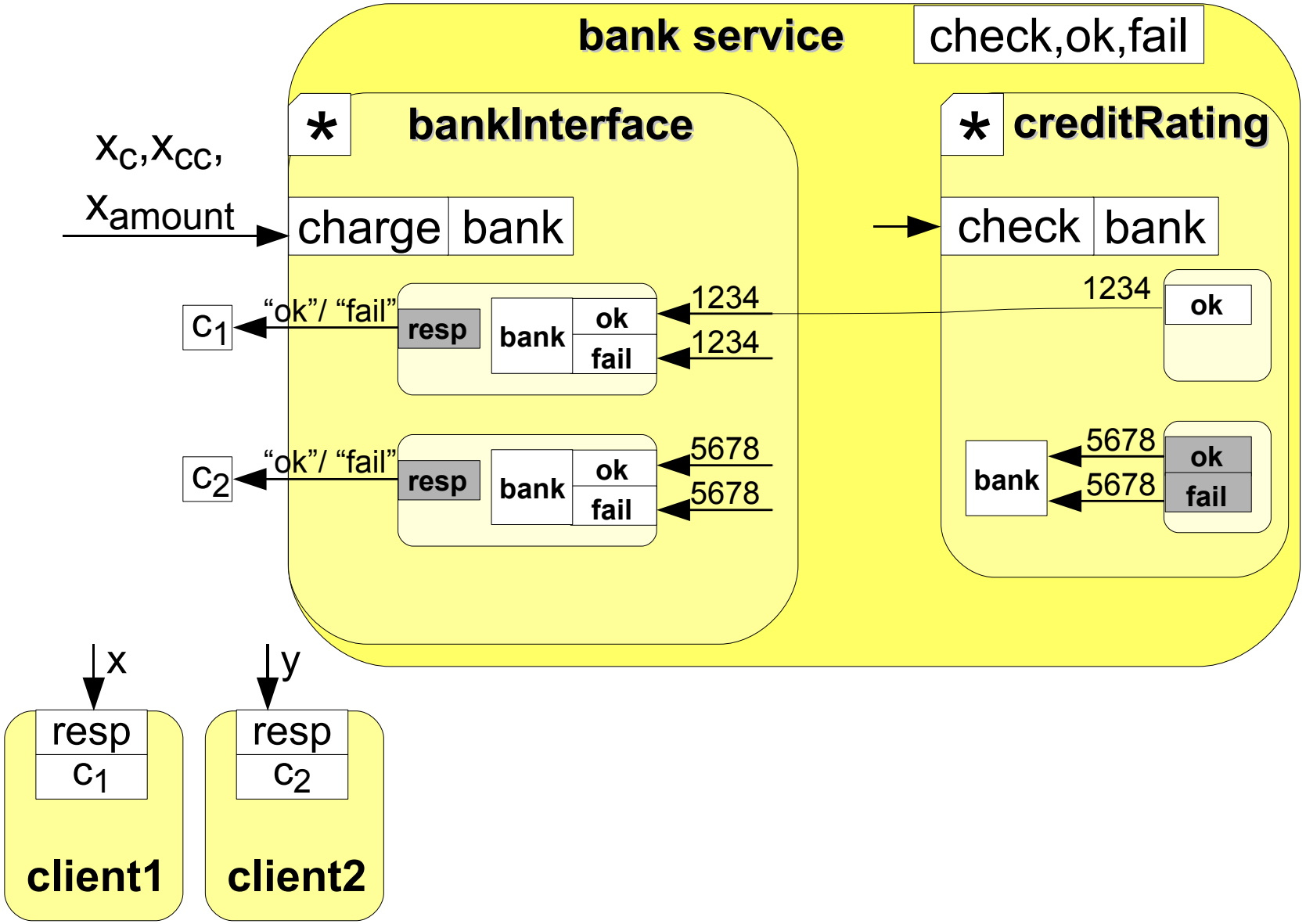
μCOWS^m: *compound* bank service example



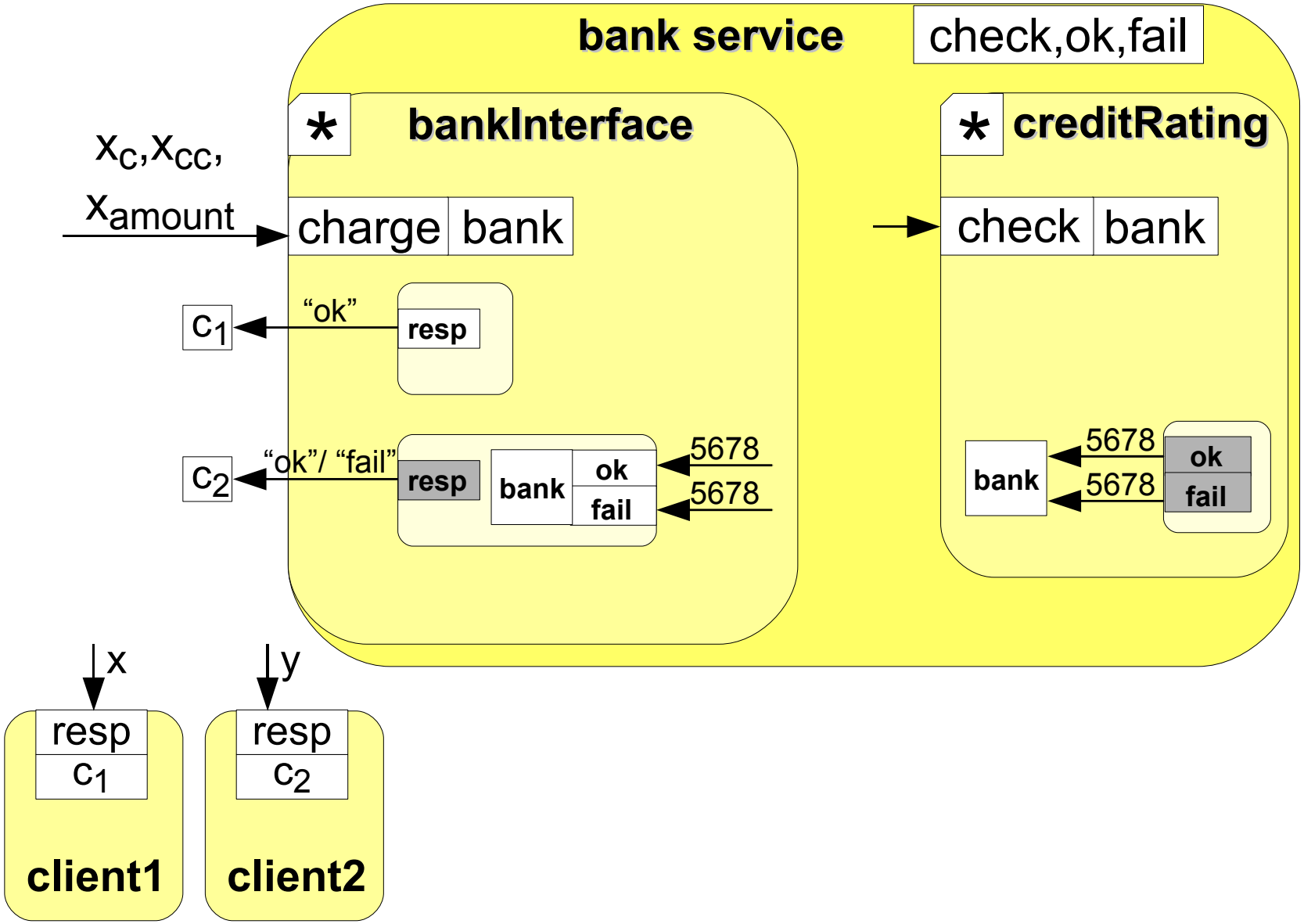
μCOWS^m: *compound* bank service example



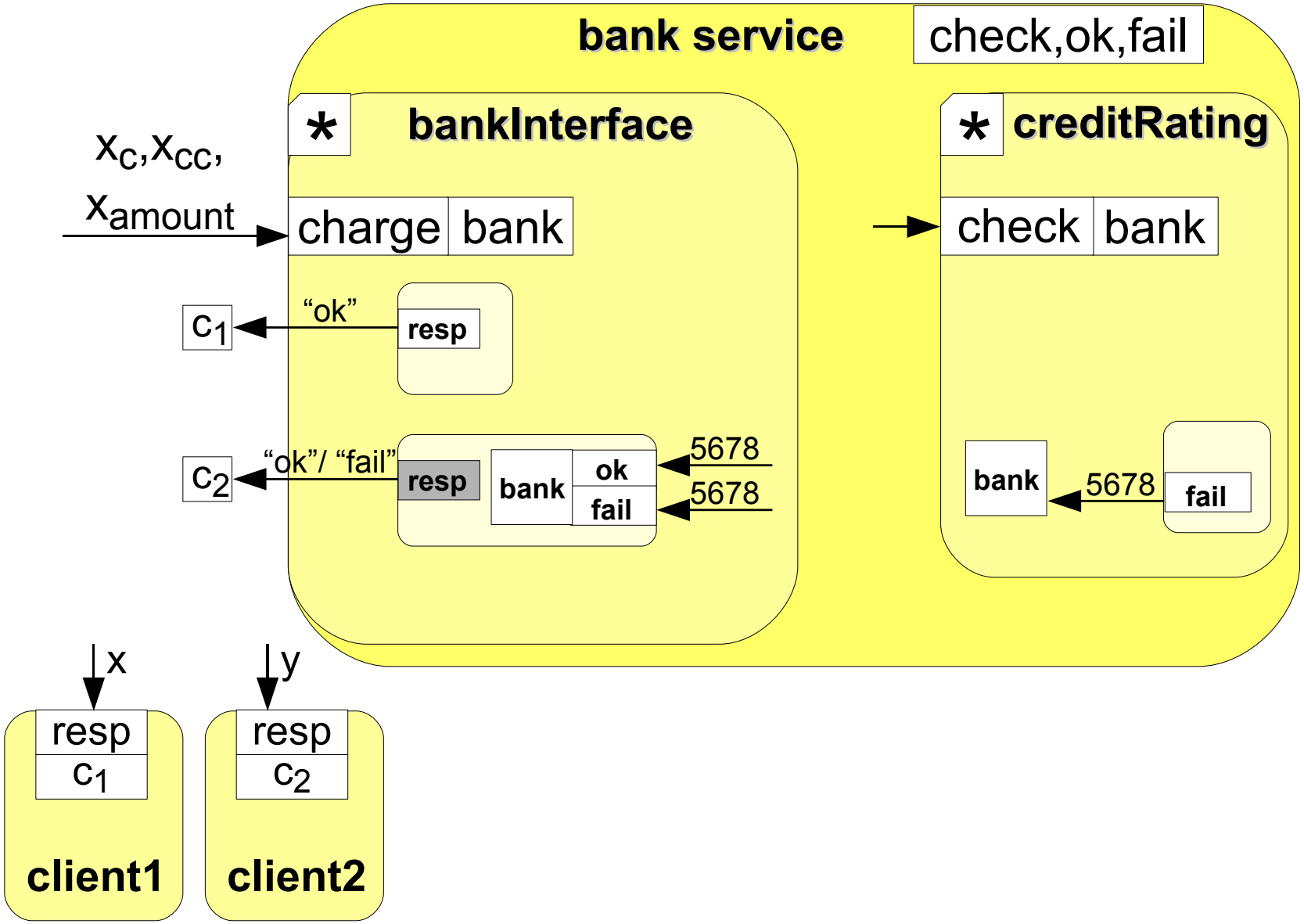
μCOWS^m: *compound* bank service example



