Mixing Metaphors

Actors as Channels and Channels as Actors

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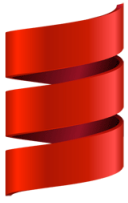
THE UNIVERSITY of EDINBURGH
informatics

EPSRC Centre for Doctoral Training in
Pervasive Parallelism

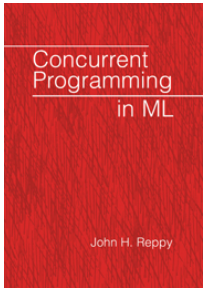
Communication-centric Programming Languages

Go

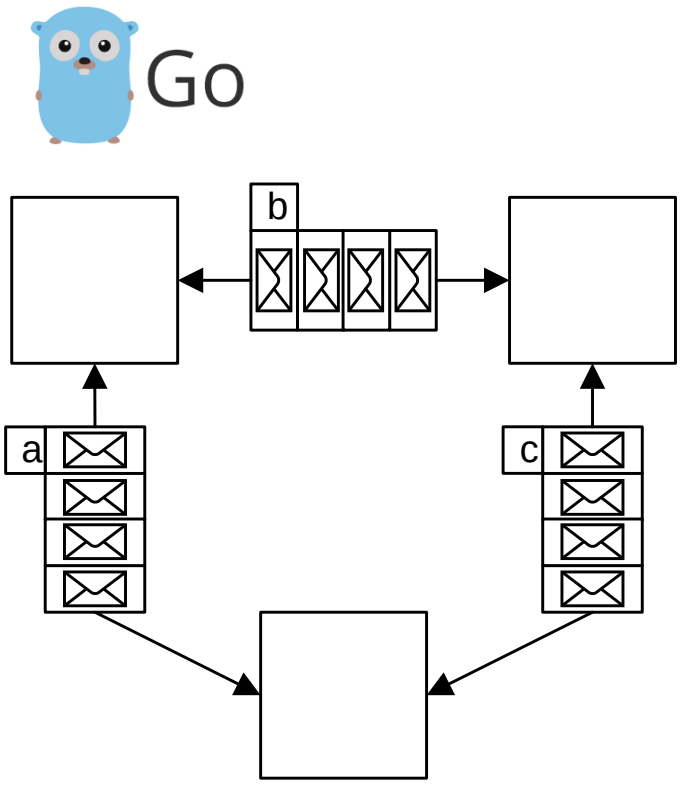


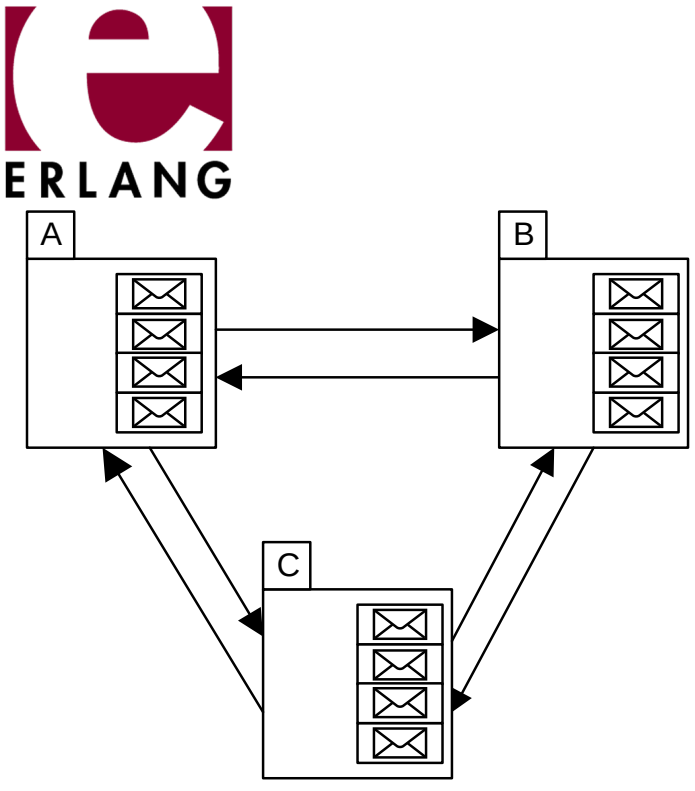
Scala

elixir

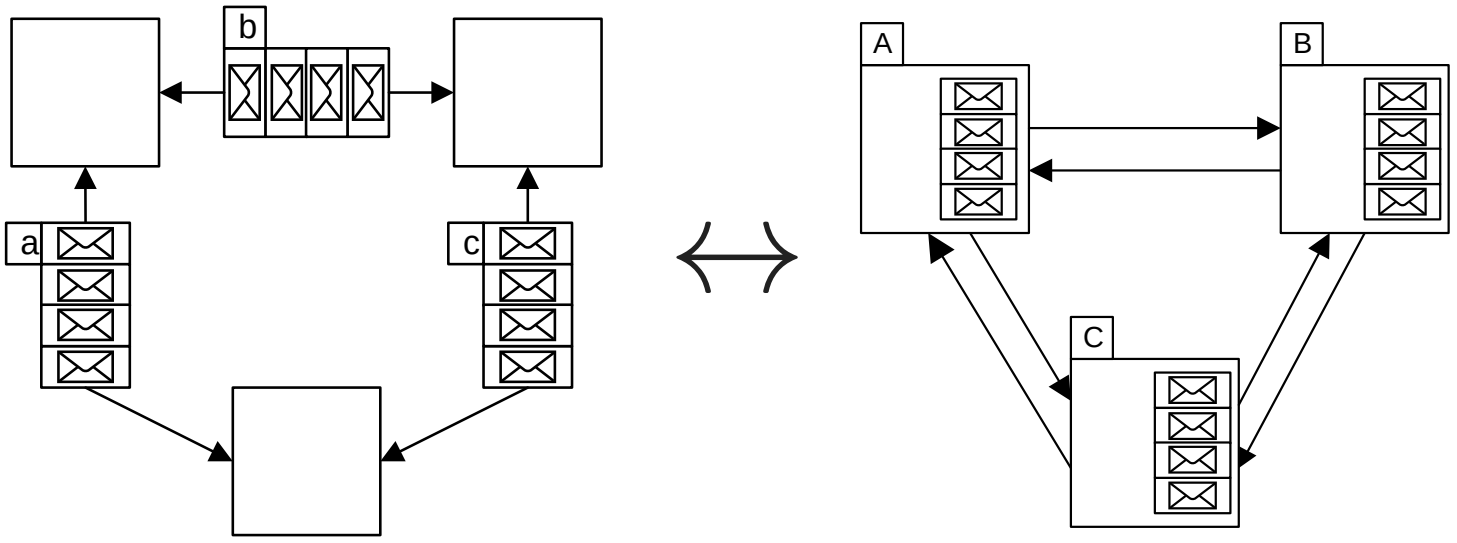


Channels and Actors





Why compare the two?



→ Concise formalisations of how the models fit into functional programming languages

→ Clear up confusion between the two models

→ Towards behavioural typing disciplines!

λ_{ch}: A concurrent λ-calculus for asynchronous channels

Syntax

$$
\begin{array}{rlll}
\text{Types} & A, B & ::= & \mathbf{1} \mid A \to B \mid \mathsf{ChanRef}(A) \\
\text{Variables} & \alpha & ::= & x \mid a \\
\text{Values} & V, W & ::= & \alpha \mid \lambda x.M \mid () \\
\text{Computations} & L, M, N & ::= & V\,W \\
 & & \mid & \mathsf{let}\ x \Leftarrow M\ \mathsf{in}\ N \mid \mathsf{return}\ V \\
 & & \mid & \mathsf{fork}\ M \mid \mathsf{give}\ V\,W \mid \mathsf{take}\ V \mid \mathsf{newCh}
\end{array}
$$

- → Separation of values and computations
- → Set of communication and concurrency primitives

λ_{act} Typing Rules

Typing for communication and concurrency primitives

GIVE
$$\frac{\Gamma \vdash V : A \quad \Gamma \vdash W : \mathsf{ChanRef}(A)}{\Gamma \vdash \mathsf{give}\ V\ W : \mathbf{1}}$$

TAKE
$$\frac{\Gamma \vdash V : \mathsf{ChanRef}(A)}{\Gamma \vdash \mathsf{take}\ V : A}$$

FORK
$$\frac{\Gamma \vdash M : \mathbf{1}}{\Gamma \vdash \mathsf{fork}\ M : \mathbf{1}}$$

NEWCH
$$\frac{}{\Gamma \vdash \mathsf{newCh} : \mathsf{ChanRef}(A)}$$

Note that fork returns **1**: processes are anonymous!

Modelling Concurrent Behaviour: Configurations

$$\mathcal{C} ::= \mathcal{C}_1 \parallel \mathcal{C}_2 \mid (\nu a)\mathcal{C} \mid a(\overrightarrow{V}) \mid M$$

Concurrent λ-calculi model concurrent behaviour by reduction on a language of configurations.

- $\mathcal{C}_1 \parallel \mathcal{C}_2$: parallel composition
- $(\nu a)\mathcal{C}$: name restriction
- $a(\overrightarrow{V})$: buffer with name a containing values of $\overrightarrow{V}$
- M: term evaluating as a thread

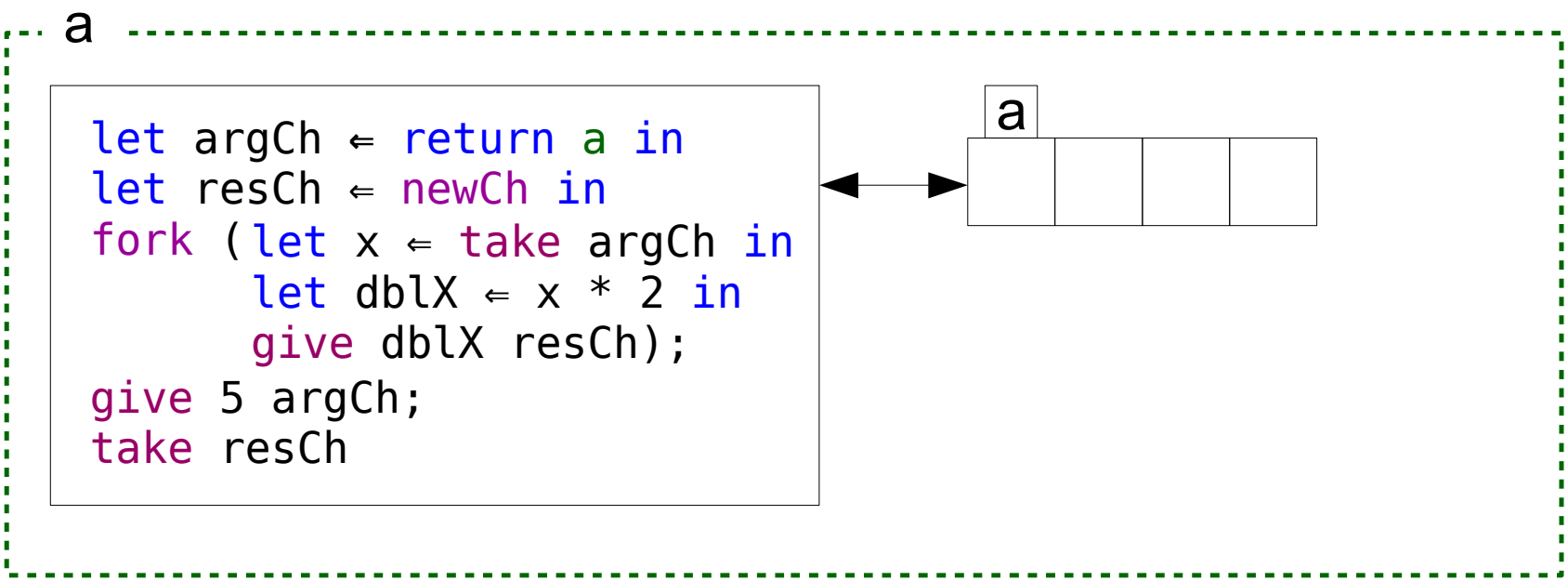
Also configuration typing rules for well-formed configurations.

