Scalable Termination Detection for Distributed Actor Systems

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UIUC

Actor Model

Actors are lightweight, stateful, async processes.

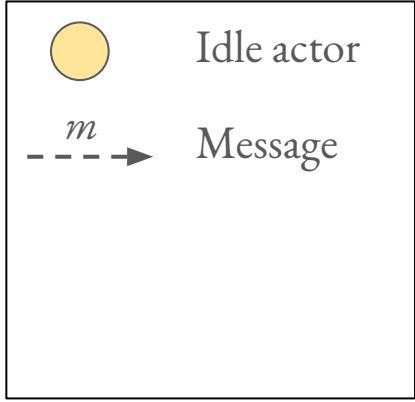
Used to build **low-latency distributed systems** (e.g. Riak, Discord, CouchDB).

Most popular frameworks (Erlang, Akka, Orleans) do not garbage collect actors.

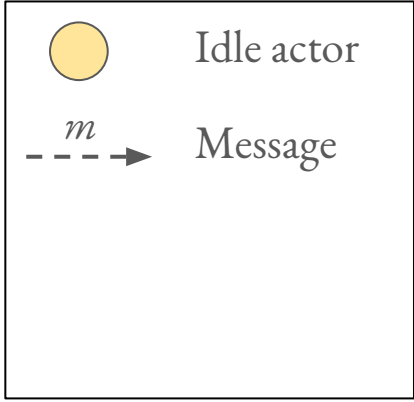
Ordinary tracing GC techniques don’t work.

Other solutions don’t scale well.

Part I: Actors


Idle actor
m
Message


m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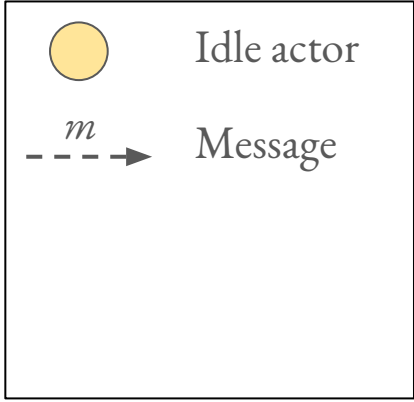
Once an **idle** actor receives a message, it becomes **busy**.



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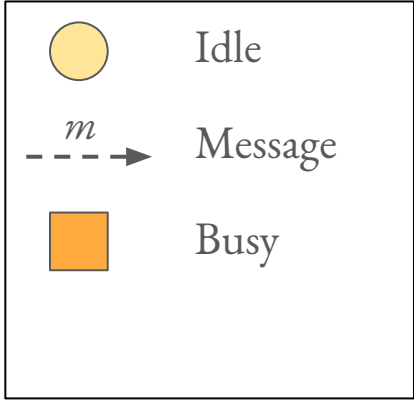

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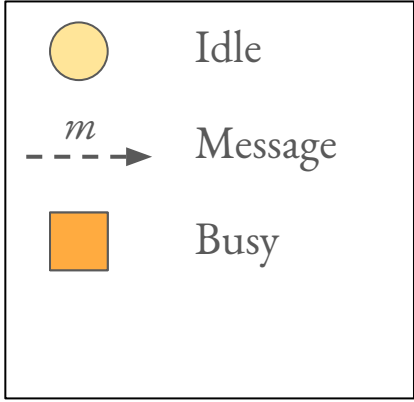

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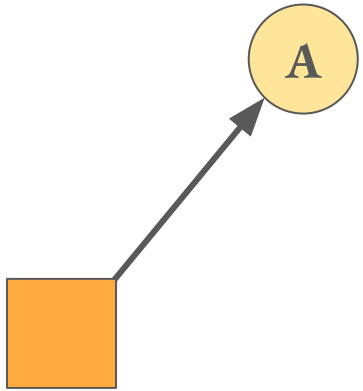

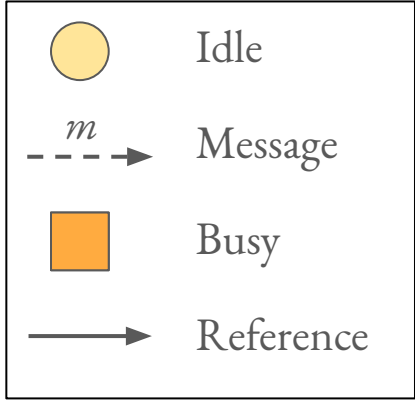

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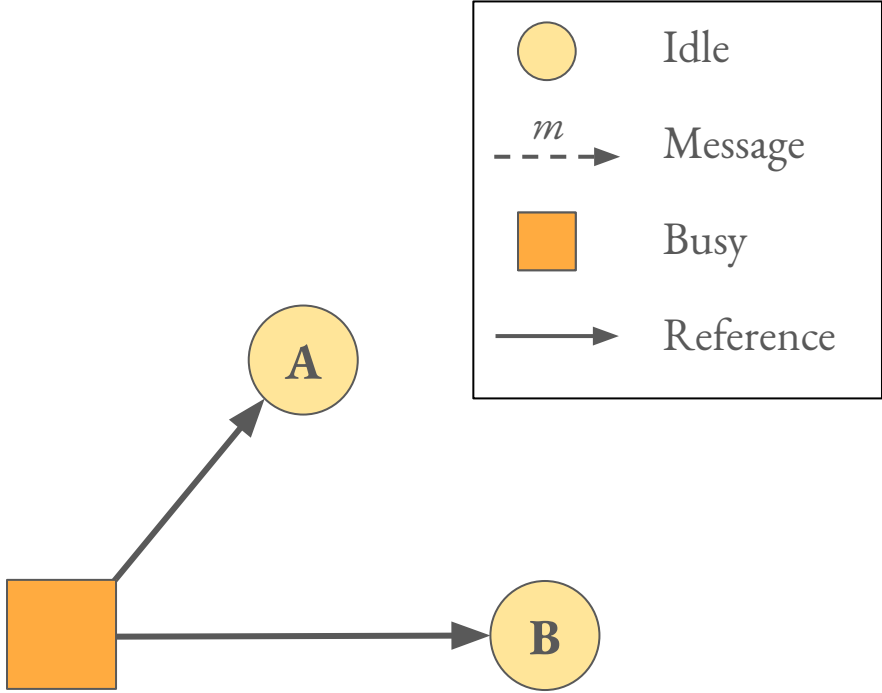

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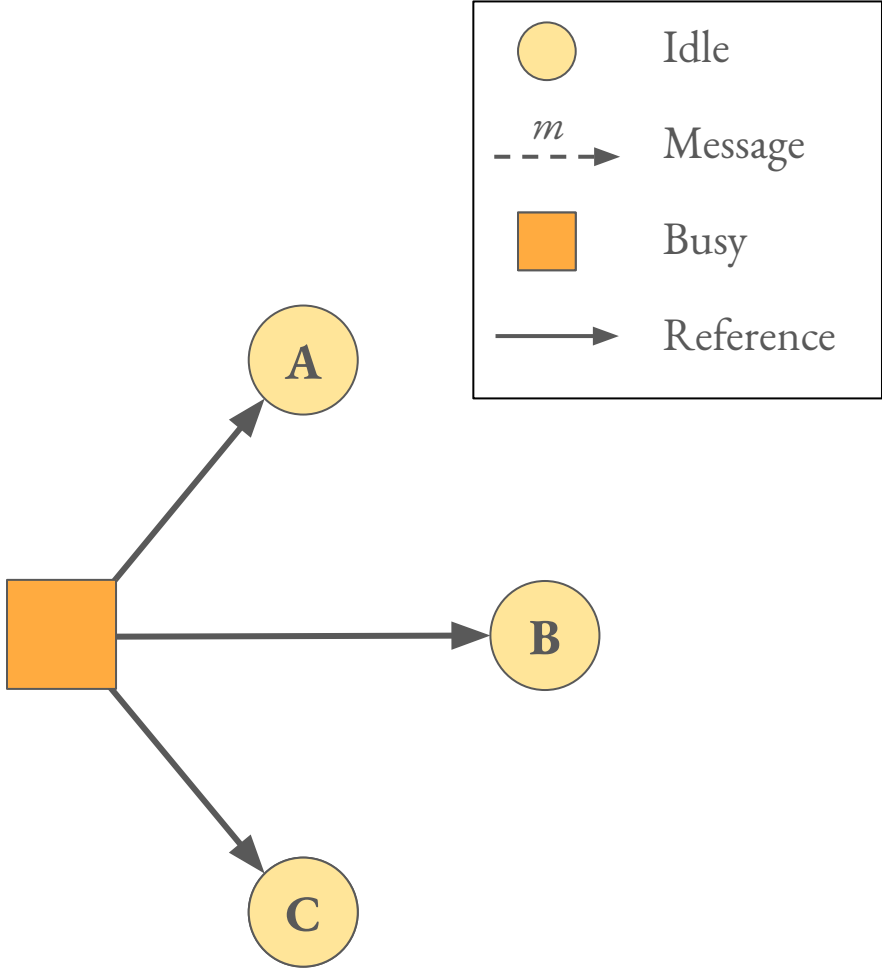

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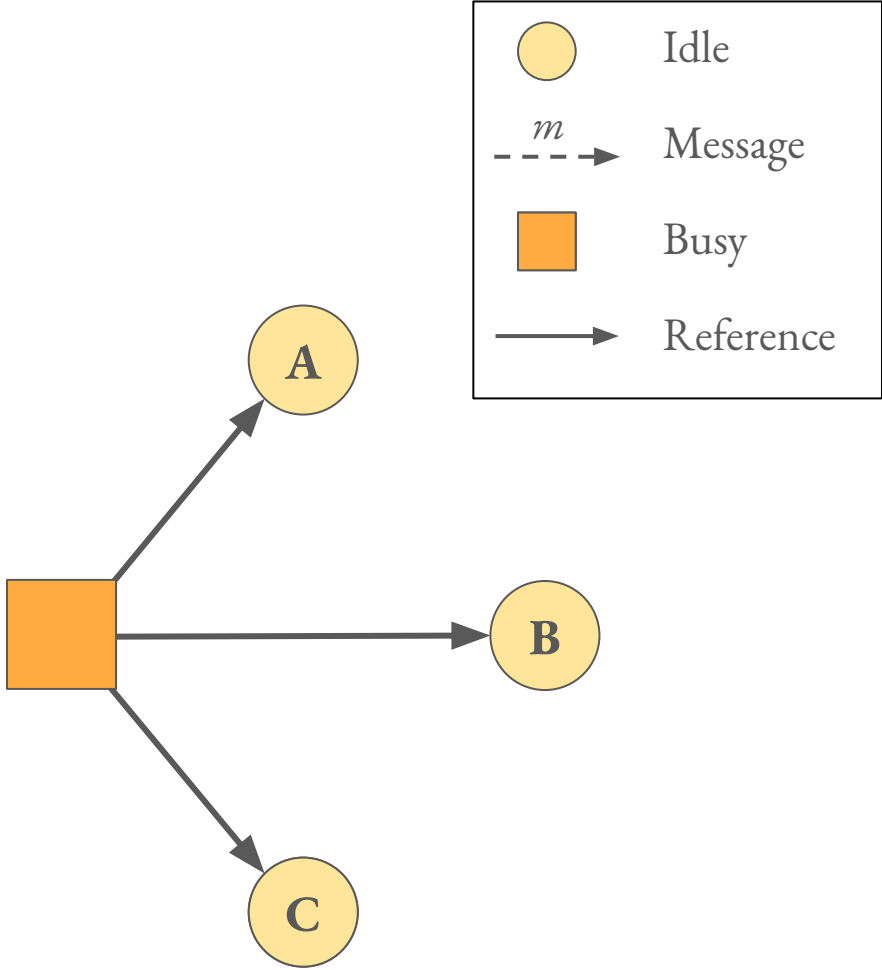

