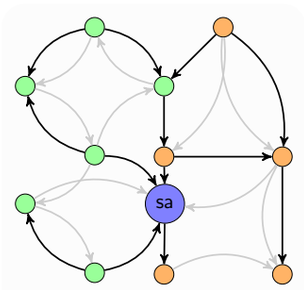
Actors without Borders:

Amnesty for Imprisoned State

Elias Castegren, Tobias Wrigstad

PLACES'17, Uppsala

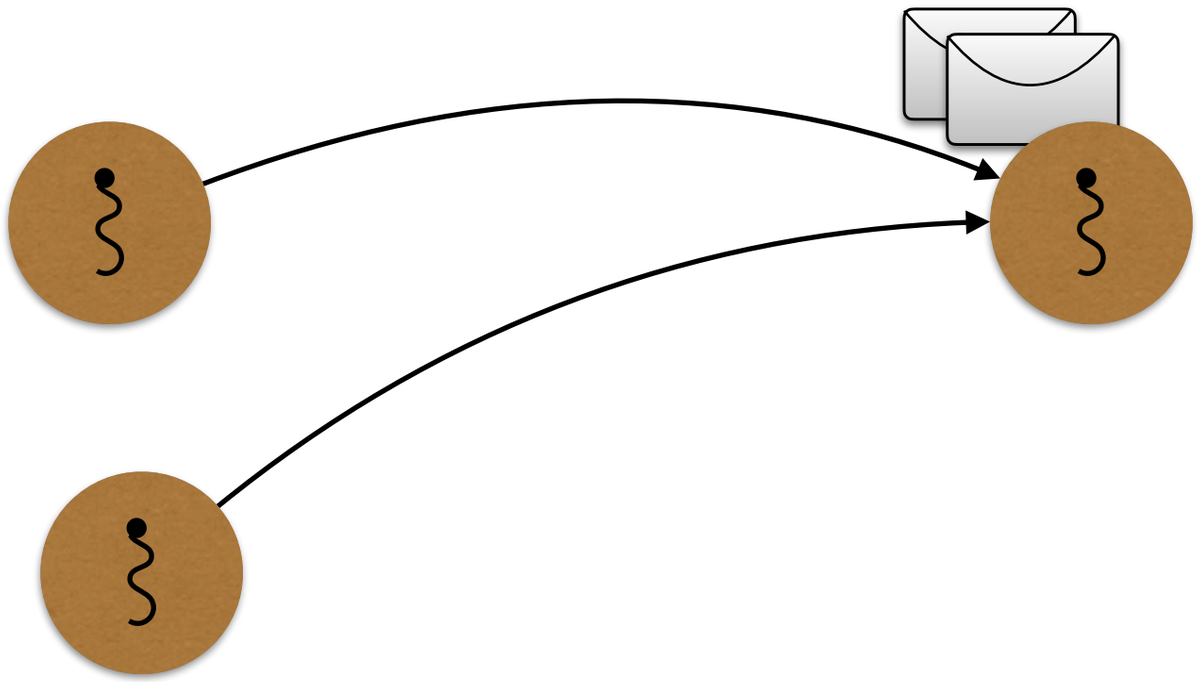
UPMARC



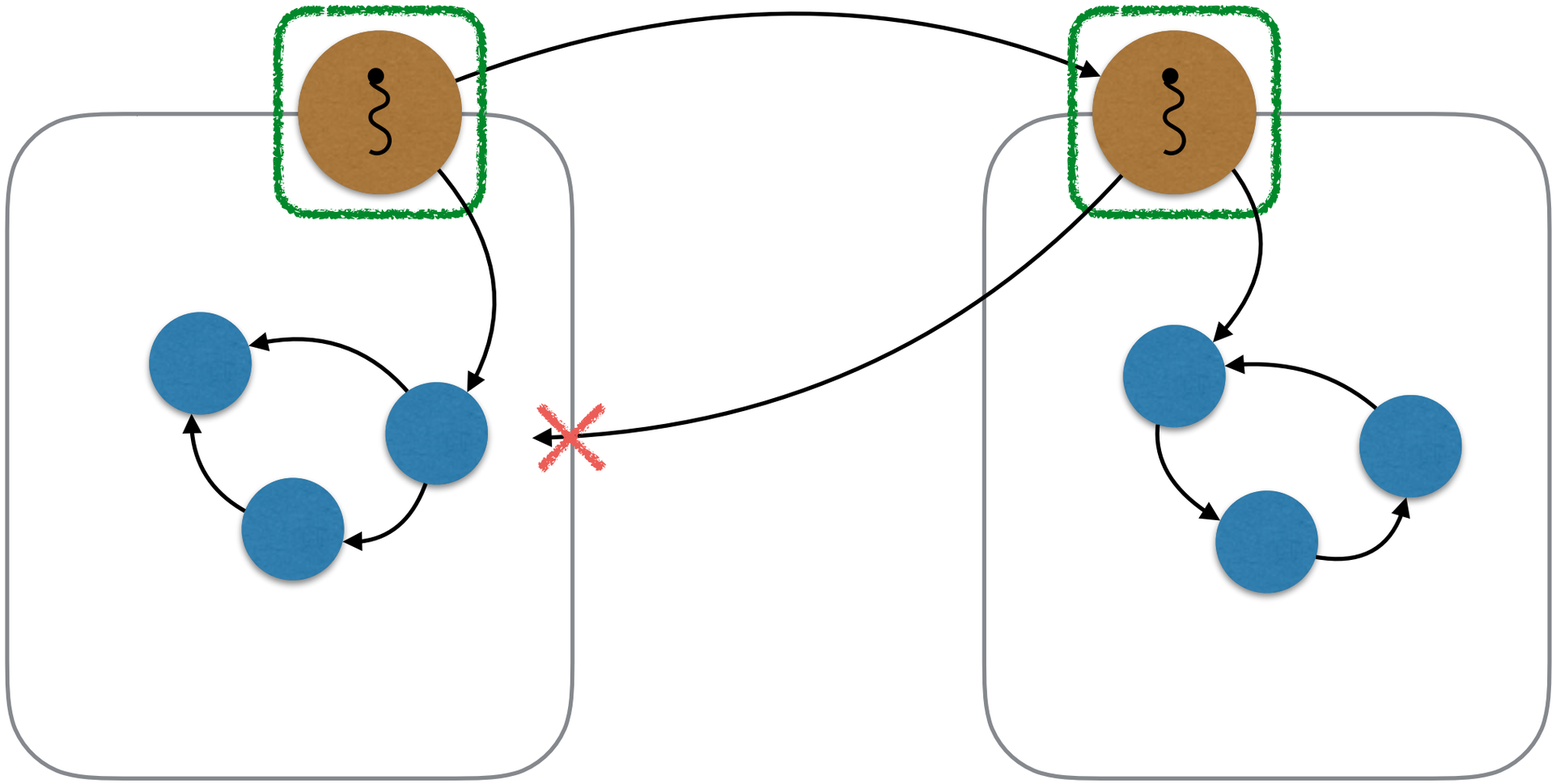
Structured Aliasing

UPSCALE

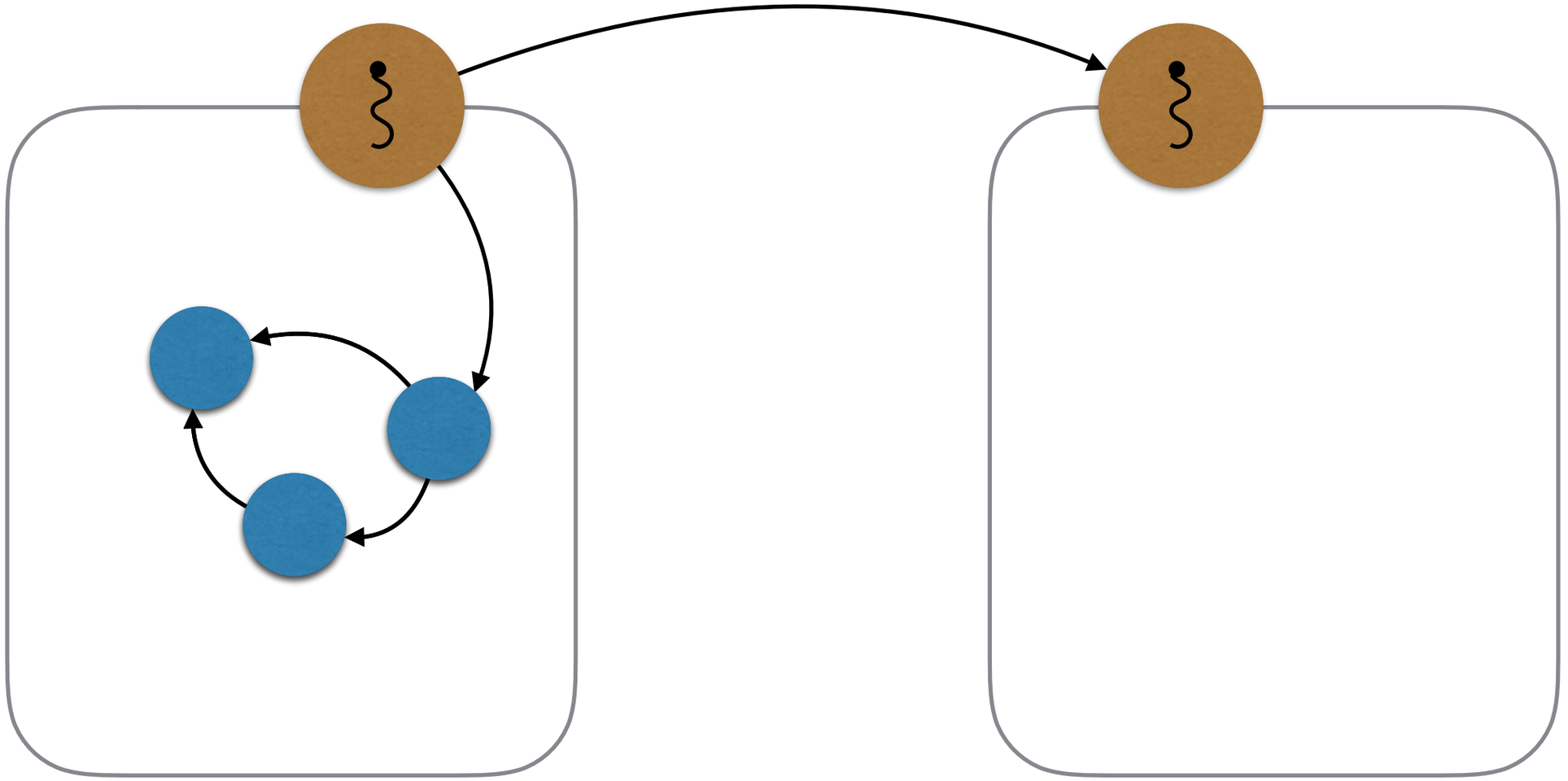
The Actor Model



Actor Isolation allows Sequential Reasoning



Passing Data Between Actors (by copy)



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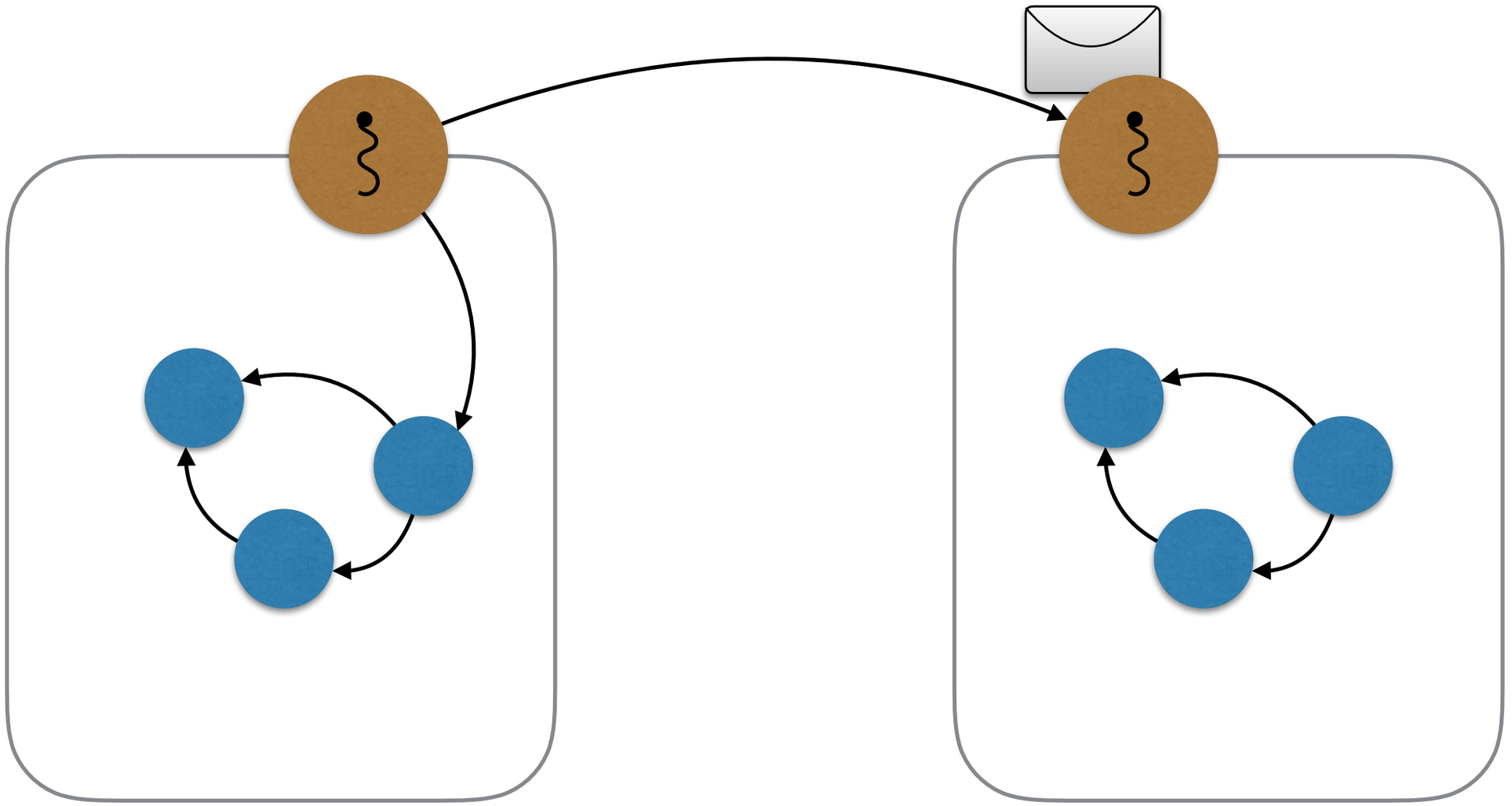
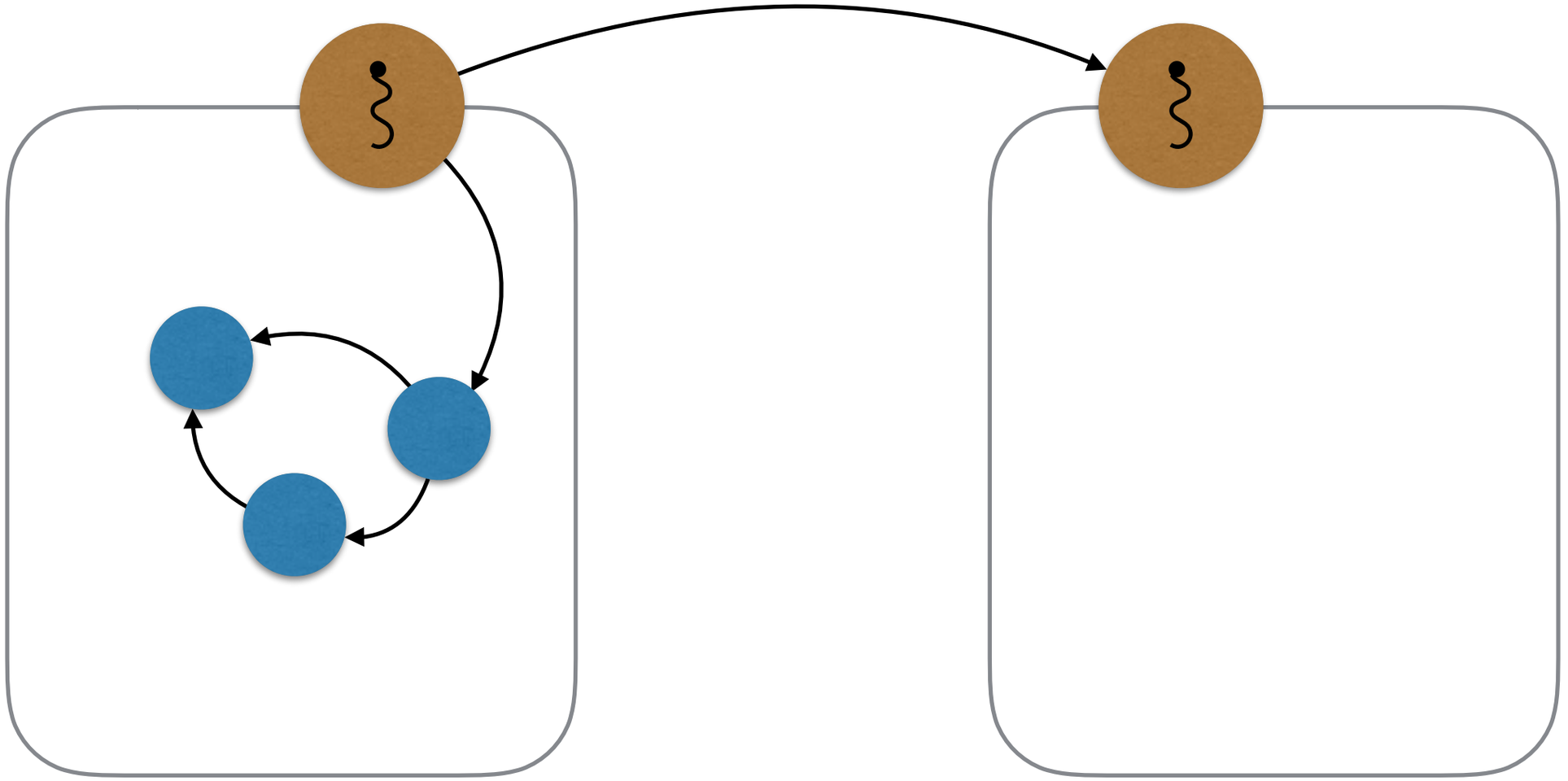