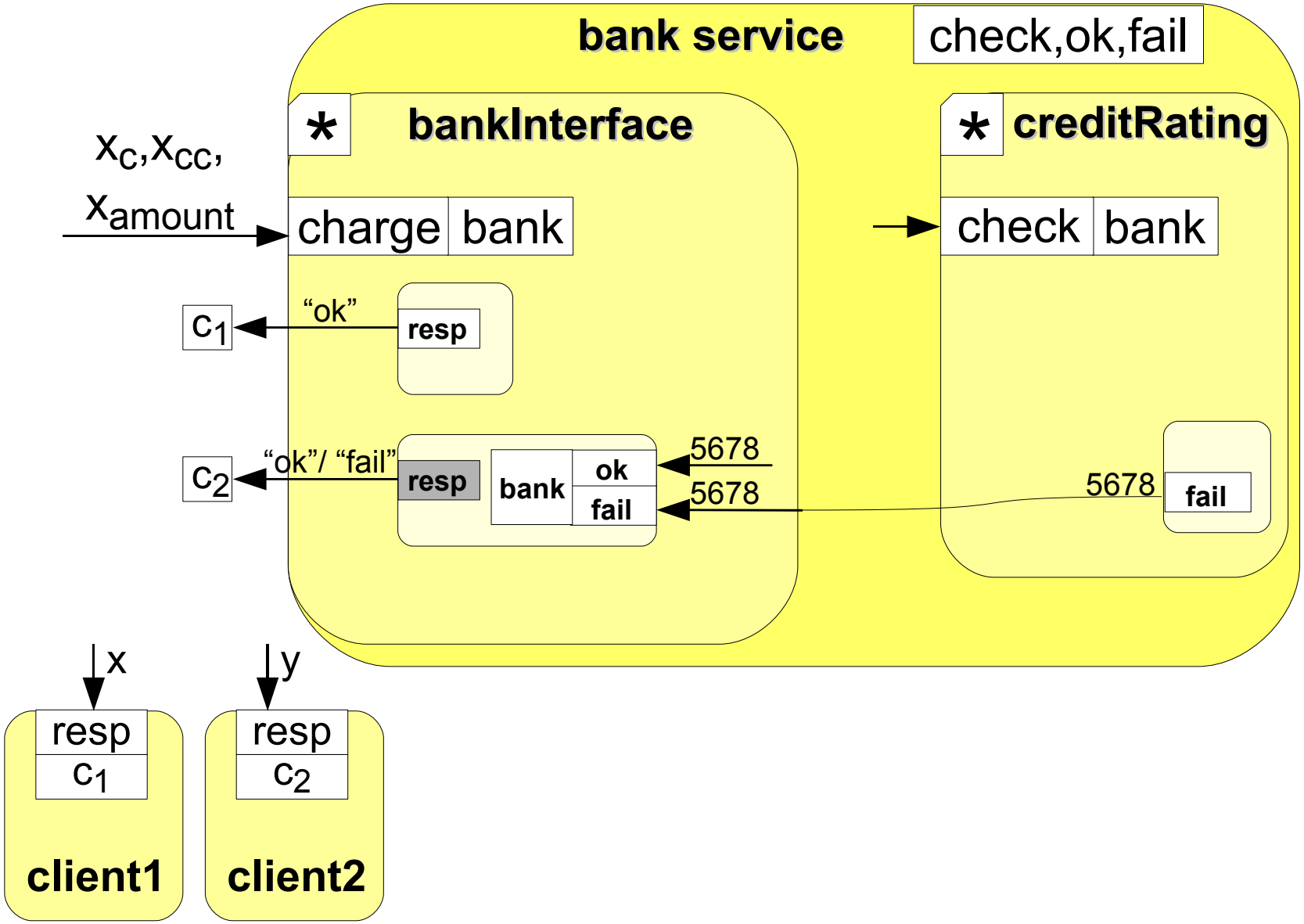
μCOWS^m: *compound* bank service example



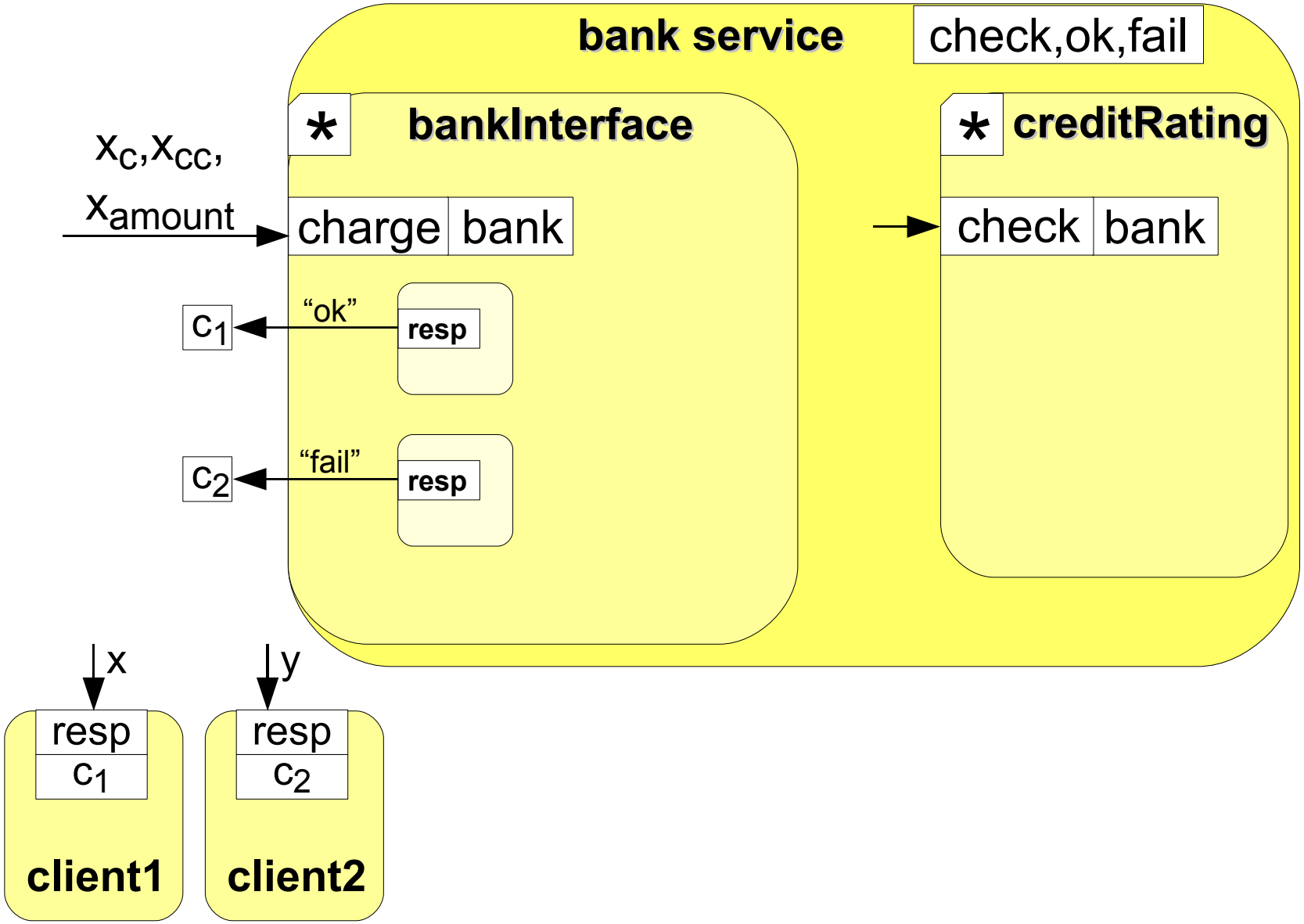
μCOWS^m: *compound* bank service example



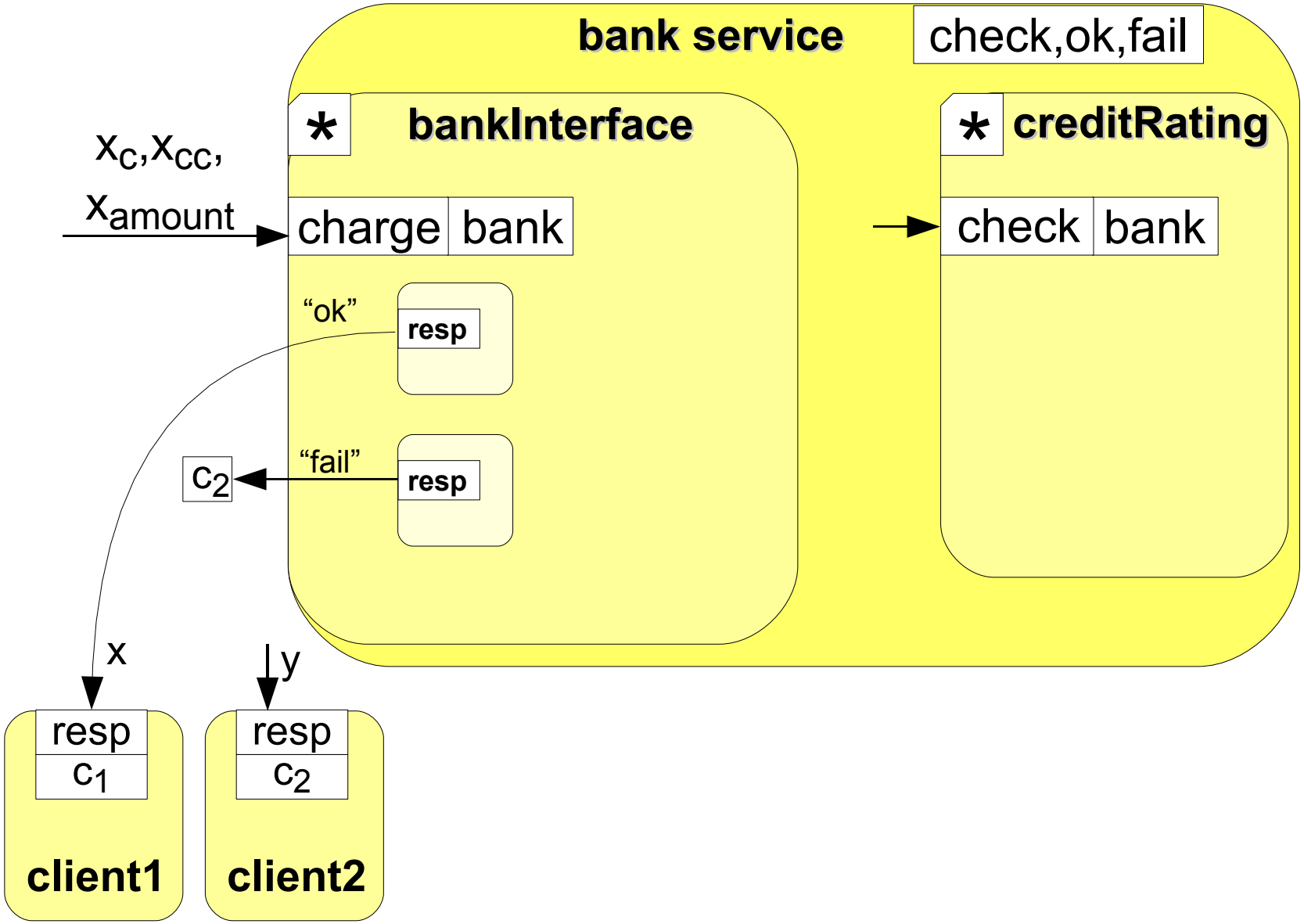
μCOWS^m: *compound* bank service example



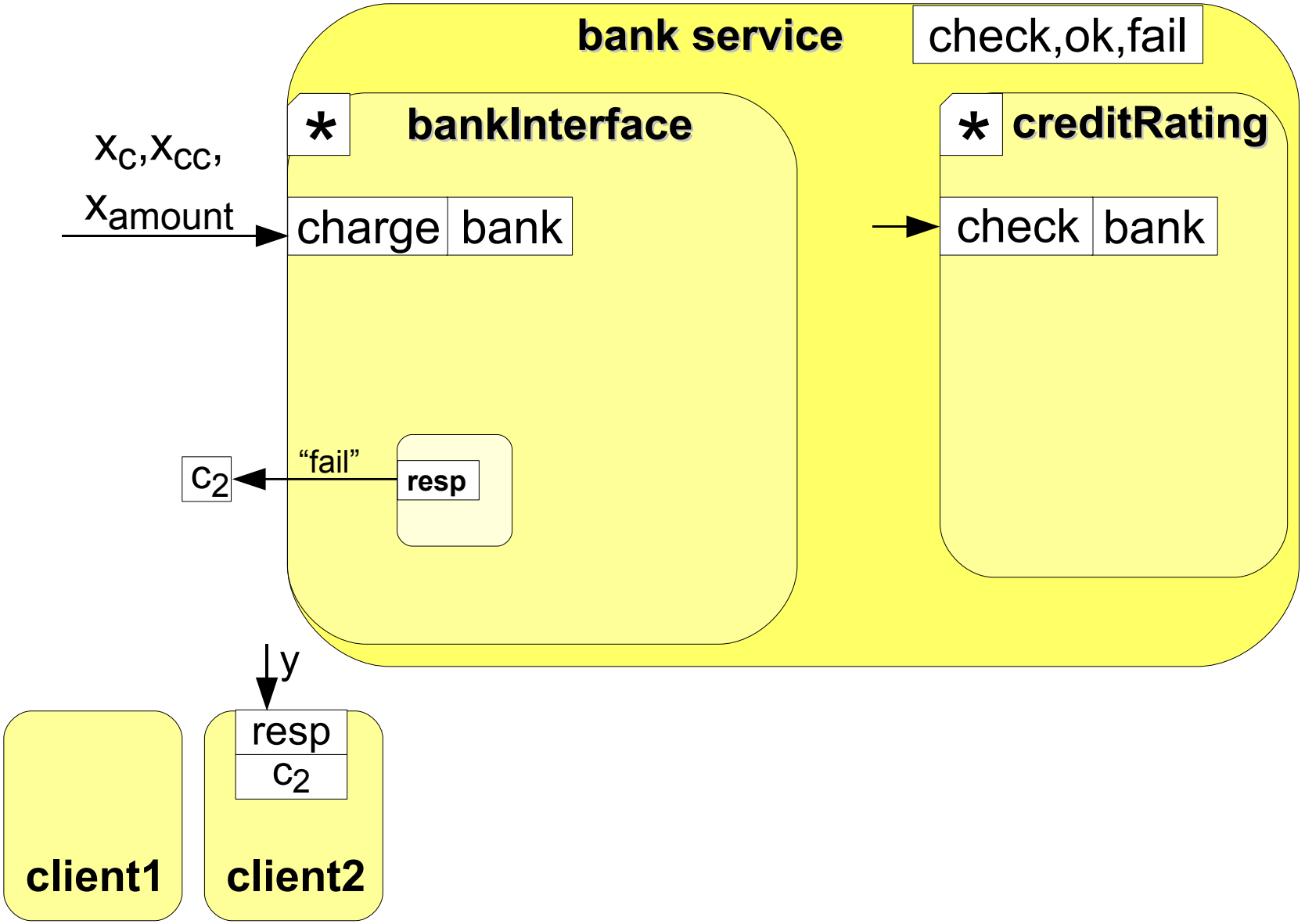
μCOWS^m: *compound* bank service example