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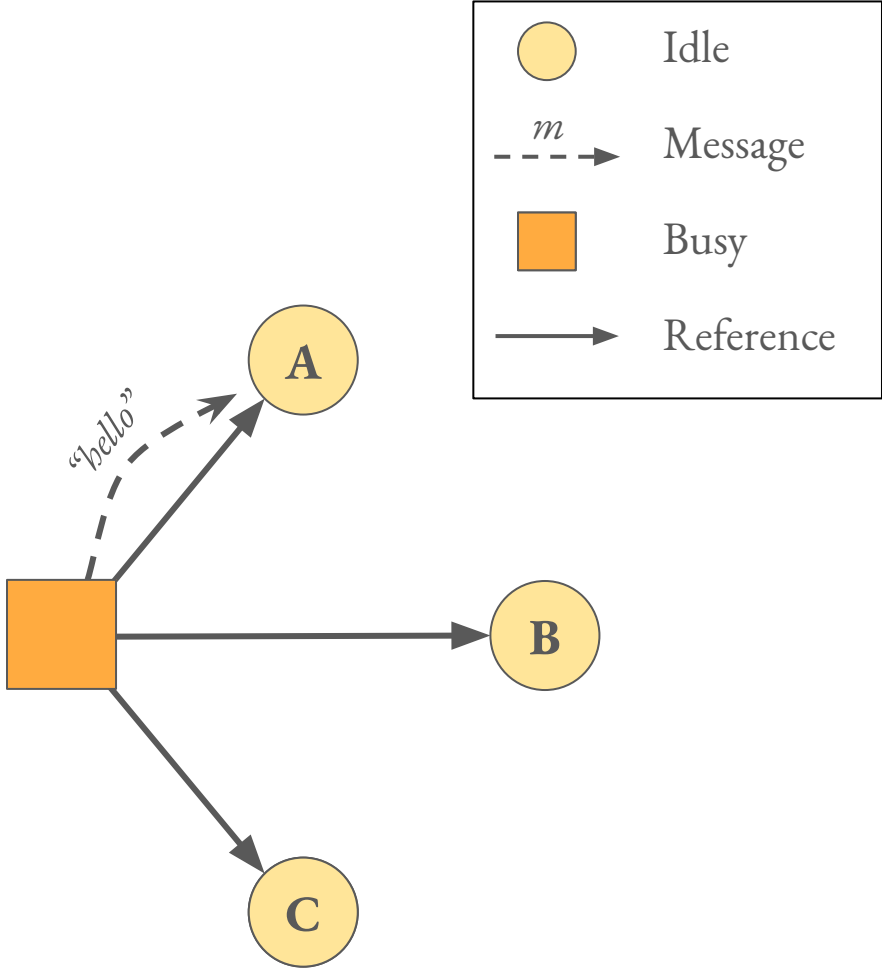

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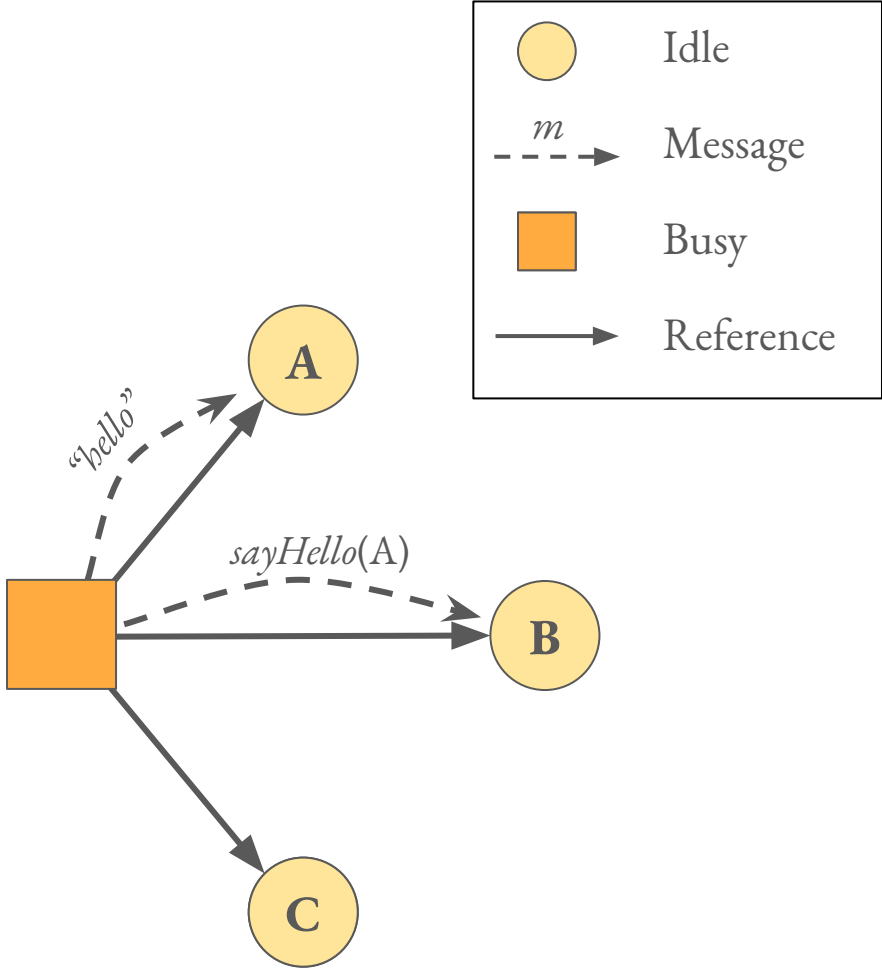

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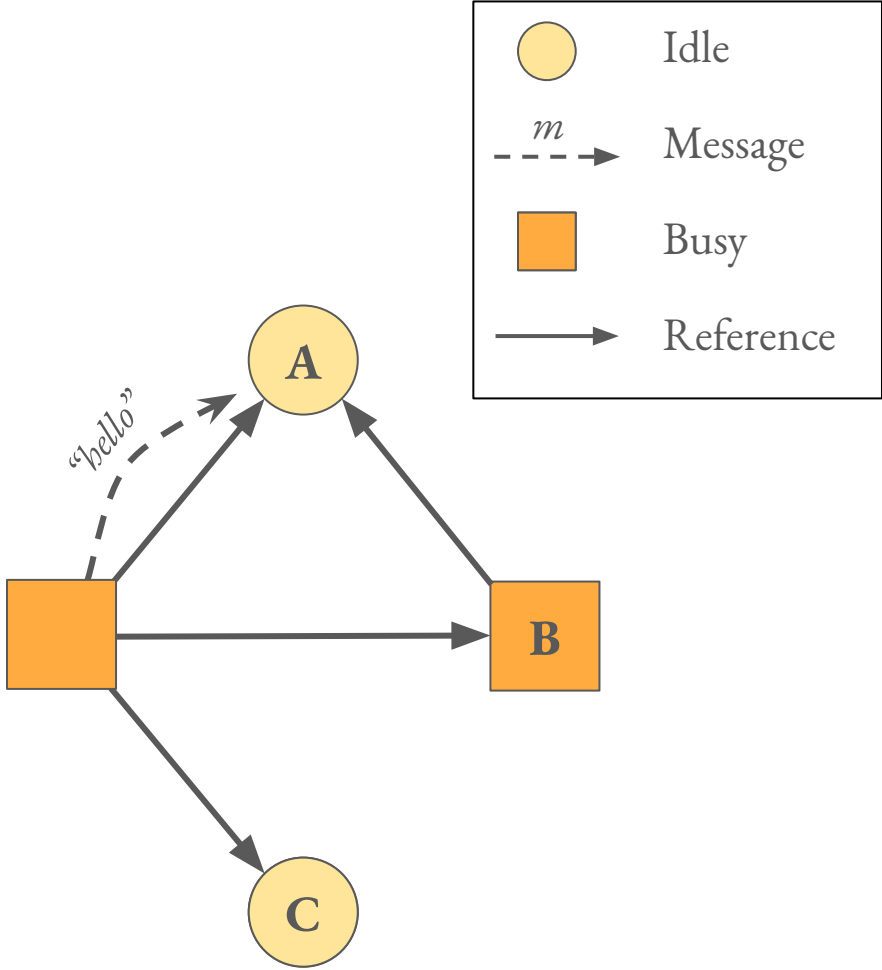

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A busy actor can...

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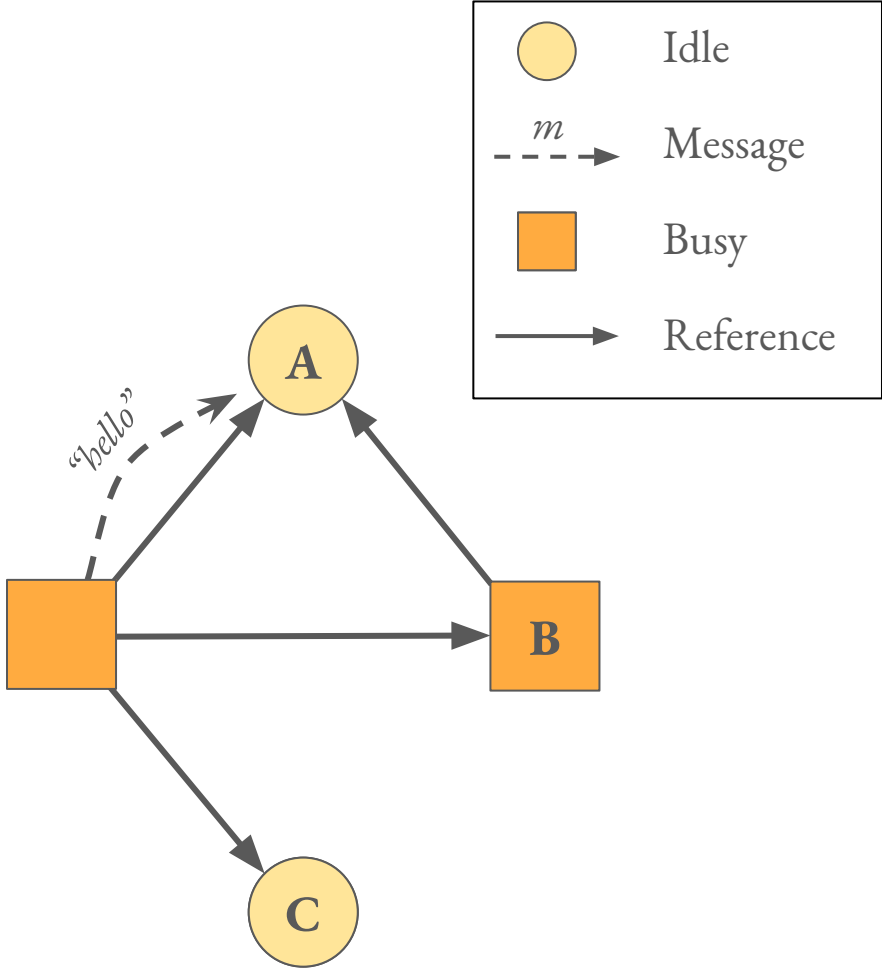