Passing Data Between Actors (by transfer)



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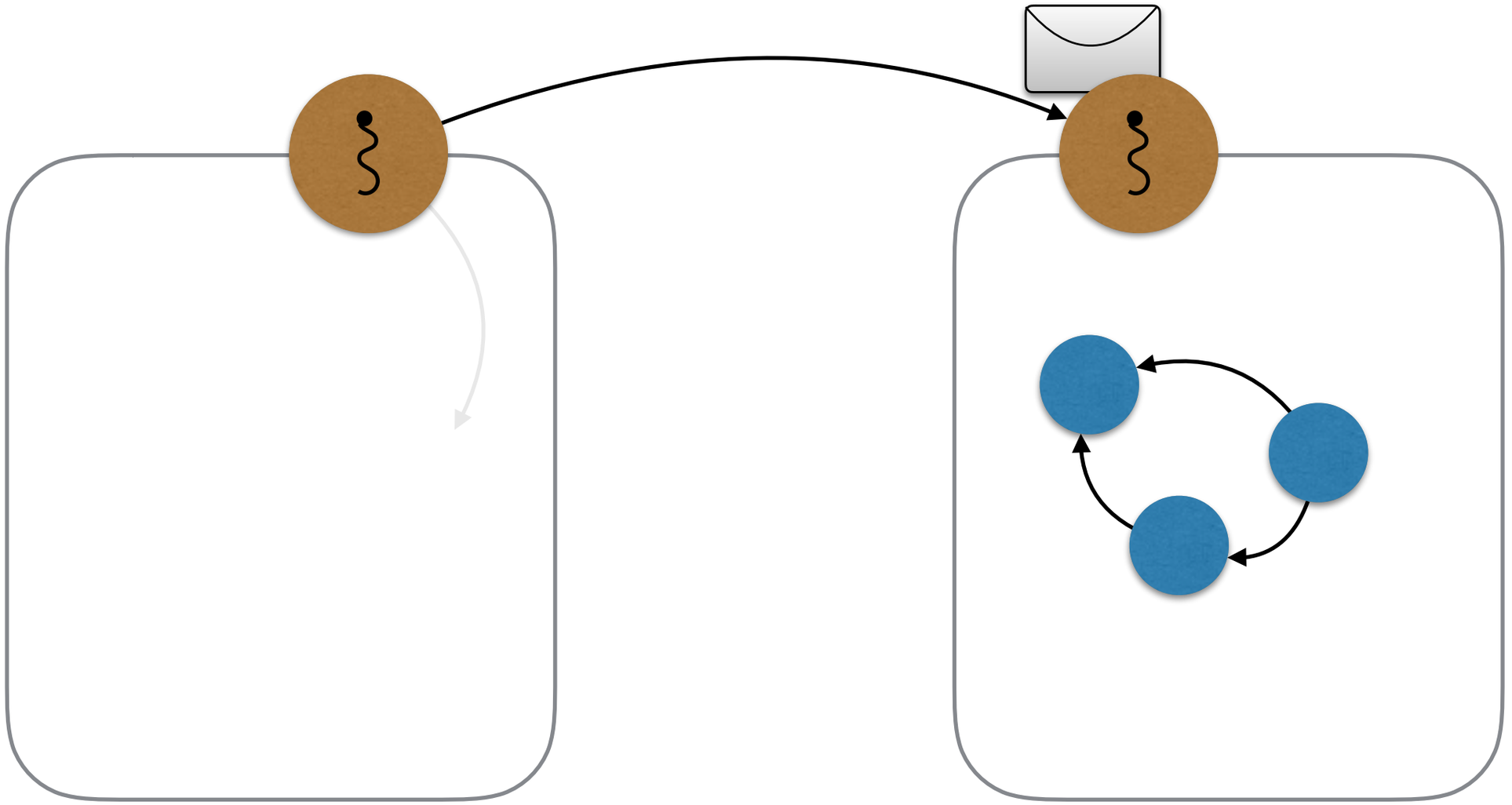
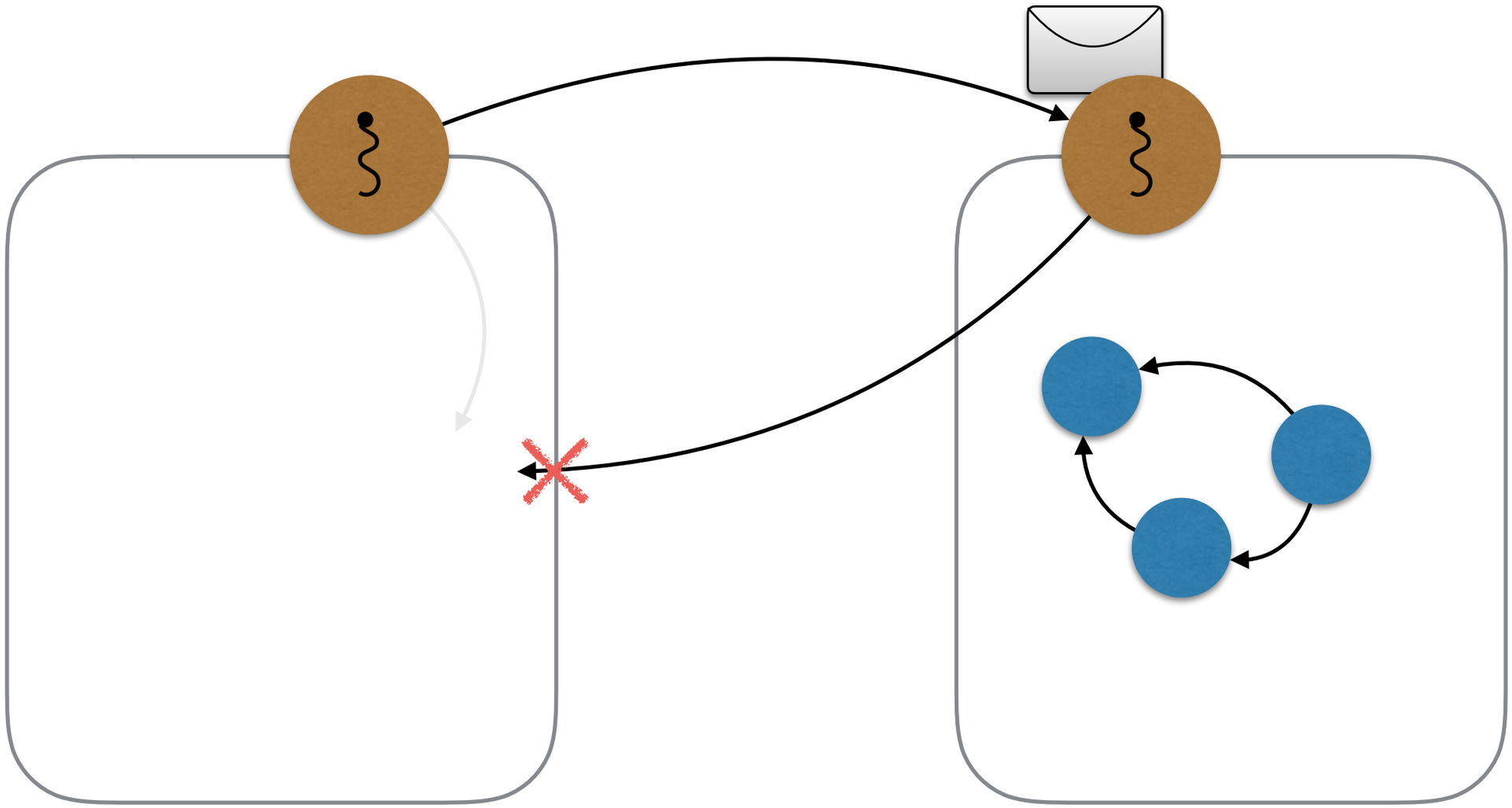
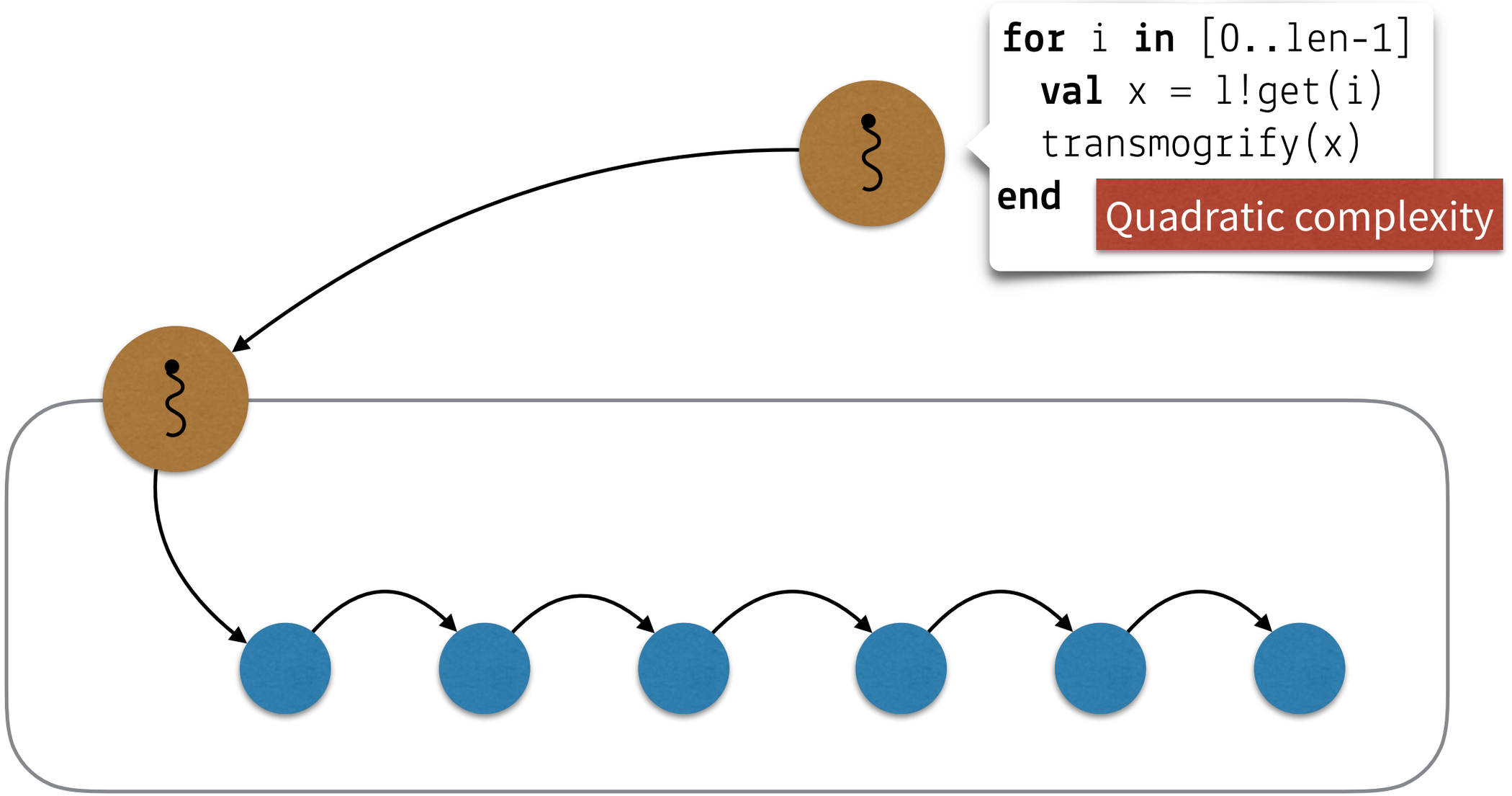


Passing Data Between Actors (by transfer)