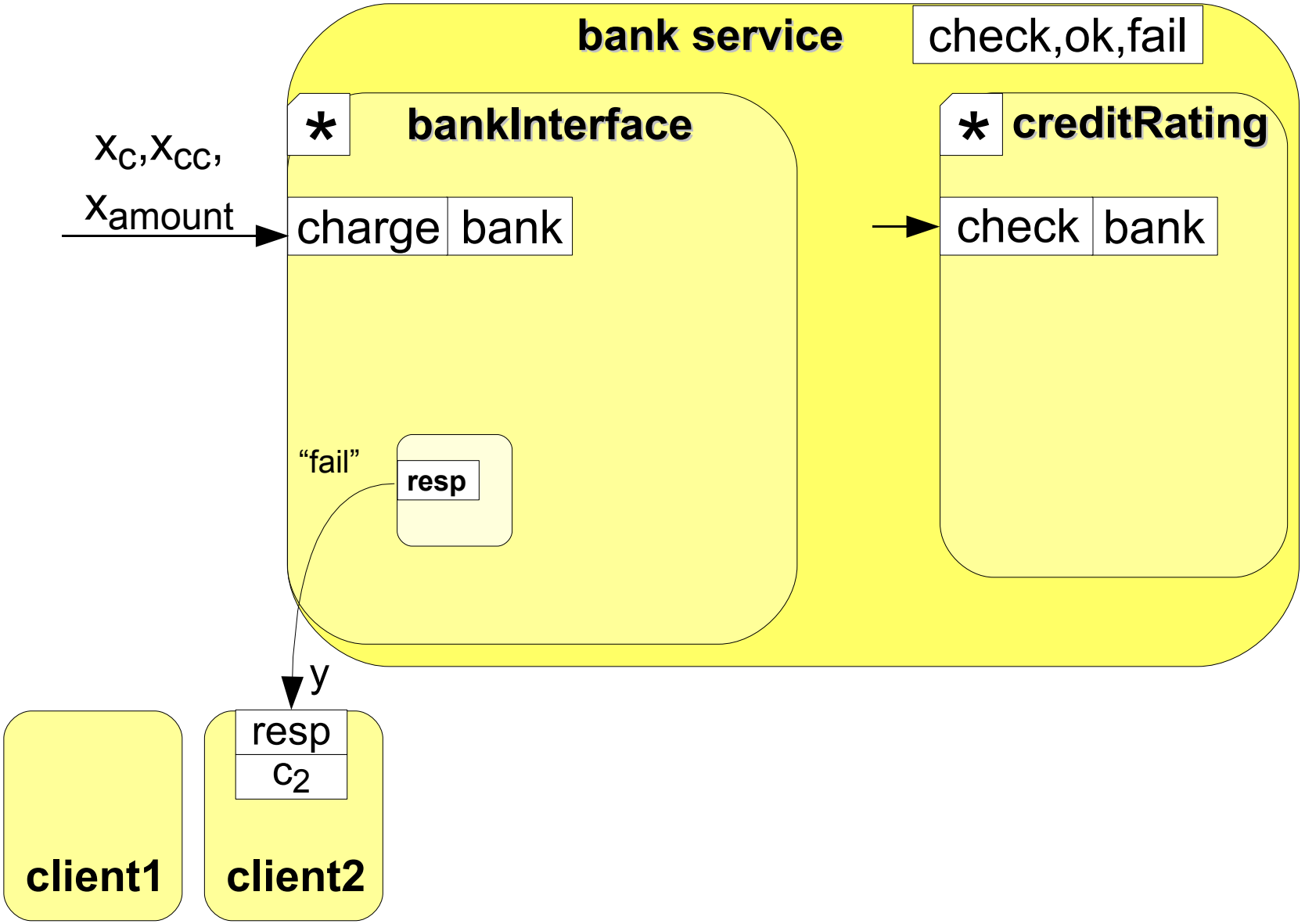
μCOWS^m: *compound* bank service example



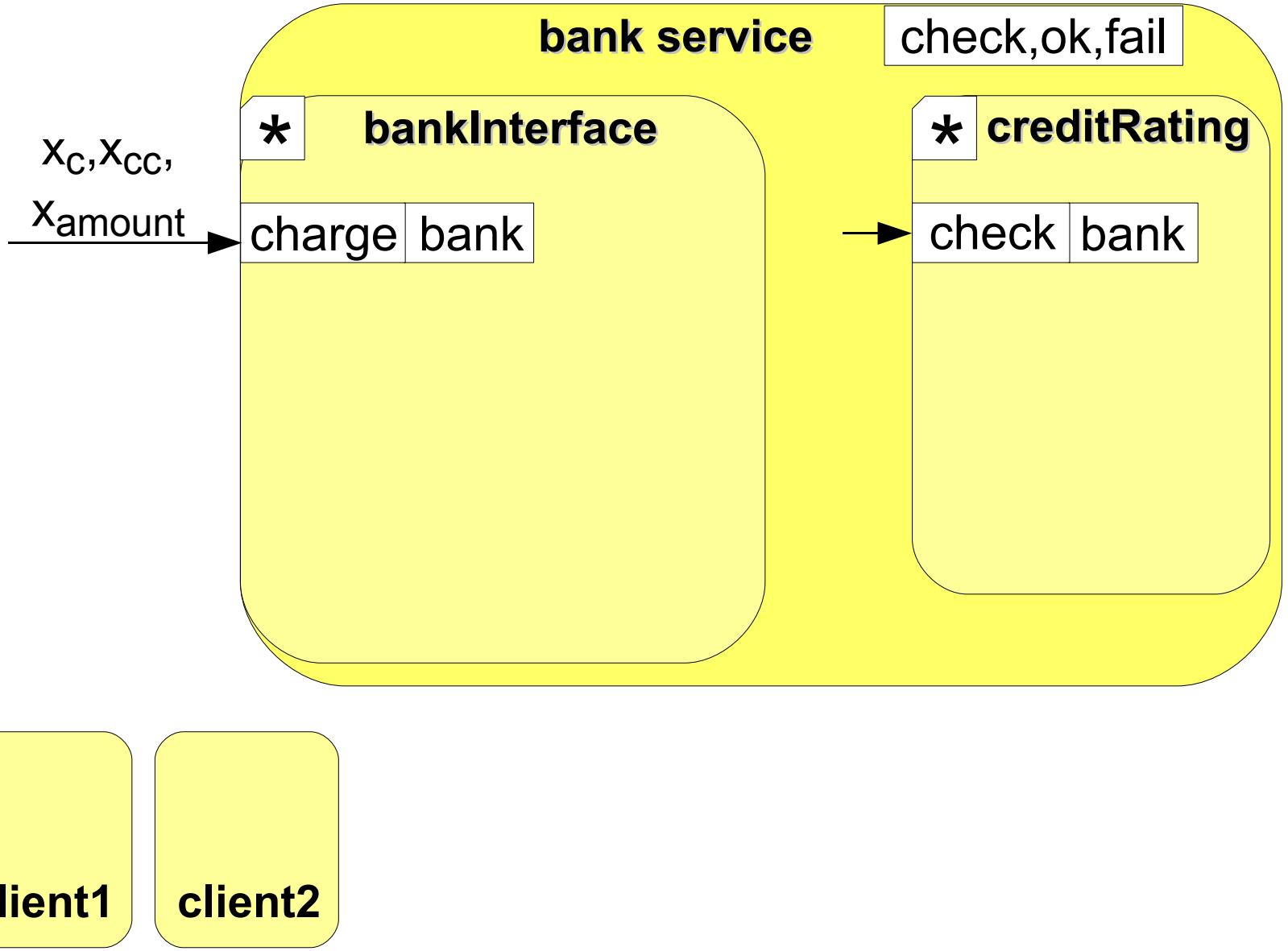
μCOWS^m: *compound* bank service example



μCOWS^m: *compound* bank service example



μCOWS^m: *compound* bank service example



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?

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, ...

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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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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

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

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

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

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

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

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

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

μCOWS: Parallel composition with priority

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

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

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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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μCOWS operational semantics

Labelled transition rules

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

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

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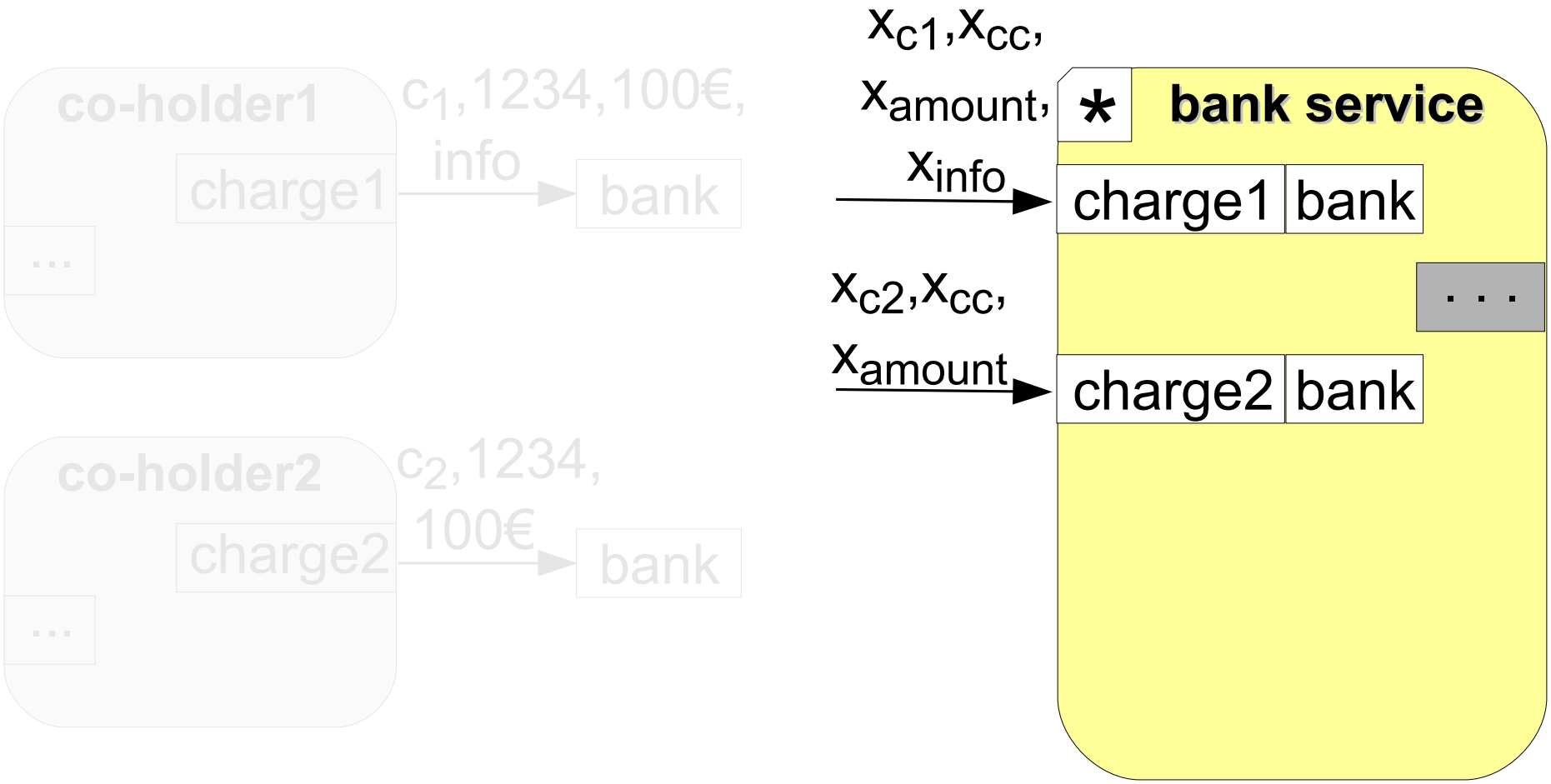
μCOWS: *joint account* service example