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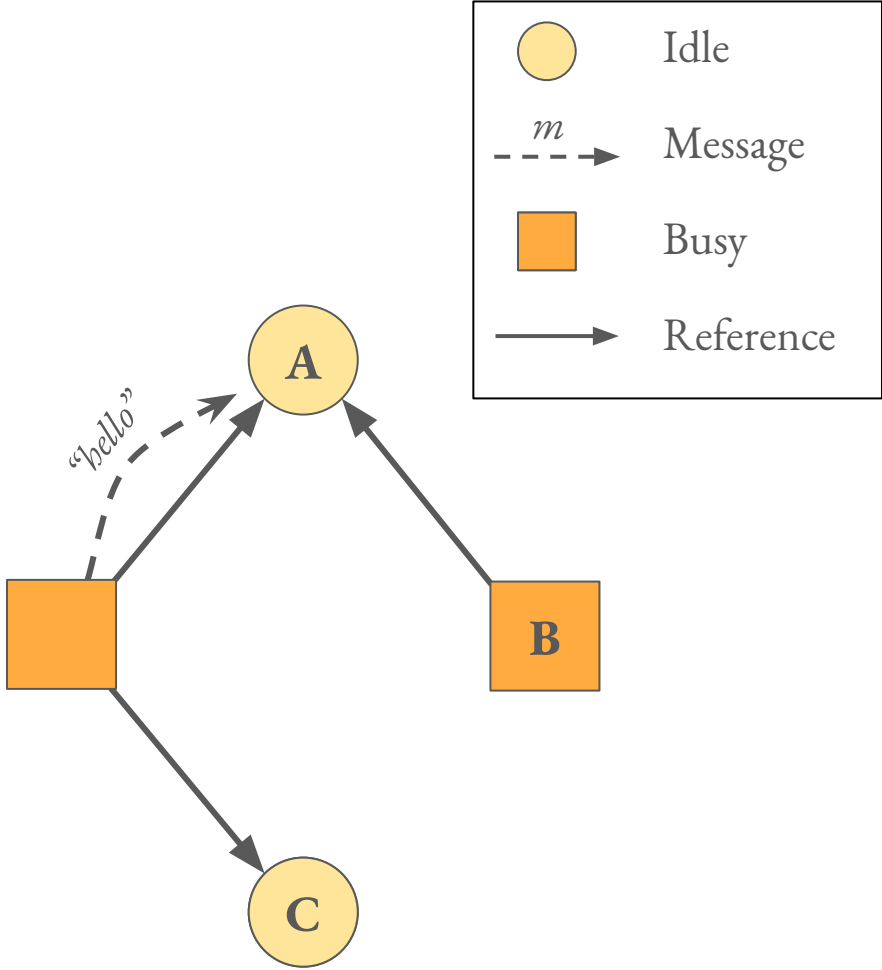

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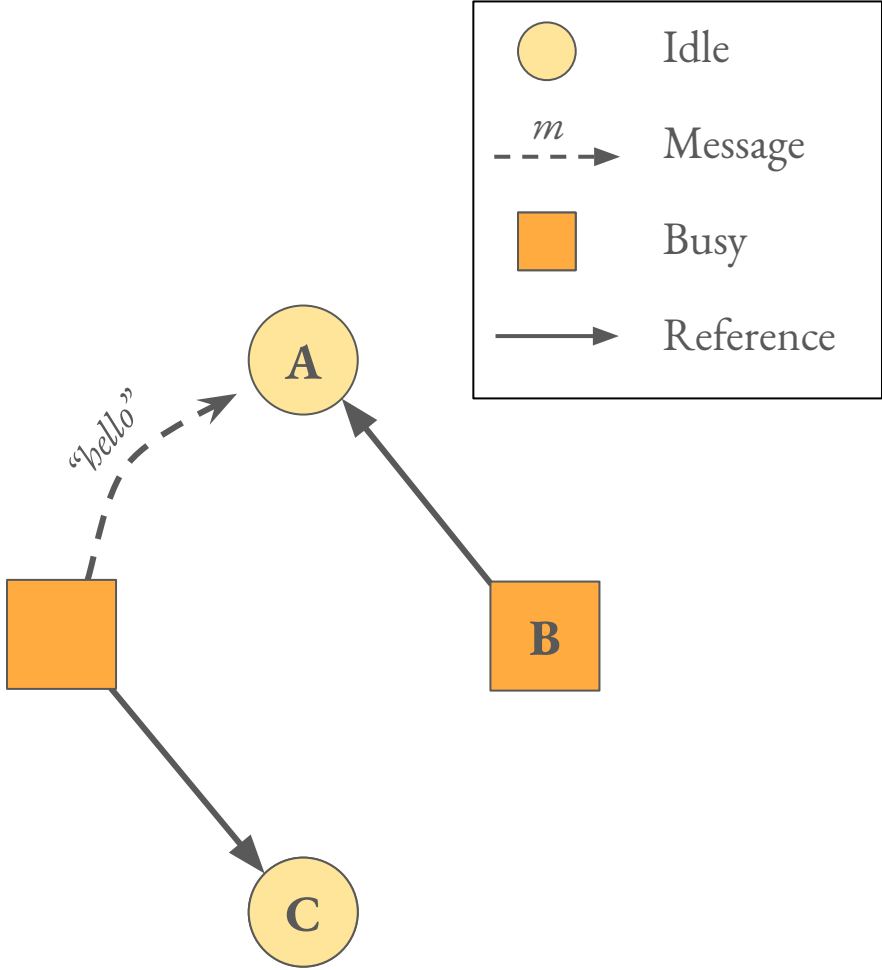

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A busy actor can...

- spawn actors...
- send async messages...
- update its local state...
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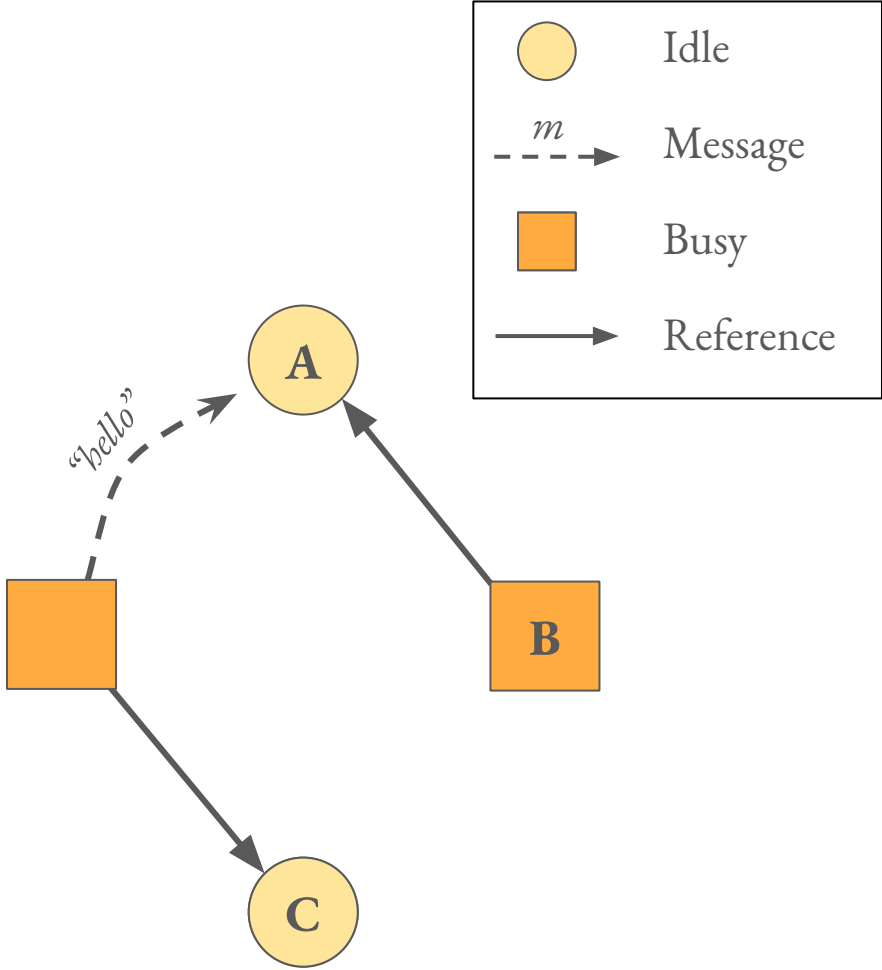

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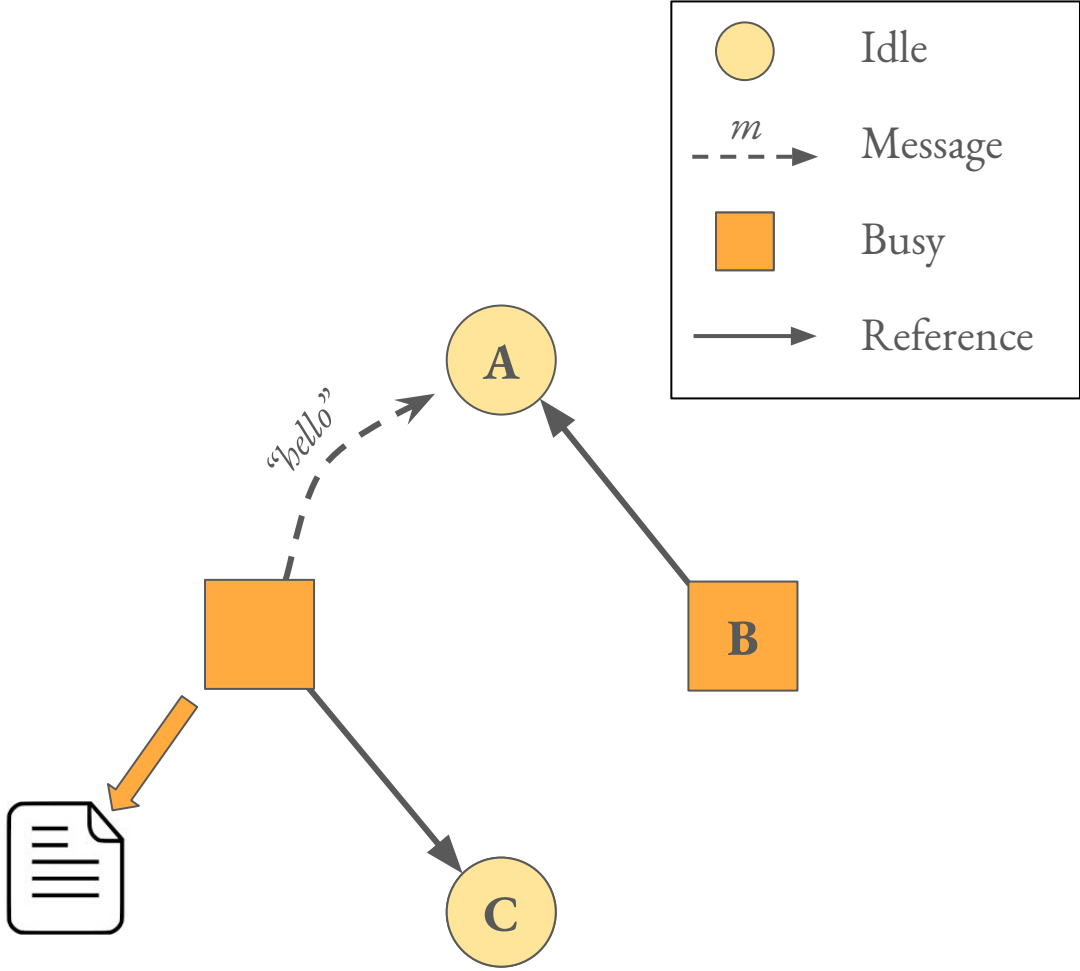