λ_{ch} Semantics, by Example

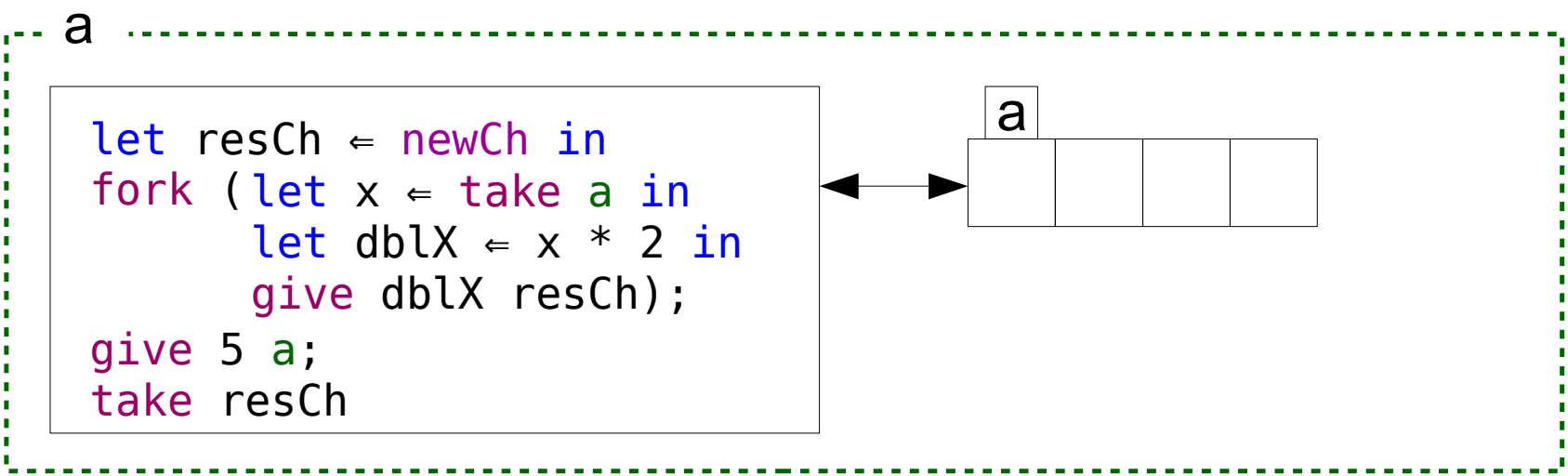
```
let argCh ⇐ newCh in
let resCh ⇐ newCh in
fork (let x ⇐ take argCh in
      let dblX ⇐ x * 2 in
      give dblX resCh);
give 5 argCh;
take resCh
```

- → Create two channels *argCh* and *resCh*
- → Spawn a process which:
  - → Receives a value along the argument channel
  - → Doubles it
  - → Sends it along the result channel
- → Then, send a value along the argument channel, and wait for the result