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

$$\mid\ (\,bank \bullet charge1!\langle c_1, 1234, 100€, info\rangle \mid s_1'\,)$$

$$\mid\ (\,bank \bullet charge2!\langle c_2, 1234, 100€\rangle \mid s_2'\,)$$

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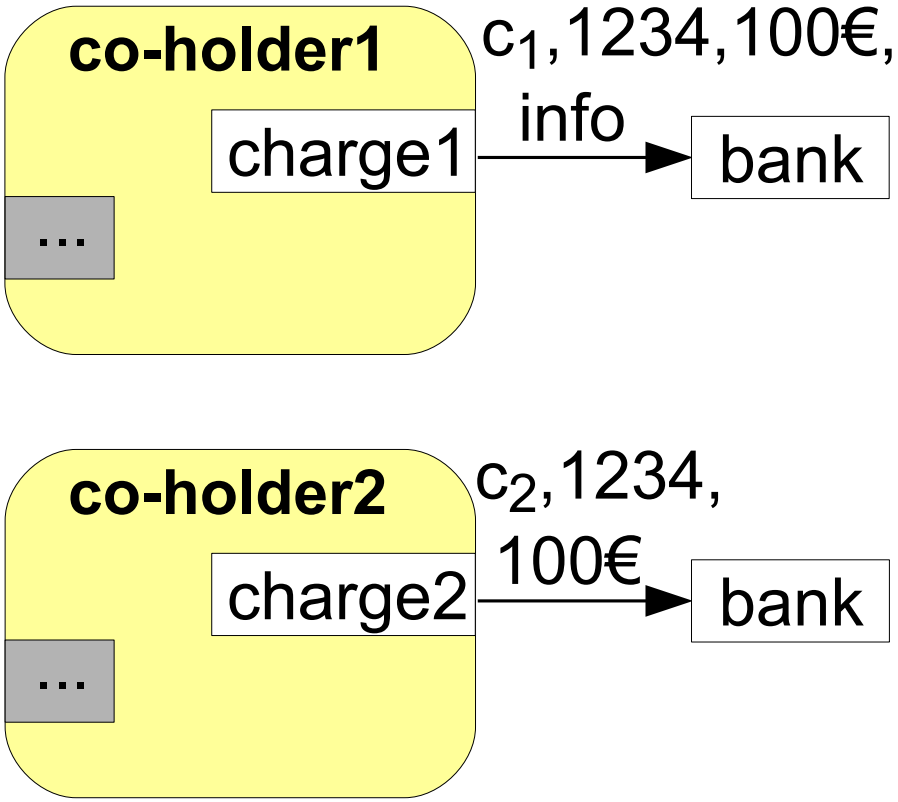

$x_{c1}, x_{cc},$
$x_{amount},$
x_{info}
$x_{c2}, x_{cc},$
x_{amount}

$*$ bank service

charge1 | bank

. . .

charge2 | bank

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

$\mid (bank \bullet charge1!\langle c_1, 1234, 100€, info \rangle \mid s_1')$
$\mid (bank \bullet charge2!\langle c_2, 1234, 100€ \rangle \mid s_2')$

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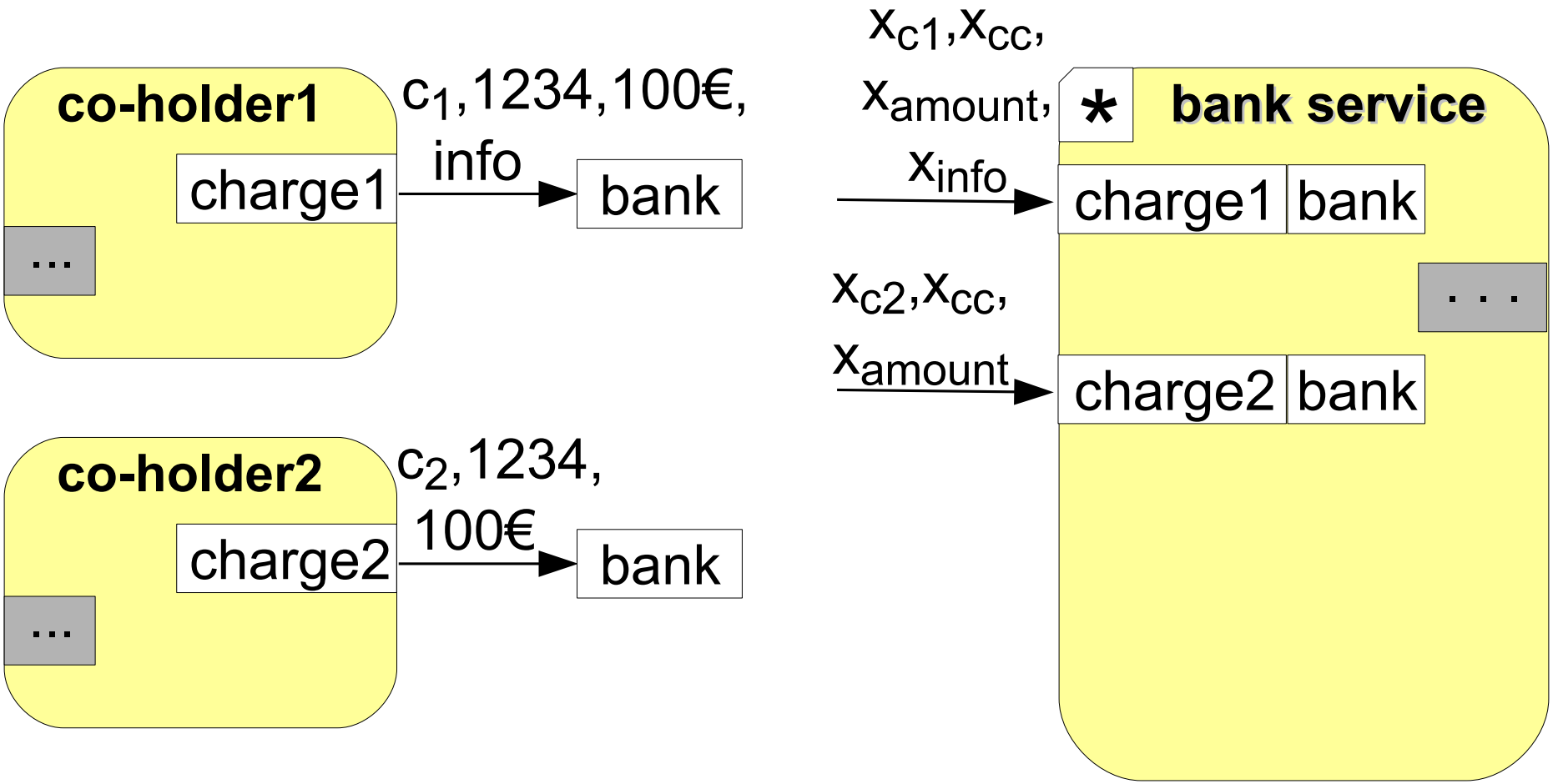

$$
\begin{aligned}
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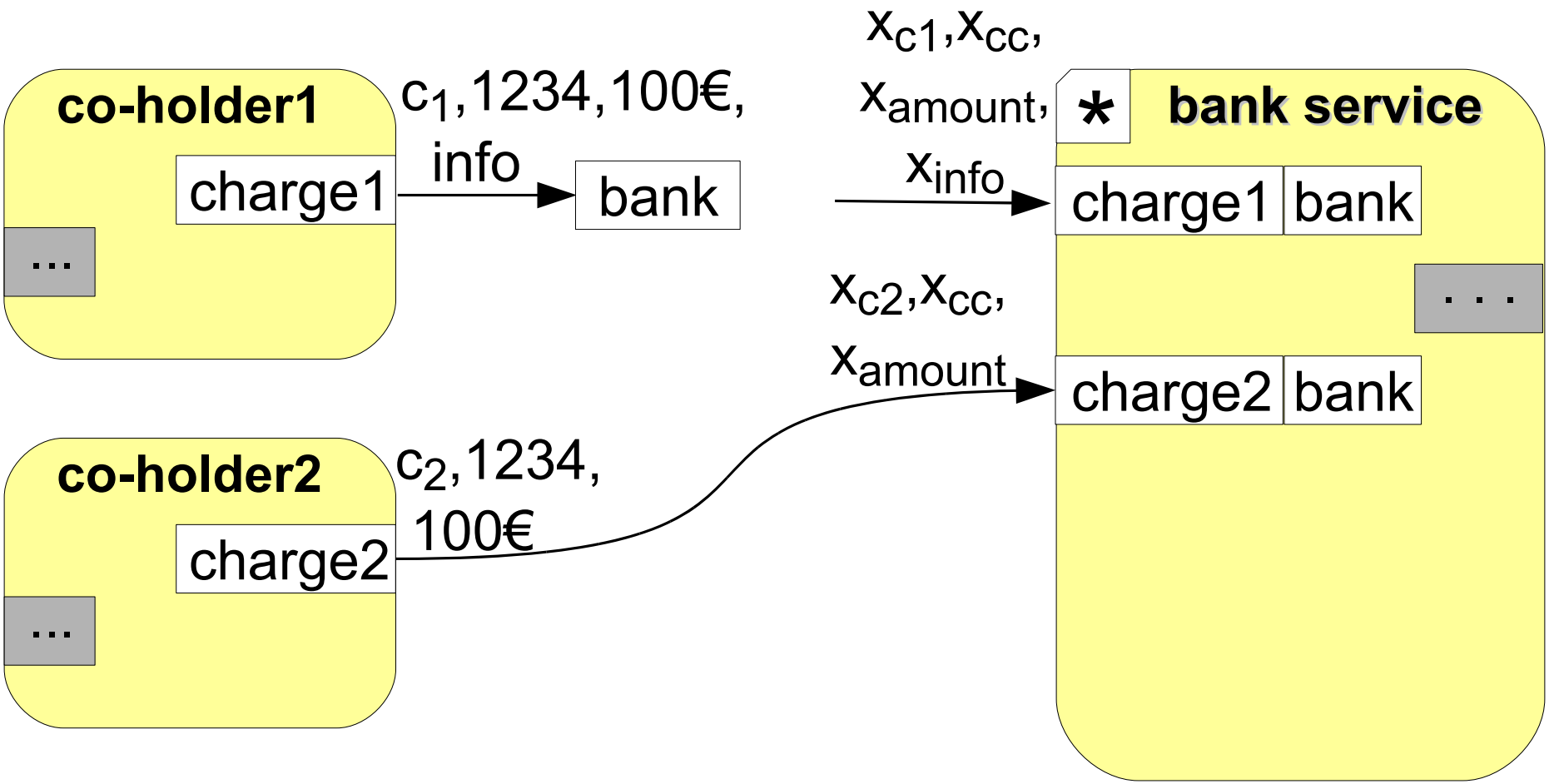