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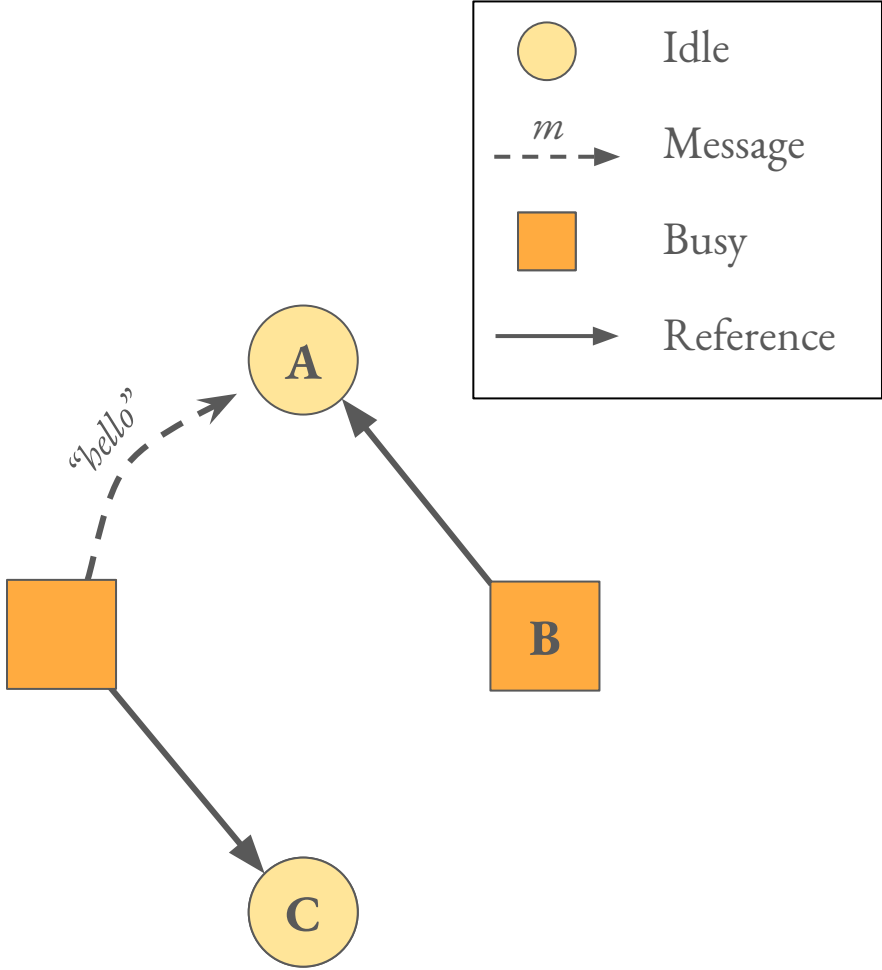

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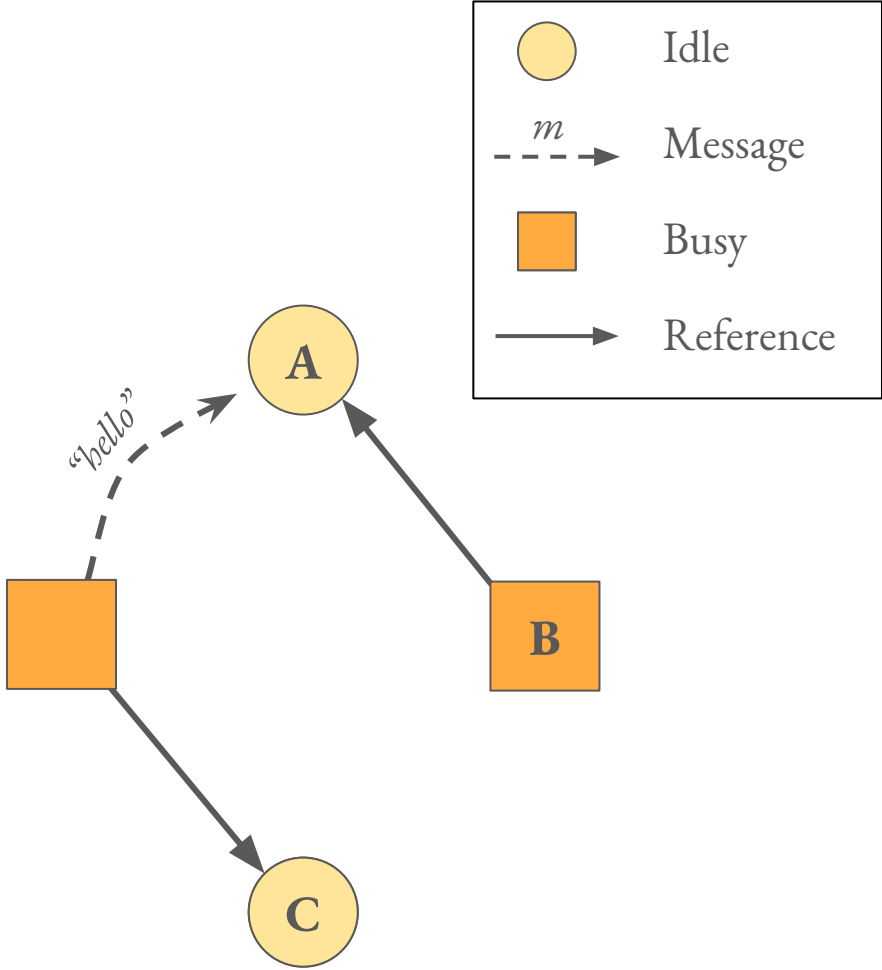

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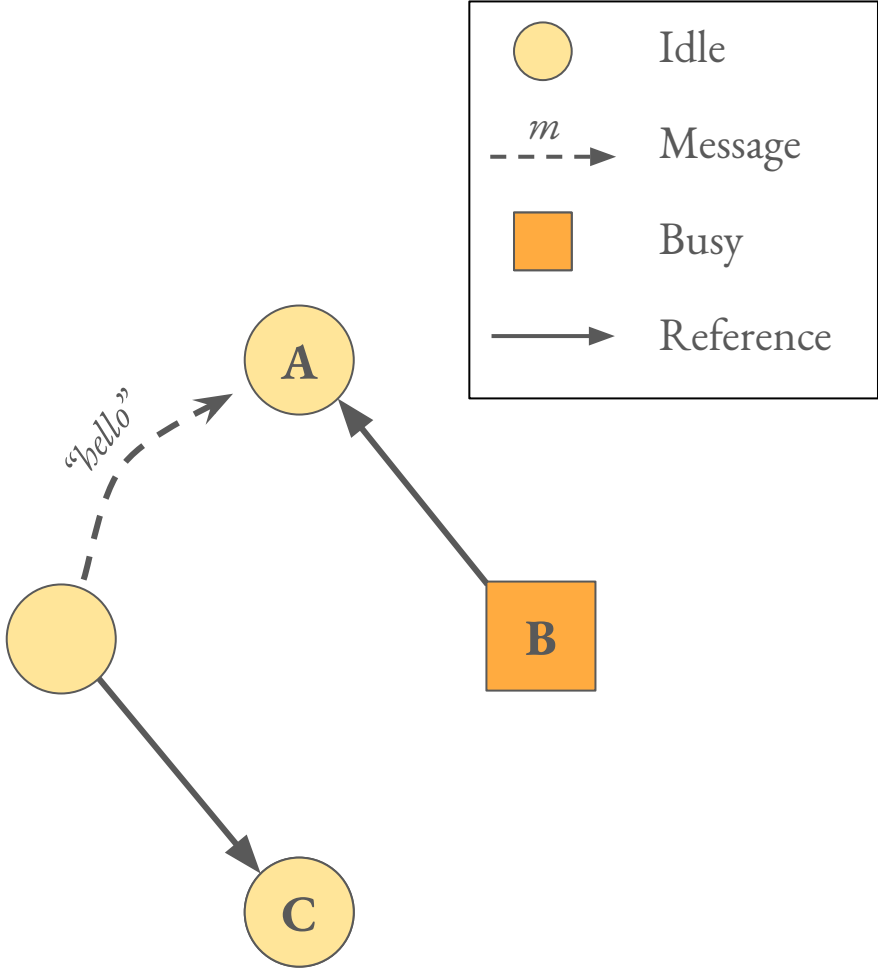
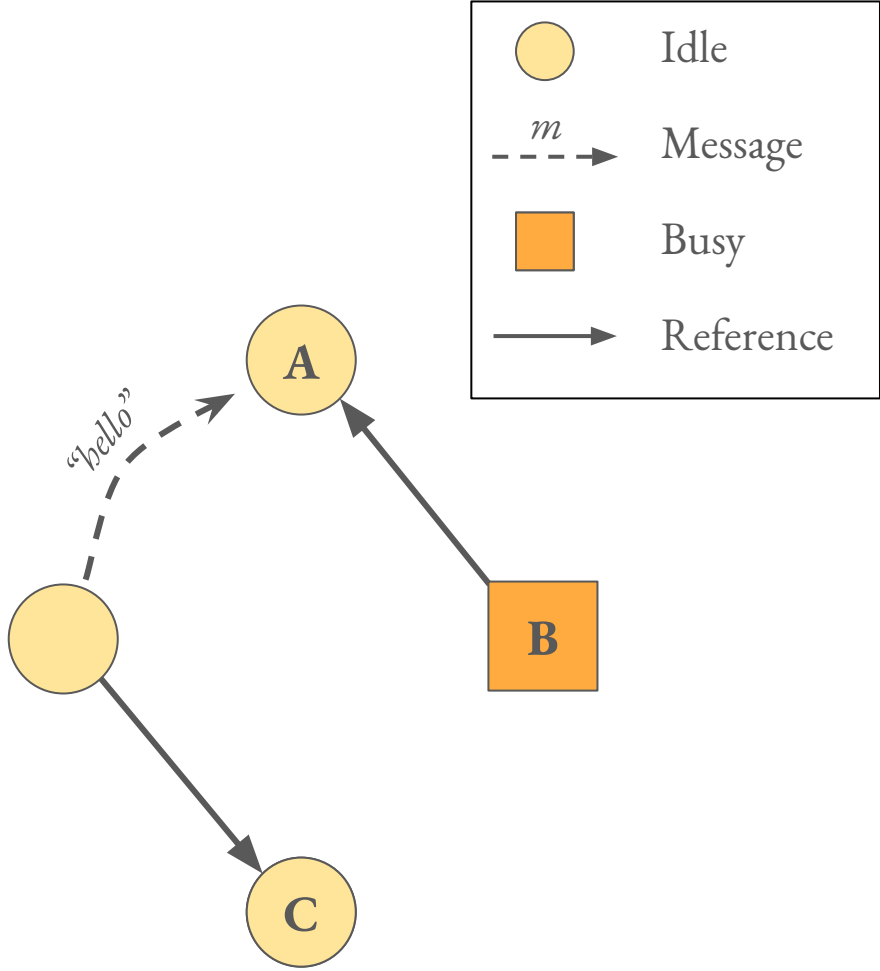


An actor is **unblocked** if:

a. it is busy, or

b. it has undelivered messages.



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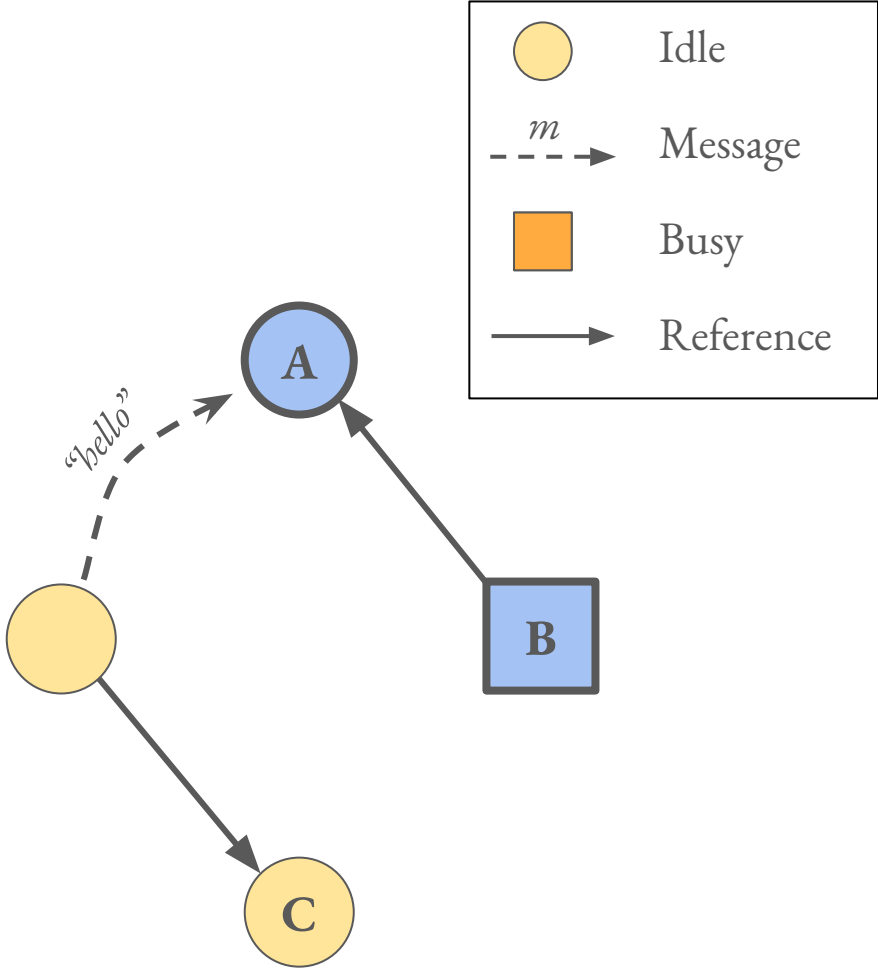

Part II: Garbage

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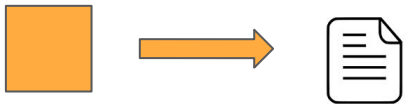
If an actor could become unblocked, we shouldn't collect it.