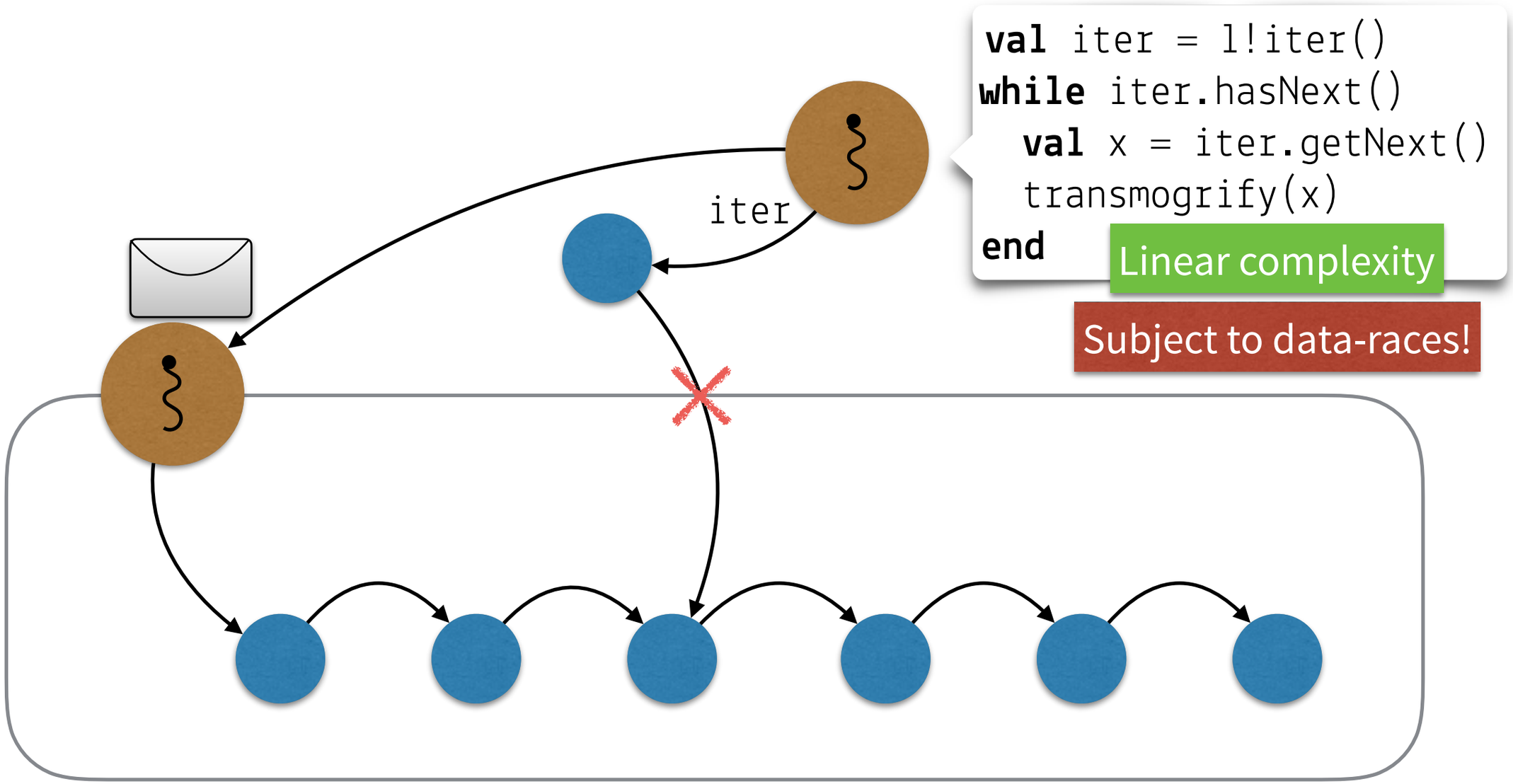
Strong Encapsulation



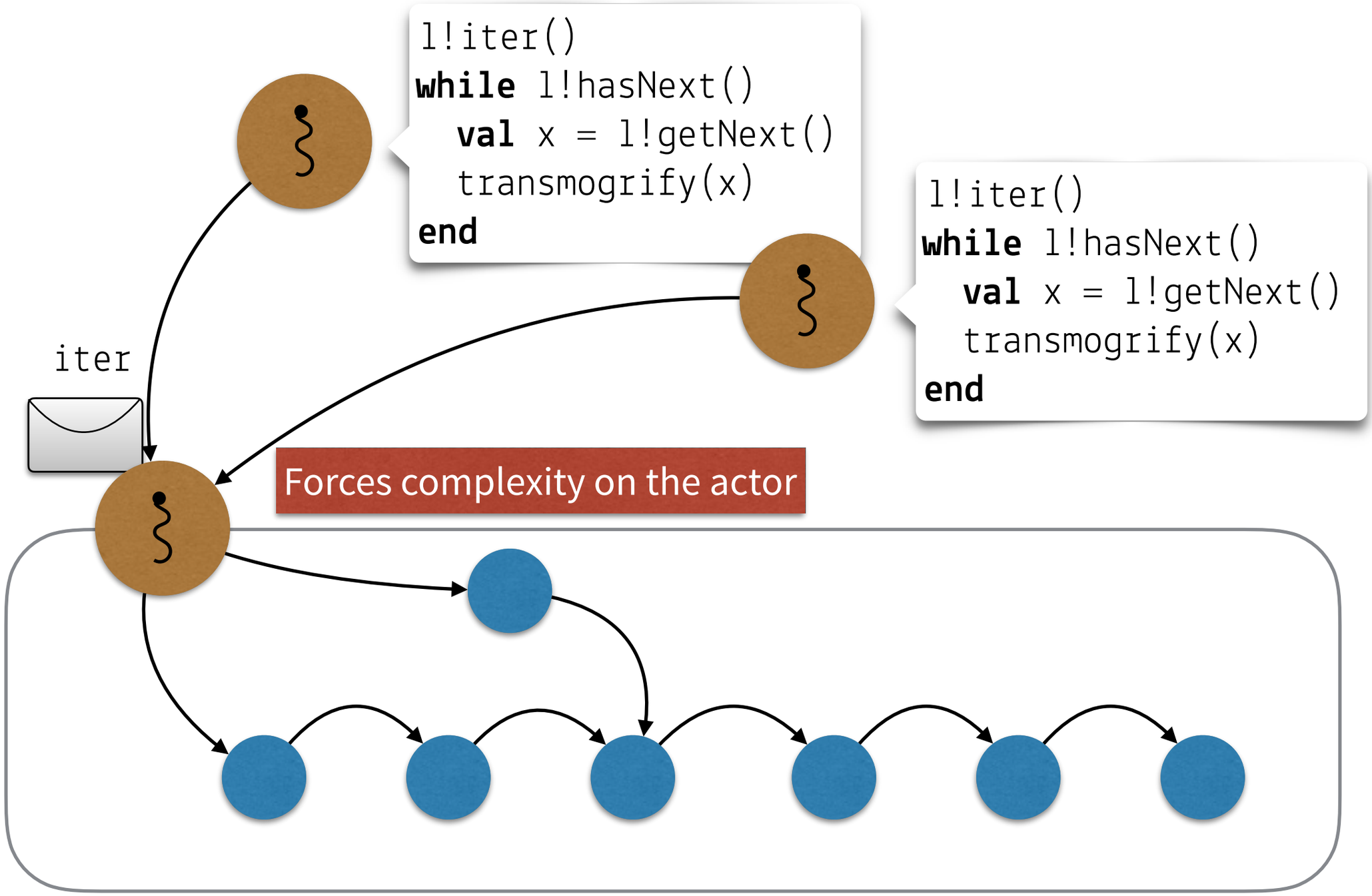
(Too) Strong Encapsulation



Solution? Breaking Actor Isolation



Solution? Keeping Complexity Isolated



Problem Overview

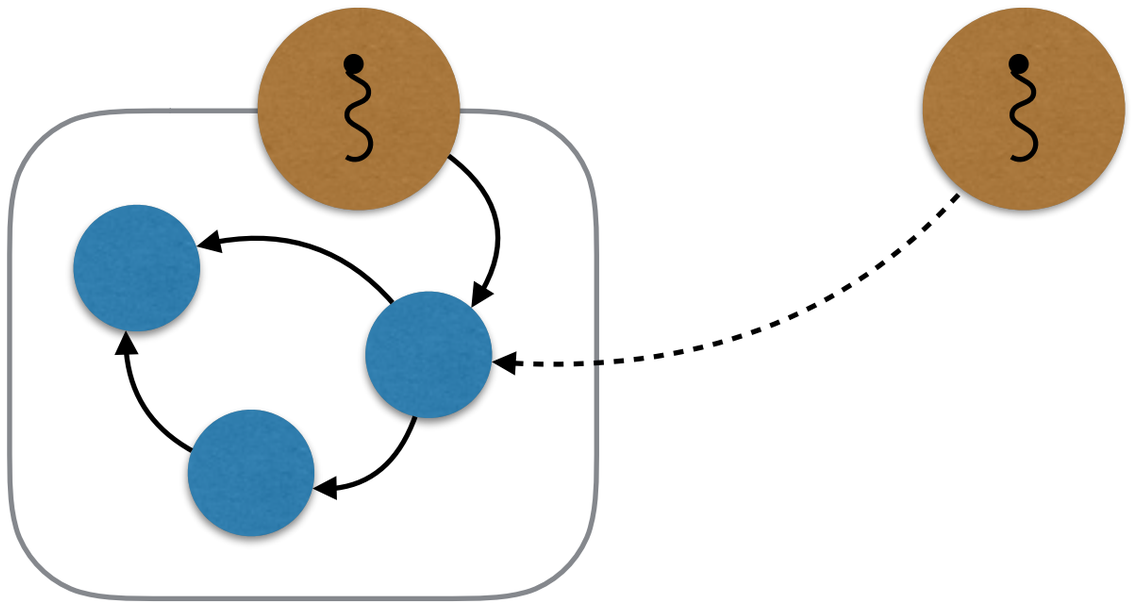
- Actors rely on isolation for sequential reasoning

  - Too strong for certain patterns

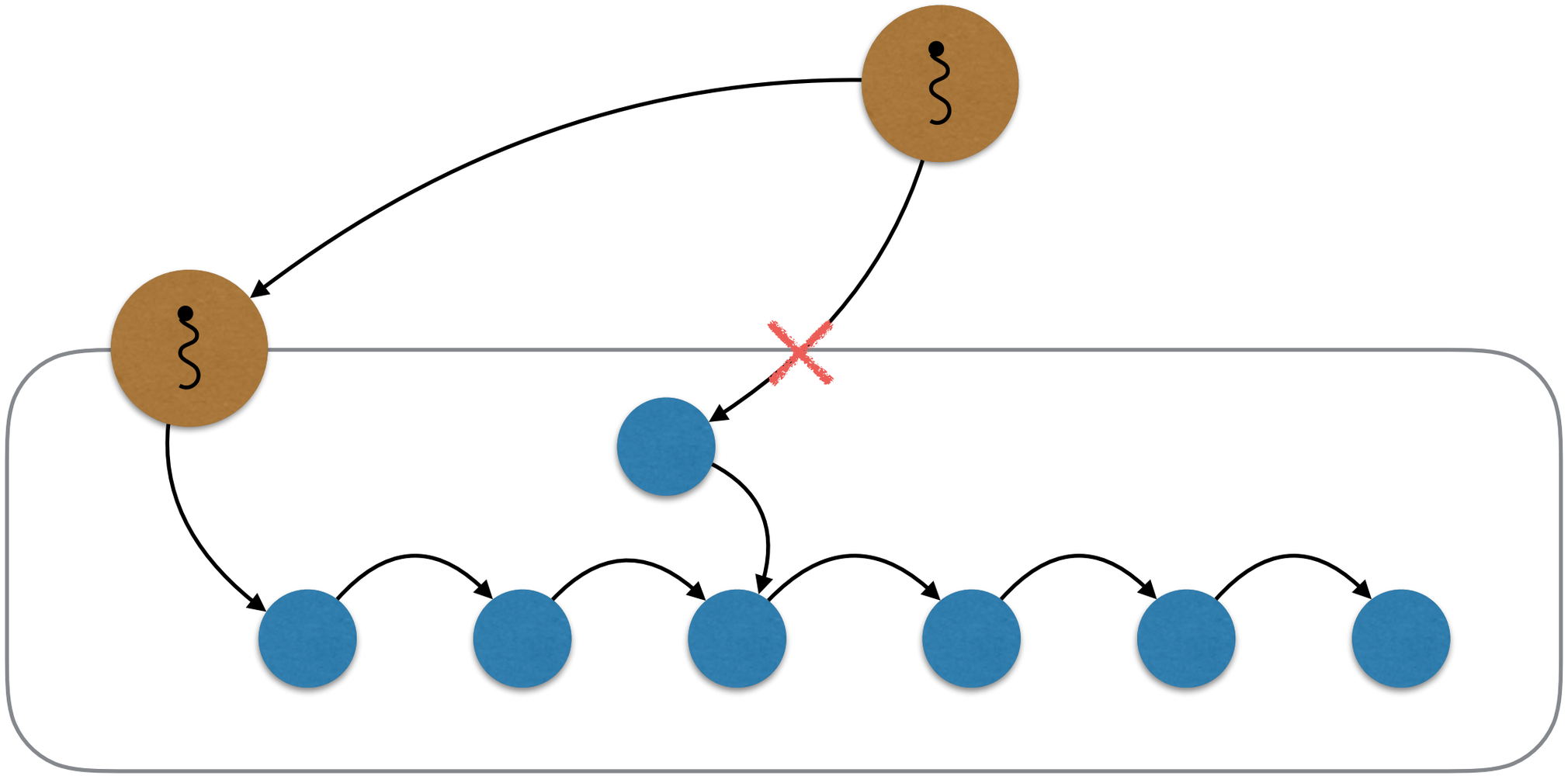
- Breaking actor isolation prevents sequential reasoning

- Extending actors to handle these patterns make them complex

- **Observation:**
  Holding a reference to an isolated object is OK as long as only the owner accesses it



Relax Actor Isolation by Bestowing Activity



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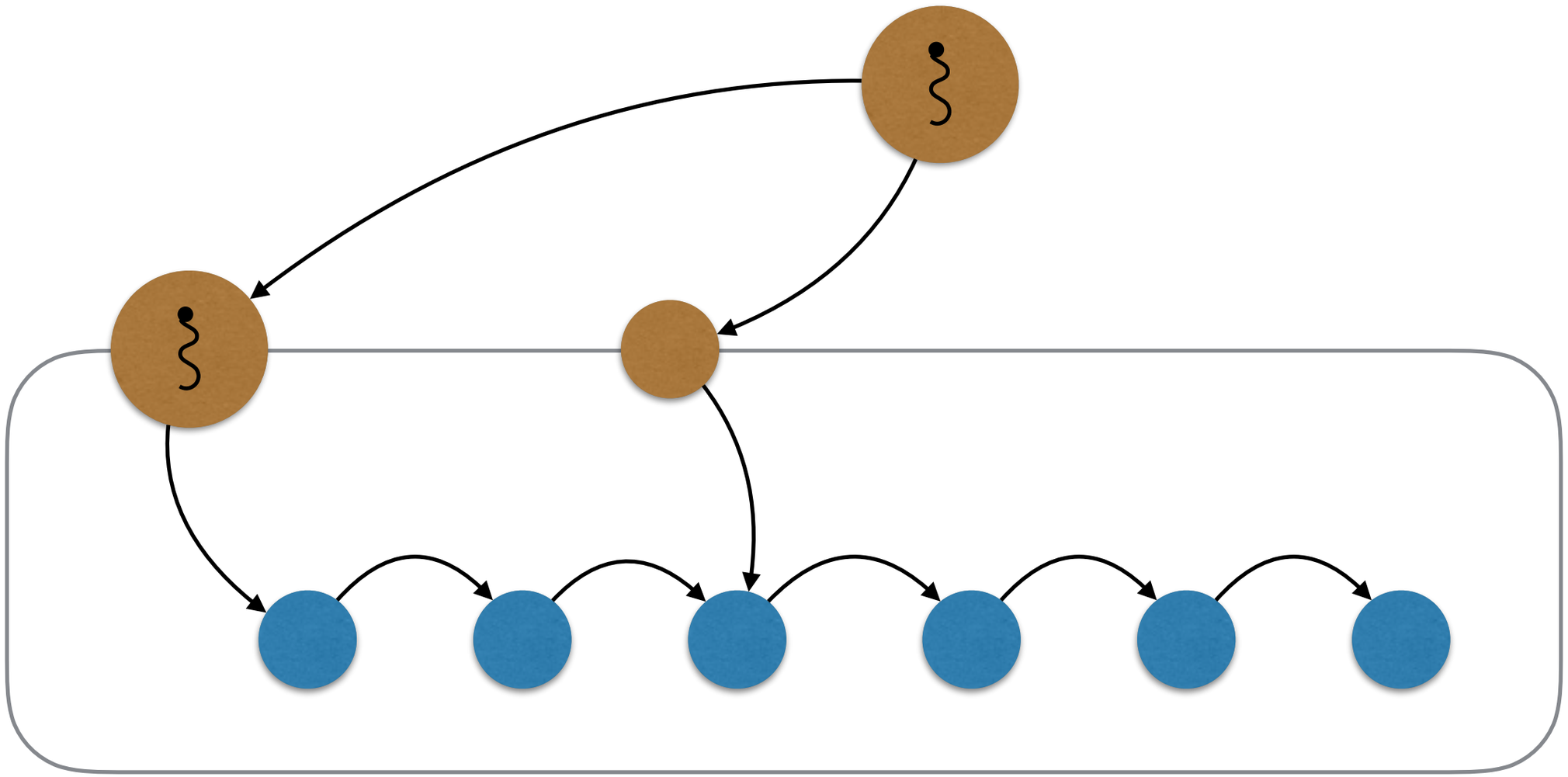

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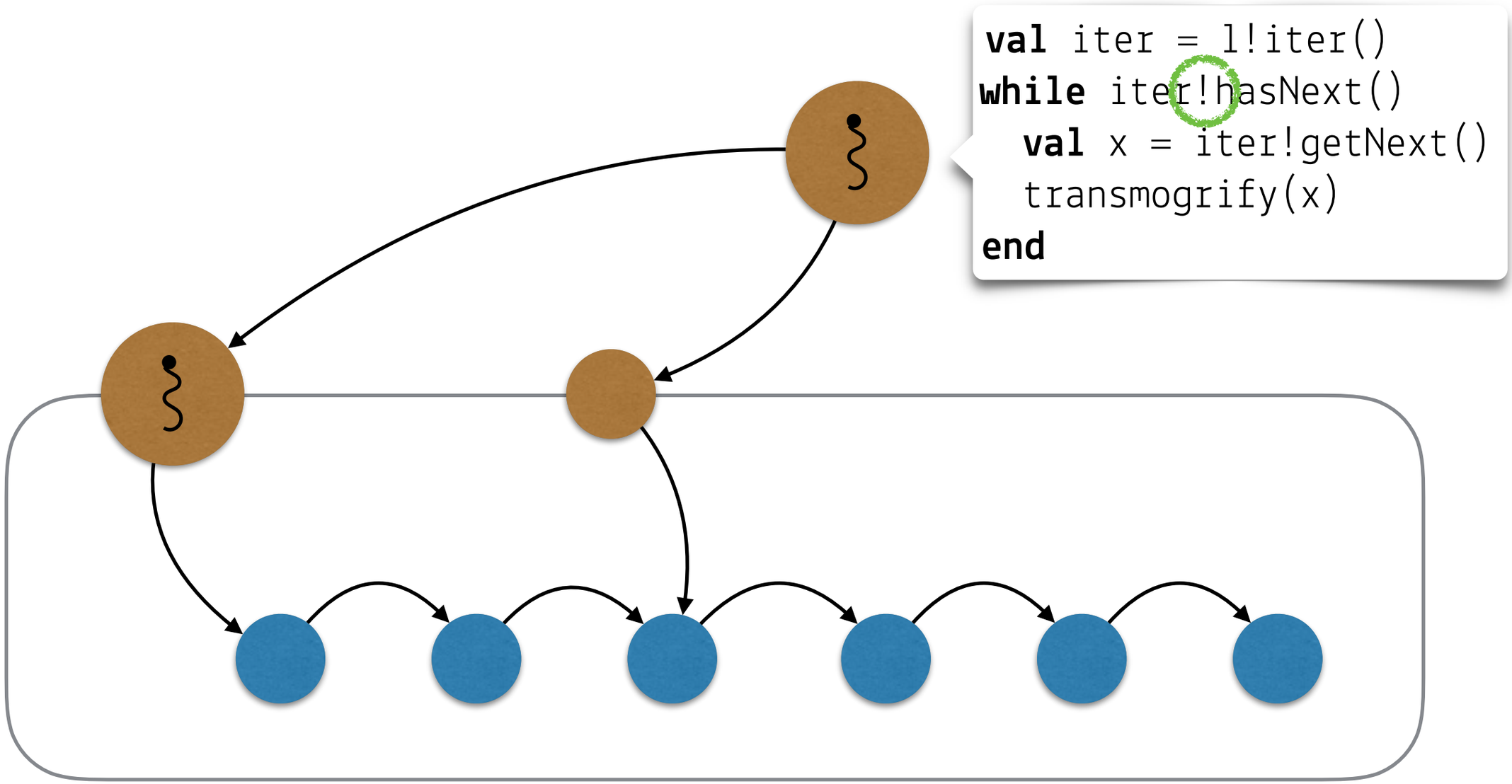

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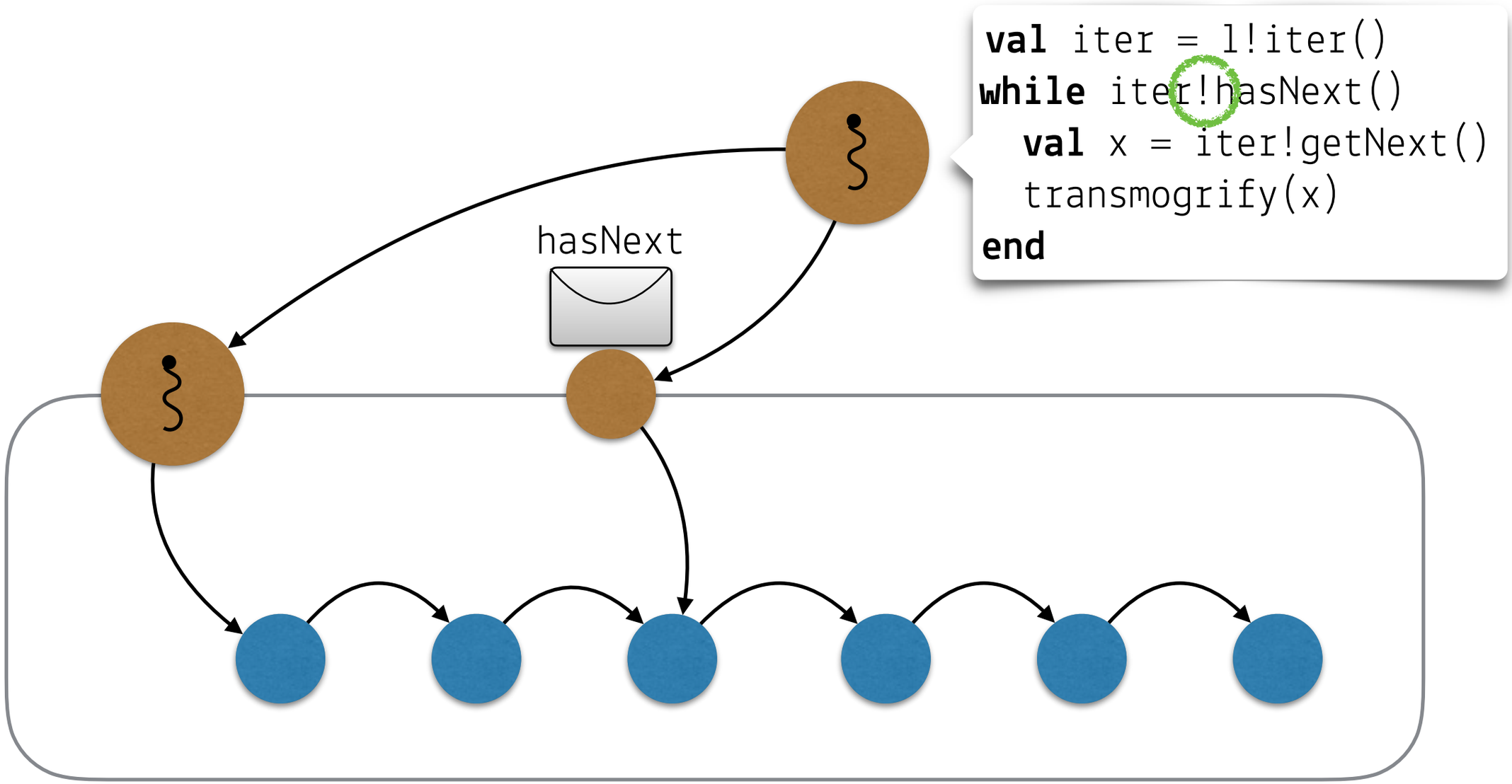