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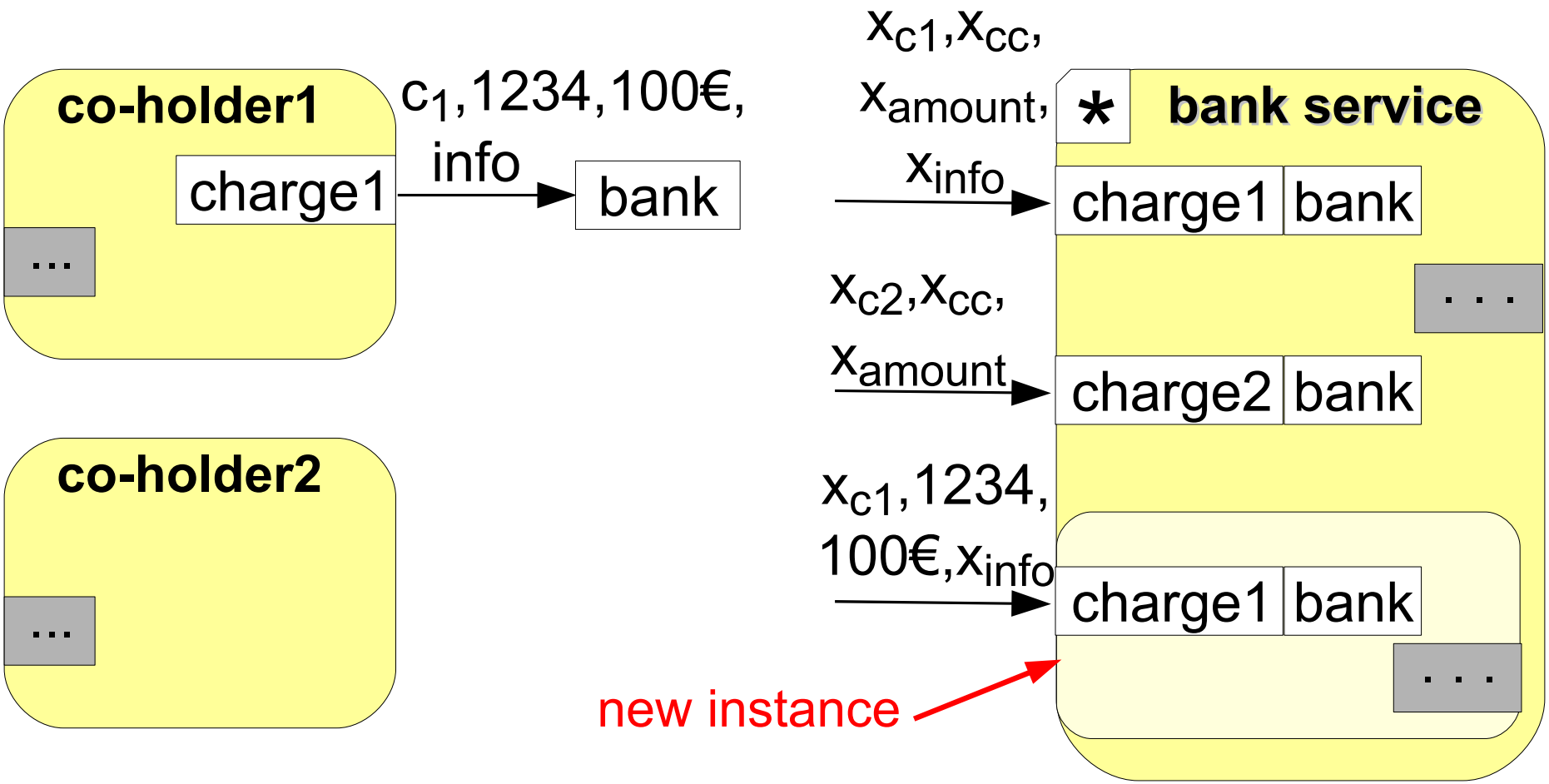

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$$\mid\ (\,bank \bullet charge1?\langle x_{c1}, 1234, 100€, x_{info}\rangle.s_1 \mid s_2\,) \cdot \{\cdots \mapsto \cdots\}$$
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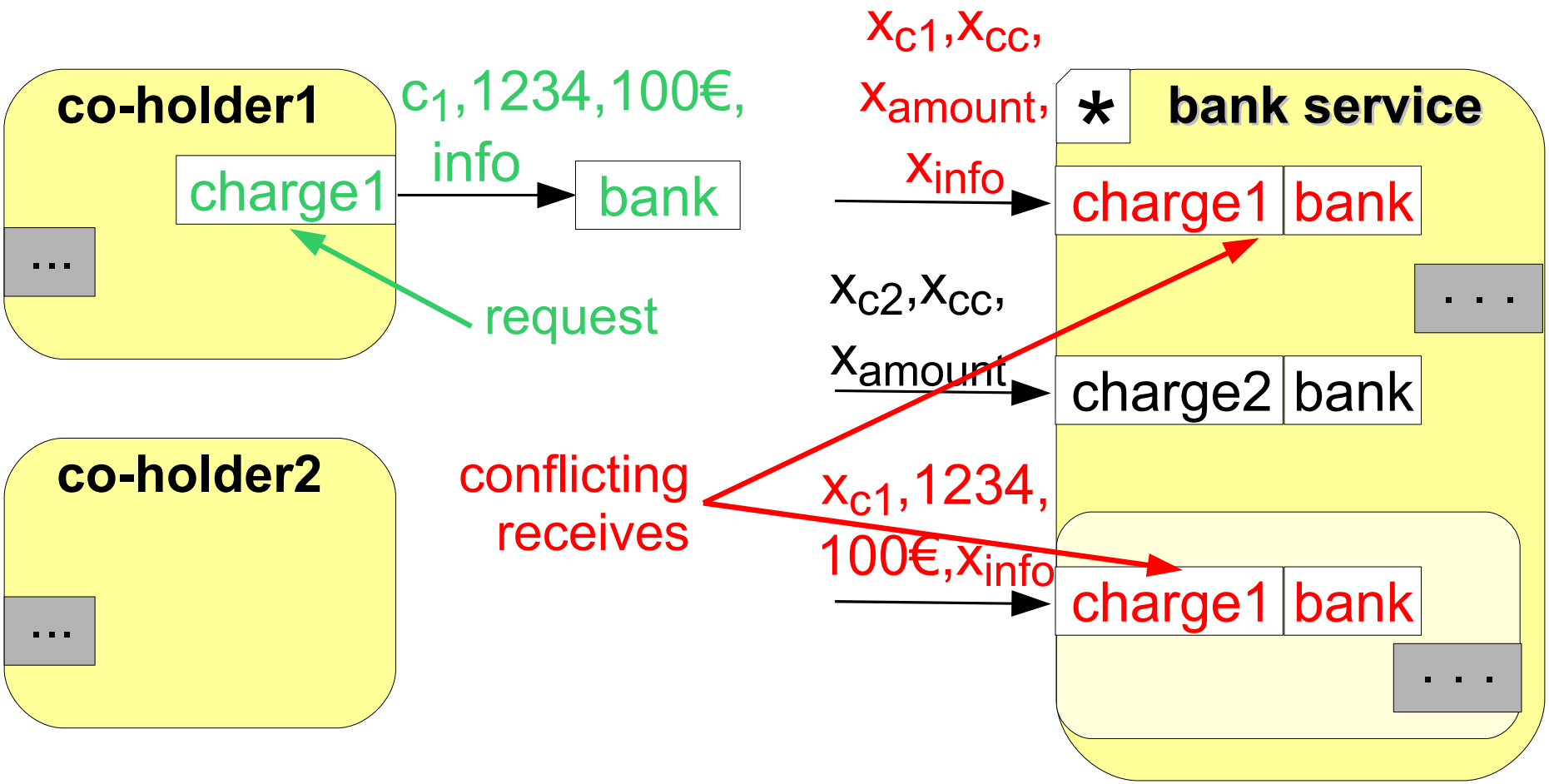

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\end{aligned}
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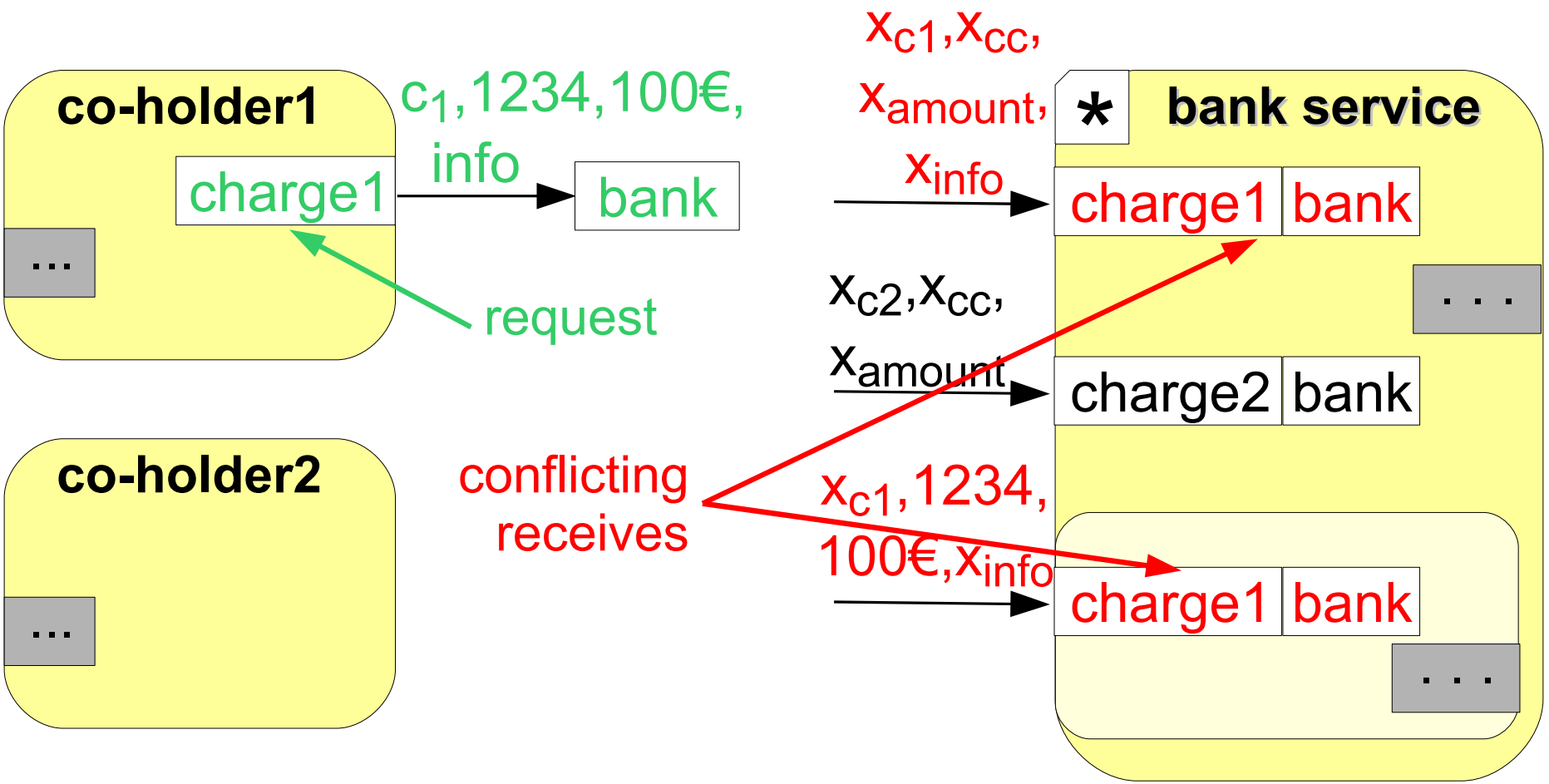
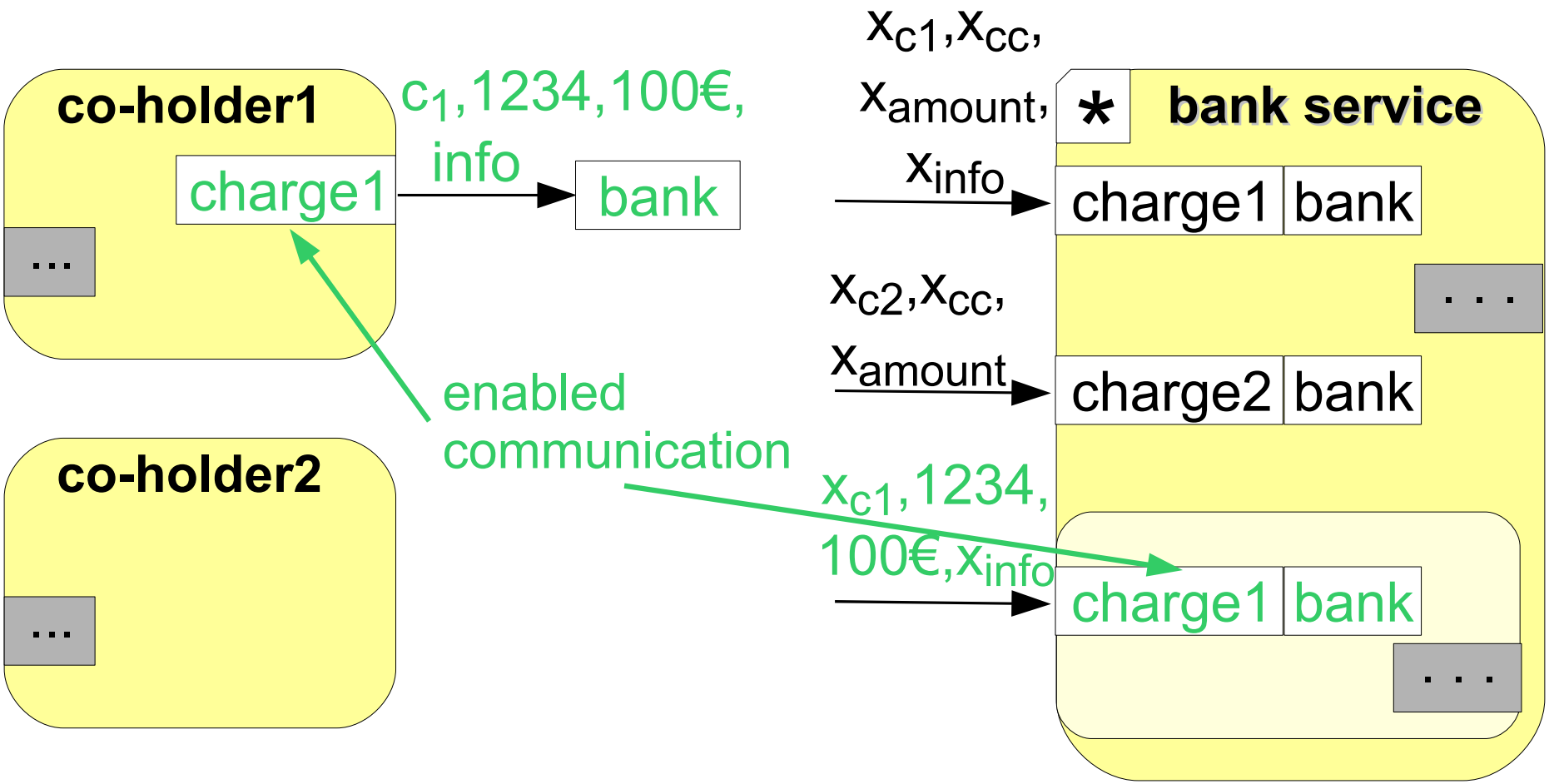