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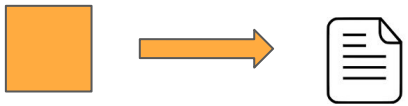
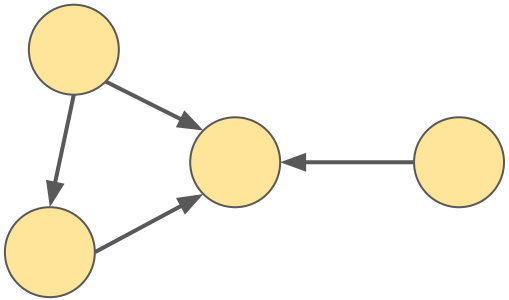
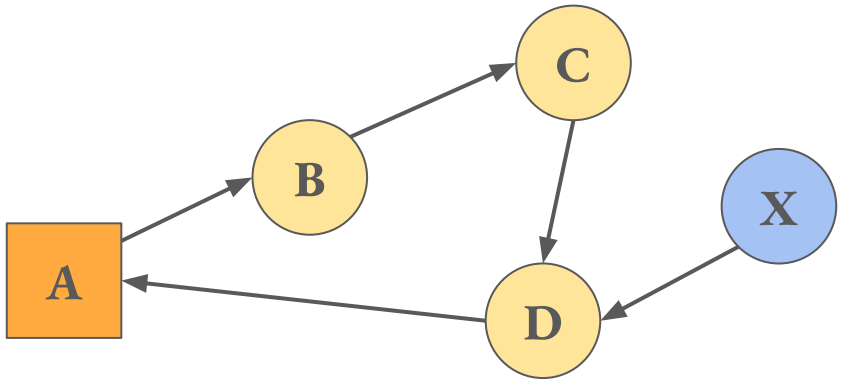


We want actors that are **permanently blocked**, aka **terminated** actors



Is X terminated?



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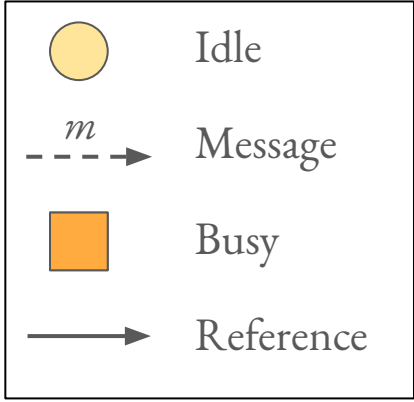

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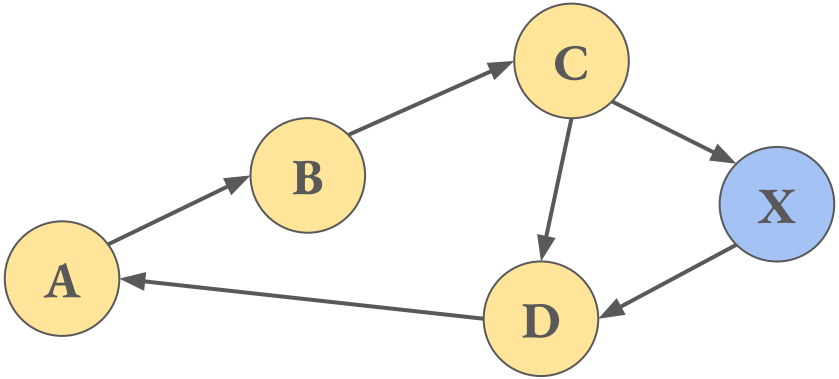

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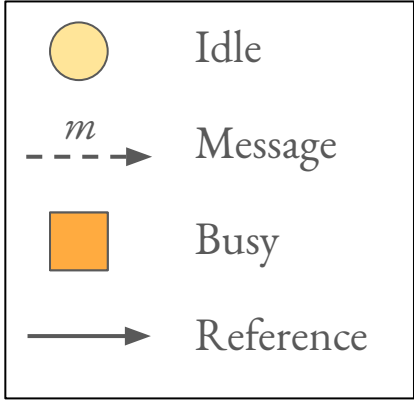

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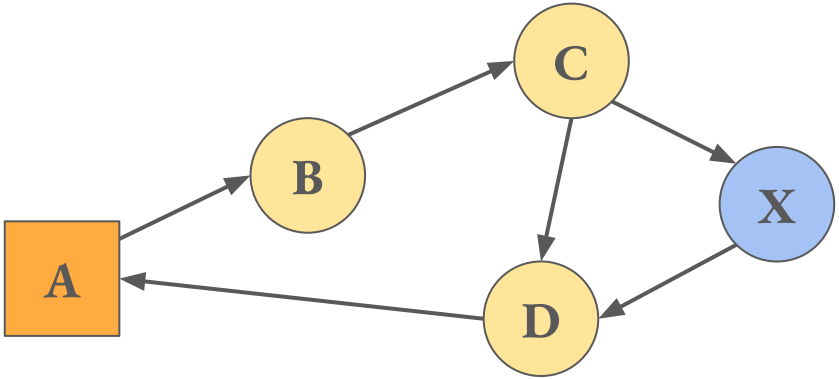

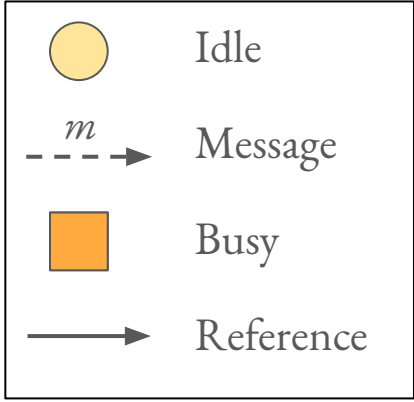

Possibly not!

So X is terminated if all actors that can “reach” it are blocked?

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Not so fast!

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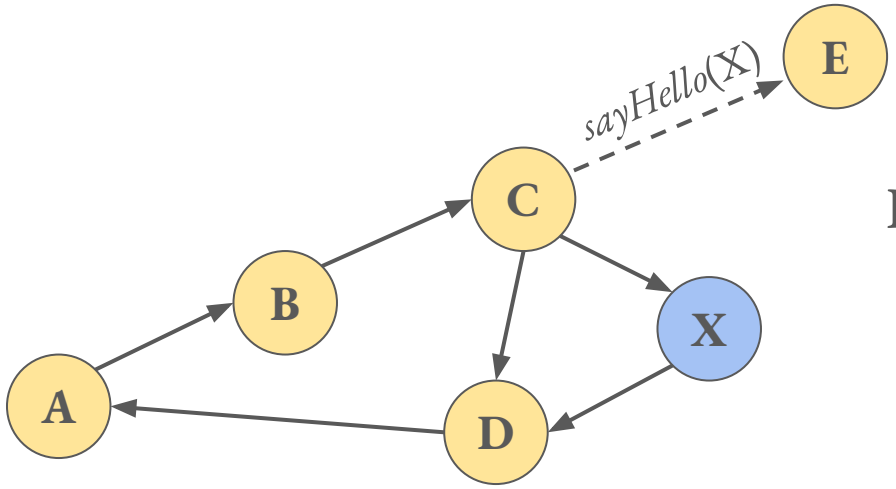

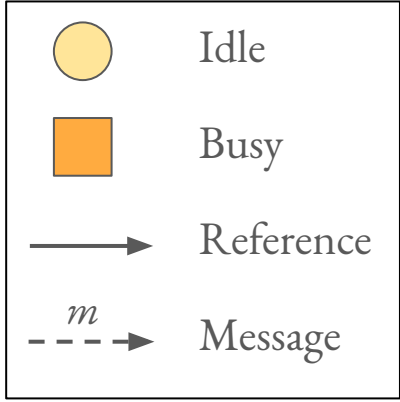

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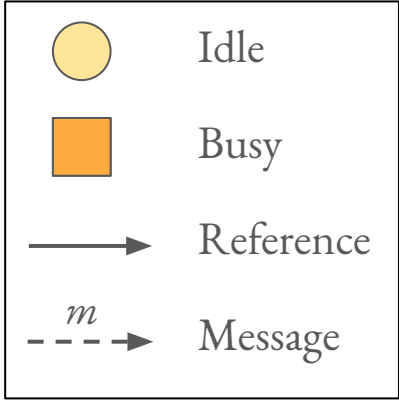
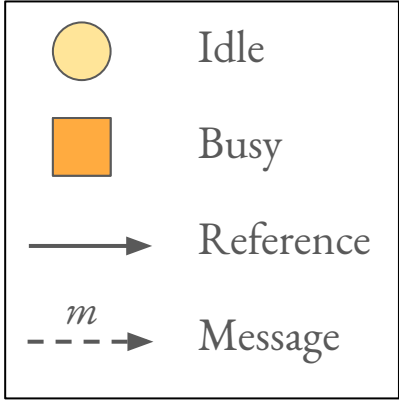


A is **potentially acquainted** with B if either:

a. A has a reference to B

b. there is an undelivered message to A that contains a reference to B



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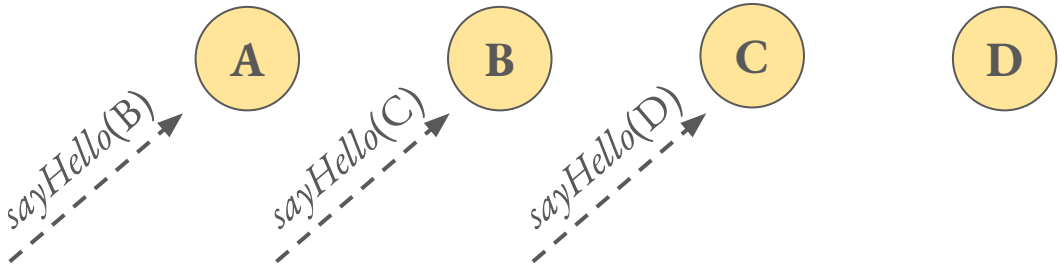
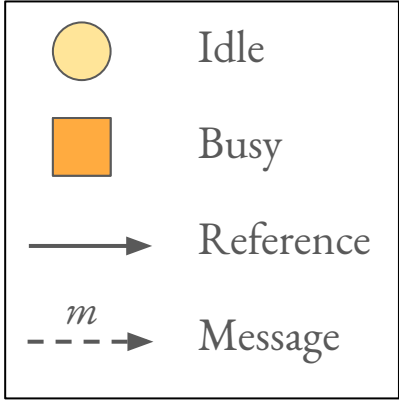
A is called a **potential inverse acquaintance** of B