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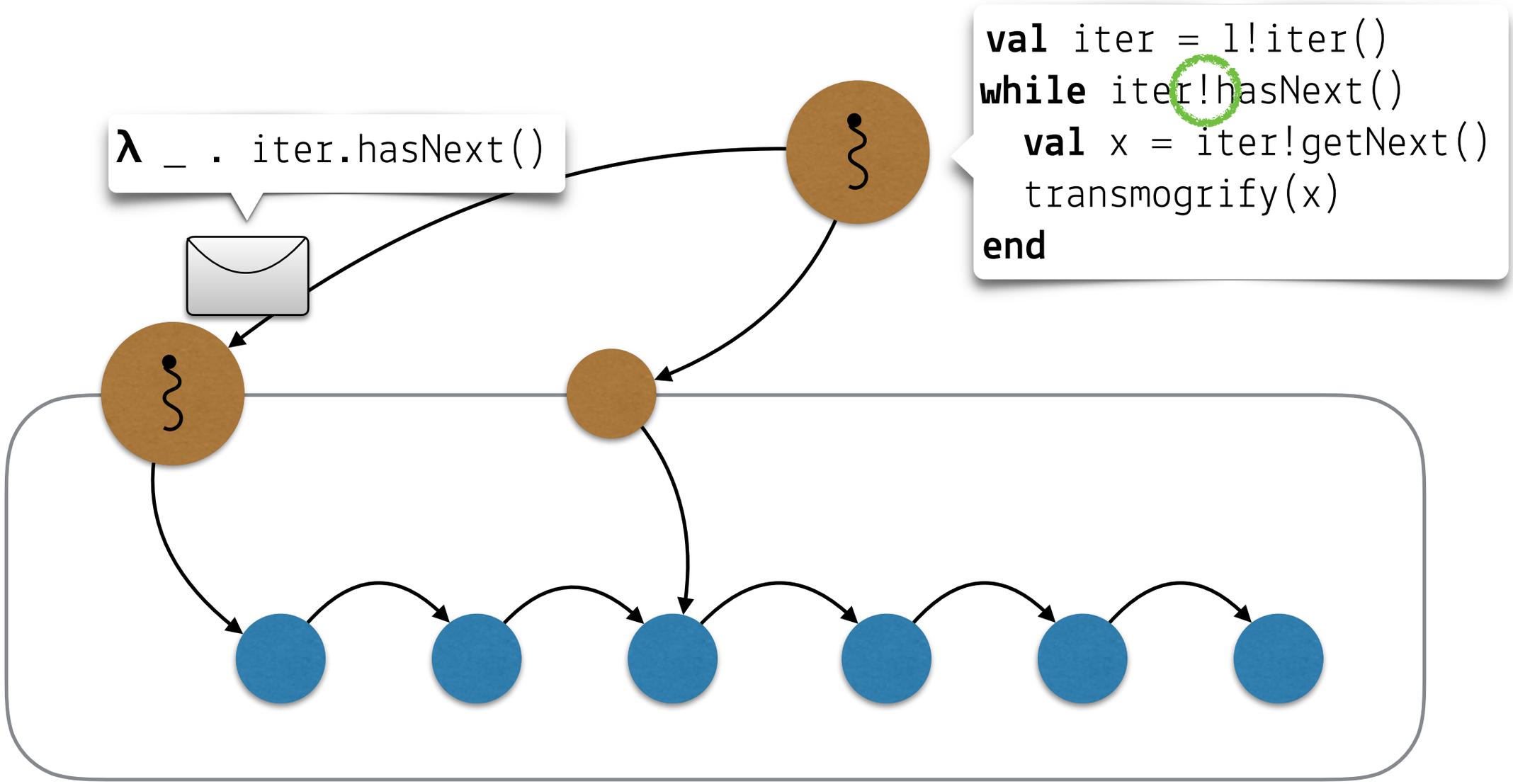

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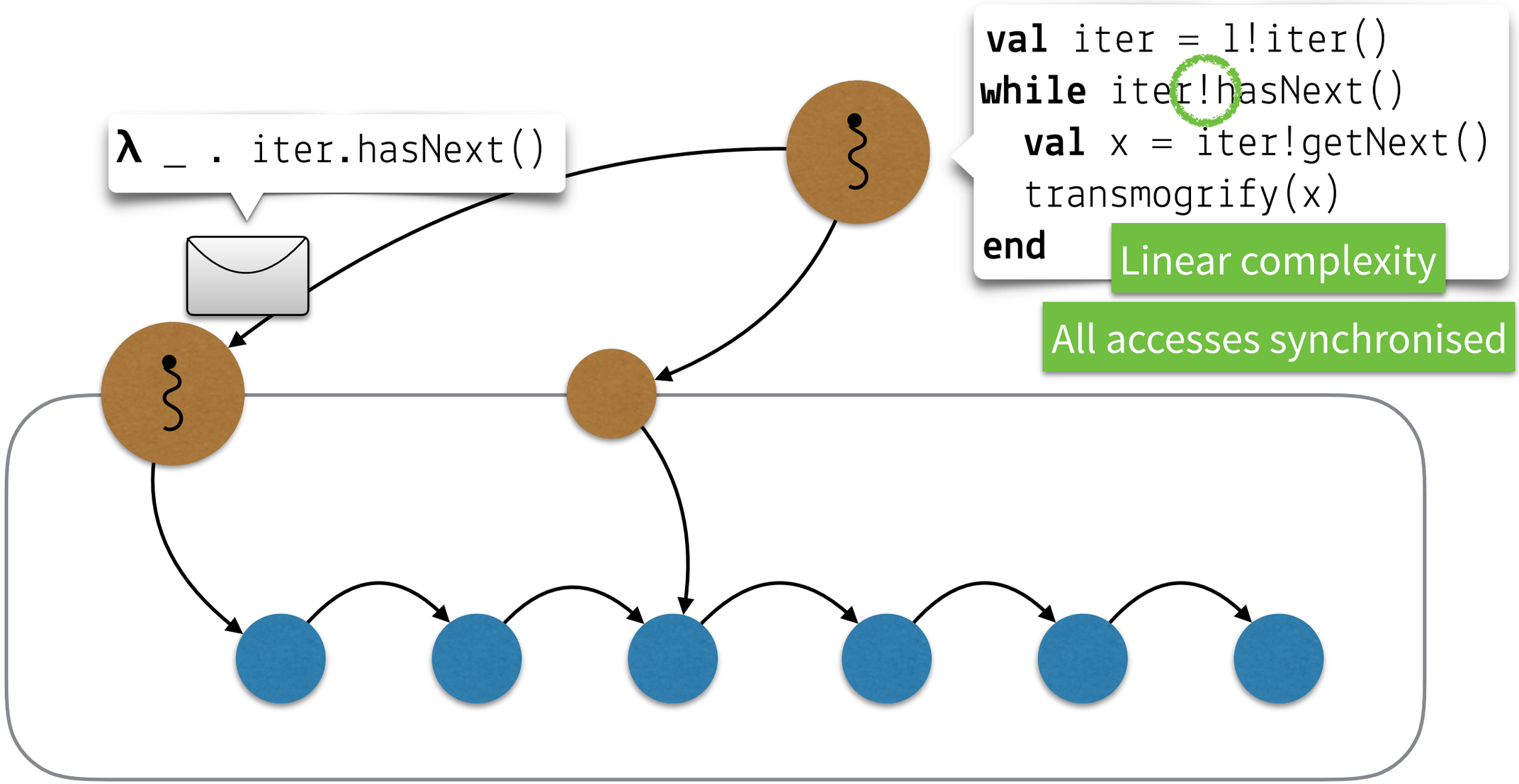

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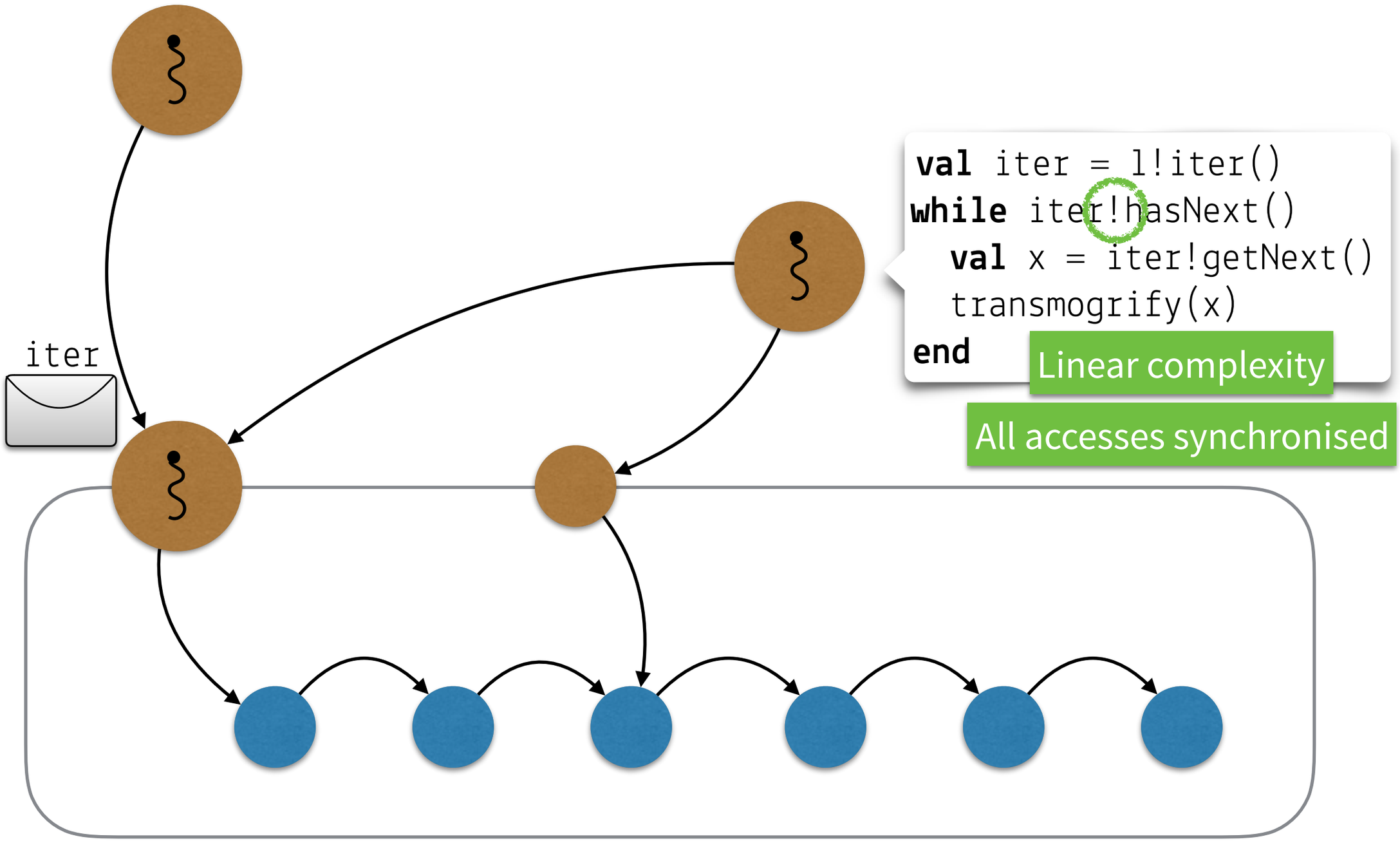

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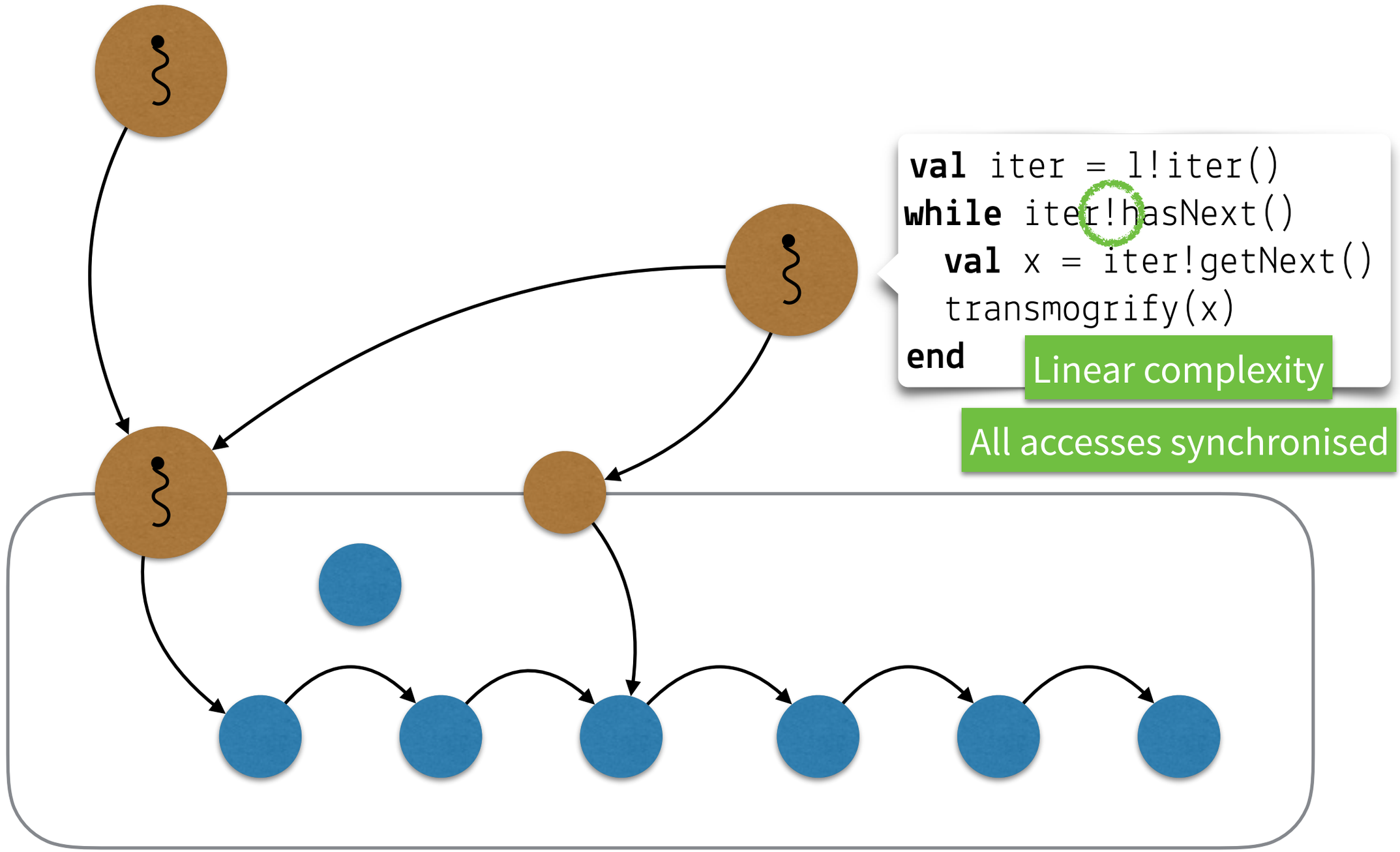

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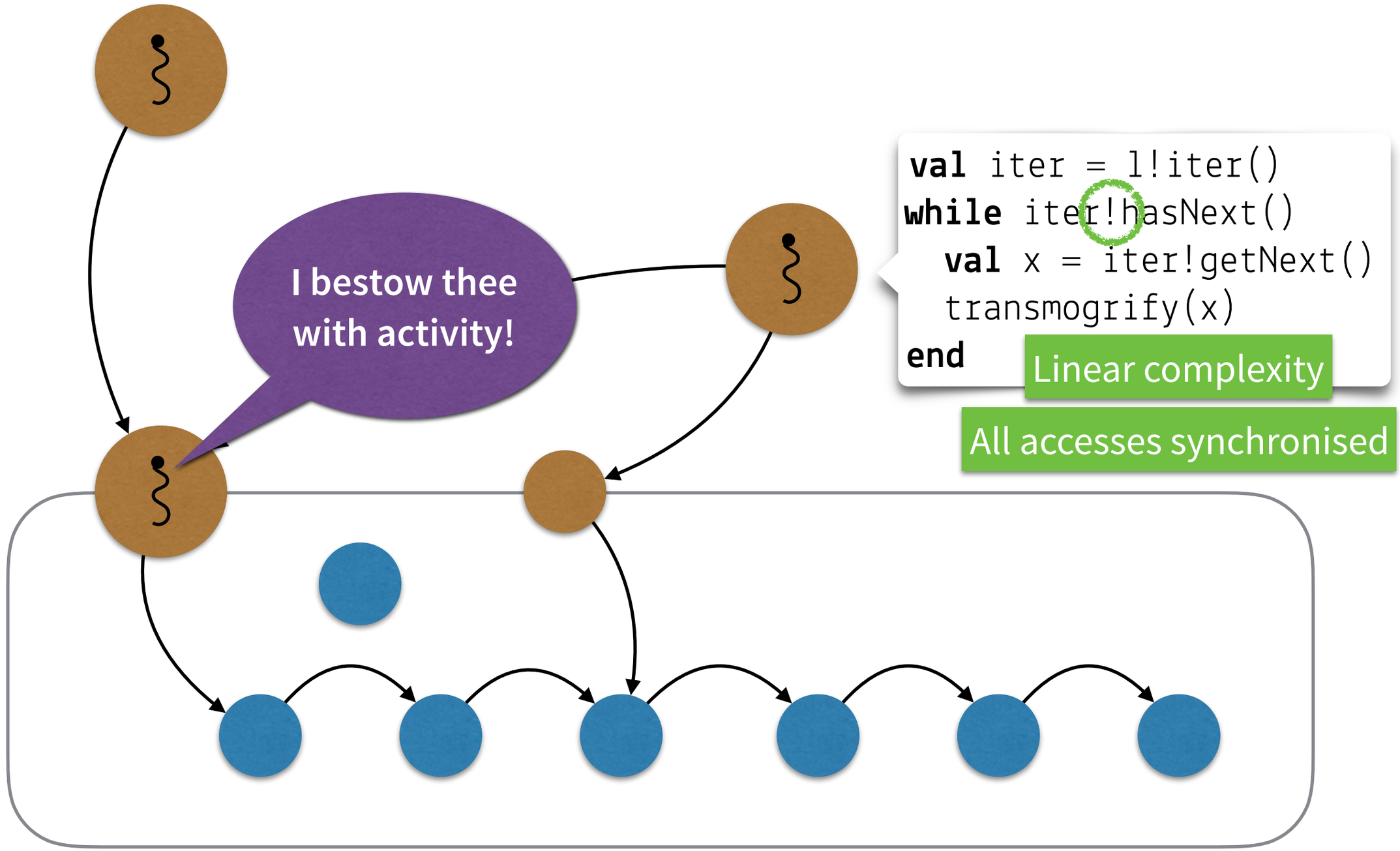