Multiple start activities

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



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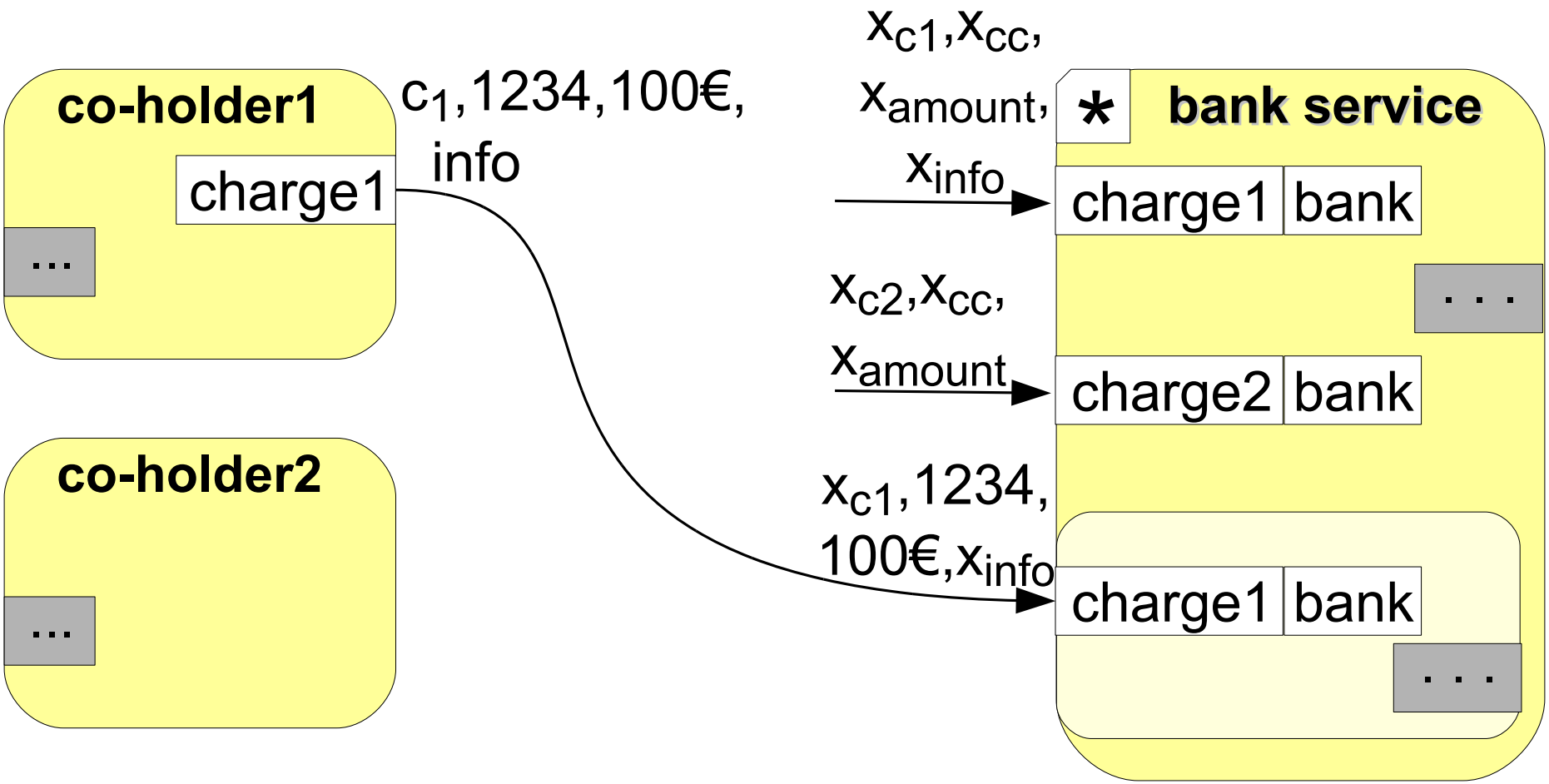

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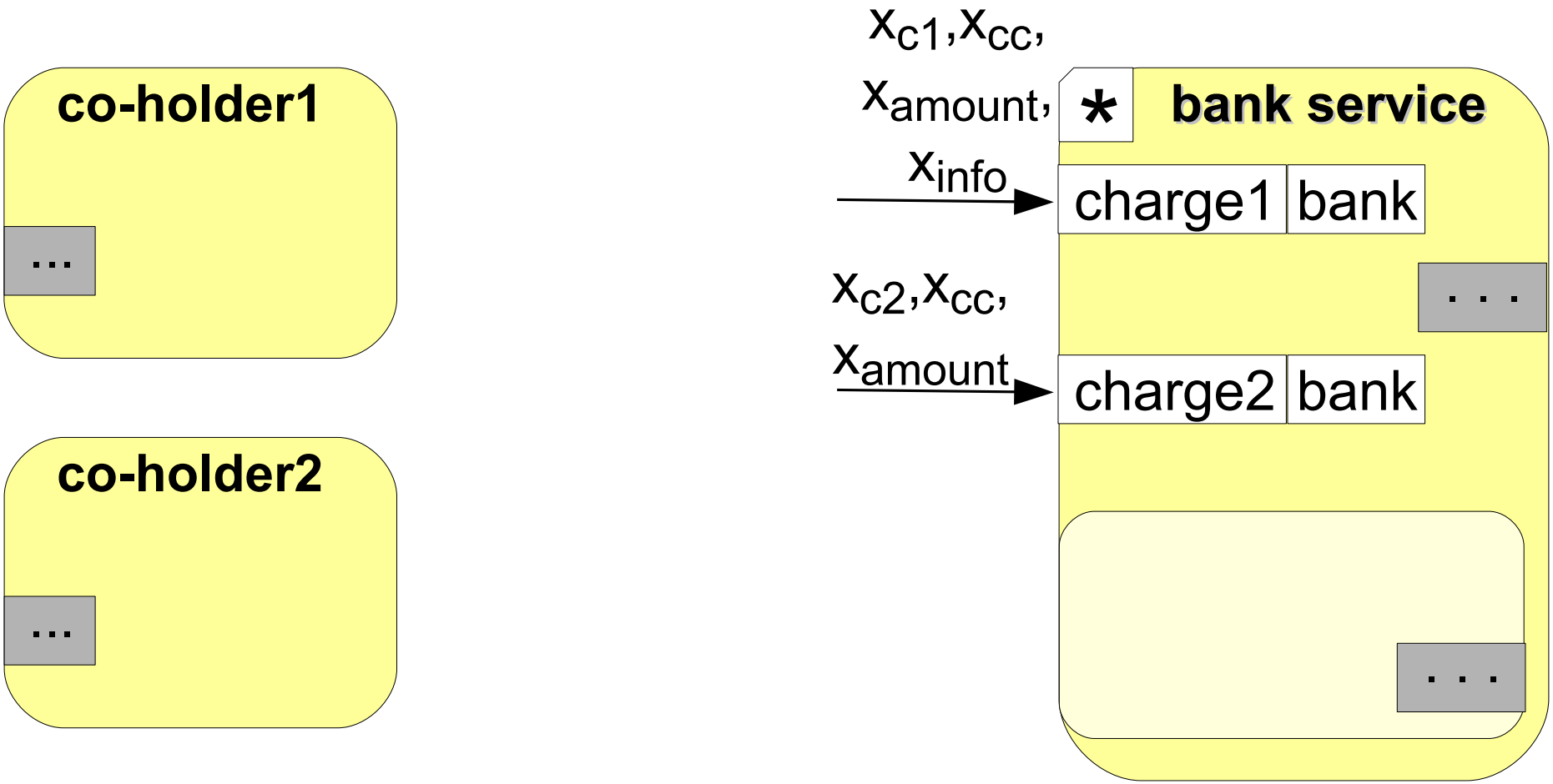

$$* [x_{c1}, x_{c2}, x_{cc}, x_{amount}, x_{info}] (bank \bullet charge1?\langle x_{c1}, x_{cc}, x_{amount}, x_{info}\rangle.s_1 \mid bank \bullet charge2?\langle x_{c2}, x_{cc}, x_{amount}\rangle.s_2) \mid (s_1 \mid s_2) \cdot \{\cdots \mapsto \cdots\} \mid (s'_1) \mid (s'_2)$$

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)

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

Parallel with priority as a coordination mechanism

‘Blind date’ session joining

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

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

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

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

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

Parallel with priority as a coordination mechanism

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& \qquad\qquad \mid x_{player3} \bullet \mathit{start}!\langle \mathit{matchId}\rangle \\
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\end{aligned}
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$$