Potential reachability is the reflexive transitive closure of the potential acquaintance relation





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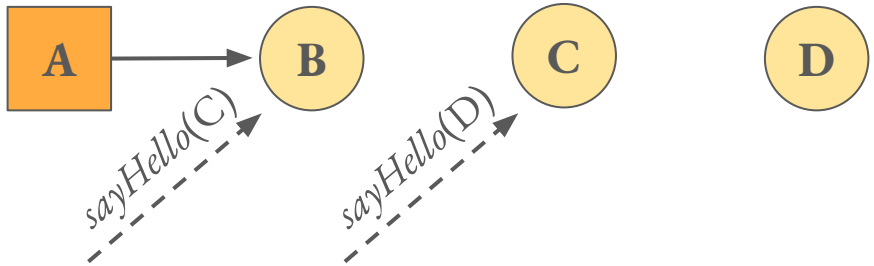

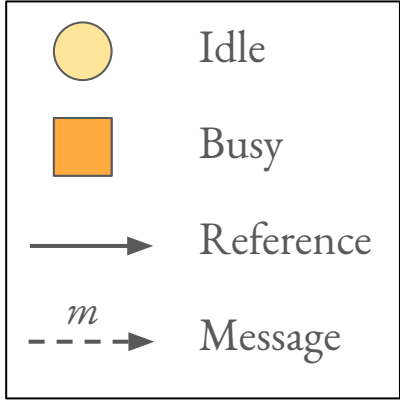

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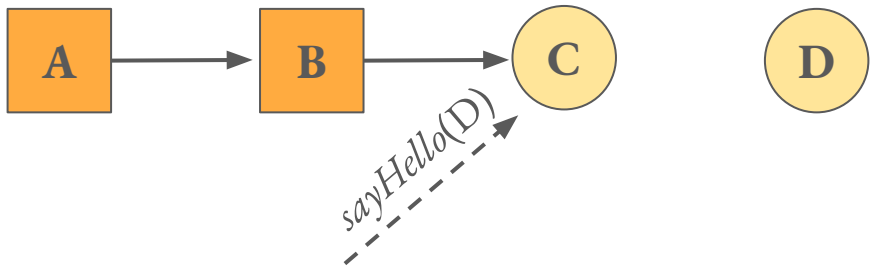

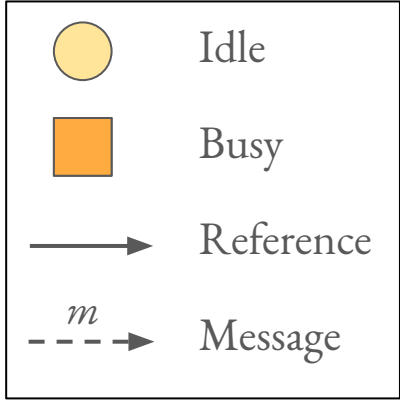

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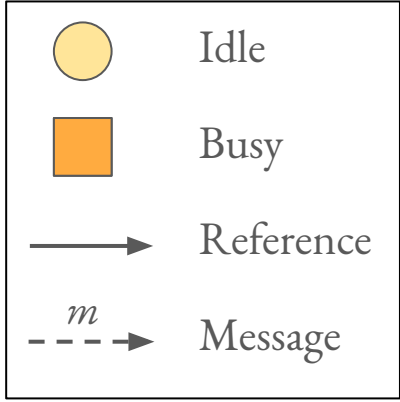
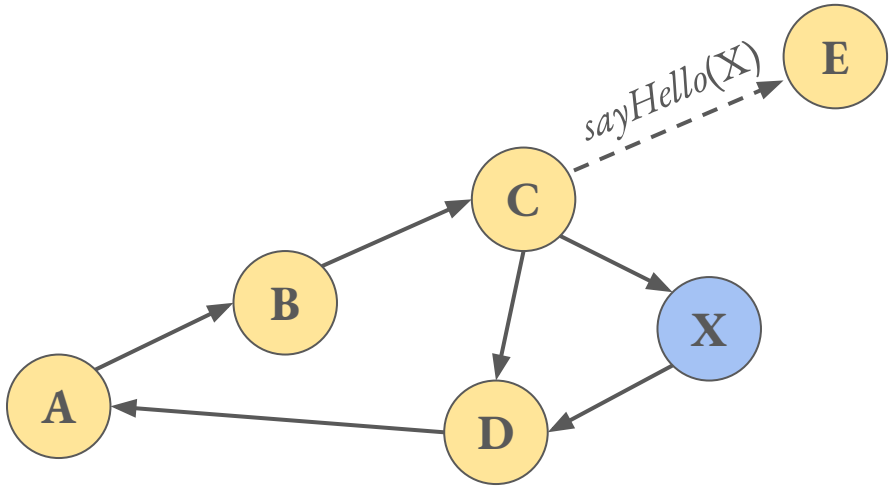
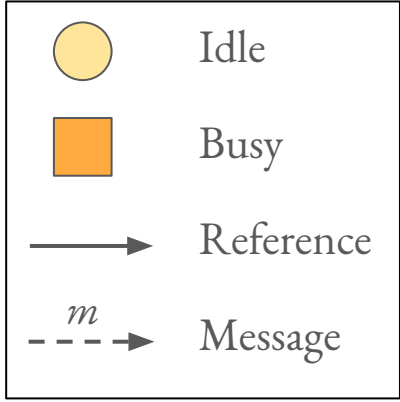


X may not be terminated if it is

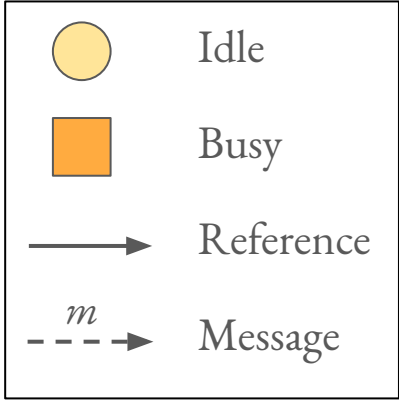
potentially reachable by an **unblocked actor**