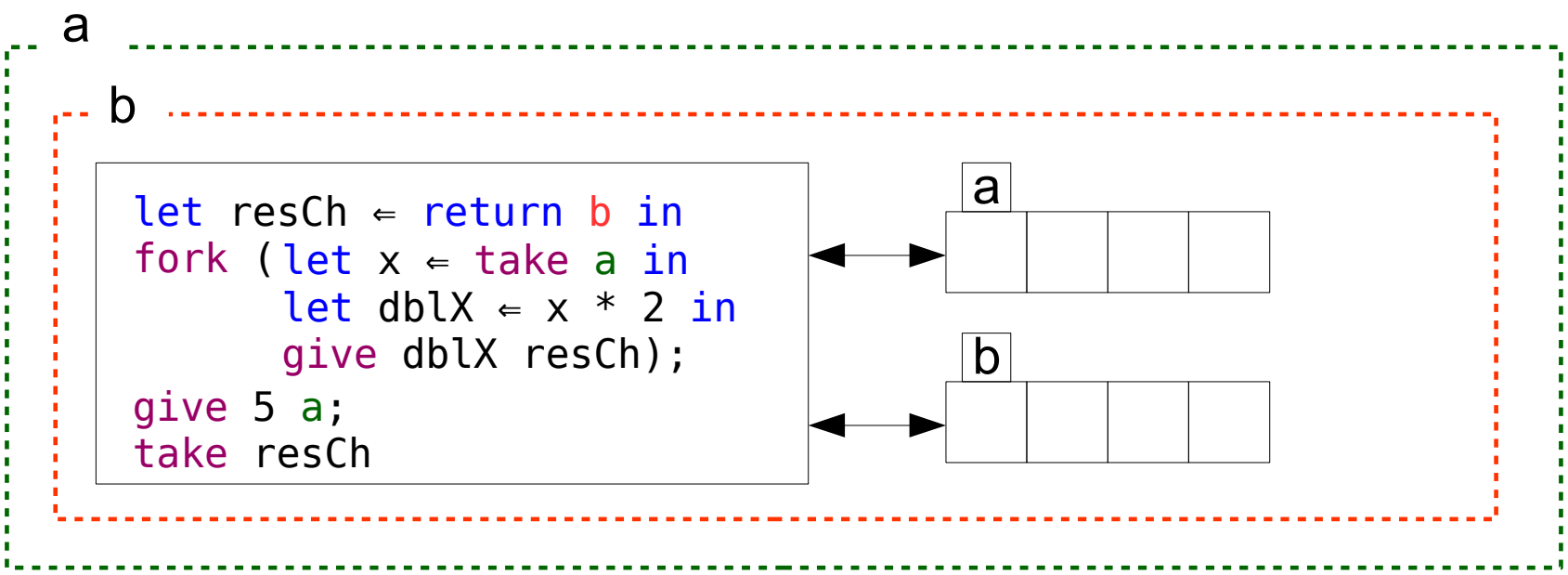
λ_{ch} Semantics, by Example



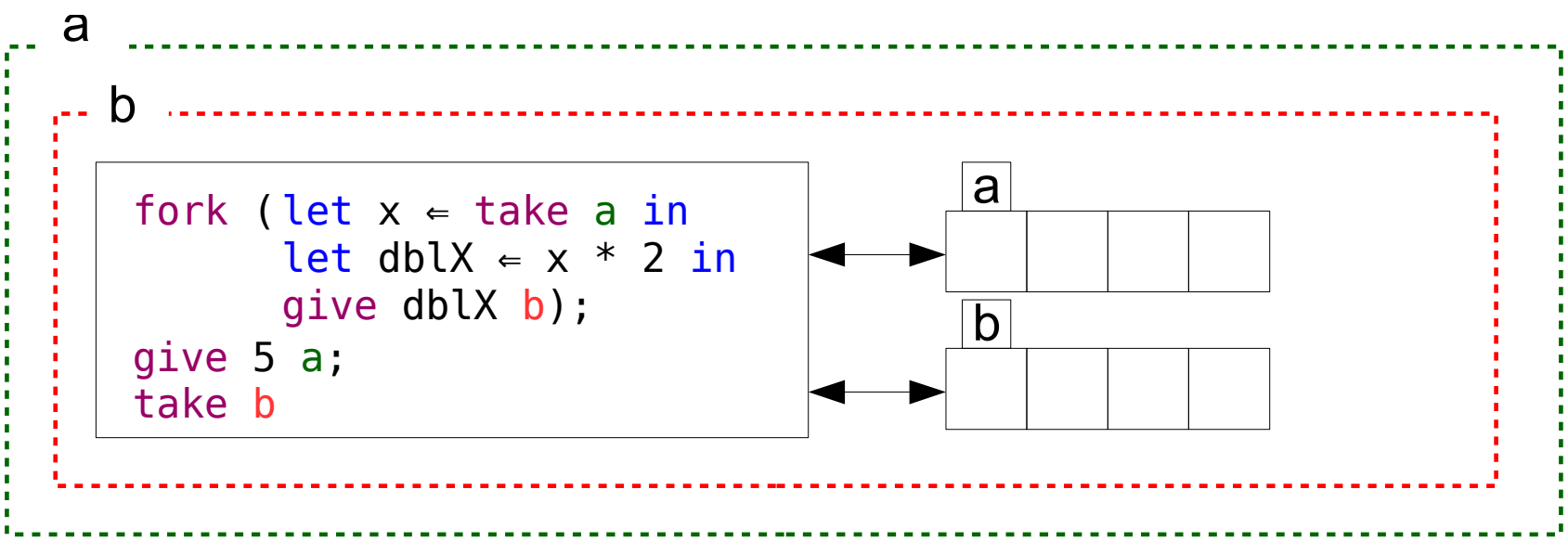
λ_{ch} Semantics, by Example



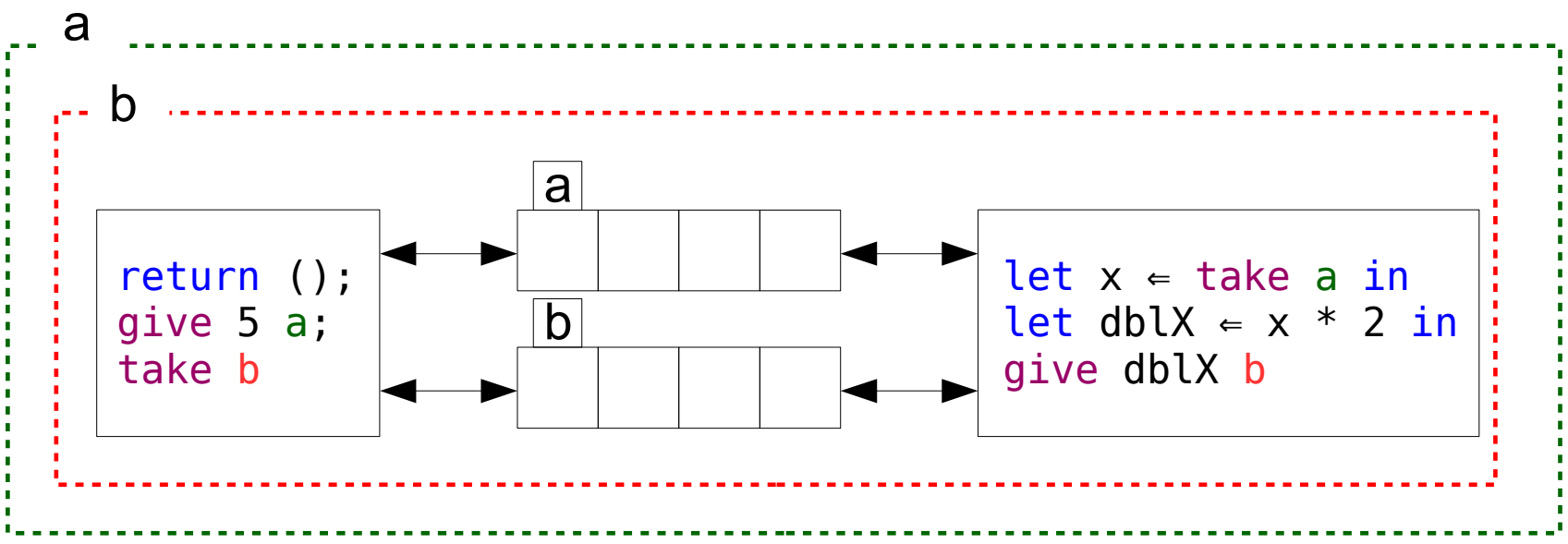
λ_{ch} Semantics, by Example



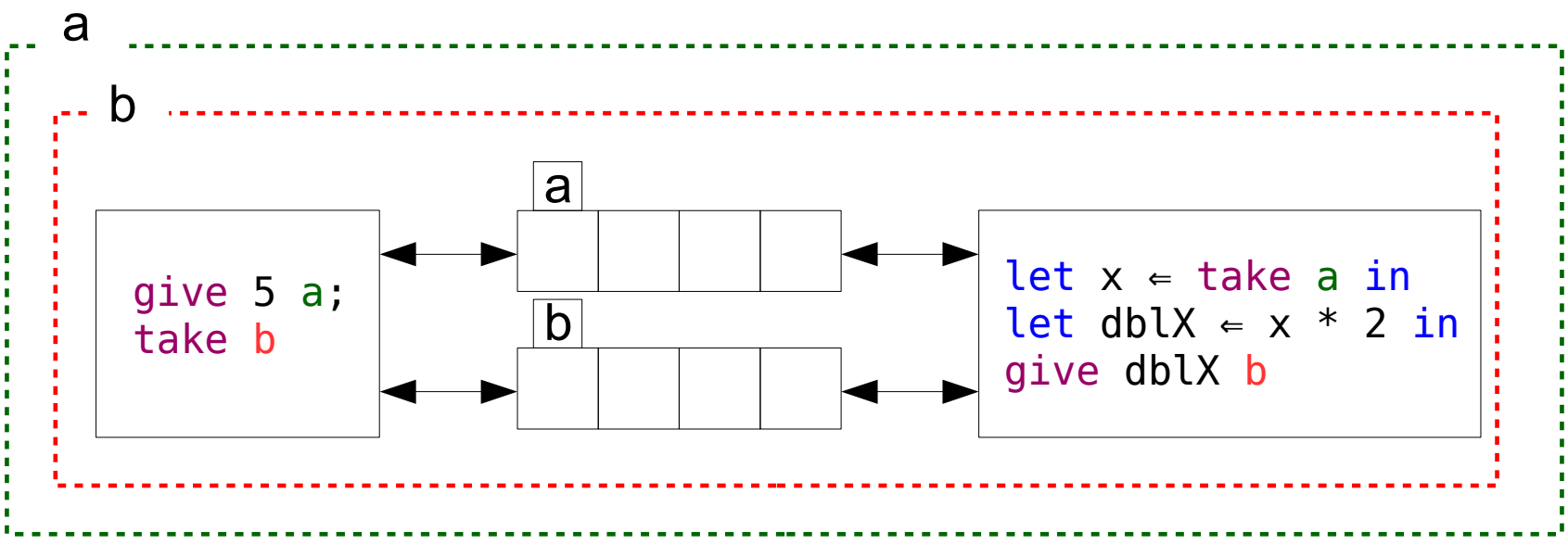
λ_{ch} Semantics, by Example



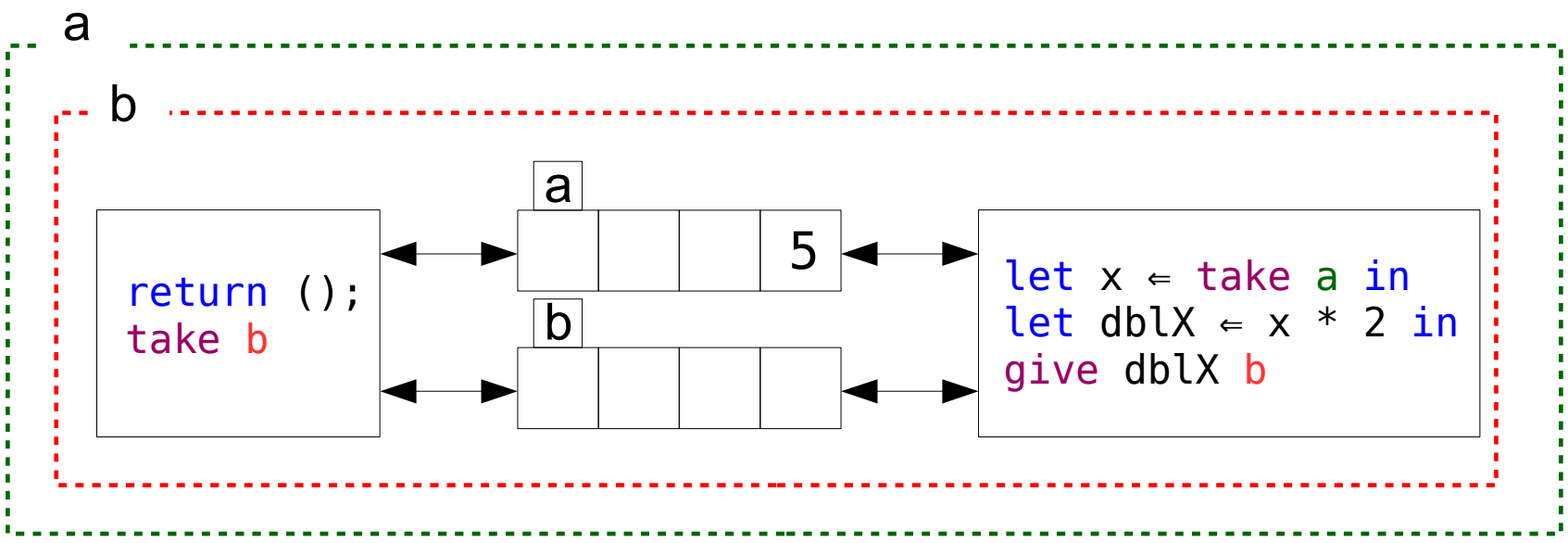
λ_{ch} Semantics, by Example



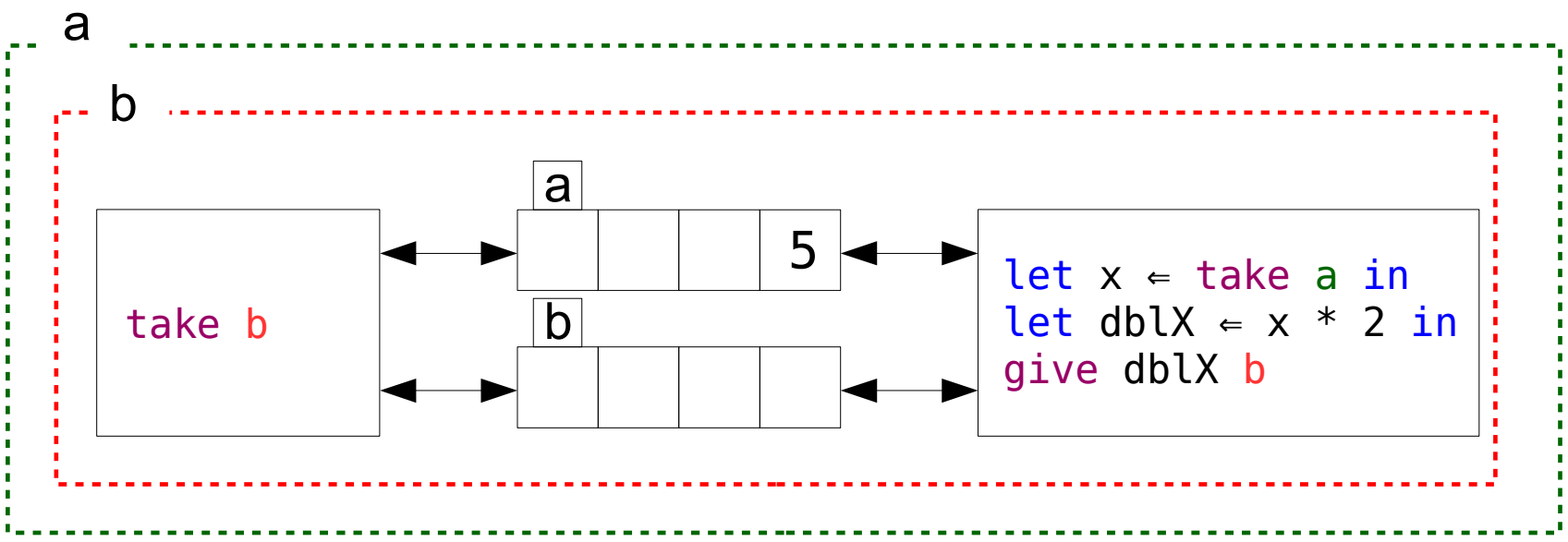
λ_{ch} Semantics, by Example



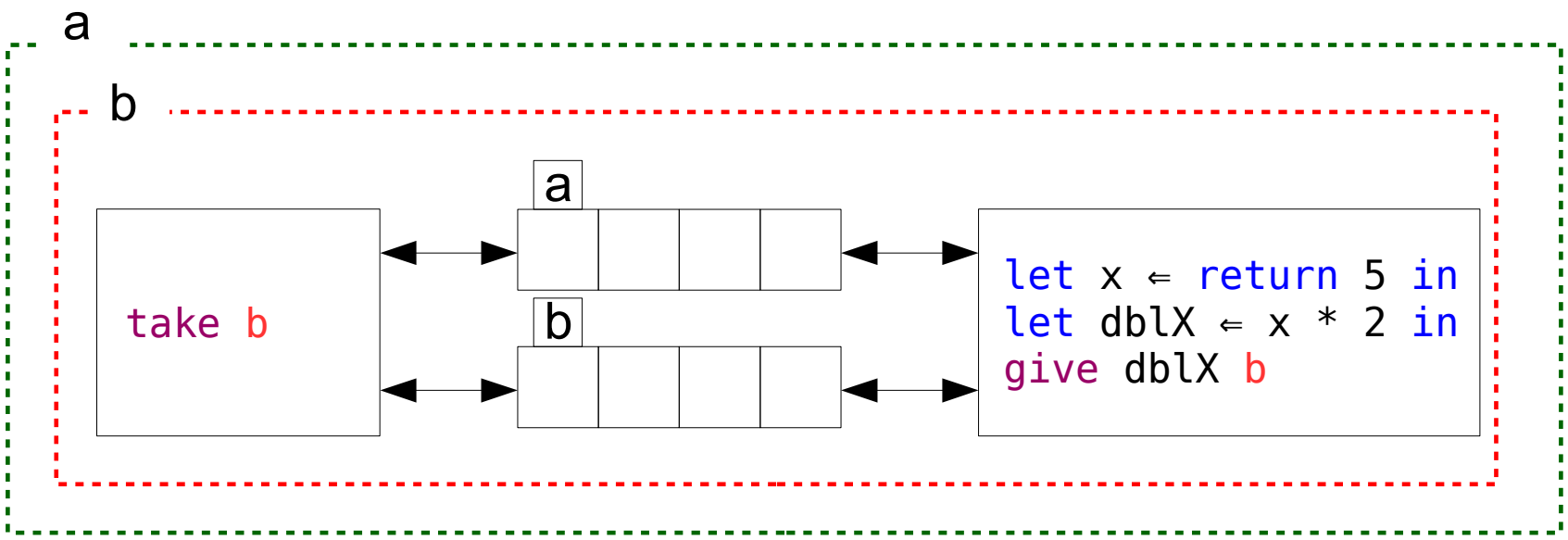
λ_{ch} Semantics, by Example



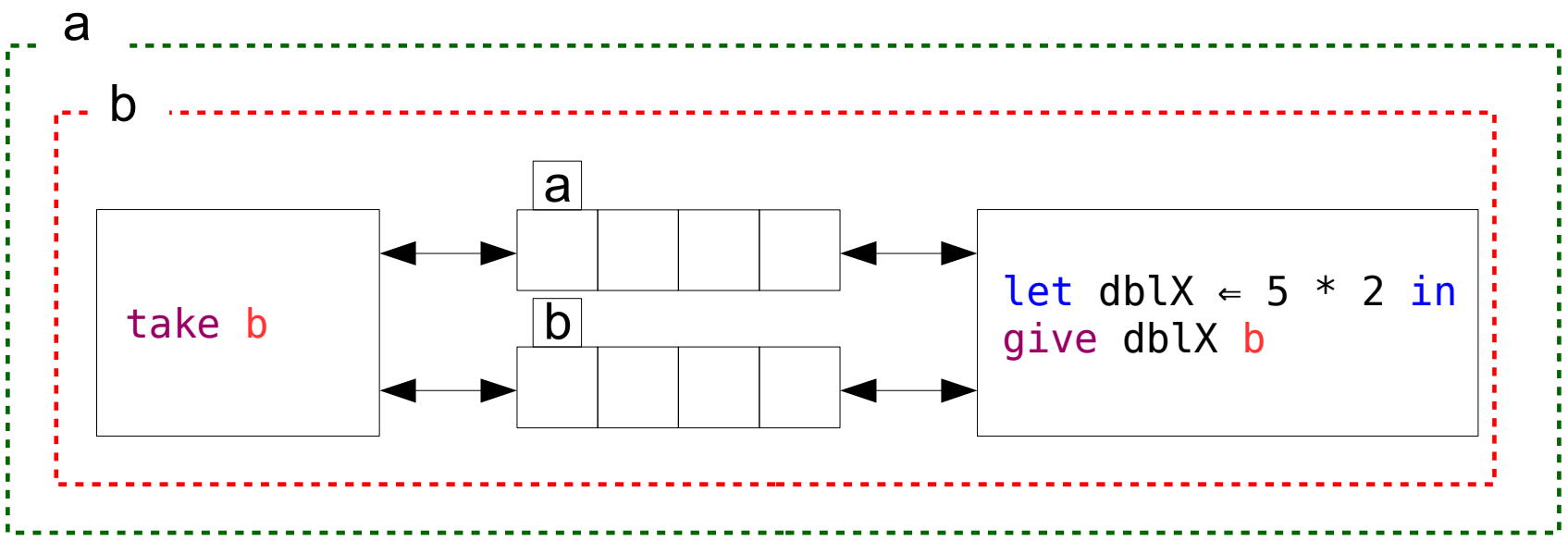
λ_{ch} Semantics, by Example



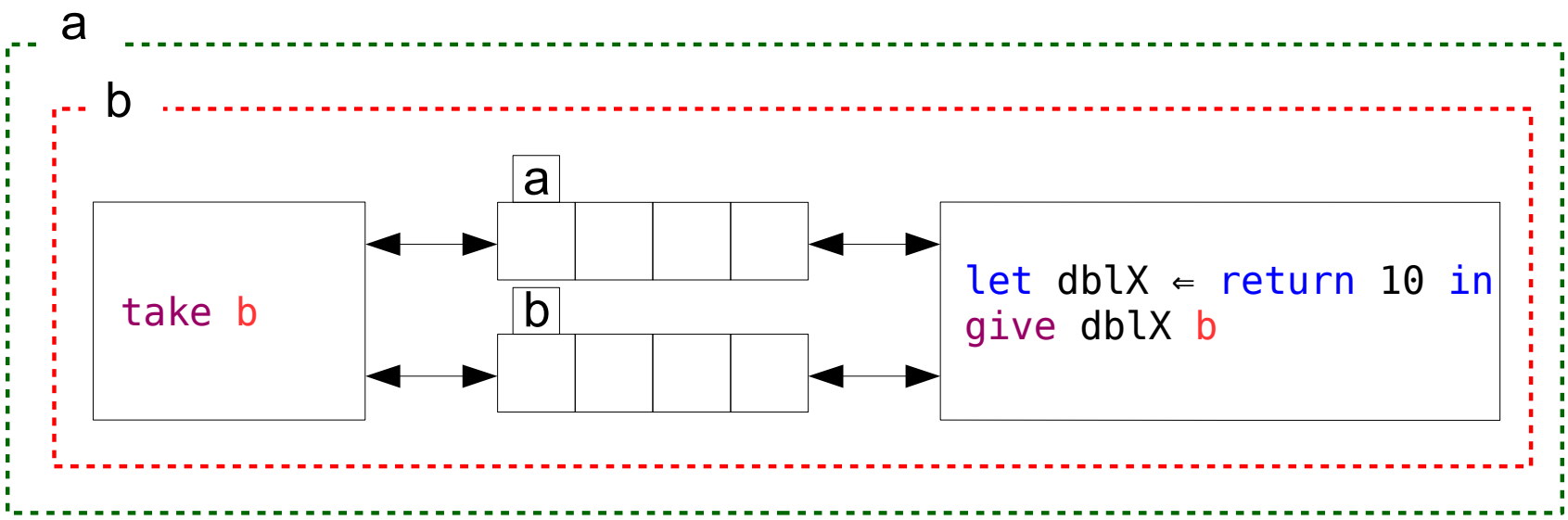
λ_{ch} Semantics, by Example



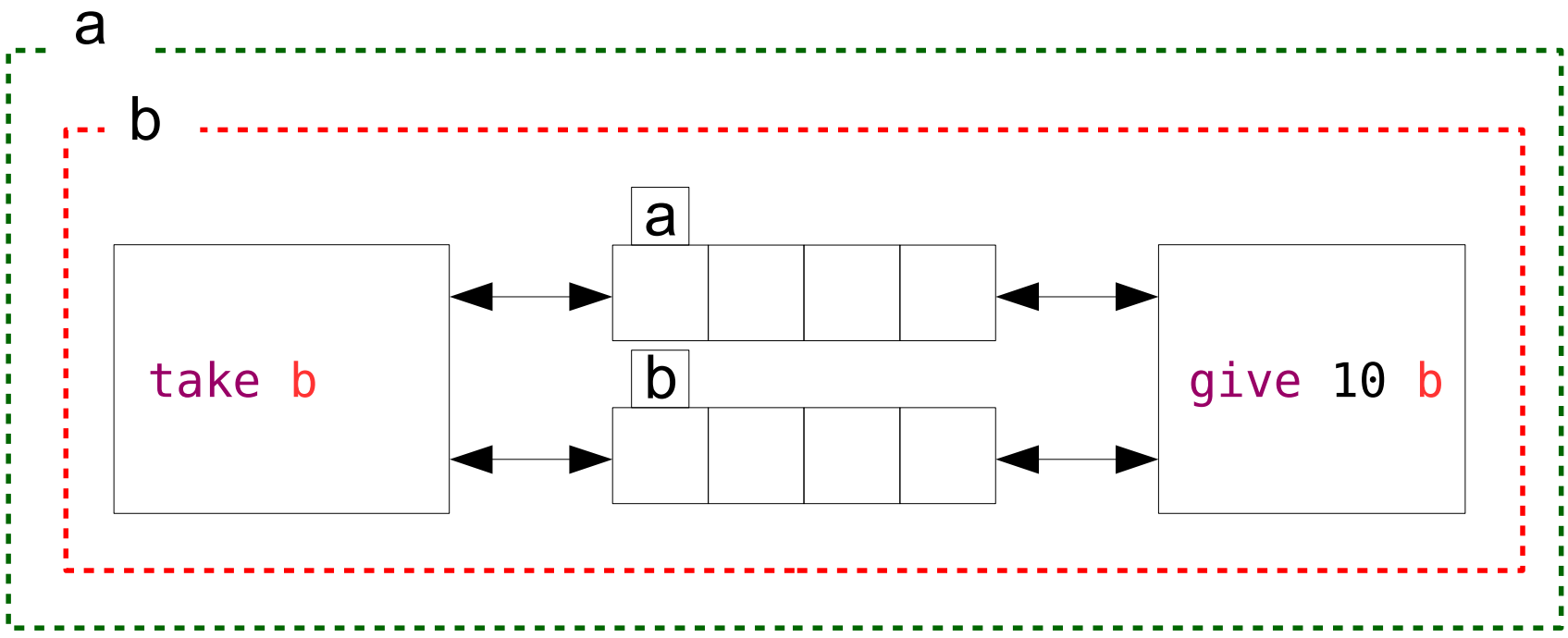
λ_{ch} Semantics, by Example



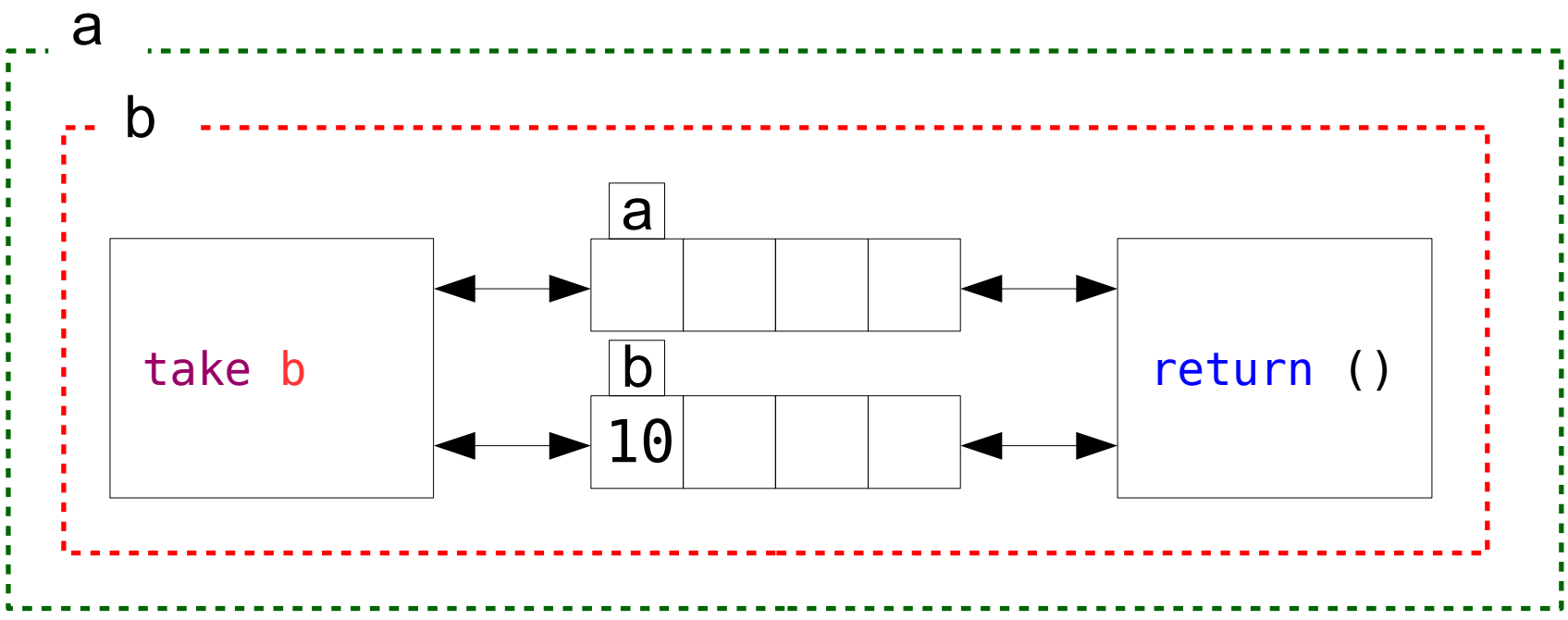
λ_{ch} Semantics, by Example



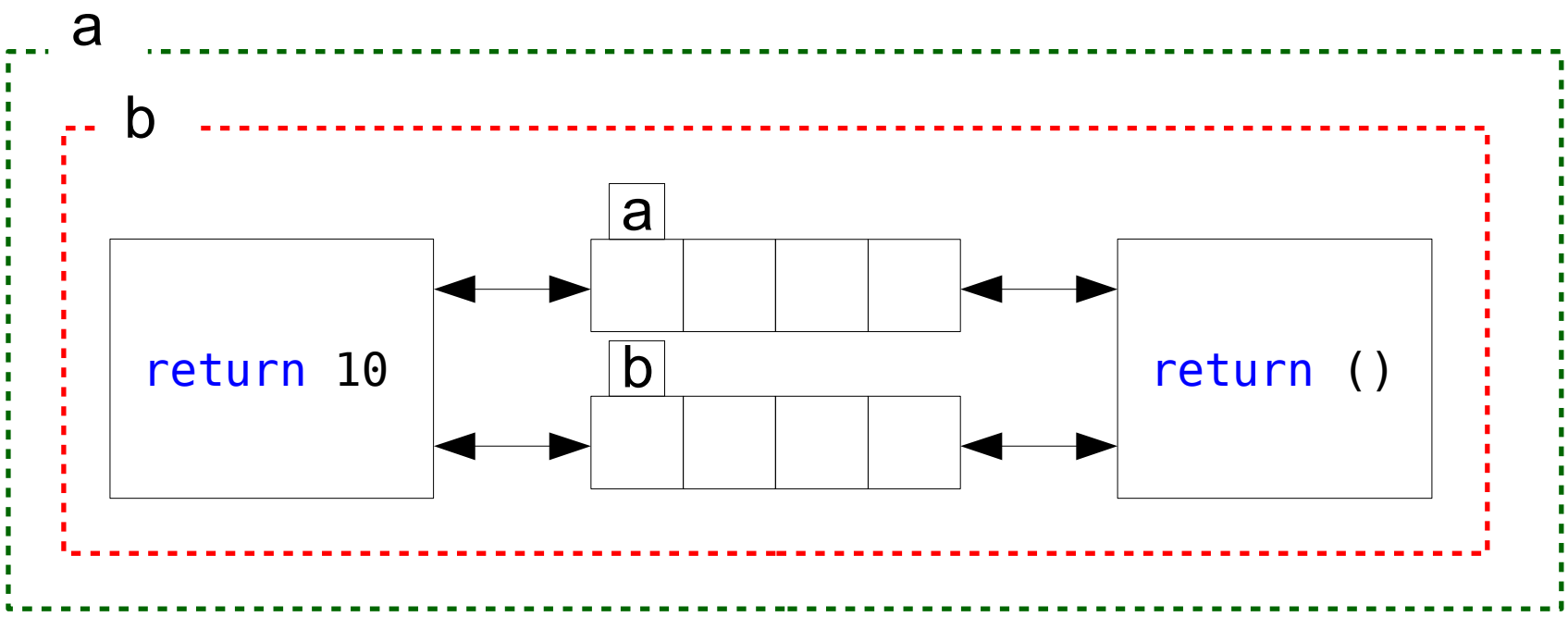
λ_{ch} Semantics, by Example



λ_{ch} Semantics, by Example



λ_{ch} Semantics, by Example



λ_{act}: A concurrent λ-calculus for type-parameterised actors

Syntax

$$
\begin{array}{rlll}
\text{Types} & A, B, C & ::= & \mathbf{1} \mid A \to^{C} B \mid \mathsf{ActorRef}(A) \\
\text{Variables} & \alpha & ::= & x \mid a \\
\text{Values} & V, W & ::= & \alpha \mid \lambda x.M \mid () \\
\text{Computations} & L, M, N & ::= & V\,W \\
 & & \mid & \mathsf{let}\ x \Leftarrow M\ \mathsf{in}\ N \mid \mathsf{return}\ V \\
 & & \mid & \mathsf{spawn}\ M \mid \mathsf{send}\ V\,W \mid \mathsf{receive} \mid \mathsf{self}
\end{array}
$$