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

From μCOWS to COWS

μCOWS

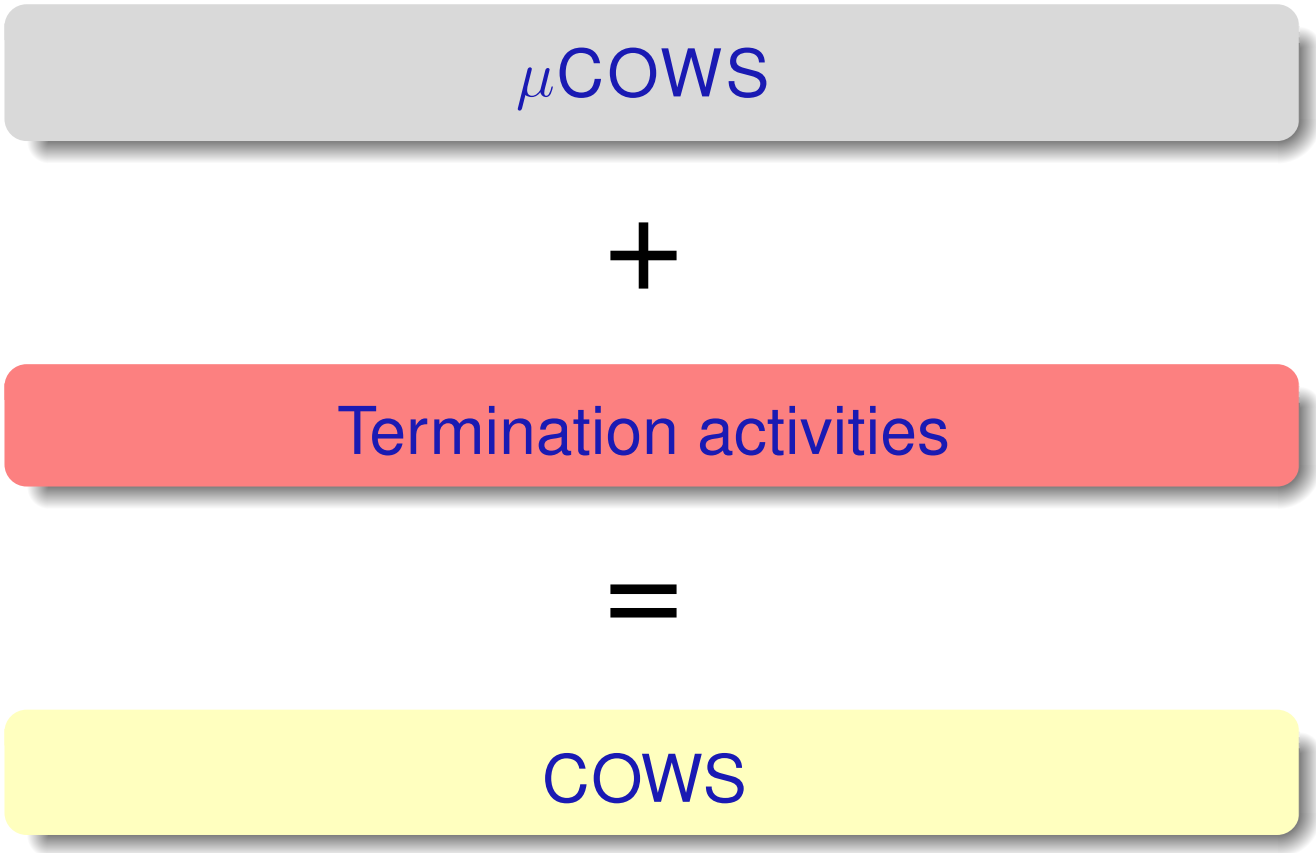
From μCOWS to COWS

μCOWS

+

Termination activities

From μCOWS to COWS



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* $\mid$ *names*

w: *variables* $\mid$ *values*

e: *labels* $\mid$ *variables* $\mid$ *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:

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

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

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

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

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

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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

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

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

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

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

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

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

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

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

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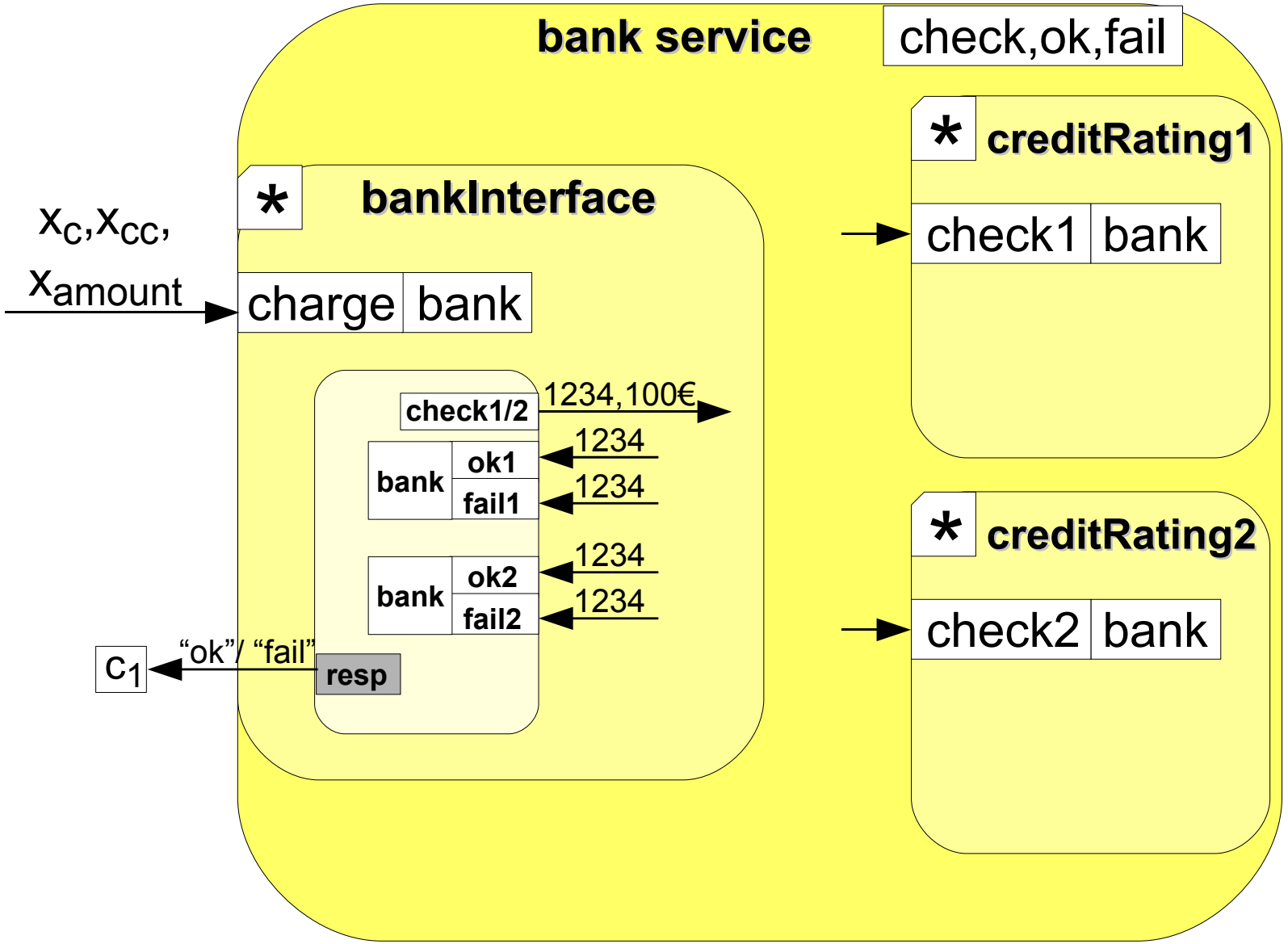
COWS: *multi rating* bank service example



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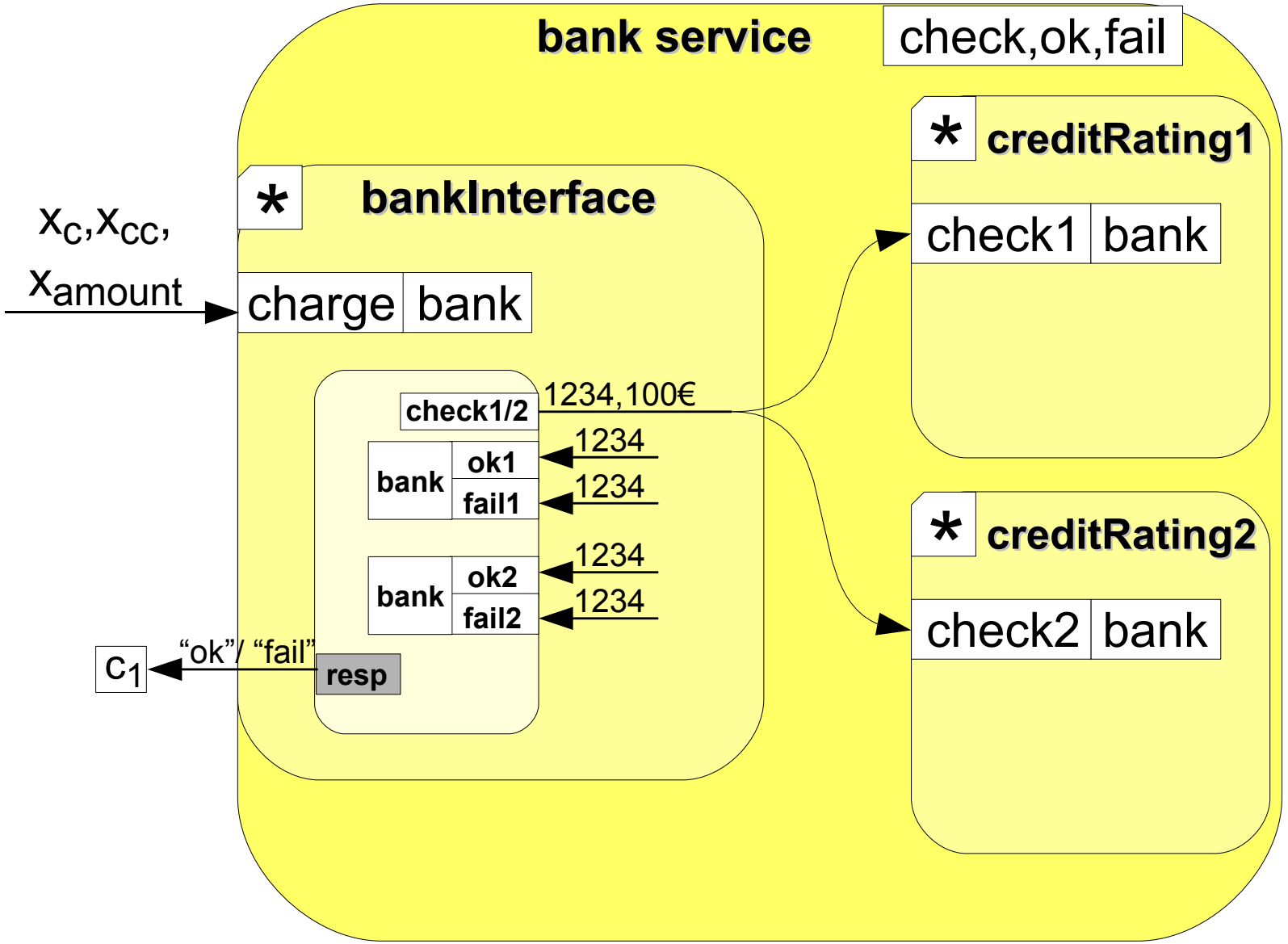

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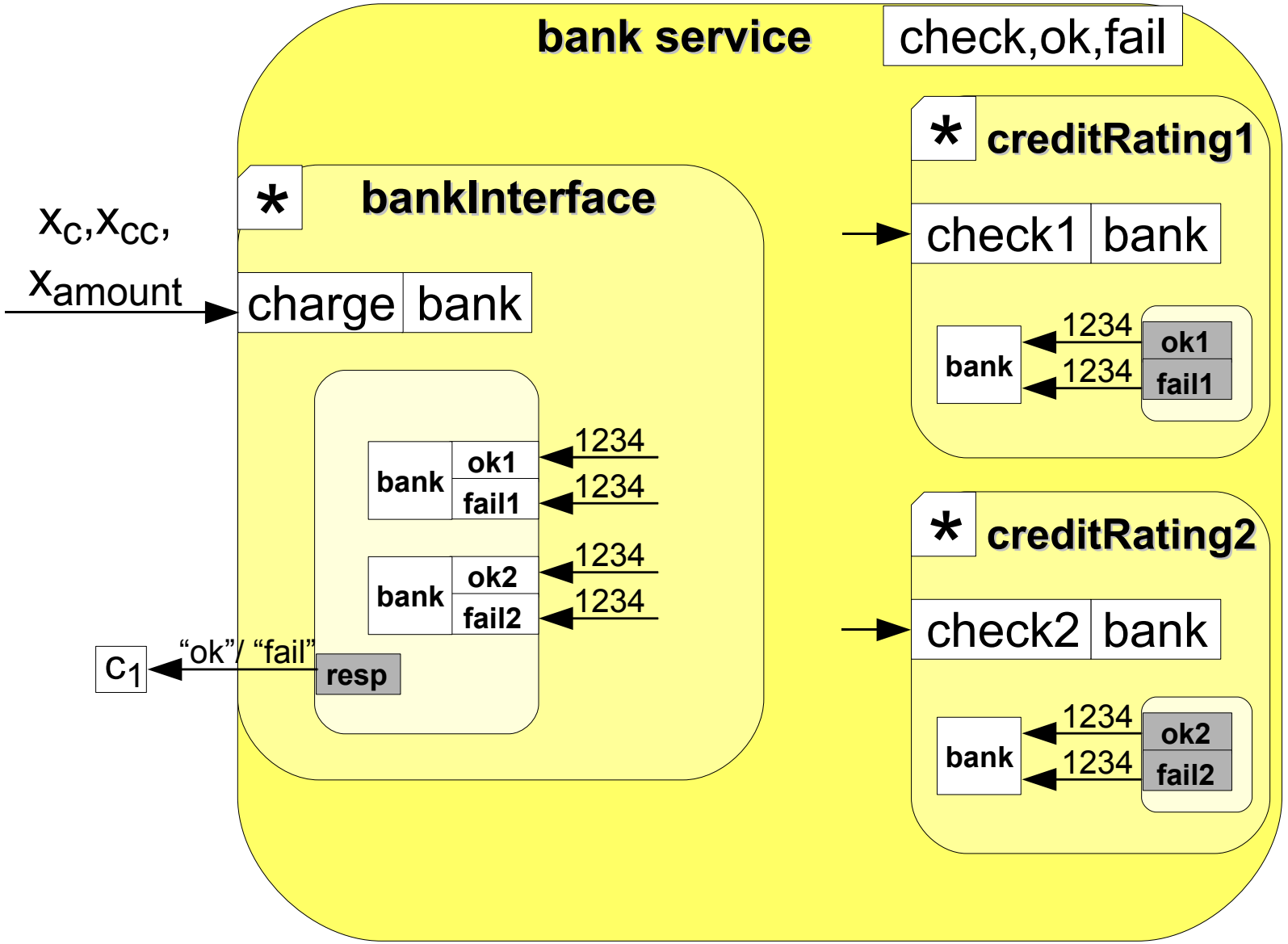