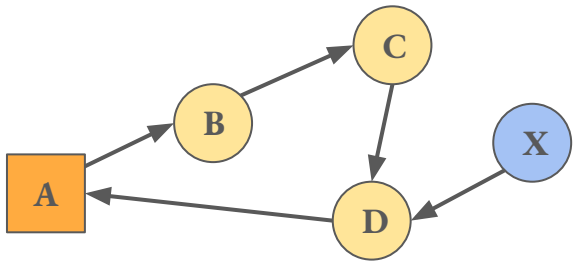


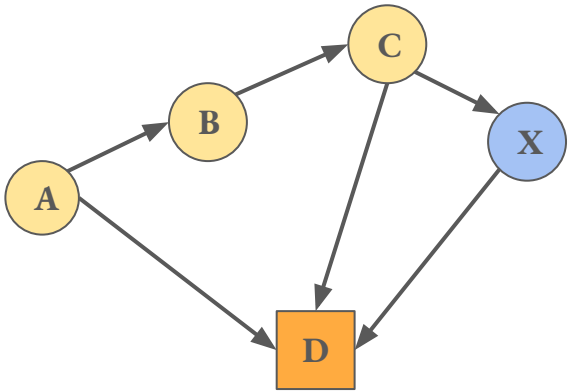


X is terminated if it is

potentially reachable only by **blocked actors**

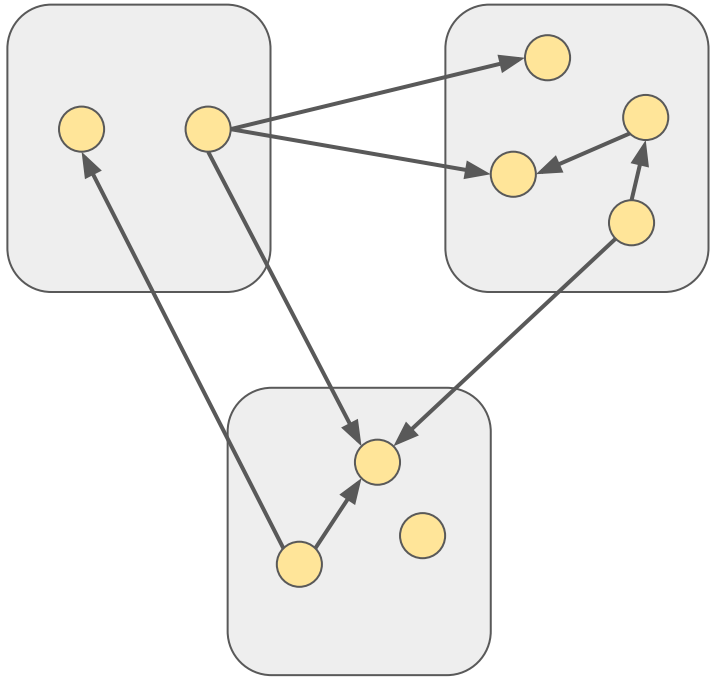




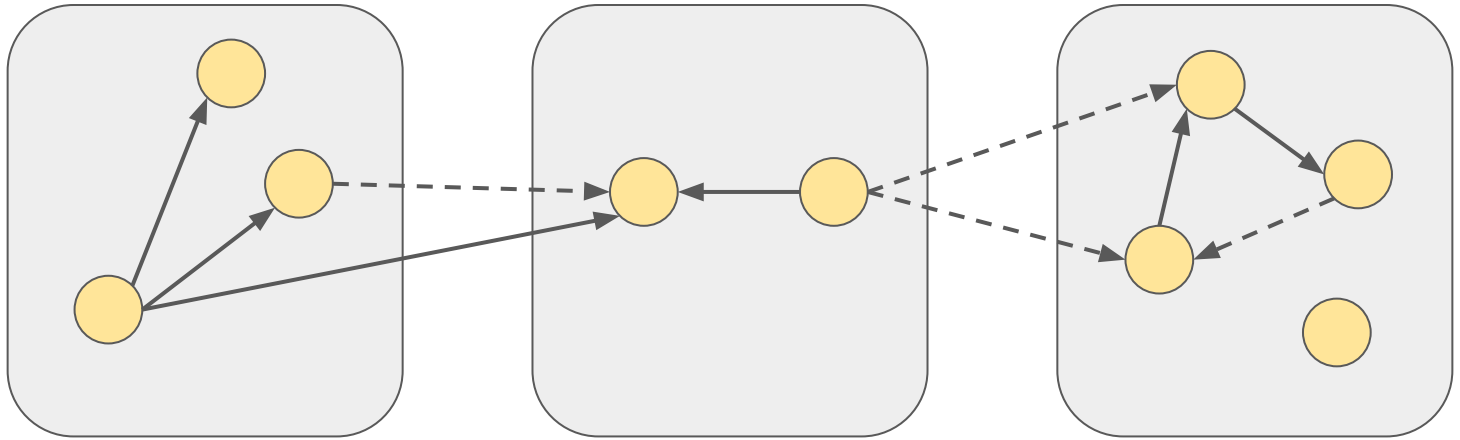


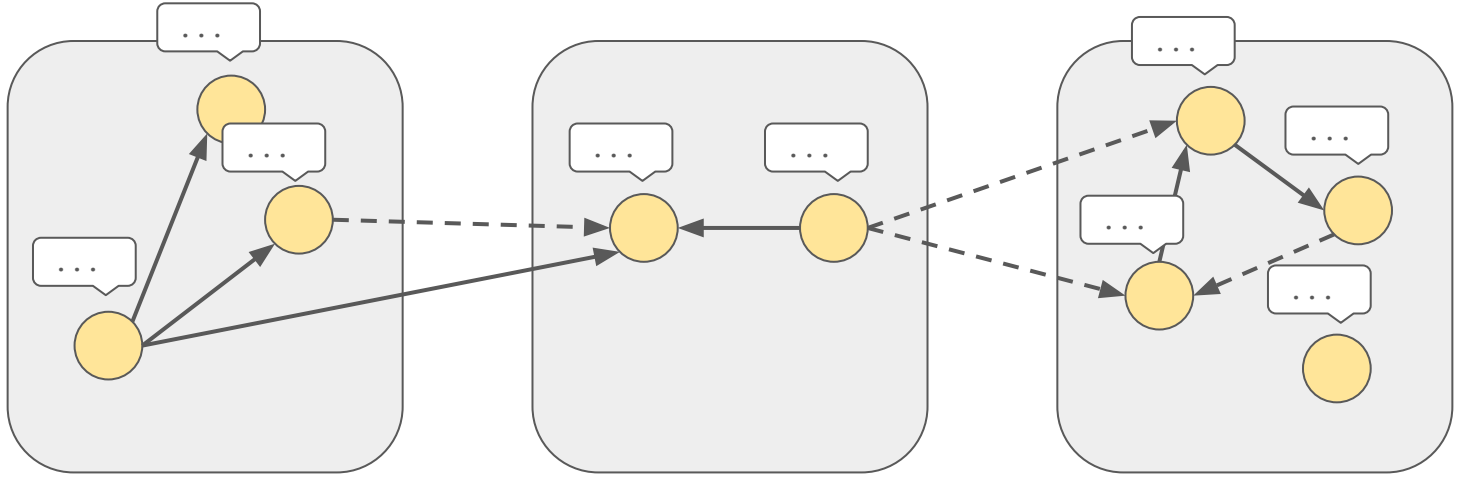
Related Work

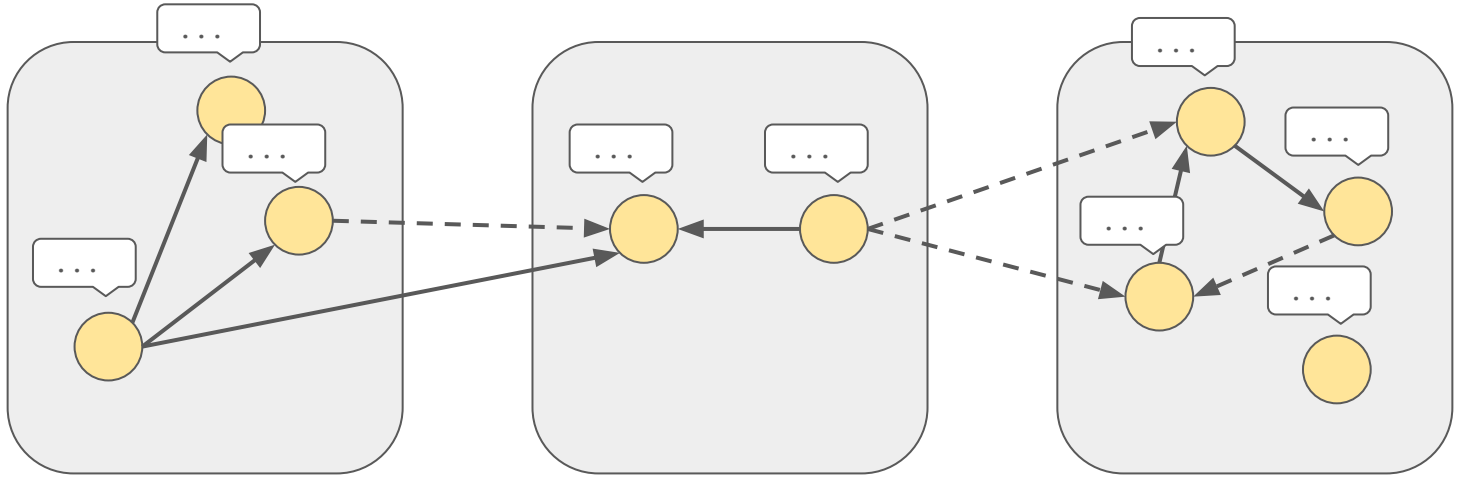
- Global snapshots
  - Not incremental
- SALSA: based on approximate snapshots
  - High overhead
- Pony: inspiration for this work
  - Causal message delivery is expensive