Note: receive takes no arguments!

λ_{act} Typing Rules

As we are considering type-parameterised actors, each actor process has a typed mailbox. Therefore our term typing judgement becomes:

$$\boxed{\Gamma \mid B \vdash M : A}$$

"Under environment Γ and with the ability to receive messages of type *B*, term *M* has type *A*".

λ_{act} Typing Rules

Adapting abstraction and application

Abs

$$\frac{\Gamma, x : A \mid C \vdash M : B}{\Gamma \vdash \lambda x.M : A \to^{C} B}$$

App

$$\frac{\Gamma \vdash V : A \to^{C} B \quad \Gamma \vdash W : A}{\Gamma \mid C \vdash V\,W : B}$$

Communication and Concurrency Primitives

Send

$$\frac{\Gamma \vdash V : A \quad \Gamma \vdash W : \mathsf{ActorRef}(A)}{\Gamma \mid B \vdash \mathsf{send}\ V\,W : \mathbf{1}}$$

Recv

$$\frac{}{\Gamma \mid A \vdash \mathsf{receive} : A}$$

Spawn

$$\frac{\Gamma \mid A \vdash M : \mathbf{1}}{\Gamma \mid B \vdash \mathsf{spawn}\ M : \mathsf{ActorRef}(A)}$$

Self

$$\frac{}{\Gamma \mid A \vdash \mathsf{self} : \mathsf{ActorRef}(A)}$$

λ_{act} Configurations

$$\boxed{\mathcal{C} ::= \mathcal{C}_1 \parallel \mathcal{C}_2 \mid (\nu a)\mathcal{C} \mid \langle a, N, \overrightarrow{V} \rangle}$$

Parallel composition and name restriction are as before. No separate buffers and terms!

$$\boxed{\langle a, N, \overrightarrow{V} \rangle}$$

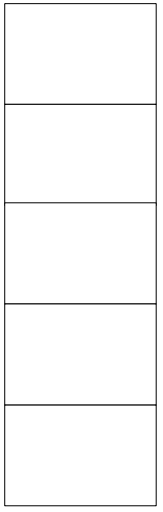
Actor with name a, evaluating term N, with mailbox $\overrightarrow{V}$. Terms must be evaluated in an actor context!