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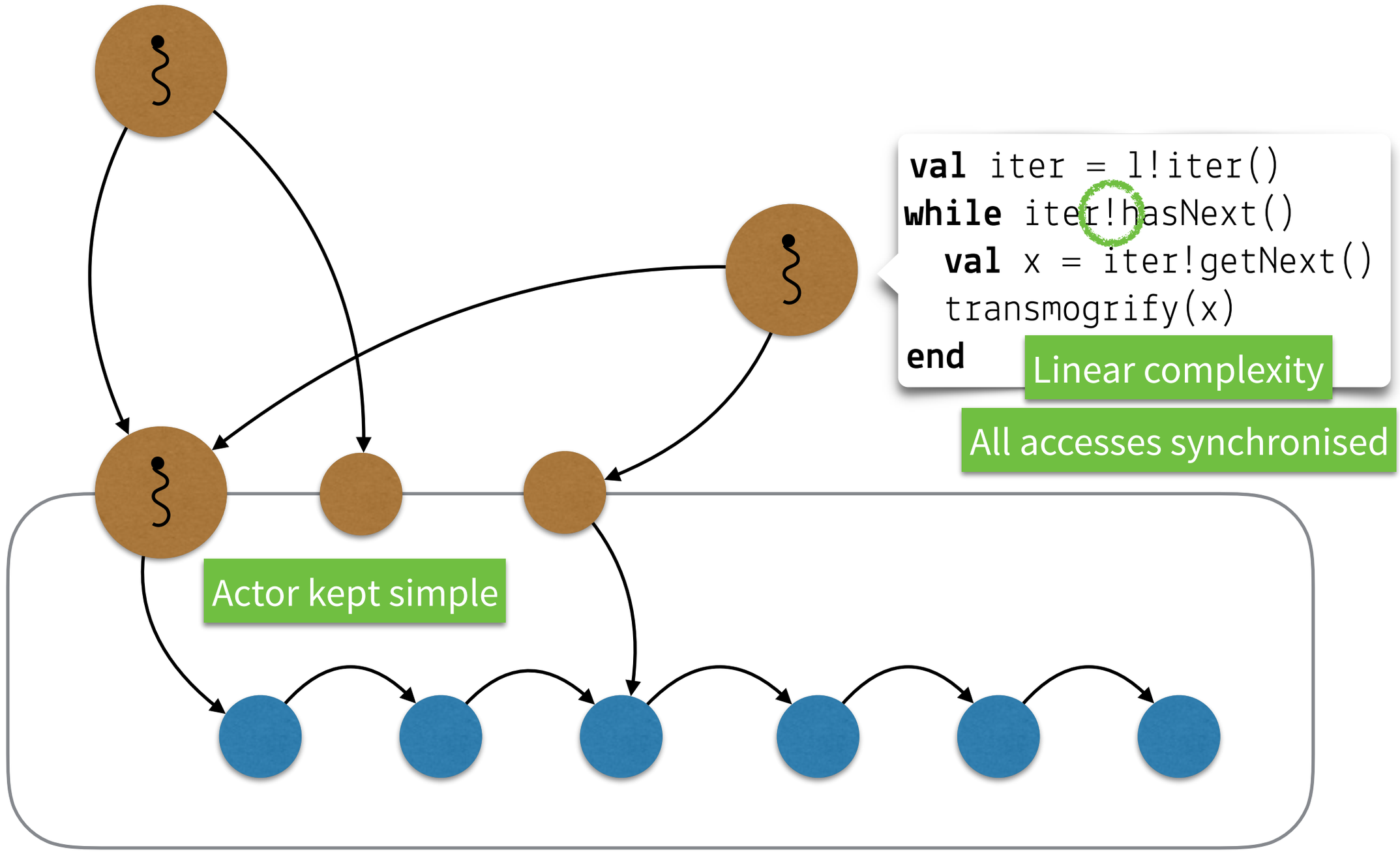
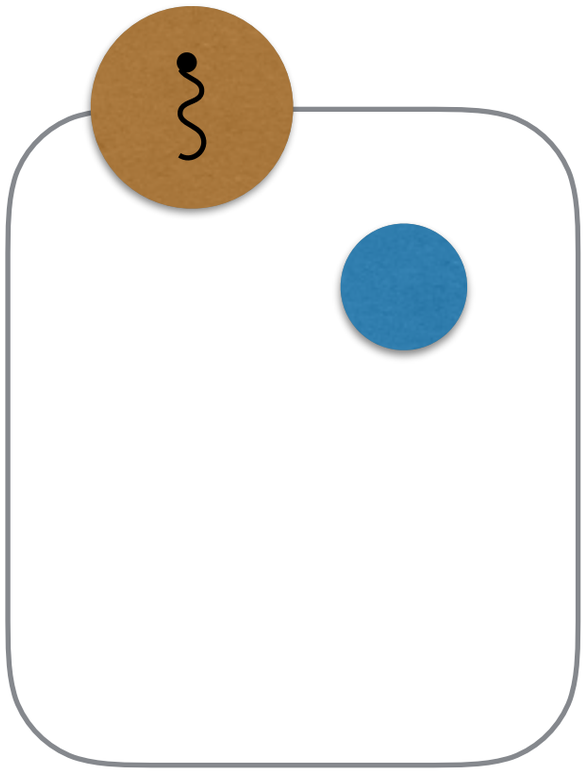


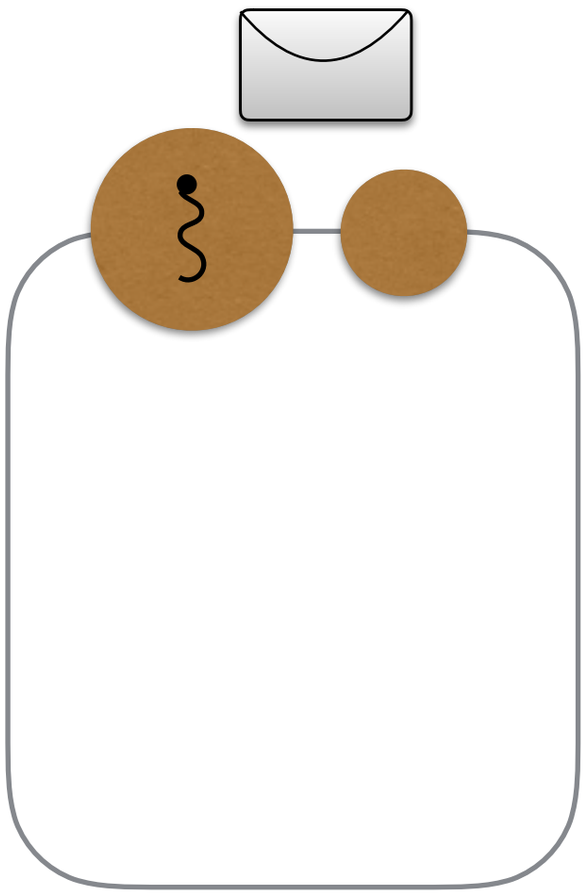
Delegating Parts of an Actor's Interface



```
actor A
  var c : C
  def foo() : unit
    …
  end
  def bar() : unit
    …
  end
  def getC : bestowed[C]
    bestow this.c
  end
end
```

```
class C
  def beep() : unit
    …
  end
  def boop() : unit
    …
  end
end
```