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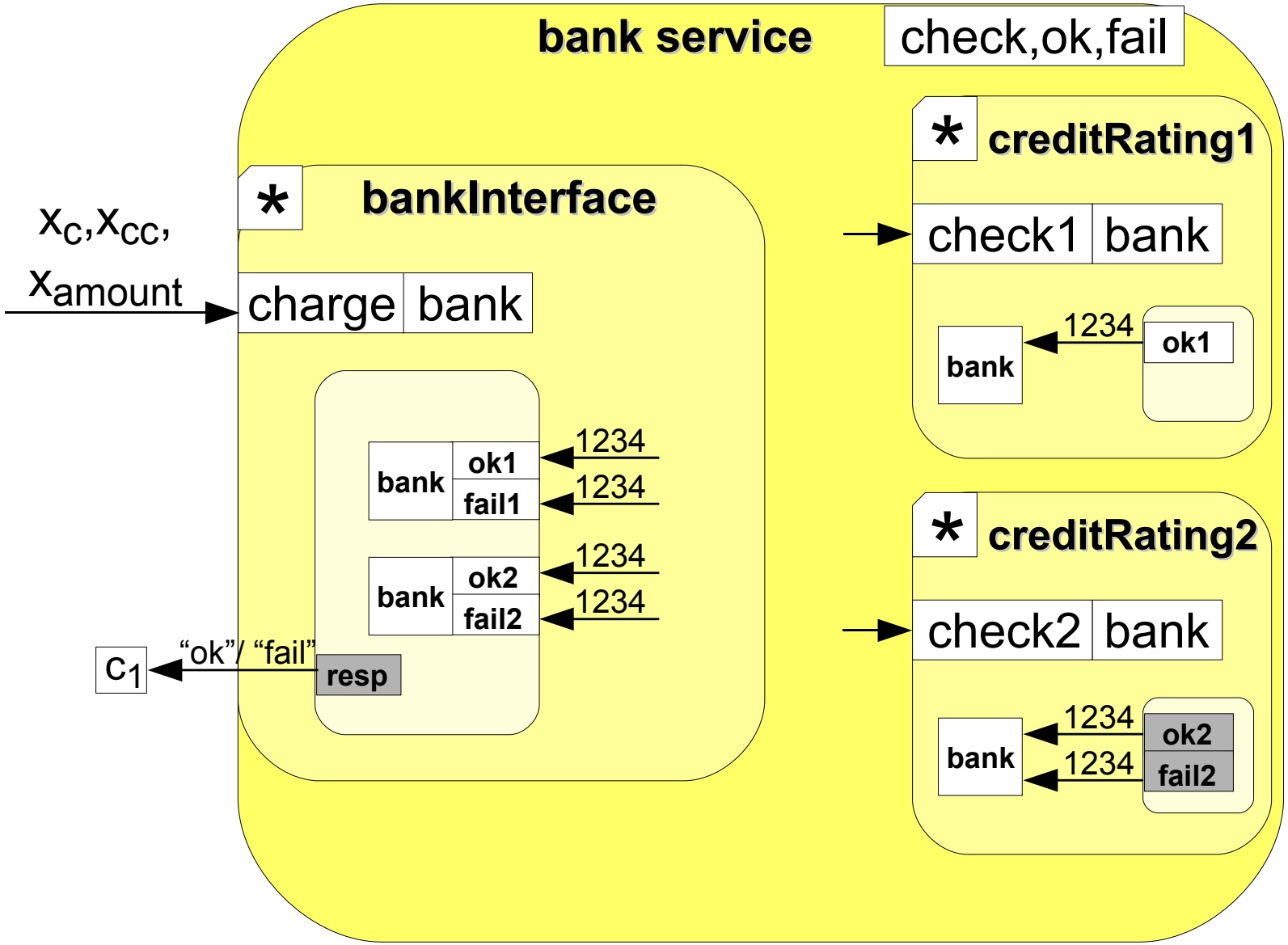

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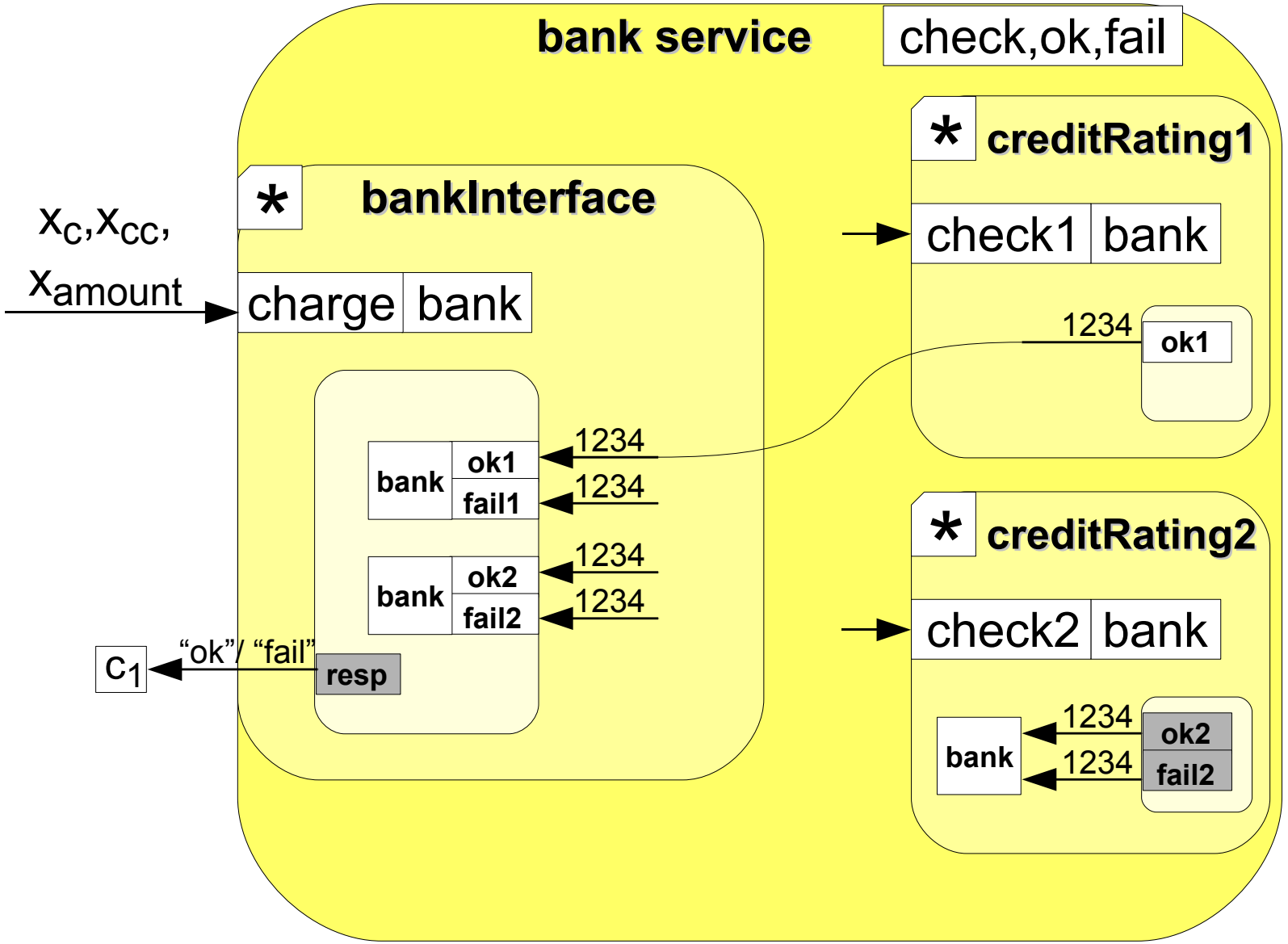

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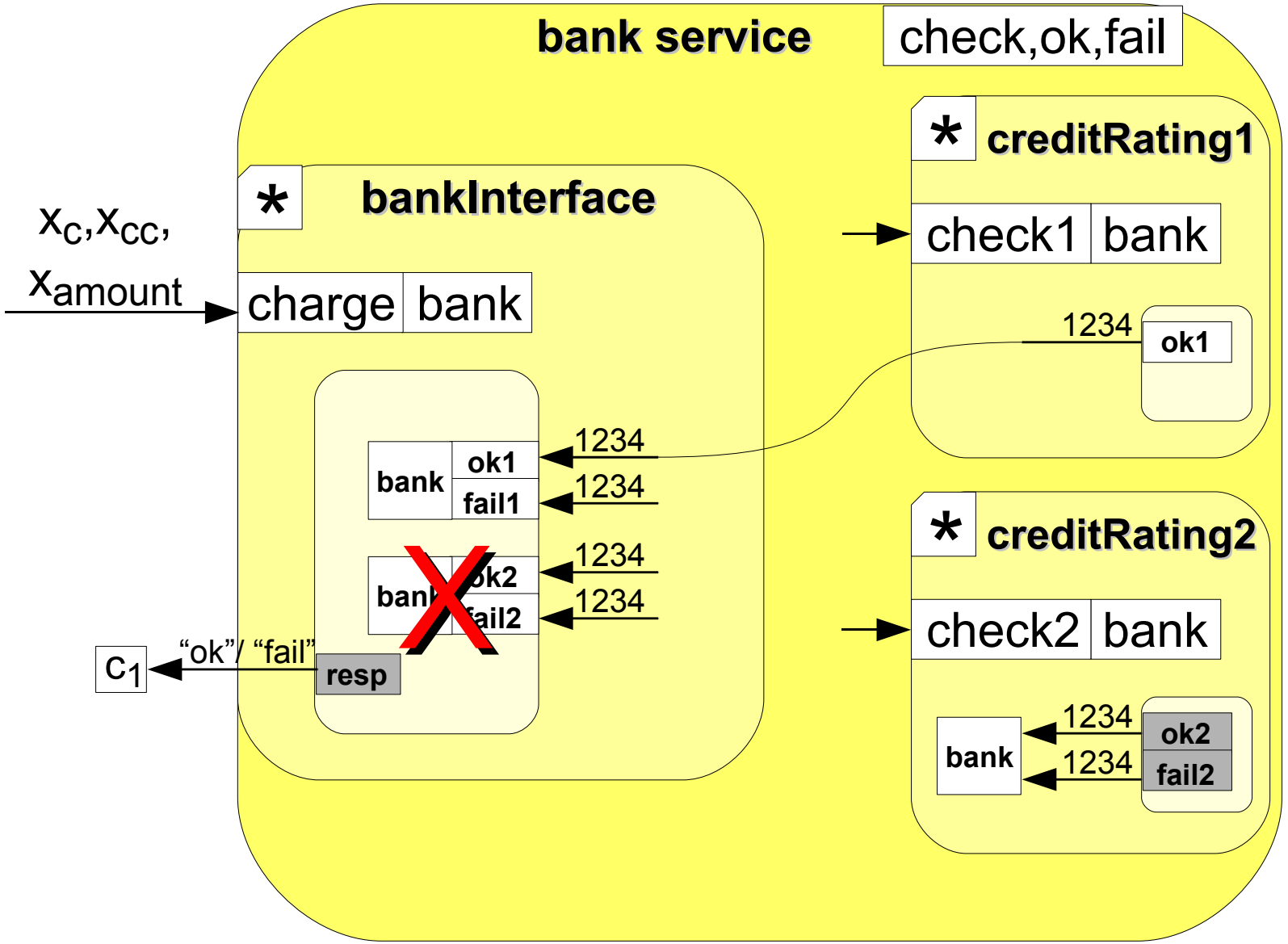

COWS: *multi rating* bank service example

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

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

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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