λ_{act} Semantics, by Example

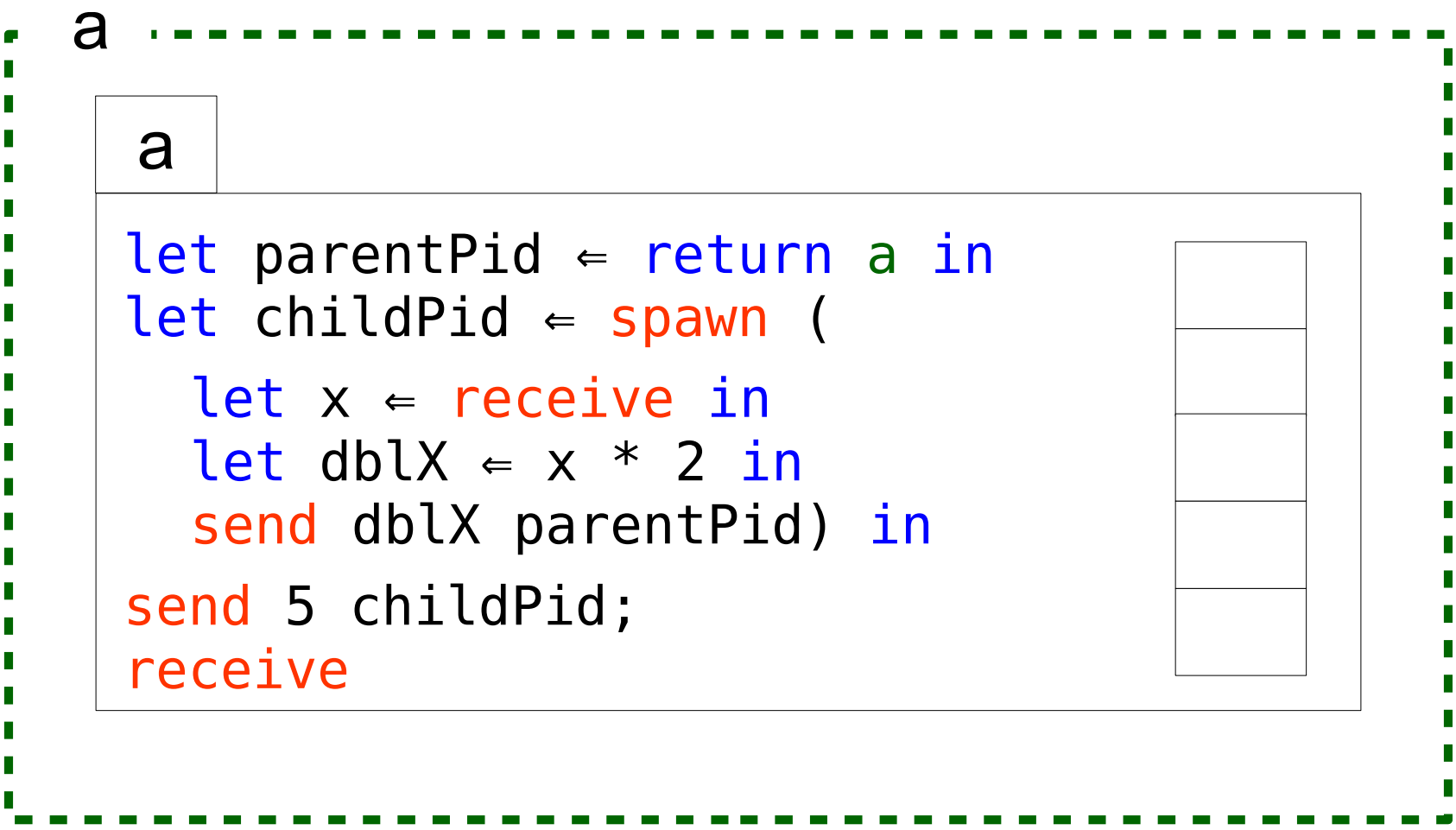
a

a

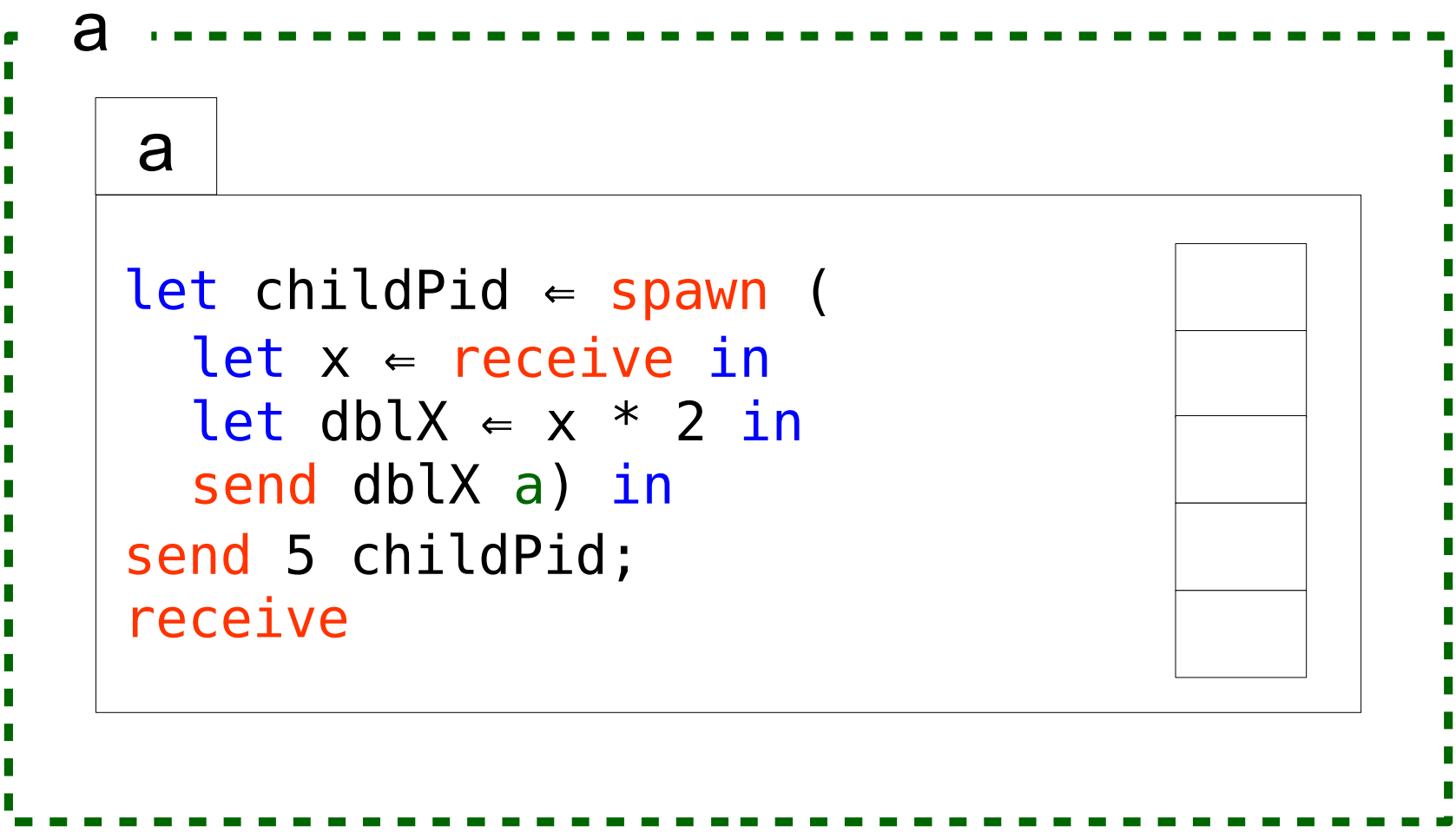
```
let parentPid ⇐ self in
let childPid ⇐ spawn (
  let x ⇐ receive in
  let dblX ⇐ x * 2 in
  send dblX parentPid) in
send 5 childPid;
receive
```



λ_{act} Semantics, by Example



λ_{act} Semantics, by Example



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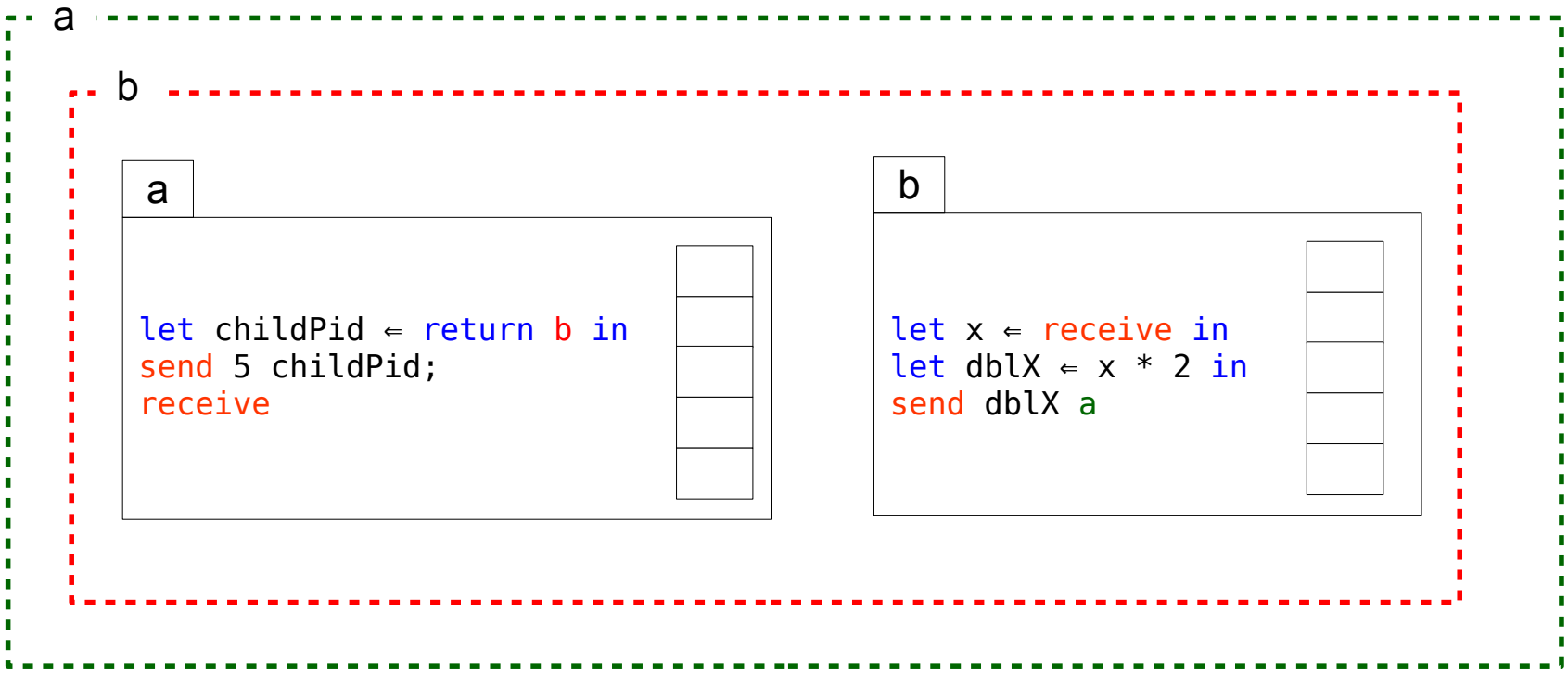

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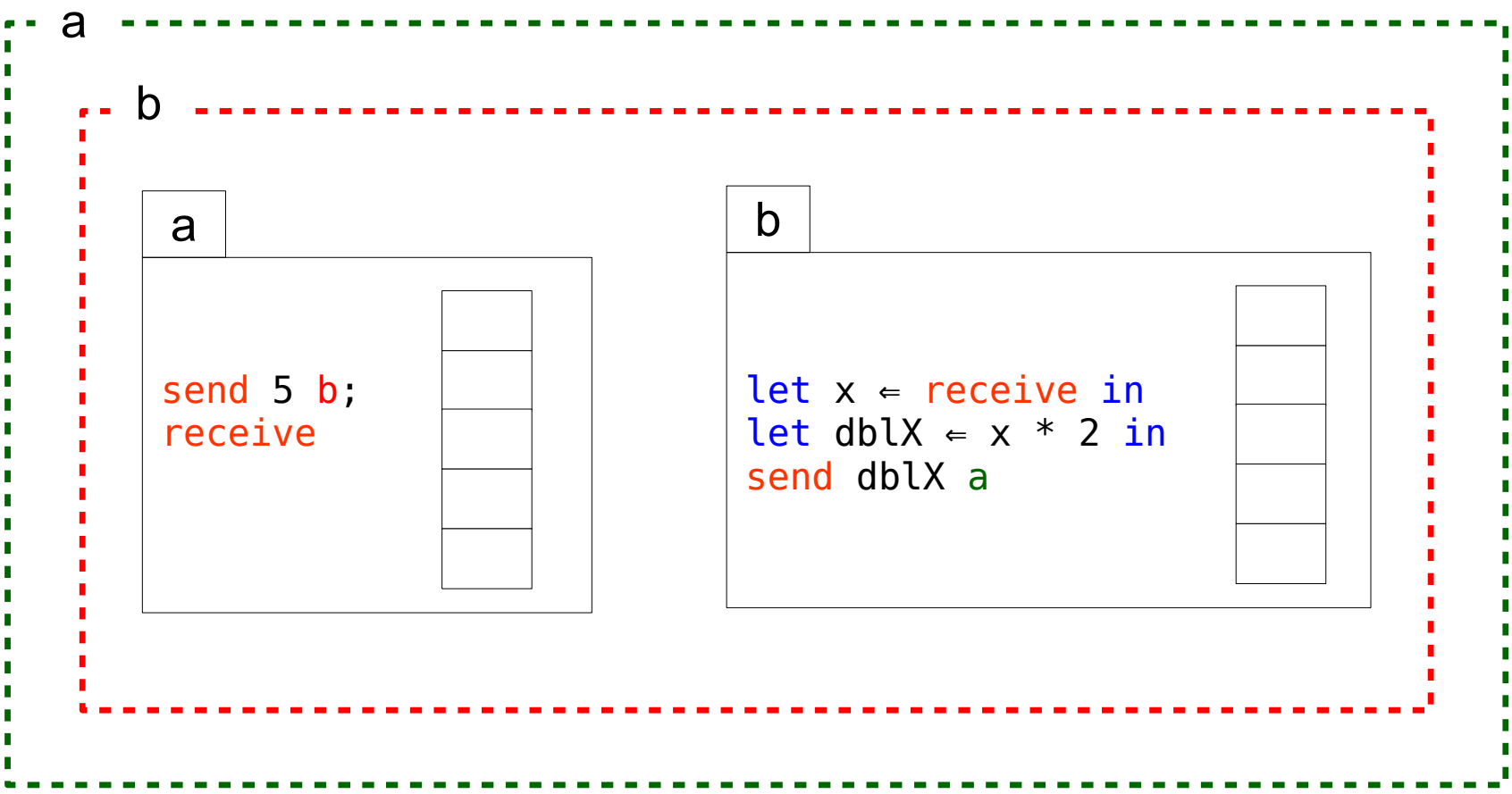