Delegating Parts of an Actor's Interface



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class C
  def beep() : unit
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  end
  def boop() : unit
    …
  end
end
```

Formalising Bestowed References

- Syntax

$$
\begin{array}{lcl}
e & ::= & x \mid e\ e \mid e!v \mid e.\texttt{mutate}() \mid \textbf{new}\ \tau \mid \textbf{bestow}\ e \mid v \\
v & ::= & \lambda x : \tau . e \mid () \mid id \mid \iota \mid \iota_{id}
\end{array}
\qquad
\begin{array}{lcl}
\tau & ::= & \alpha \mid \mathsf{p} \mid \tau \to \tau \mid \texttt{Unit} \\
\alpha & ::= & \mathsf{c} \mid \mathbf{B}(\mathsf{p})
\end{array}
$$

Formalising Bestowed References

- Syntax

Message send

Bestowing

Passive type

$$e ::= x \mid e\ e \mid e!v \mid e.\texttt{mutate}() \mid \textbf{new}\ \tau \mid \textbf{bestow}\ e \mid v \qquad \tau ::= \alpha \mid \mathsf{p} \mid \tau \to \tau \mid \texttt{Unit}$$

$$v ::= \lambda x : \tau . e \mid () \mid id \mid \iota \mid \iota_{id} \qquad \alpha ::= \mathsf{c} \mid \mathbf{B}(\mathsf{p})$$

Bestowed type

Actor type

Bestowed value

- Static semantics

$\boxed{\Gamma \vdash e : \tau}$

(Expressions)

$$\text{E-VAR}\ \frac{\Gamma(x) = \tau}{\Gamma \vdash x : \tau} \qquad \text{E-APPLY}\ \frac{\Gamma \vdash e : \tau' \to \tau \quad \Gamma \vdash e' : \tau'}{\Gamma \vdash e\,e' : \tau} \qquad \text{E-NEW-PASSIVE}\ \frac{}{\Gamma \vdash \textbf{new}\,\mathsf{p} : \mathsf{p}} \qquad \text{E-NEW-ACTOR}\ \frac{}{\Gamma \vdash \textbf{new}\,\mathsf{c} : \mathsf{c}}$$

$$\text{E-MUTATE}\ \frac{\Gamma \vdash e : \mathsf{p}}{\Gamma \vdash e.\texttt{mutate}() : \texttt{Unit}} \qquad \text{E-BESTOW}\ \frac{\Gamma \vdash e : \mathsf{p}}{\Gamma \vdash \textbf{bestow}\,e : \mathbf{B}(p)} \qquad \text{E-SEND}\ \frac{\Gamma \vdash e : \alpha \quad \Gamma_\alpha, x : \mathsf{p} \vdash e' : \tau' \quad \nexists\, \iota\ .\ \iota \in e'}{\Gamma \vdash e!\lambda x : \mathsf{p}.e' : \texttt{Unit}}$$

$$\text{E-FN}\ \frac{\Gamma, x : \tau \vdash e : \tau'}{\Gamma \vdash (\lambda x : \tau . e) : \tau \to \tau'} \qquad \text{E-UNIT}\ \frac{}{\Gamma \vdash () : \texttt{Unit}} \qquad \text{E-LOC}\ \frac{}{\Gamma \vdash \iota : \mathsf{p}} \qquad \text{E-ID}\ \frac{}{\Gamma \vdash id : \mathsf{c}} \qquad \text{E-BESTOWED}\ \frac{}{\Gamma \vdash \iota_{id} : \mathbf{B}(p)}$$

Formalising Bestowed References

- Syntax

Message send

Bestowing

Passive type

$$e ::= x \mid e\ e \mid e!v \mid e.\texttt{mutate}() \mid \textbf{new}\ \tau \mid \textbf{bestow}\ e \mid v \qquad \tau ::= \alpha \mid \mathsf{p} \mid \tau \to \tau \mid \texttt{Unit}$$

$$v ::= \lambda x : \tau . e \mid () \mid id \mid \iota \mid \iota_{id} \qquad \alpha ::= \mathsf{c} \mid \mathbf{B}(\mathsf{p})$$

Bestowed type

Bestowed value

Actor type

- Static semantics

$\boxed{\Gamma \vdash e : \tau}$

(Expressions)

E-VAR
$$\frac{\Gamma(x) = \tau}{\Gamma \vdash x : \tau}$$

E-APPLY
$$\frac{\Gamma \vdash e : \tau' \to \tau \qquad \Gamma \vdash e' : \tau'}{\Gamma \vdash e\,e' : \tau}$$

E-NEW-PASSIVE
$$\frac{}{\Gamma \vdash \textbf{new}\,\mathsf{p} : \mathsf{p}}$$

E-NEW-ACTOR
$$\frac{}{\Gamma \vdash \textbf{new}\,\mathsf{c} : \mathsf{c}}$$

E-MUTATE
$$\frac{\Gamma \vdash e : \mathsf{p}}{\Gamma \vdash e.\texttt{mutate}() : \texttt{Unit}}$$

E-FN
$$\frac{\Gamma, x : \tau \vdash e : \tau'}{\Gamma \vdash (\lambda x : \tau . e) : \tau \to \tau'}$$

E-UNIT
$$\frac{}{\Gamma \vdash () : \texttt{Unit}}$$

E-LOC
$$\frac{}{\Gamma \vdash \iota : \mathsf{p}}$$

E-ID
$$\frac{}{\Gamma \vdash id : \mathsf{c}}$$

E-BESTOWED
$$\frac{}{\Gamma \vdash \iota_{id} : \mathbf{B}(p)}$$

E-BESTOW
$$\frac{\Gamma \vdash e : \mathsf{p}}{\Gamma \vdash \textbf{bestow}\ e : \mathbf{B}(p)}$$

E-SEND
$$\frac{\Gamma \vdash e : \alpha \qquad \Gamma_\alpha, x : \mathsf{p} \vdash e' : \tau' \qquad \nexists\, \iota\ .\ \iota \in e'}{\Gamma \vdash e!\lambda x : \mathsf{p} . e' : \texttt{Unit}}$$

Formalising Bestowed References

- Dynamic semantics

$$\boxed{id \vdash \langle H, e\rangle \hookrightarrow \langle H', e'\rangle} \qquad \textit{(Evaluation of expressions)}$$

EVAL-SEND-ACTOR

$$\frac{H(id') = (\iota, L, Q, e) \qquad H' = H[id' \mapsto (\iota, L, v\,Q, e)]}{id \vdash \langle H, id' ! v\rangle \hookrightarrow \langle H', ()\rangle}$$

EVAL-SEND-BESTOWED

$$\frac{H(id') = (\iota', L, Q, e) \qquad H' = H[id' \mapsto (\iota', L, (\lambda x : \mathsf{p}.v\,\iota)\,Q, e)]}{id \vdash \langle H, \iota_{id'} ! v\rangle \hookrightarrow \langle H', ()\rangle}$$

EVAL-APPLY

$$\frac{e' = e[x \mapsto v]}{id \vdash \langle H, (\lambda x : \tau.e)\,v\rangle \hookrightarrow \langle H, e'\rangle}$$

EVAL-MUTATE

$$\frac{}{id \vdash \langle H, \iota.\texttt{mutate}()\rangle \hookrightarrow \langle H, ()\rangle}$$

EVAL-BESTOW

$$\frac{}{id \vdash \langle H, \mathbf{bestow}\,\iota\rangle \hookrightarrow \langle H, \iota_{id}\rangle}$$

EVAL-NEW-PASSIVE

$$\frac{H(id) = (\iota, L, Q, e) \qquad \iota' \textbf{ fresh} \qquad H' = H[id \mapsto (\iota, L \cup \{\iota'\}, Q, e)]}{id \vdash \langle H, \mathbf{new}\,\mathsf{p}\rangle \hookrightarrow \langle H', \iota'\rangle}$$

EVAL-NEW-ACTOR

$$\frac{id' \textbf{ fresh} \qquad \iota' \textbf{ fresh} \qquad H' = H[id' \mapsto (\iota', \{\iota'\}, \epsilon, ())]}{id \vdash \langle H, \mathbf{new}\,\alpha\rangle \hookrightarrow \langle H', id'\rangle}$$

EVAL-CONTEXT

$$\frac{id \vdash \langle H, e\rangle \hookrightarrow \langle H', e'\rangle}{id \vdash \langle H, E[e]\rangle \hookrightarrow \langle H', E[e']\rangle}$$

Formalising Bestowed References

- Dynamic semantics

$id \vdash \langle H, e\rangle \hookrightarrow \langle H', e'\rangle$ *(Evaluation of expressions)*

EVAL-SEND-ACTOR

$$\frac{H(id') = (\iota, L, Q, e) \qquad H' = H[id' \mapsto (\iota, L, v\,Q, e)]}{id \vdash \langle H, id' ! v\rangle \hookrightarrow \langle H', ()\rangle}$$

EVAL-SEND-BESTOWED

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EVAL-CONTEXT

$$\frac{id \vdash \langle H, e\rangle \hookrightarrow \langle H', e'\rangle}{id \vdash \langle H, E[e]\rangle \hookrightarrow \langle H', E[e']\rangle}$$

Properties of the Formalism

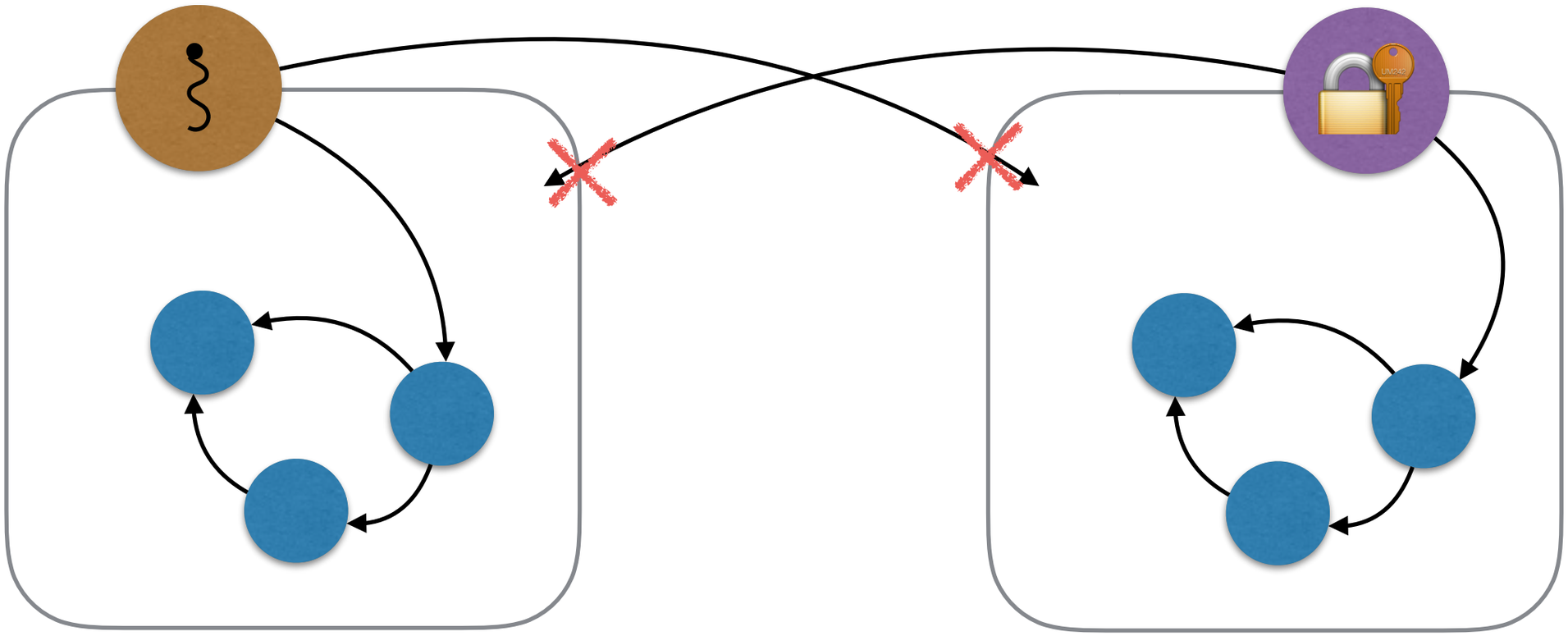
- **Progress:** $\vdash H \implies (\exists H' \,.\, H \hookrightarrow H') \;\vee\; (\forall id \in \mathbf{dom}(H) \,.\, H(id) = (\iota, L, \epsilon, v))$
- **Preservation:** $\vdash H \wedge H \hookrightarrow H' \implies \vdash H'$
- **Data-race freedom:** Two actors will never mutate the same passive object

$$\left(\begin{array}{c} id_1 \neq id_2 \\ \wedge\, H(id_1) = (\iota_1, L_1, Q_1, \iota.\texttt{mutate}()) \\ \wedge\, H(id_2) = (\iota_2, L_2, Q_2, \iota'.\texttt{mutate}()) \end{array}\right) \implies \iota \neq \iota'$$

The Big Picture

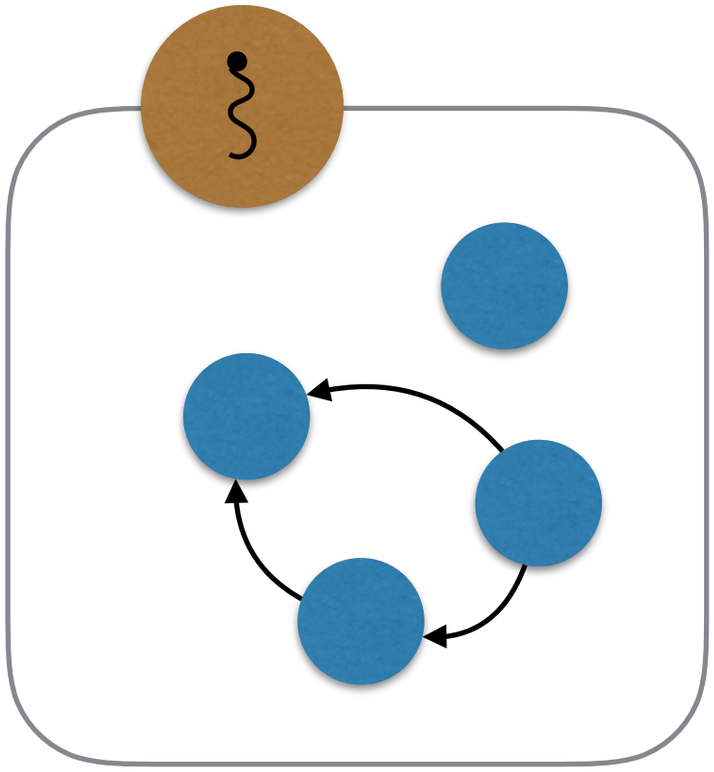
- Kappa is a capability based type-system for concurrent OO-programming [ECOOP'16]

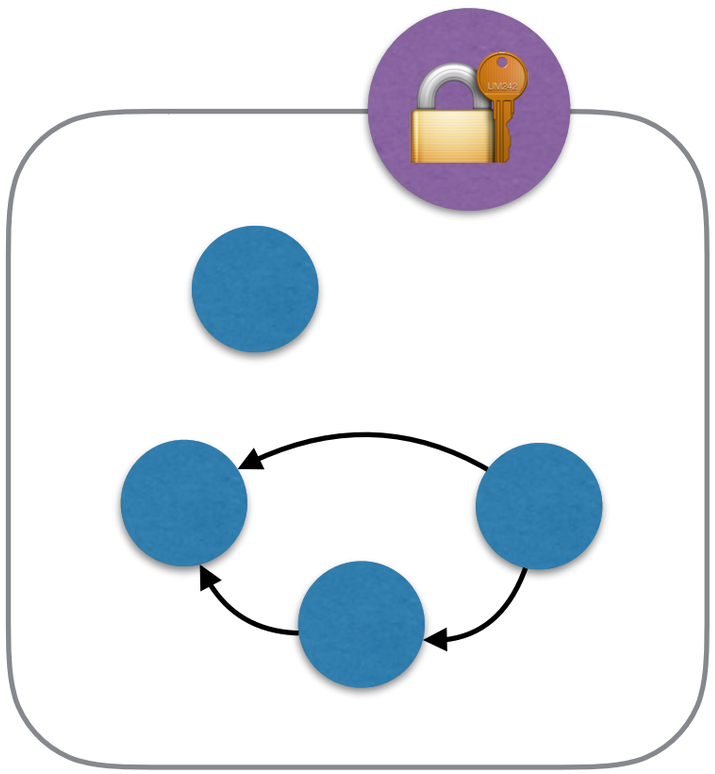
  - Tracks the boundaries of objects to achieve strong encapsulation



Generalizing Bestowed References

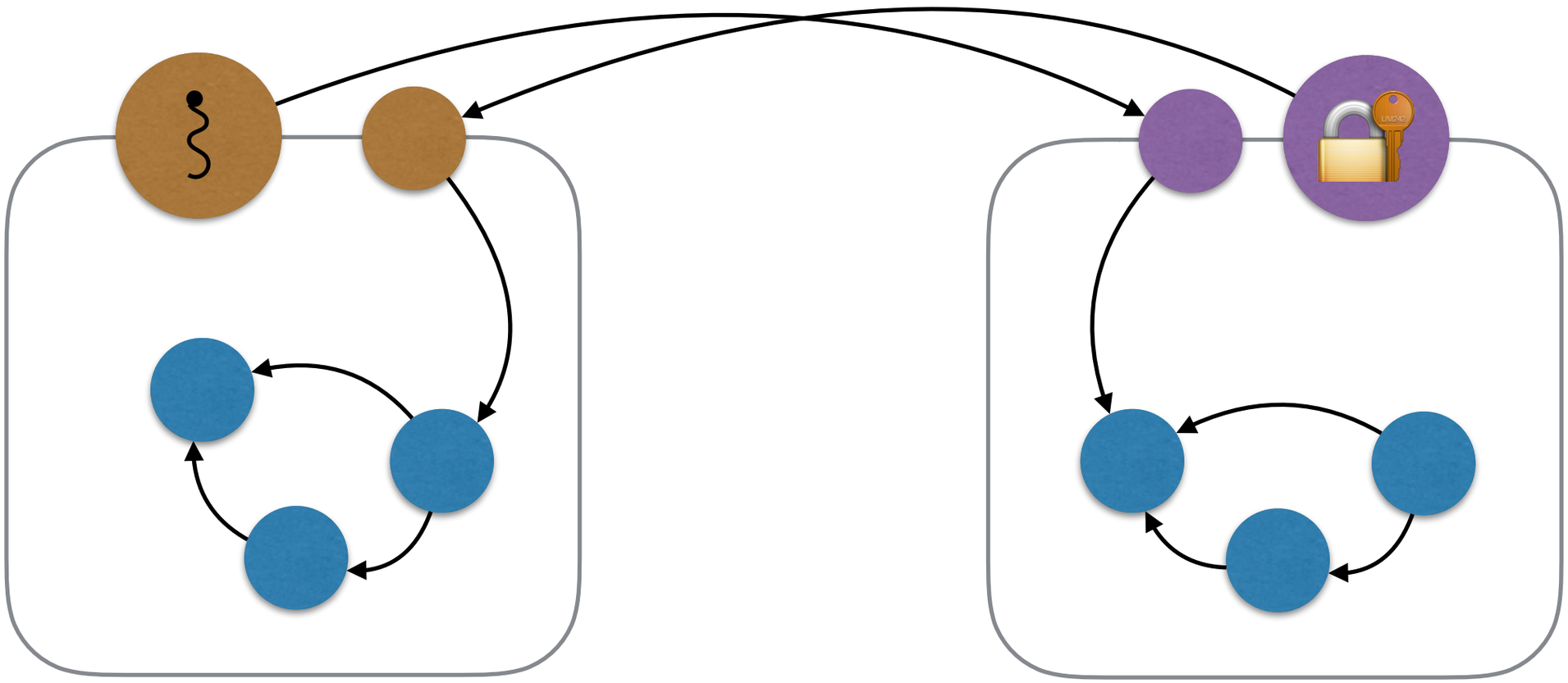
- Bestowed references provide a thread-safe way to break encapsulation





Generalizing Bestowed References

- Bestowed references provide a thread-safe way to break encapsulation



Future Work

- Implementation in Encore

```
active class Foo
    var box : IntBox
    def bestowBox() : Bestowed[IntBox]
        bestow this.box
    end
end