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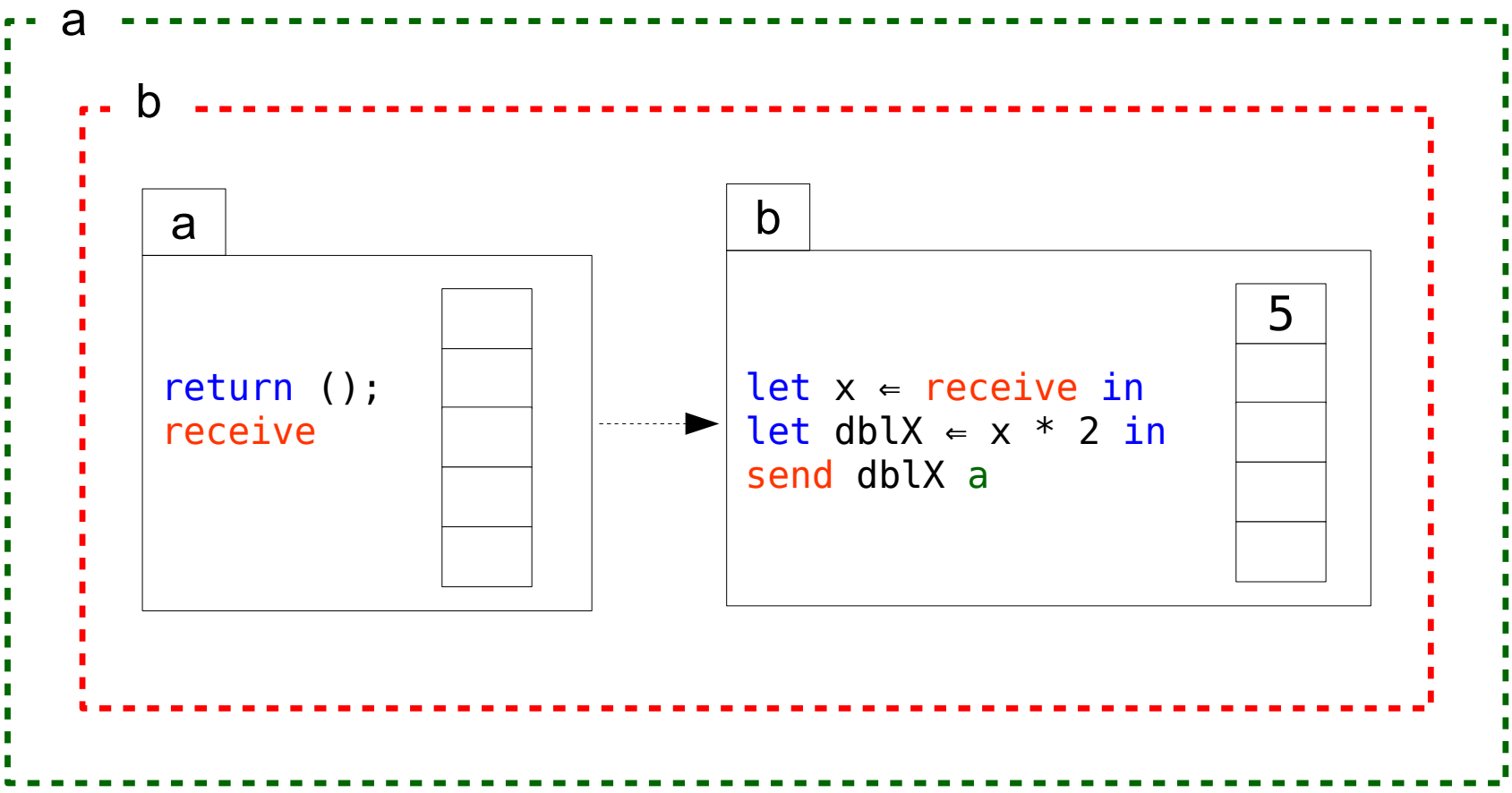
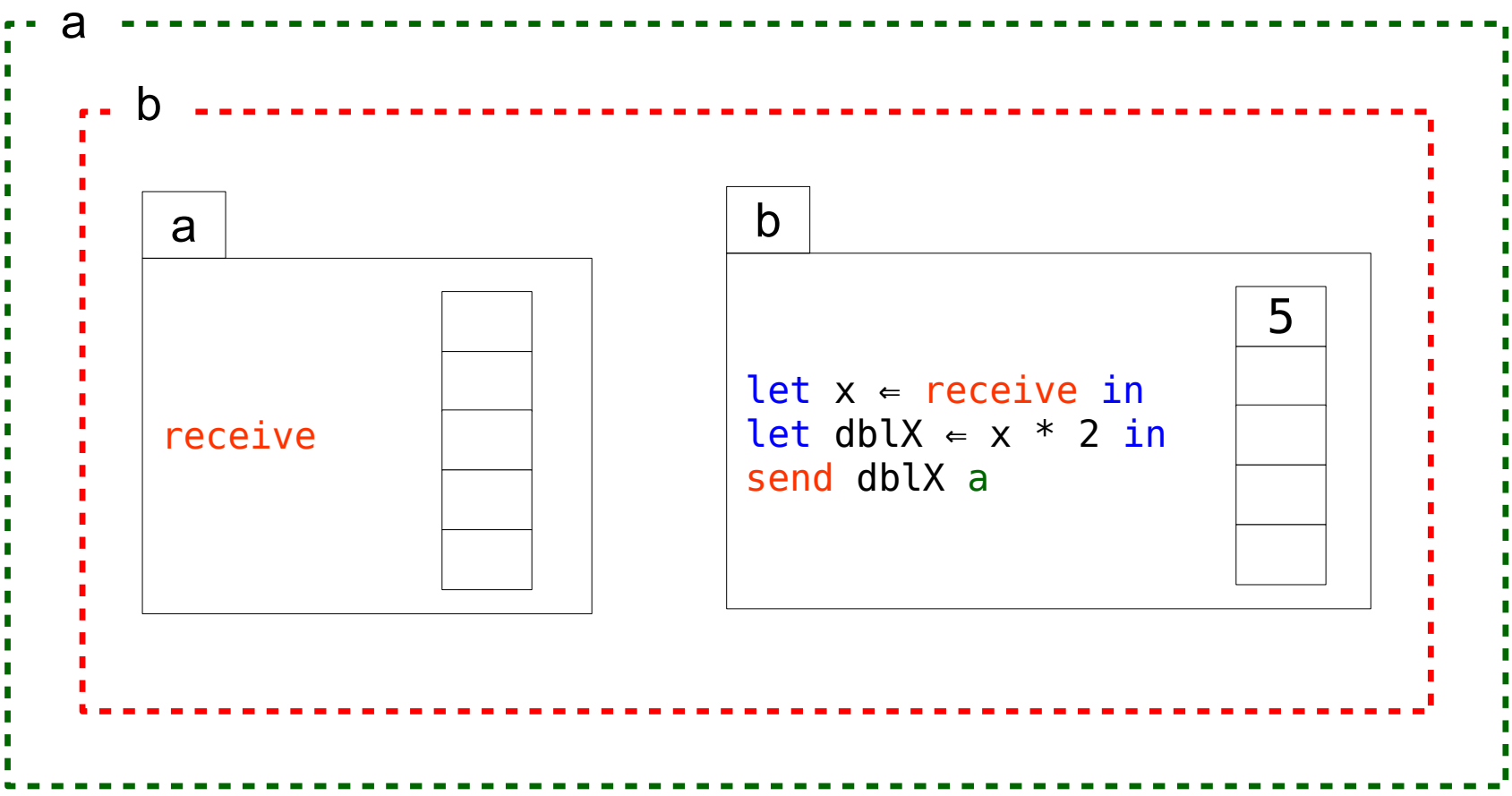


λ_{act} Semantics, by Example



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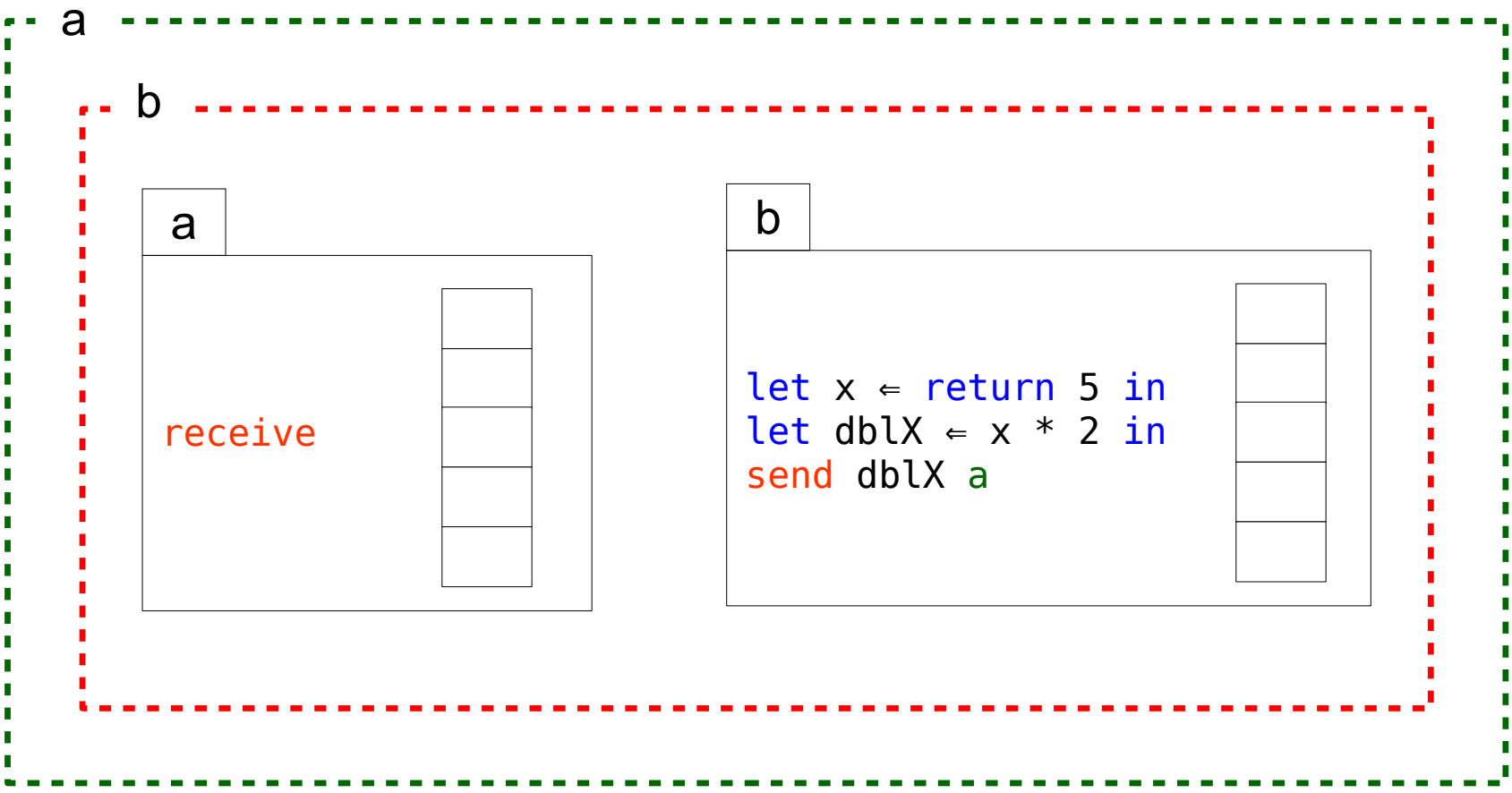

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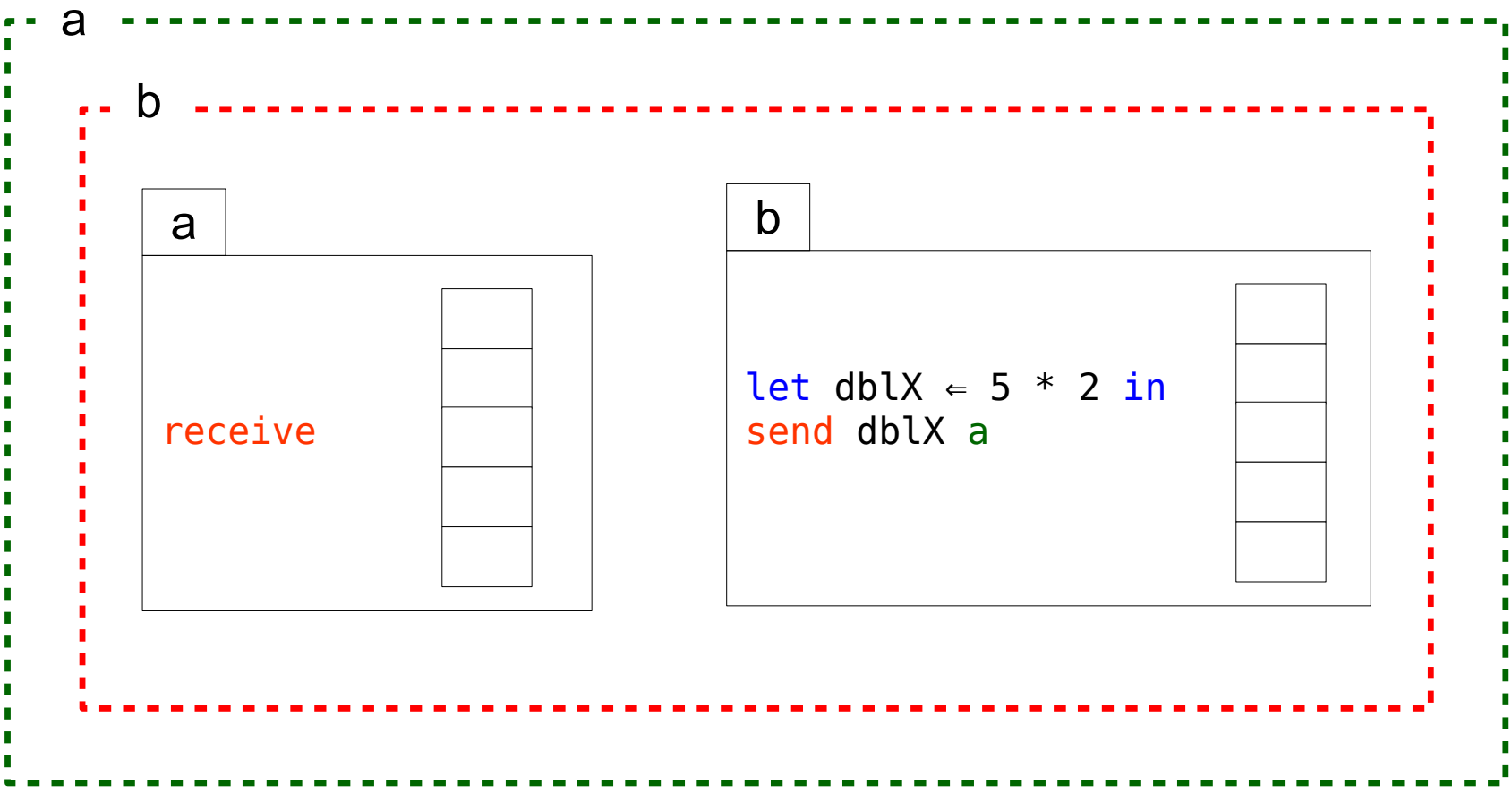

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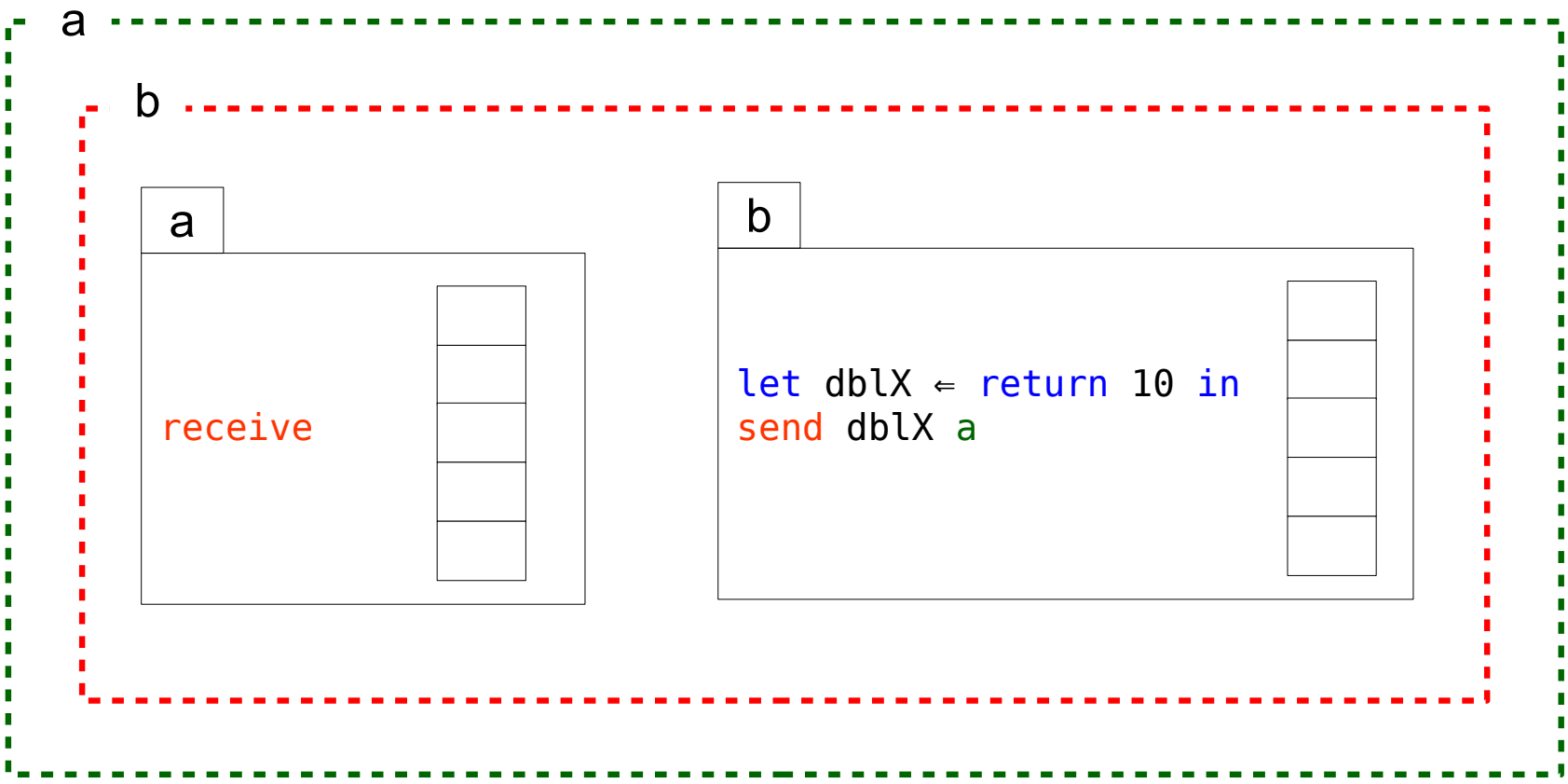

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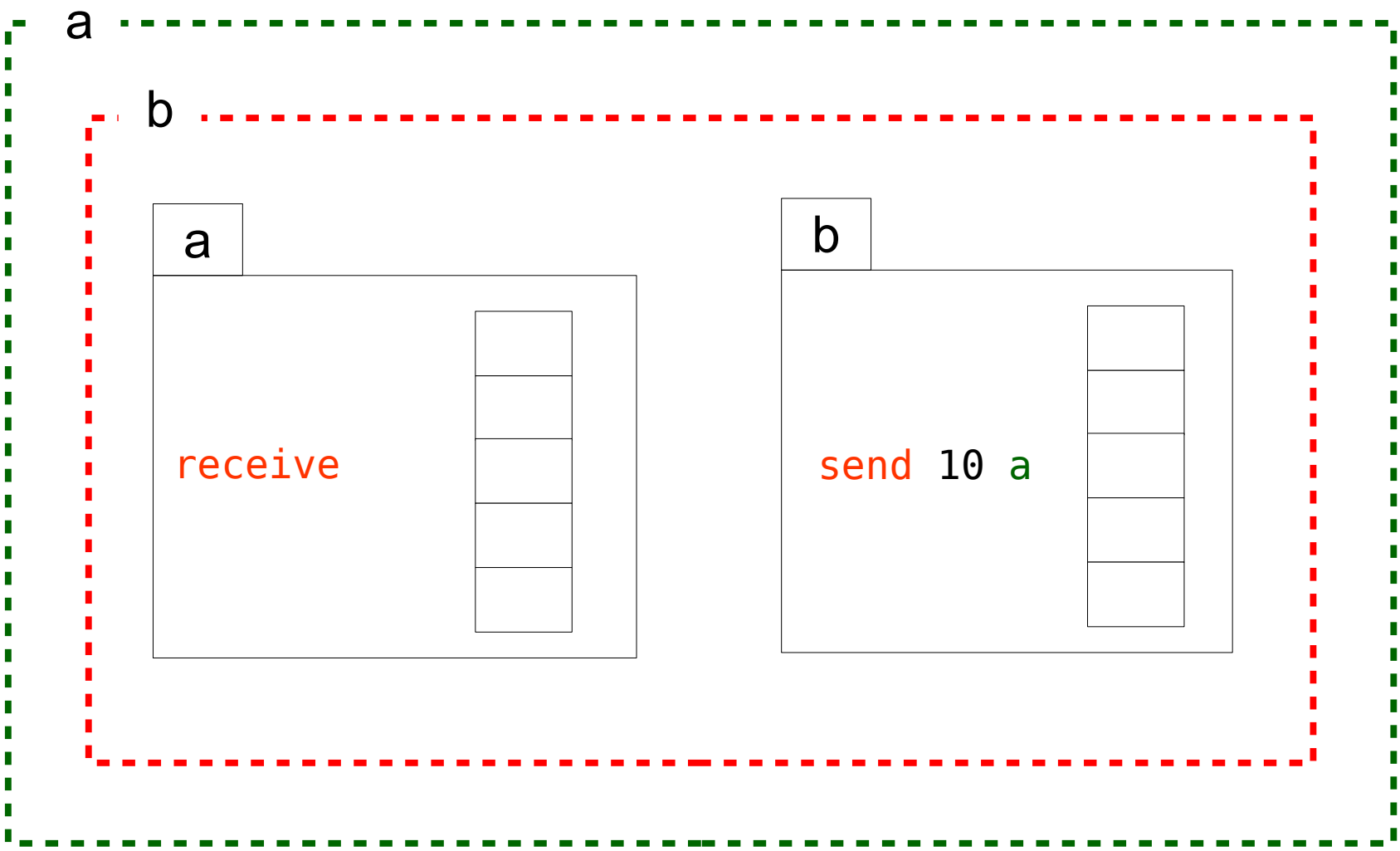
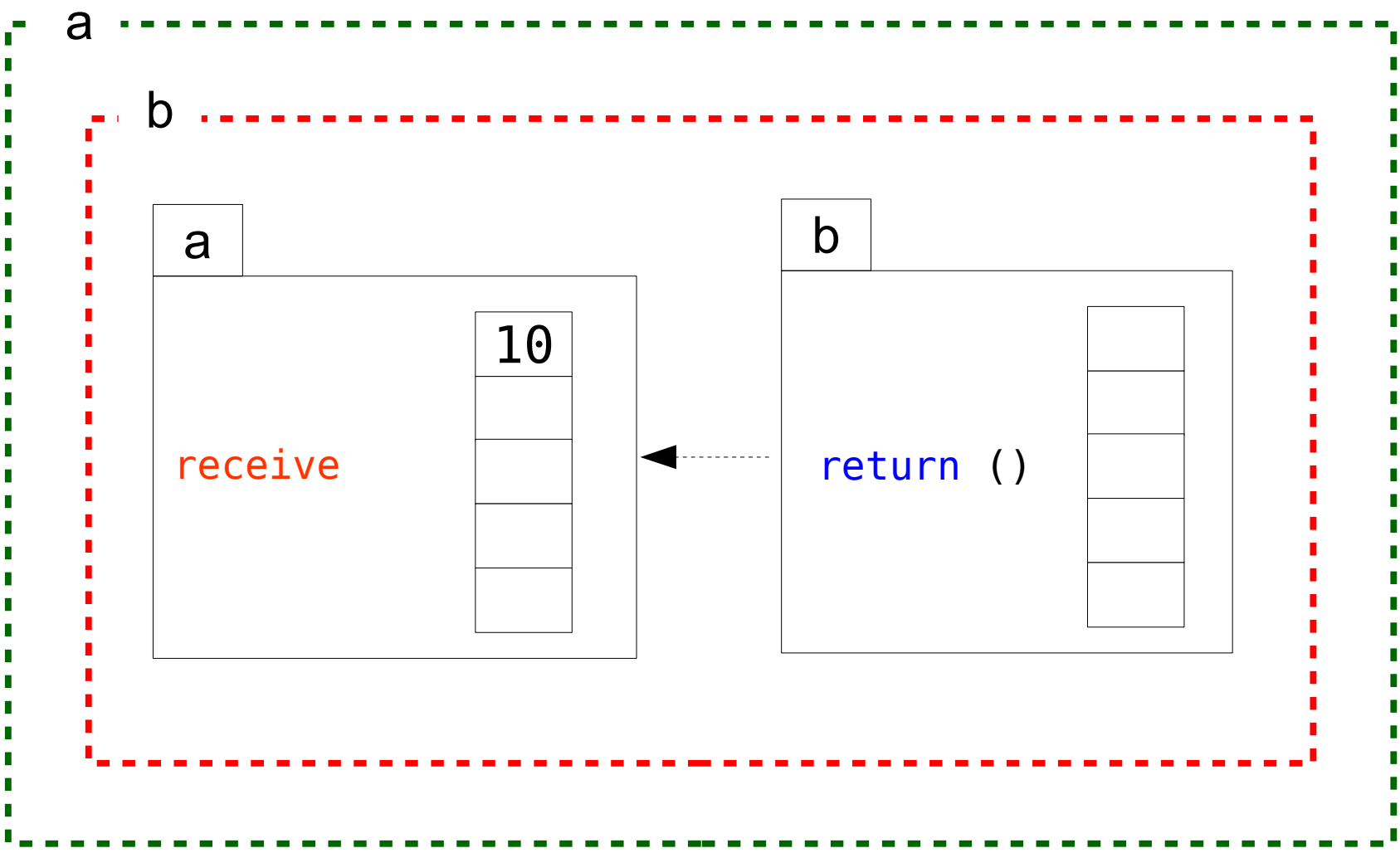
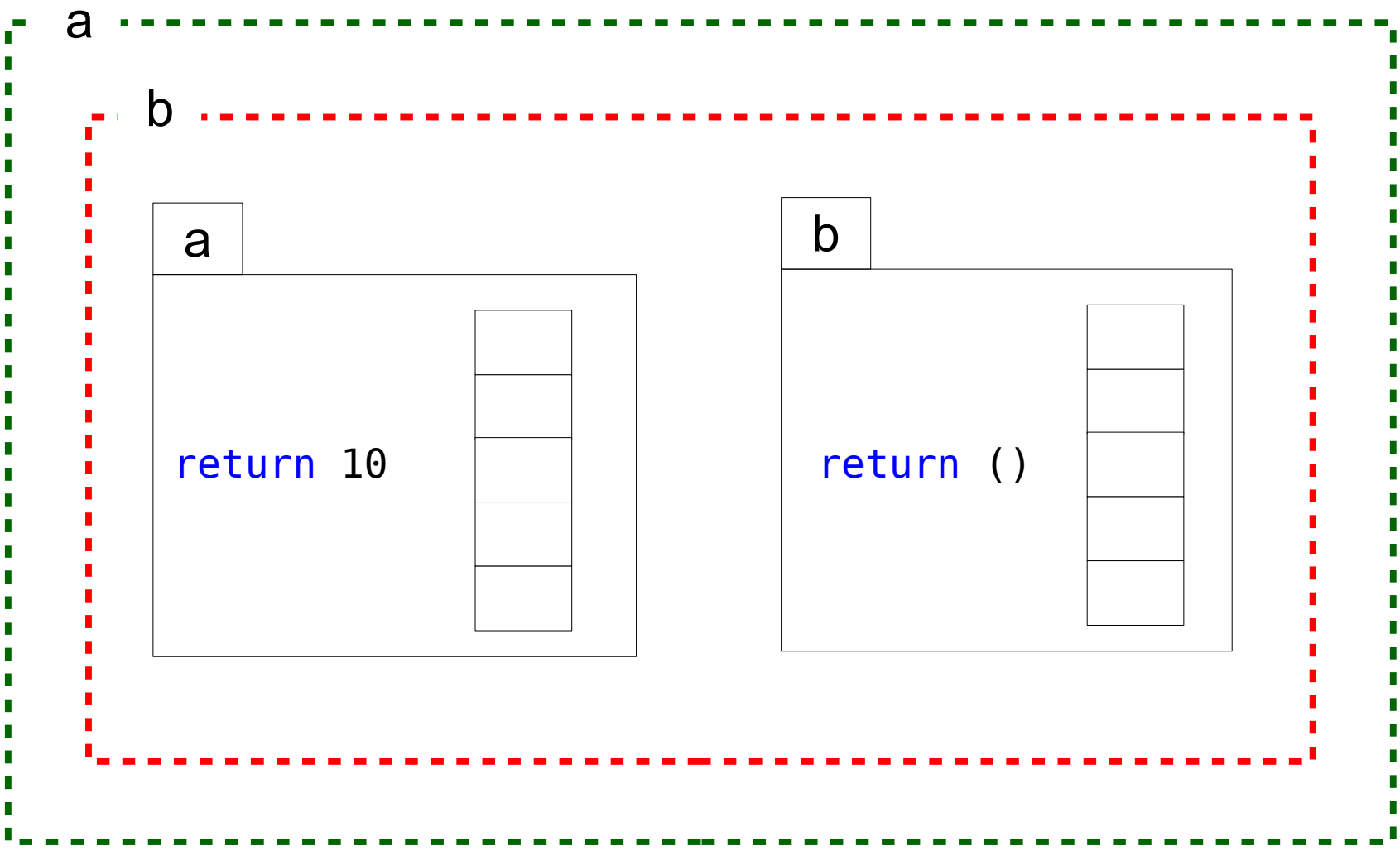