active class Main
    def main() : unit
        var b = new Foo()
        var box = get(b ! bestowBox())
        box ! inc()
    end
end
```

- Enriched formalism with copying and ownership transfer

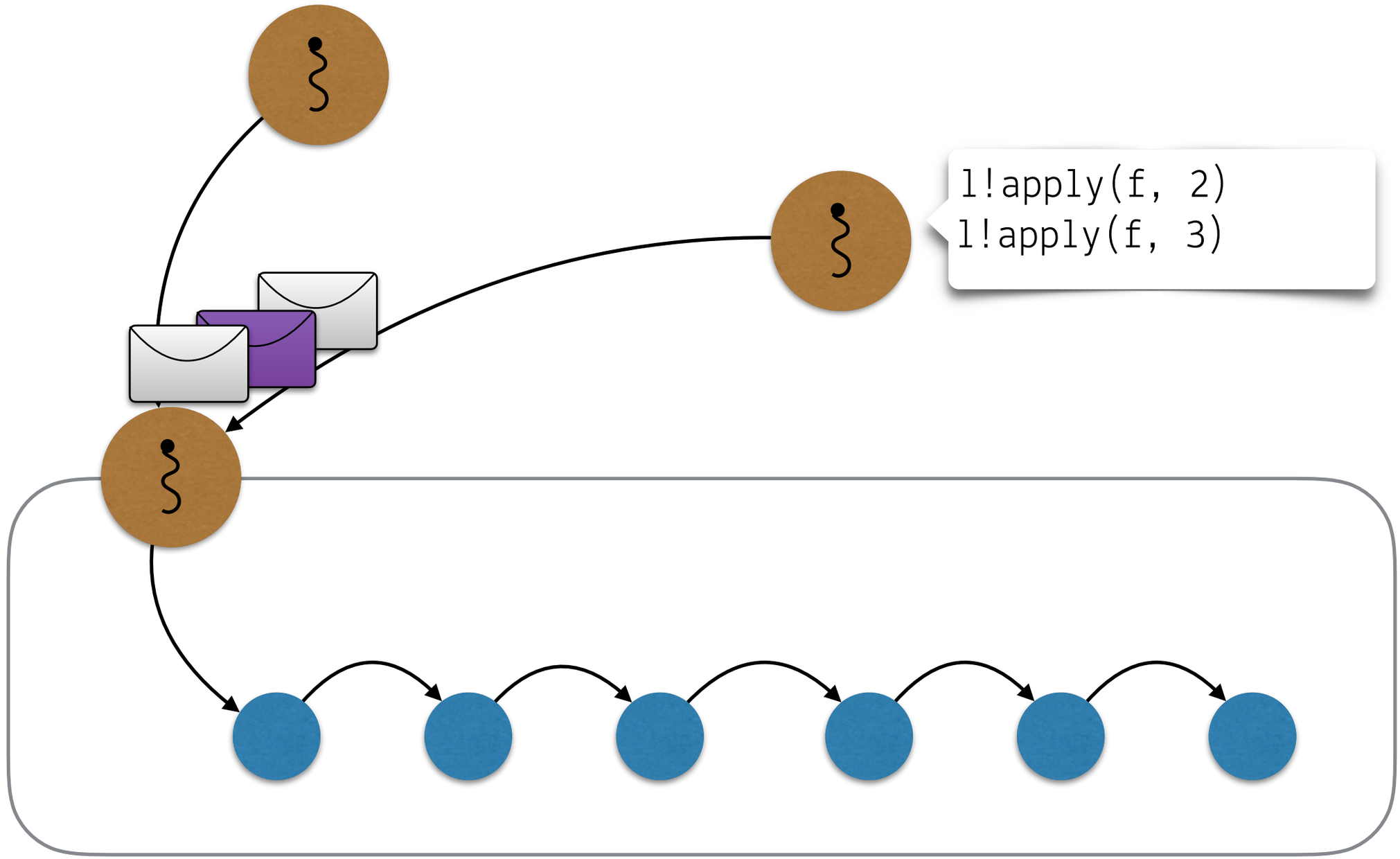
Summary

- Actor isolation can be relaxed by **bestowing** encapsulated objects with activity
  - All accesses will be synchronised via the message queue of the owning actor
  - Actors do not need to know the implementation of their bestowed objects
  - A bestowed object does not need to know that it is bestowed
- The same kind of relaxed encapsulation works for locks
  - All accesses will be synchronised via the lock of the owning object
- **Also in the paper:**

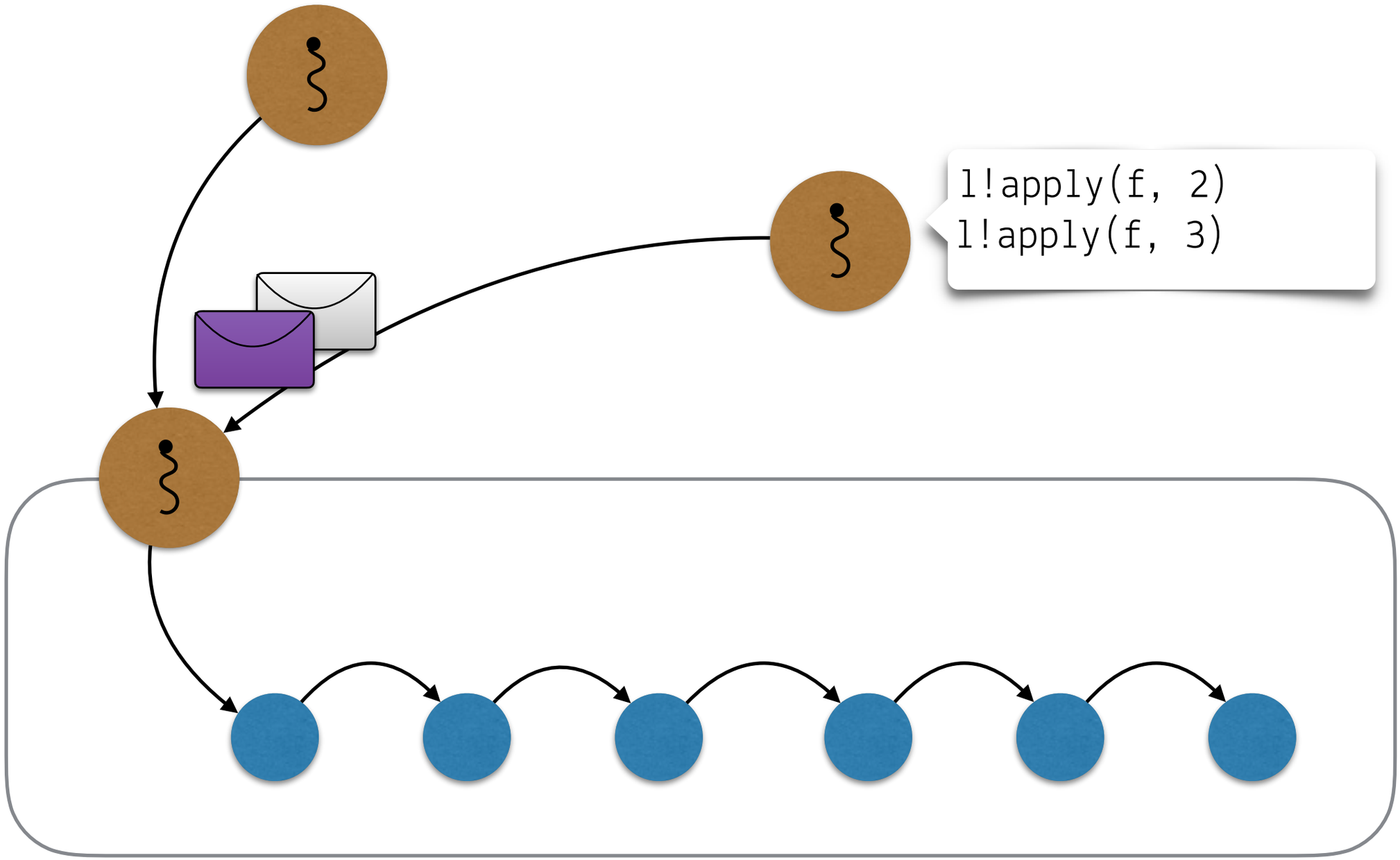
  Atomic blocks to group operations
  Implementation sketches
  Polymorphic concurrency control

Tack! Frågor?

Incompatible Interleaving



Incompatible Interleaving



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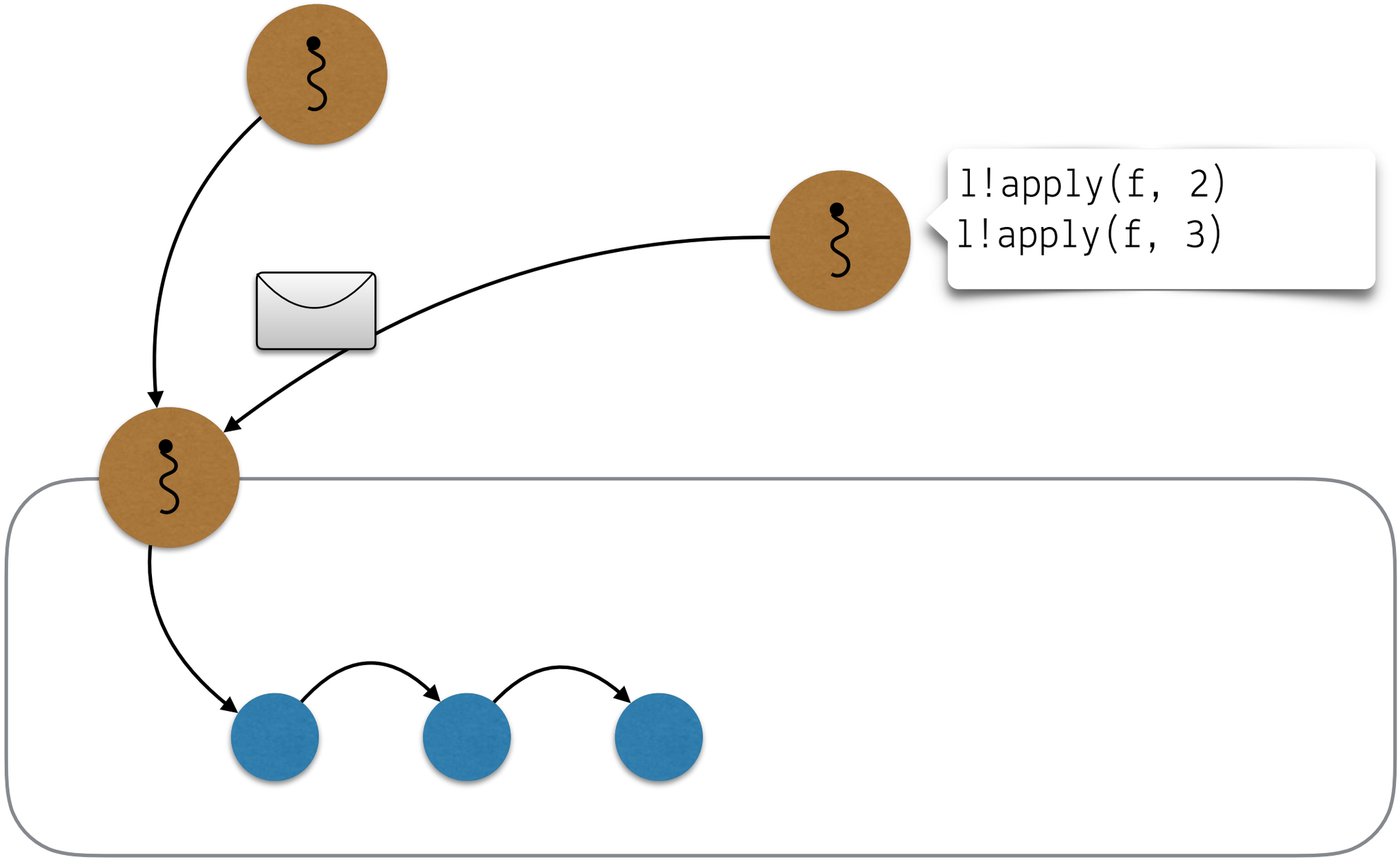
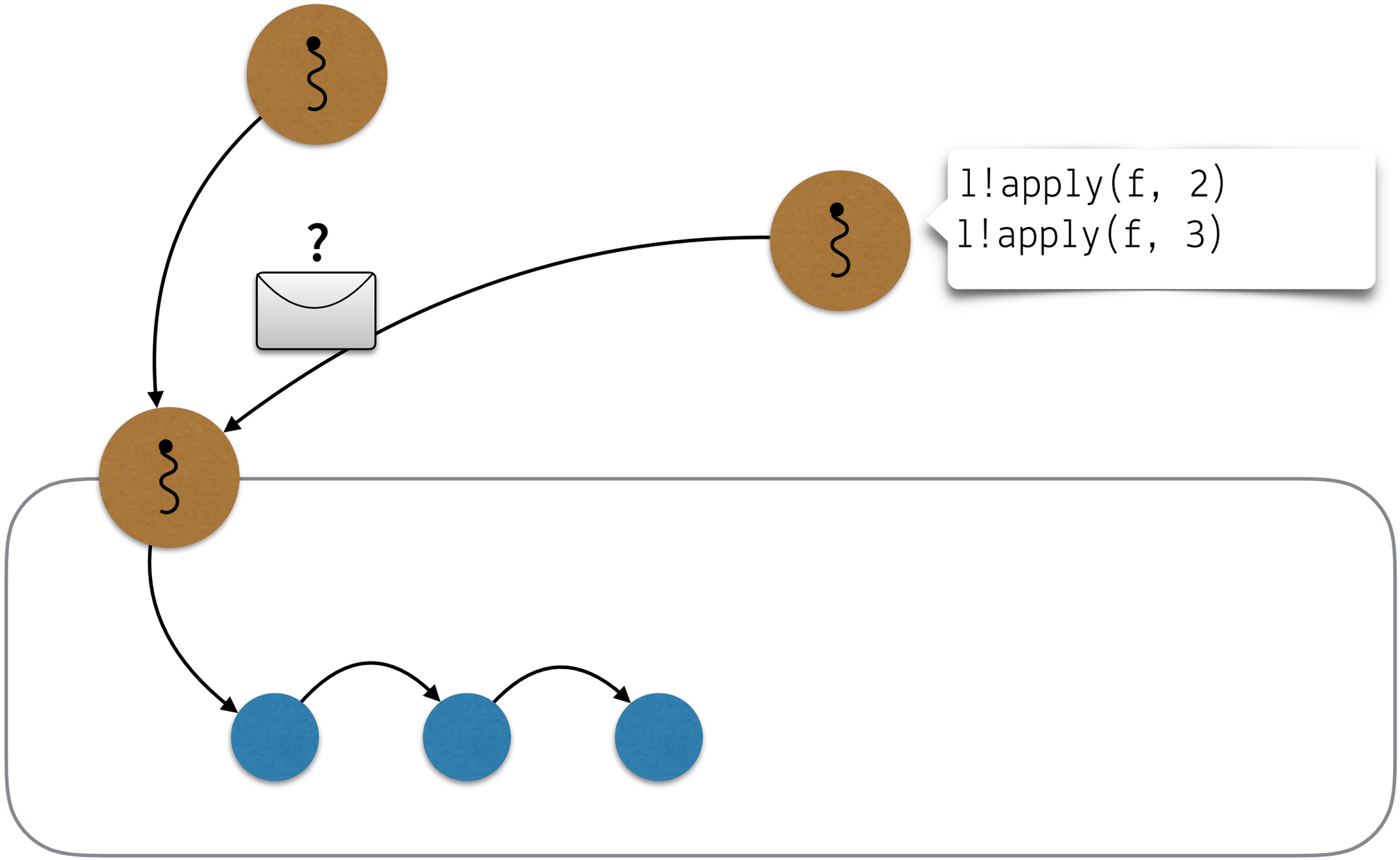
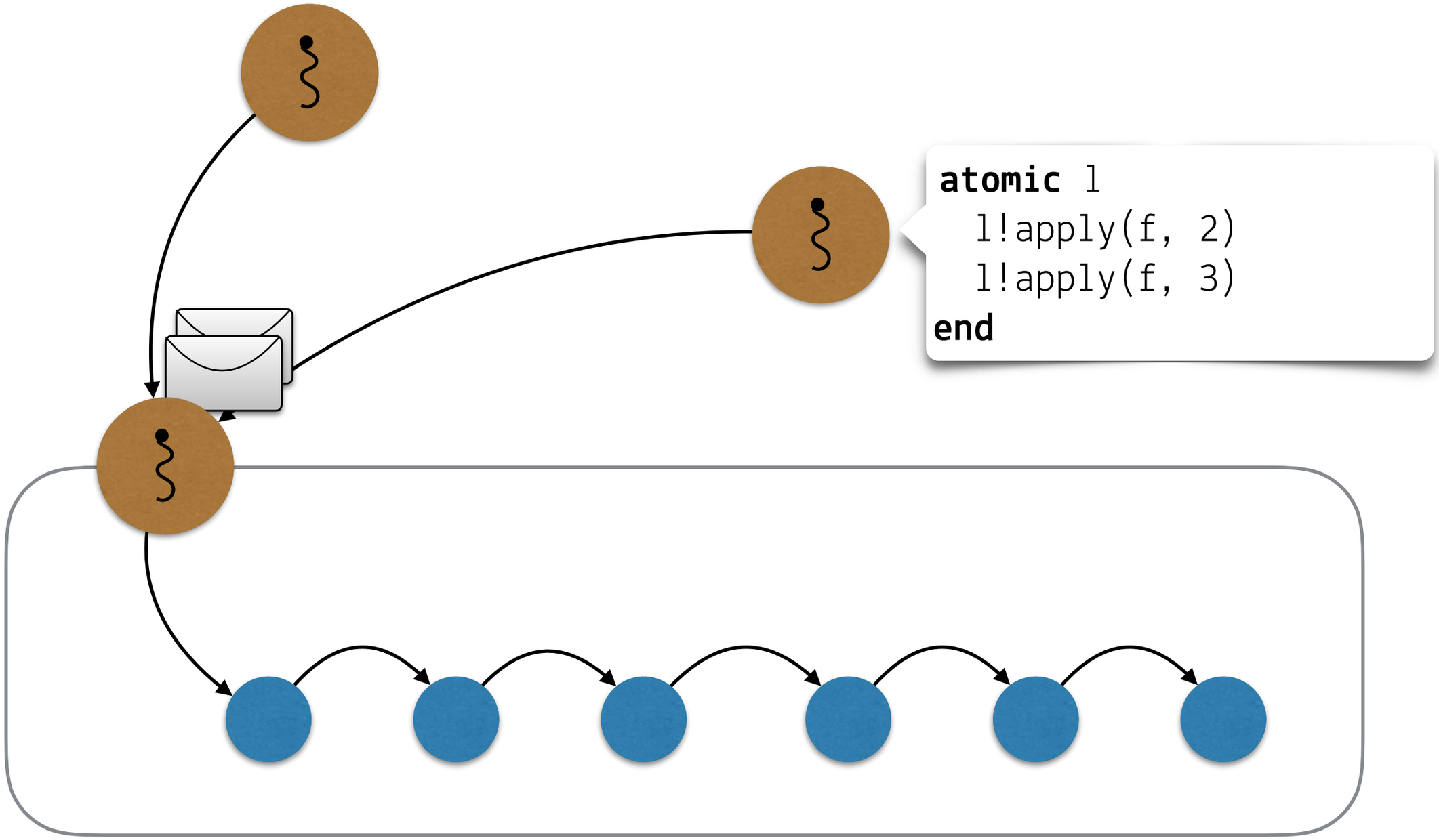


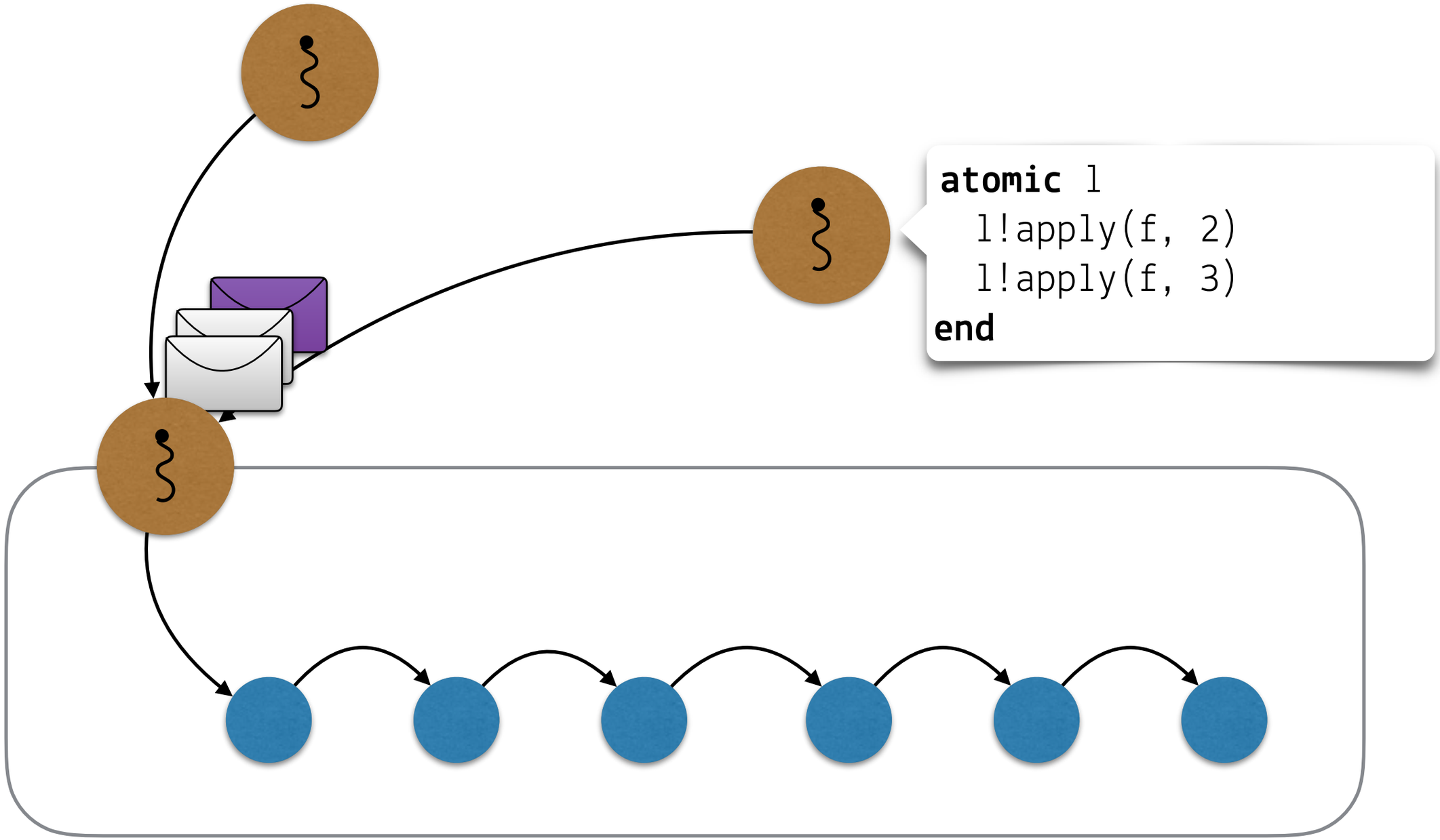