λ_{act} Semantics, by Example

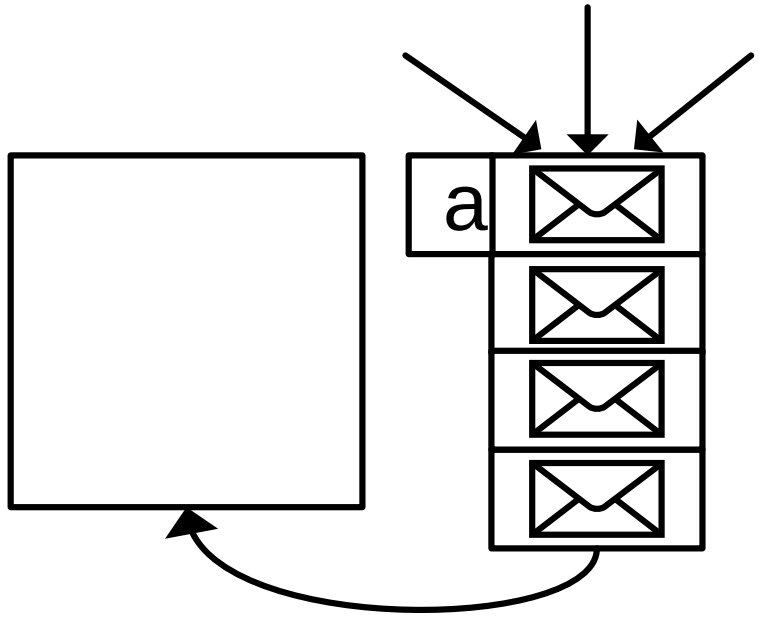


λ_{act} Semantics, by Example



From λ_{act} to λ_{ch}

The Idea



Main idea: emulate the mailbox using a channel, which is ‘pinned’ to a process.

The Translation, Formally (1)

Main technical idea: thread the 'mailbox channel' through the translation on terms.

Translation on Types $\boxed{[\![A]\!]}$

$$
\begin{aligned}
[\![\mathsf{ActorRef}(A)]\!] &= \mathsf{ChanRef}([\![A]\!]) \\
[\![\mathbf{1}]\!] &= \mathbf{1} \\
[\![A \to^{C} B]\!] &= [\![A]\!] \to \mathsf{ChanRef}([\![C]\!]) \to [\![B]\!]
\end{aligned}
$$

Translation on Values $\boxed{[\![V]\!]}$

$$[\![x]\!] = x \qquad [\![a]\!] = a \qquad [\![\lambda x.M]\!] = \lambda x.\lambda ch.([\![M]\!]\ ch) \qquad [\![()]\!] = ()$$

The Translation, Formally (2)

Translation on communication and concurrency primitives $\boxed{[\![M]\!]\ x}$

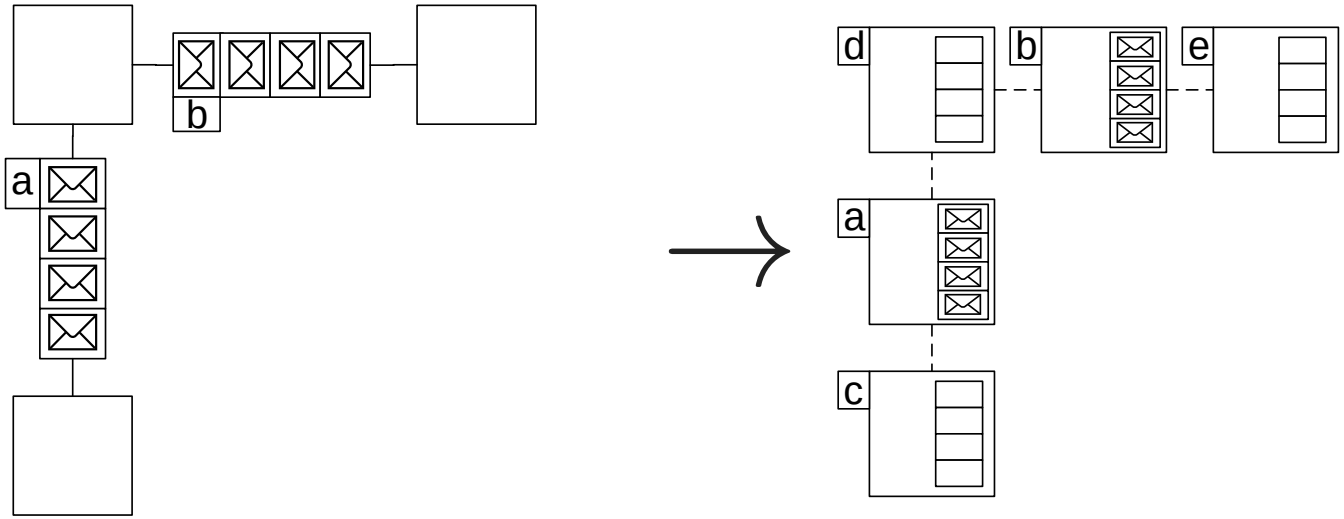
$$
\begin{array}{rcl}
[\![\mathsf{self}]\!]\ ch & = & \mathsf{return}\ ch \\
[\![\mathsf{receive}]\!]\ ch & = & \mathsf{take}\ ch \\
[\![\mathsf{spawn}\ M]\!]\ ch & = & \mathsf{let}\ chMb \Leftarrow \mathsf{newCh}\ \mathsf{in} \\
 & & \mathsf{fork}\ ([\![M]\!]\ chMb); \\
 & & \mathsf{return}\ chMb \\
[\![\mathsf{send}\ V\ W]\!]\ ch & = & \mathsf{give}\ ([\![V]\!])\ ([\![W]\!])
\end{array}
$$

Translation on configurations $\boxed{[\![\mathcal{C}]\!]}$

$$
\begin{array}{rcl}
[\![\mathcal{C}_1 \parallel \mathcal{C}_2]\!] & = & [\![\mathcal{C}_1]\!] \parallel [\![\mathcal{C}_2]\!] \\
[\![(\nu a)\mathcal{C}]\!] & = & (\nu a)\,[\![\mathcal{C}]\!] \\
[\![\langle a, M, \overrightarrow{V} \rangle]\!] & = & a([\![\overrightarrow{V}]\!]) \parallel ([\![M]\!]\ a)
\end{array}
$$

From λ_{ch} to λ_{act}

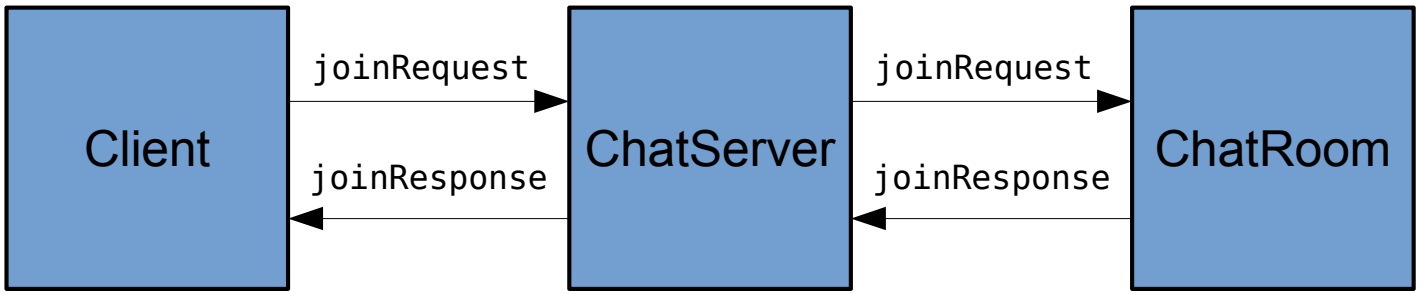
The Idea



Emulate each channel using an actor: can receive requests to queue or dequeue values. Must do this to preserve ability to pass channel endpoints!

Type Pollution Rears its Ugly Head...

Problem with typed actors: type pollution! Type of an ActorRef must handle all types that the actor can receive.



ChatServer reference has type
ActorRef(`joinRequest` + `joinResponse`)

Dealing with type pollution

Type pollution is problematic for the translation—which types are given to mailboxes of actors emulating threads?

- → Require all channels in the system to have the same type
- → If not, perform coalescing translation to assign general enough type to all mailboxes

Can then write judgements of the form $\{B\}\ \Gamma \vdash M : A$

- → Under environment Γ, where all channels carry values of type B, M has type A.

Translation (1)

body is an event loop which receives requests to either store a value, or dequeue a value and send it back to a given PID.

Translation on types $\boxed{(\!|\, A \,|\!)\ B}$

$$
\begin{aligned}
(\!|\, \mathsf{Chan}\, |\!)\ C &= \mathsf{ActorRef}((\!|\, C \,|\!)\ C + \mathsf{ActorRef}((\!|\, C \,|\!)\ C)) \\
(\!|\, A \to B \,|\!)\ C &= ((\!|\, A \,|\!)\ C) \to^{(\!|\, C \,|\!)\ C} ((\!|\, B \,|\!)\ C)
\end{aligned}
$$

Translation on communication and concurrency primitives $\boxed{(\!|\, M \,|\!)}$

$$
\begin{aligned}
(\!|\, \mathsf{fork}\ M \,|\!) &= \mathsf{let}\ x \Leftarrow \mathsf{spawn}\ (\!|\, M \,|\!)\ \mathsf{in}\ \mathsf{return}\ () \\
(\!|\, \mathsf{give}\ V\ W \,|\!) &= \mathsf{send}\ (\mathsf{inl}\ (\!|\, V \,|\!))\ (\!|\, W \,|\!) \\
(\!|\, \mathsf{take}\ V \,|\!) &= \mathsf{let}\ \mathit{selfPid} \Leftarrow \mathsf{self}\ \mathsf{in} \\
&\quad\ \mathsf{send}\ (\mathsf{inr}\ \mathit{selfPid})\ (\!|\, V \,|\!); \\
&\quad\ \mathsf{receive} \\
(\!|\, \mathsf{newCh} \,|\!) &= \mathsf{spawn}\ (\mathsf{body}\ (\mathbf{[\,]}, \mathbf{[\,]}))
\end{aligned}
$$

Translation (2)

Translation on configurations

$(\!| \mathcal{C} |\!)$

$$
\begin{array}{rcll}
(\!| \mathcal{C}_1 \parallel \mathcal{C}_2 |\!) & = & (\!| \mathcal{C}_1 |\!) \parallel (\!| \mathcal{C}_2 |\!) & \\
(\!| (\nu a)\mathcal{C} |\!) & = & (\nu a)(\!| \mathcal{C} |\!) & \\
(\!| M |\!) & = & (\nu a)(\langle a, (\!| M |\!), \epsilon \rangle) & a \text{ is a fresh name} \\
(\!| a(\overrightarrow{V}) |\!) & = & \langle a, \text{body}\ ((\!| \overrightarrow{V} |\!), \mathbf{[]}), \epsilon \rangle & \\
 & & \text{where } (\!| \overrightarrow{V} |\!) = (\!| V_0 |\!) :: \ldots :: (\!| V_n |\!) :: \mathbf{[]} &
\end{array}
$$

Wrapping Up

Parting Thoughts

- → Two small models for languages based on channels, and languages based on actors, and translations between them.
- → Also: extensions for λ_{act} with synchronous calls (sidesteps type pollution); λ_{ch} with nondeterministic choice
  - → Relating channels with choice to actors is still a challenging open problem
- → Given many insights into behaviourally-typed versions – that's up next!

Thanks!