Incompatible Interleaving



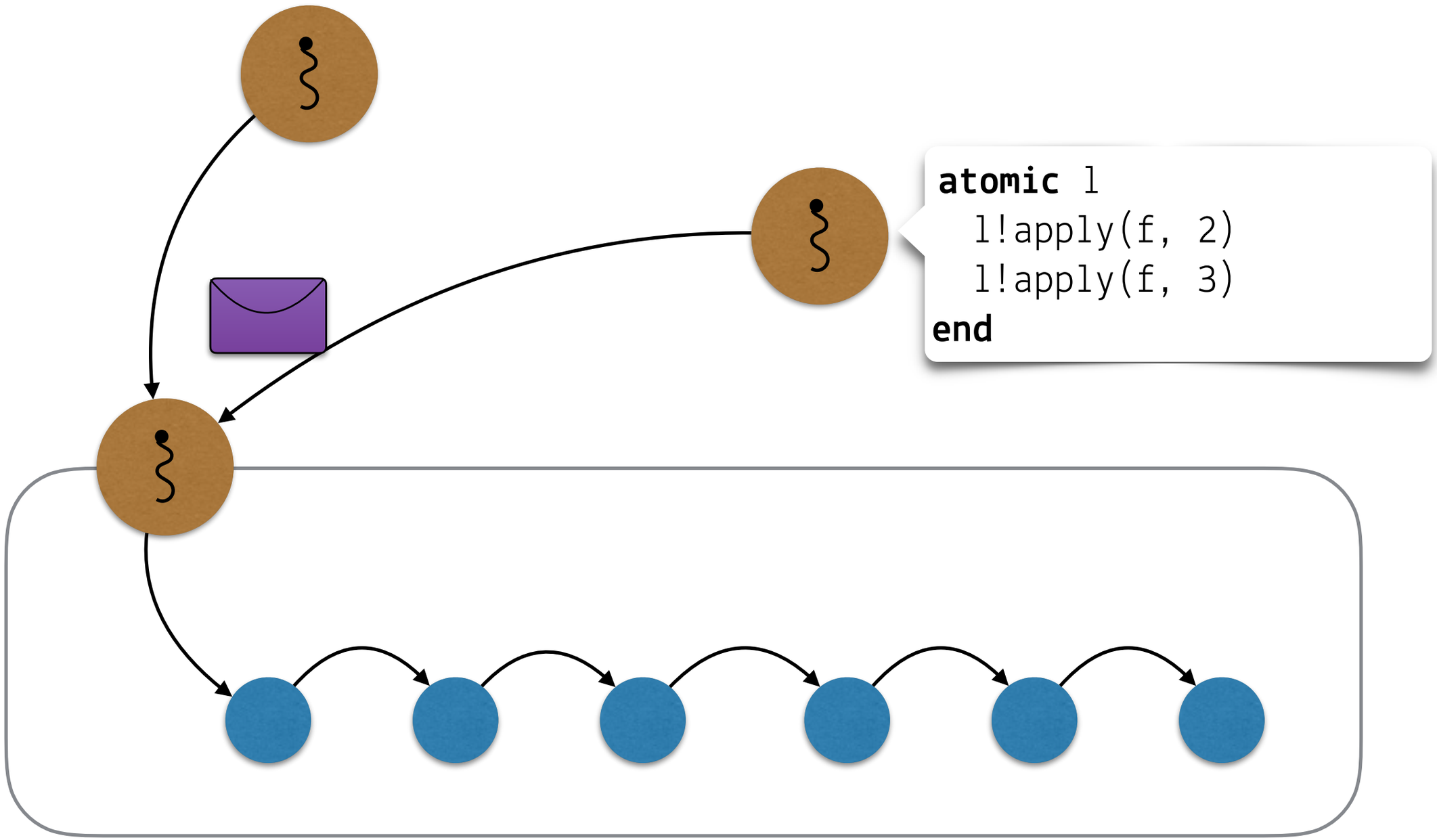
Grouping Messages



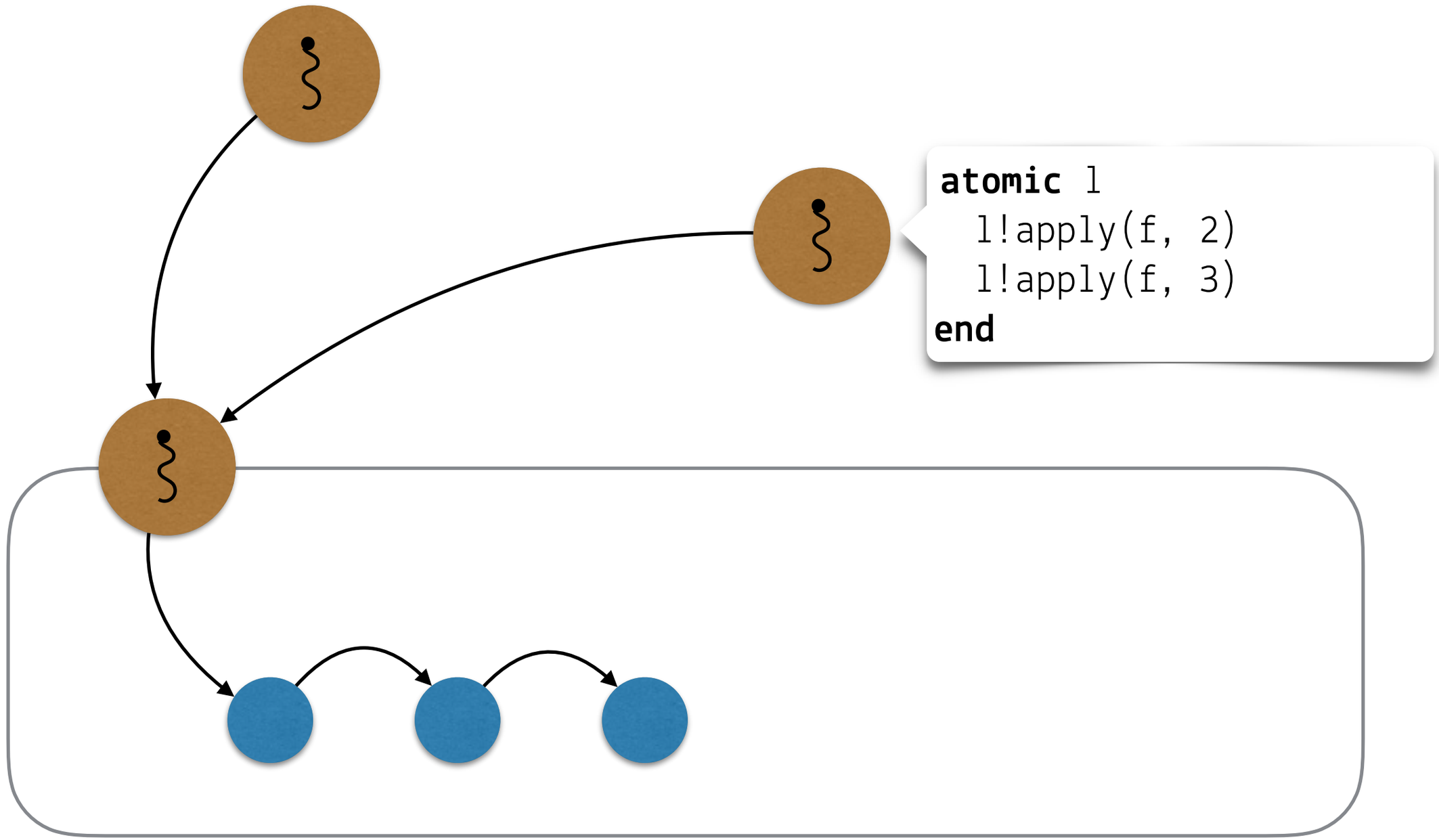
Grouping Messages



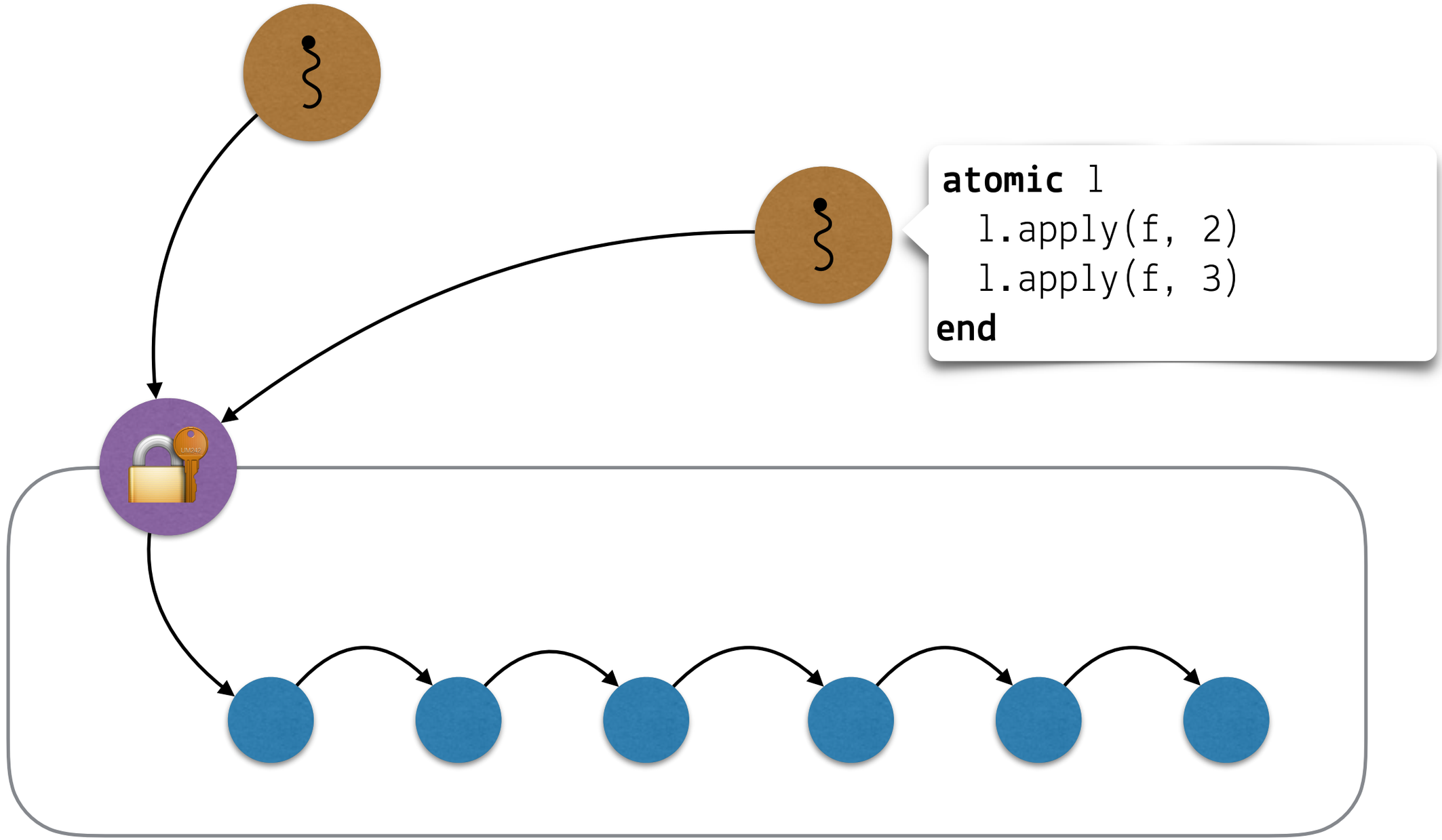
Grouping Messages



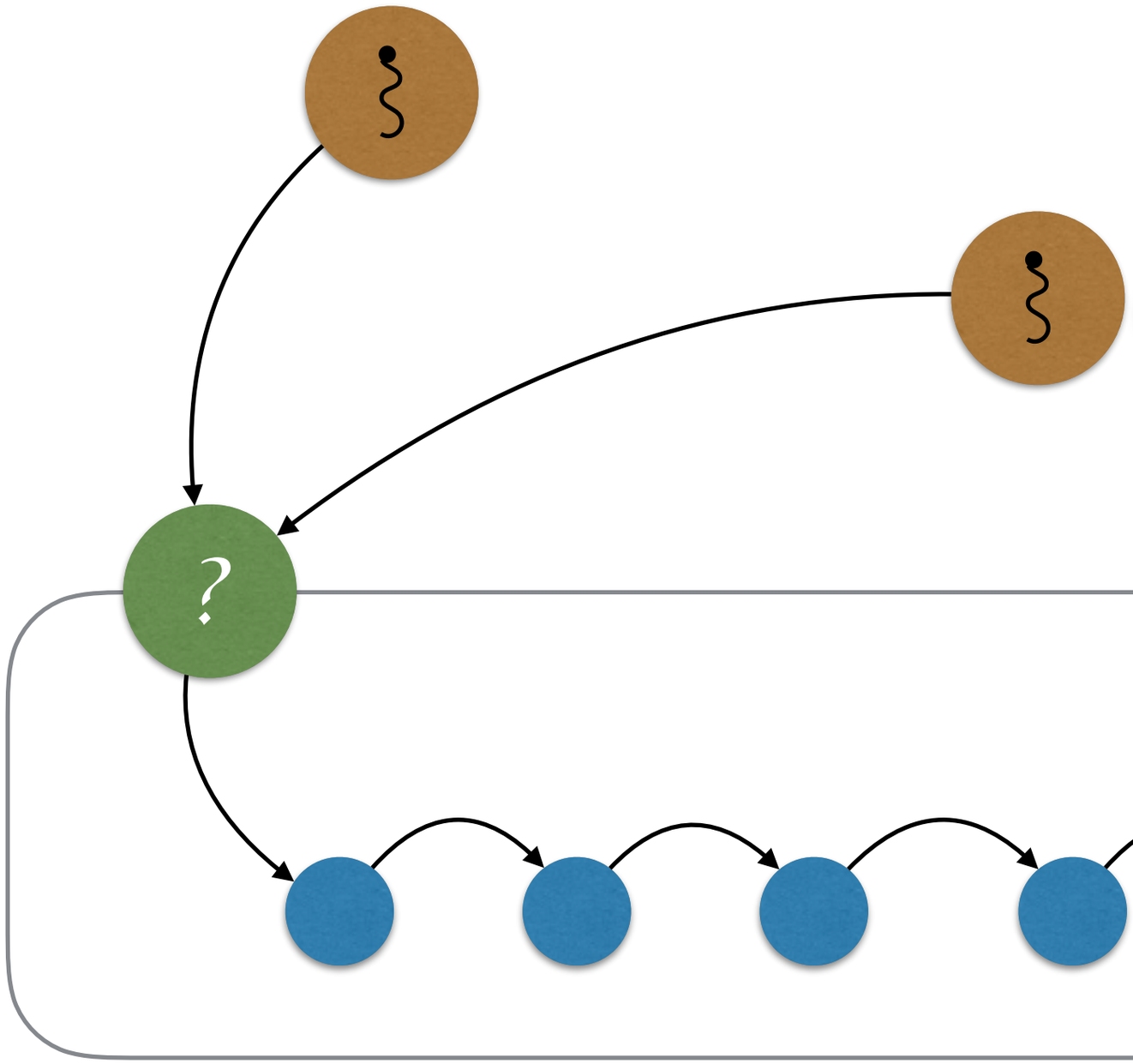
Grouping Messages



Grouping Locked operations

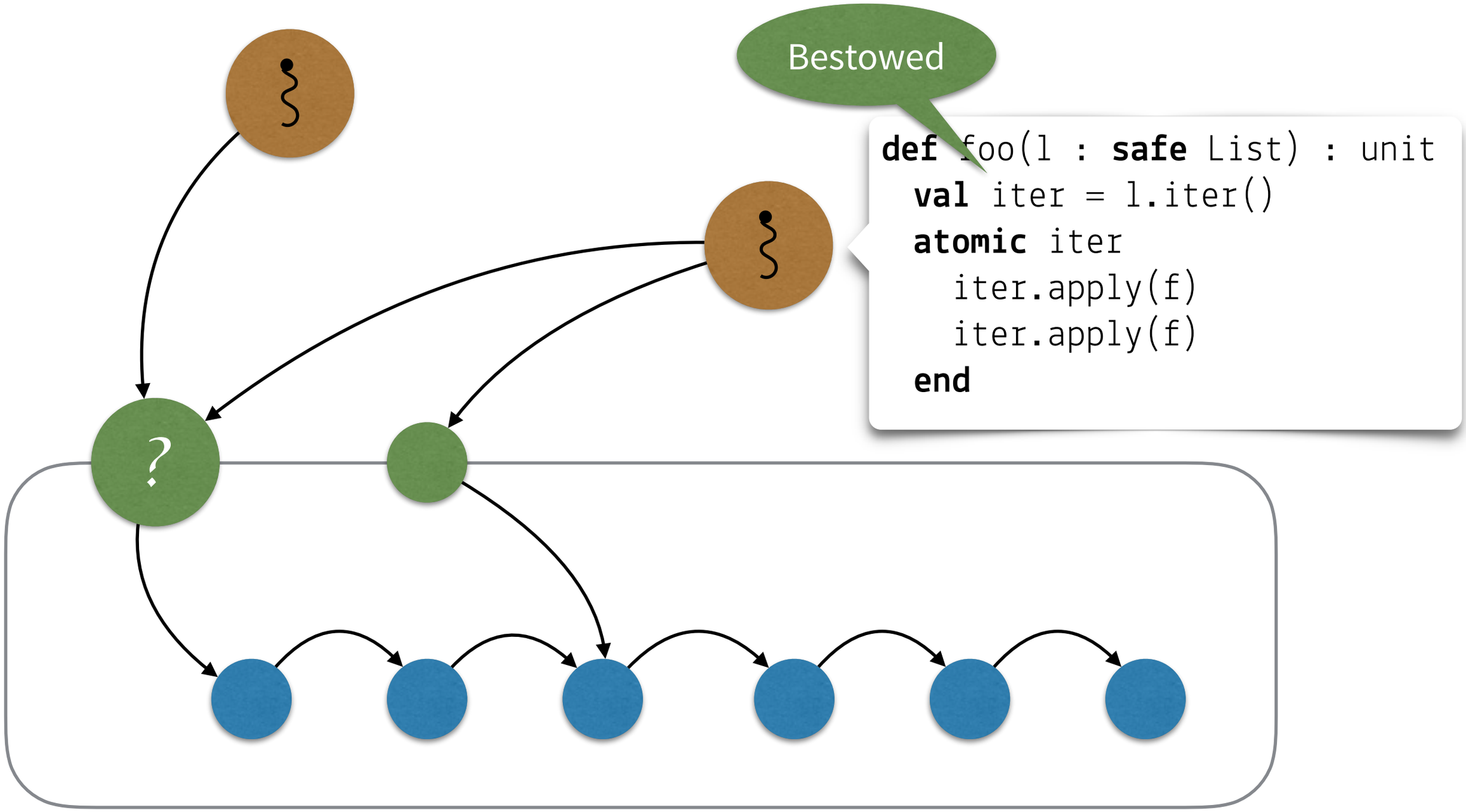


Polymorphic Concurrency Control




```
def foo(l : safe List) : unit
  val iter = l.iter()
  atomic iter
    iter.apply(f)
    iter.apply(f)
end
```

Polymorphic Concurrency Control



Tack! Frågor?

Summary

- Actor isolation can be relaxed by **bestowing** encapsulated objects with activity

  - All accesses will be synchronised via the message queue of the owning actor

  - Actors do not need to know the implementation of their bestowed objects

  - A bestowed object does not need to know that it is bestowed

- The same kind of relaxed encapsulation works for locks

  - All accesses will be synchronised via the lock of the owning object

- **Also in the paper:**

  Atomic blocks to group operations
  Implementation sketches
  Polymorphic concurrency control