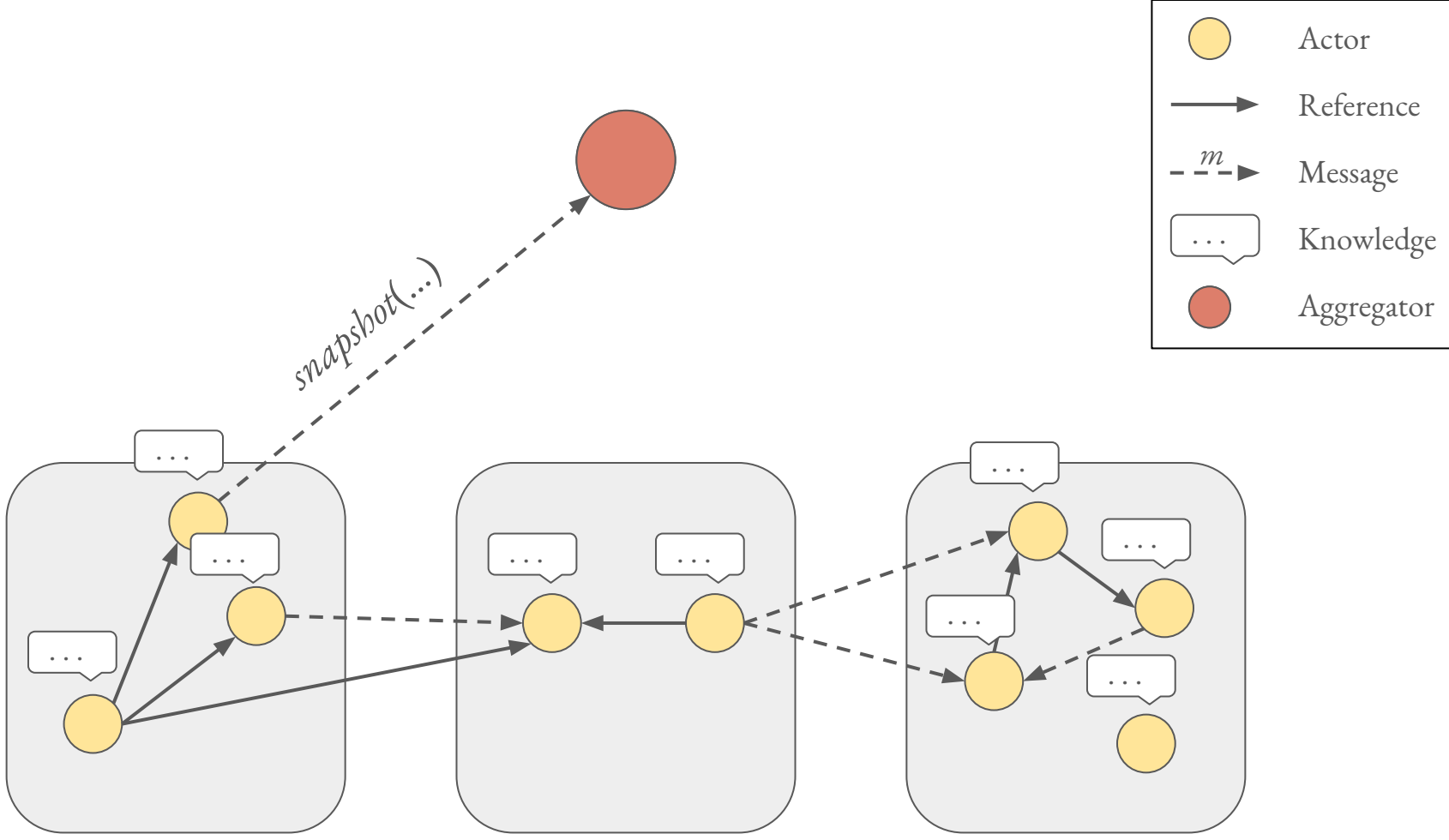


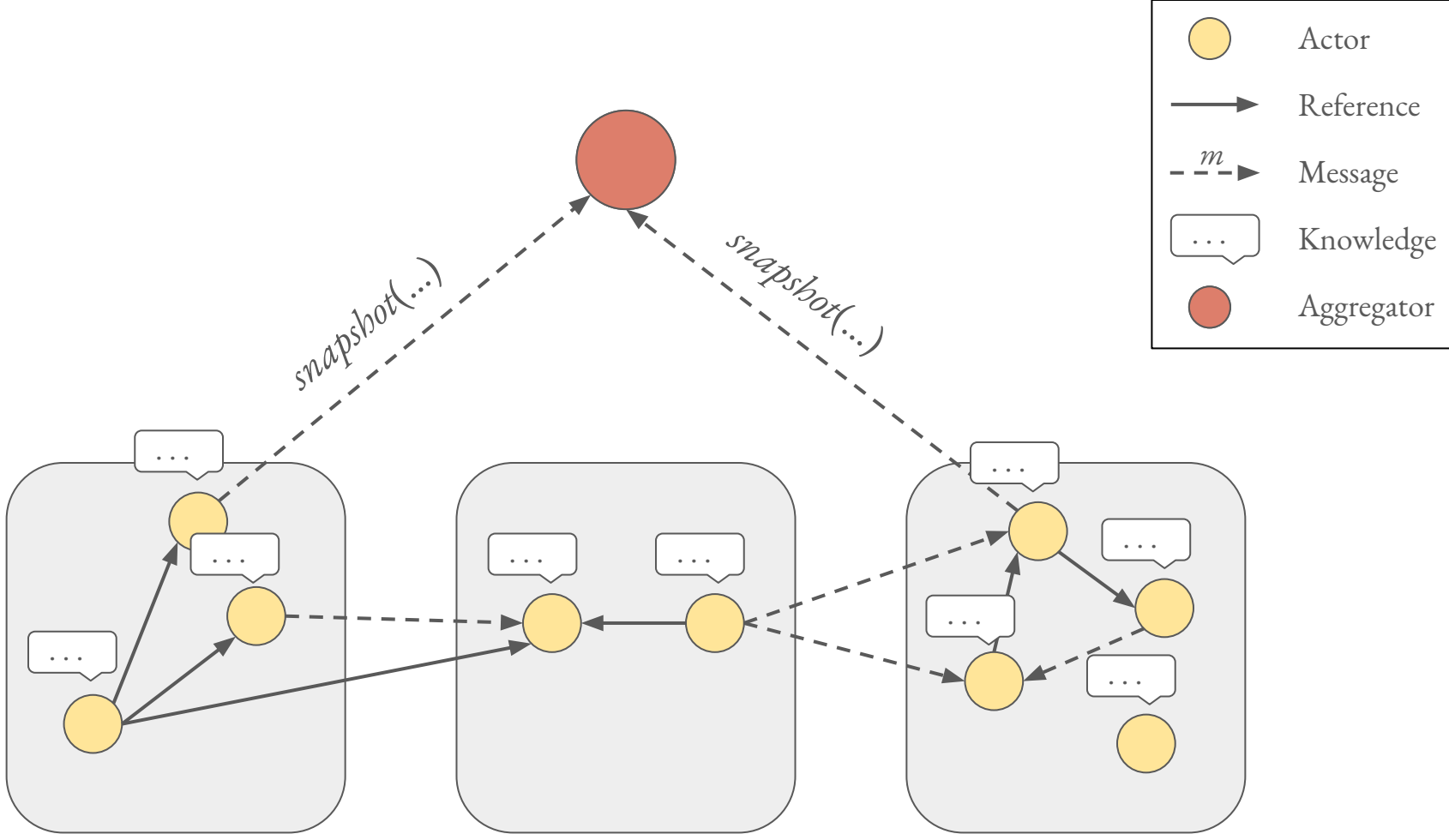
Demo

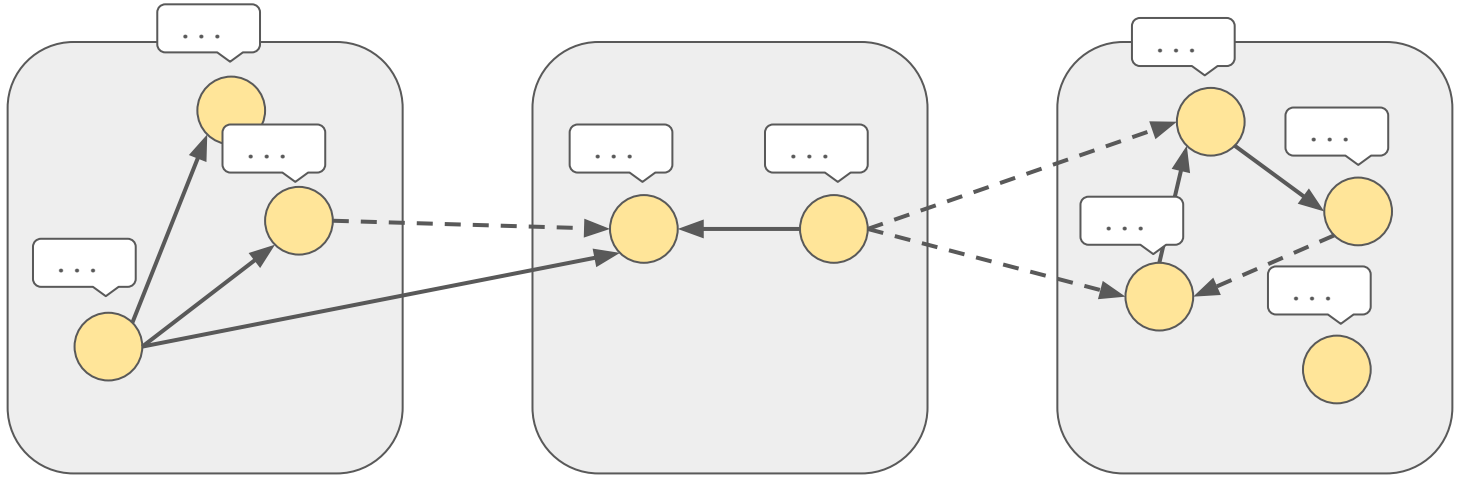

Actor
Reference
m
Message

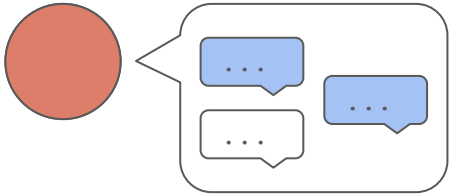

Actor
Reference
m
Message
Knowledge

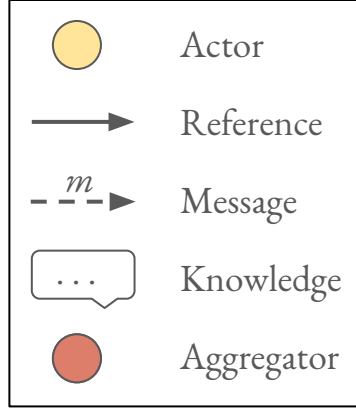

Actor
Reference
m
Message
Knowledge
Aggregator

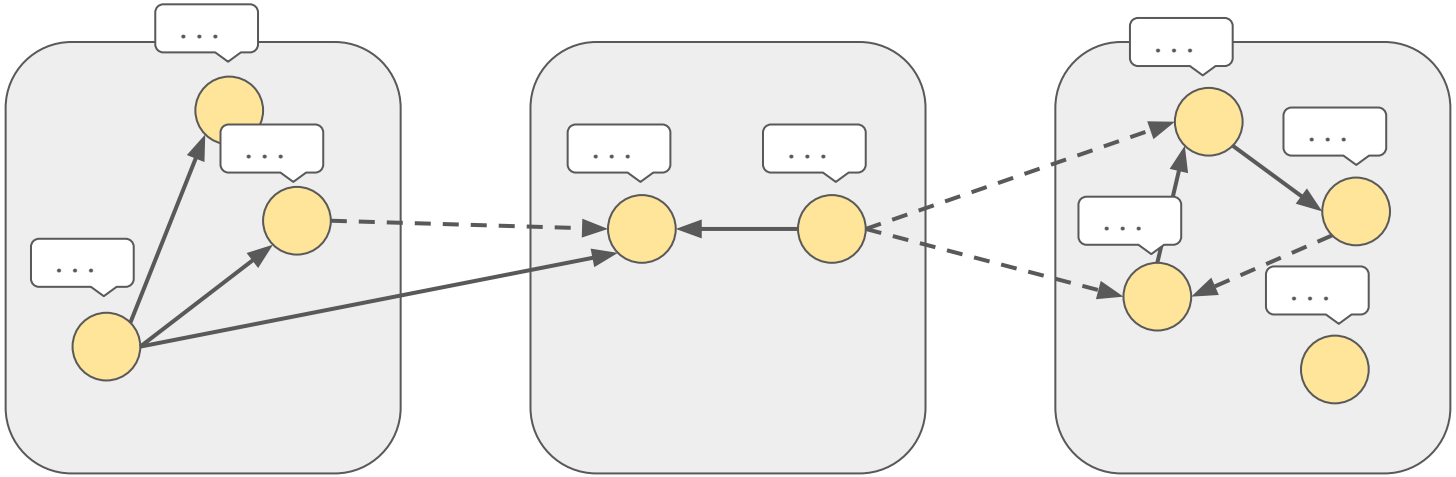

Actor
Reference
m
Message
Knowledge
Aggregator
snapshot(...)

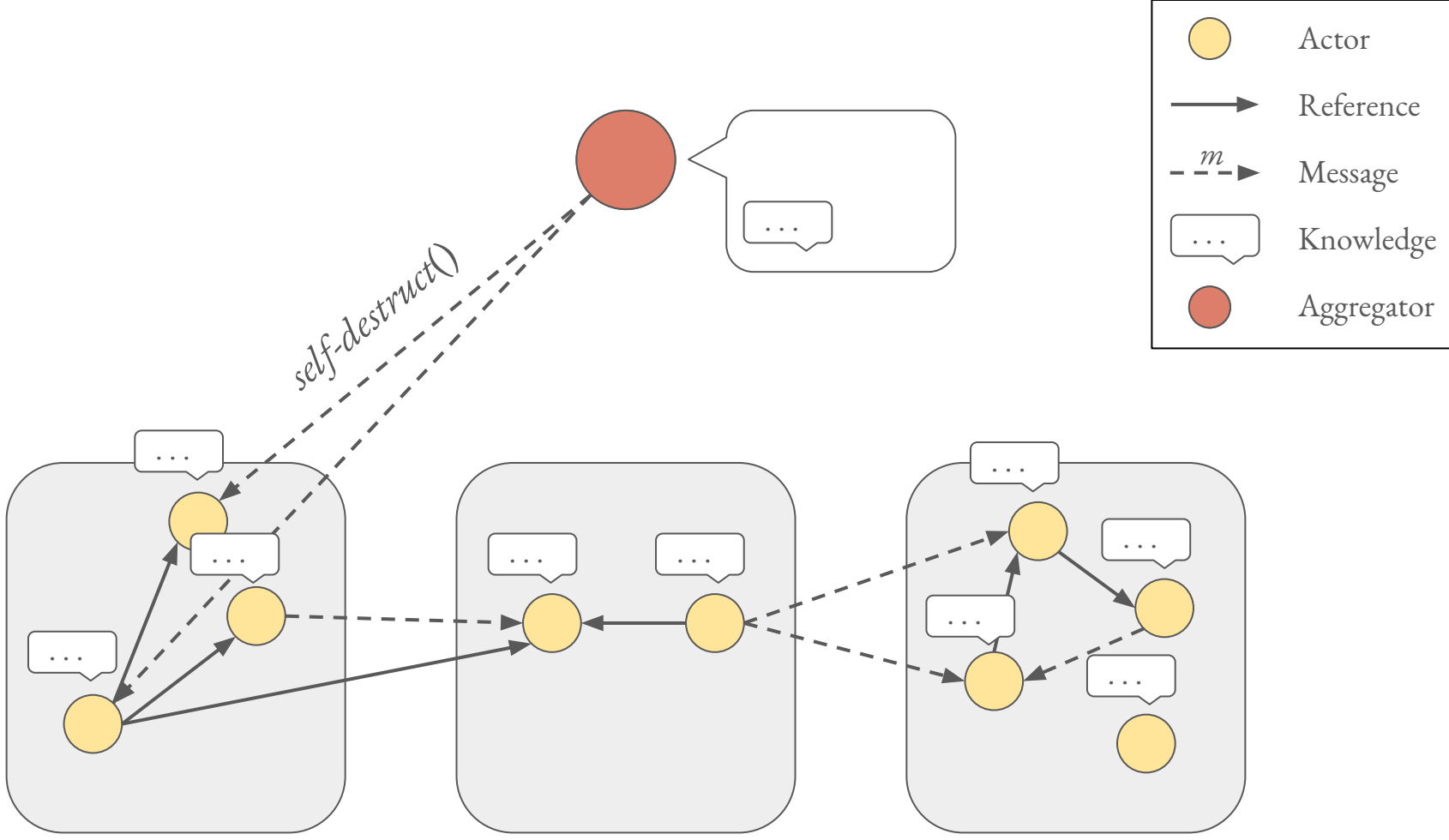

Actor
Reference
m
Message
Knowledge
Aggregator
snapshot(...)
snapshot(...)

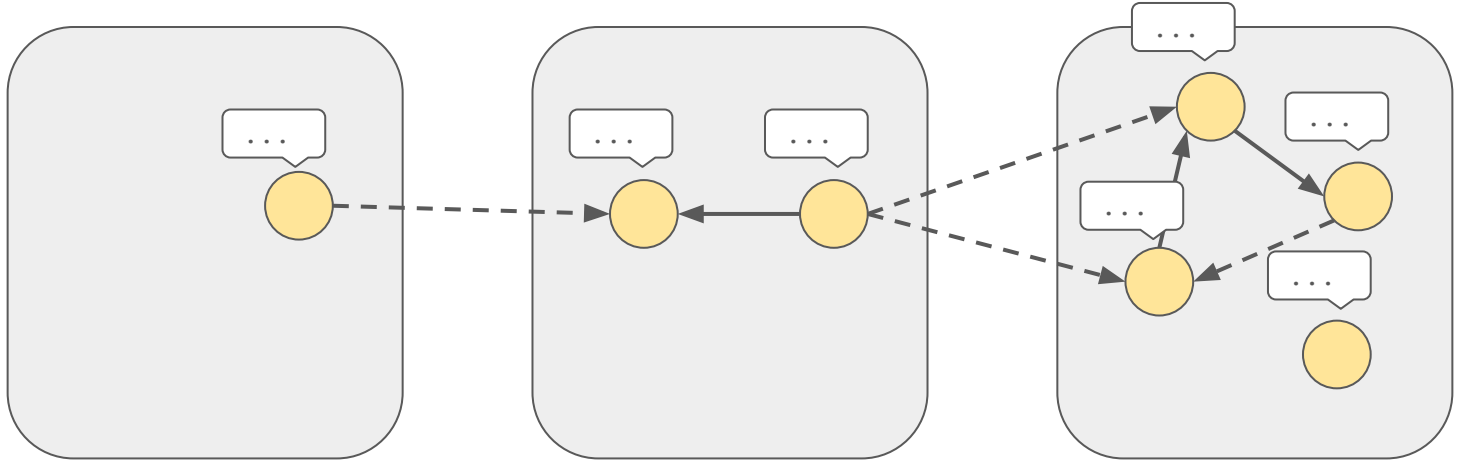

Actor
Reference
m
Message
Knowledge
Aggregator

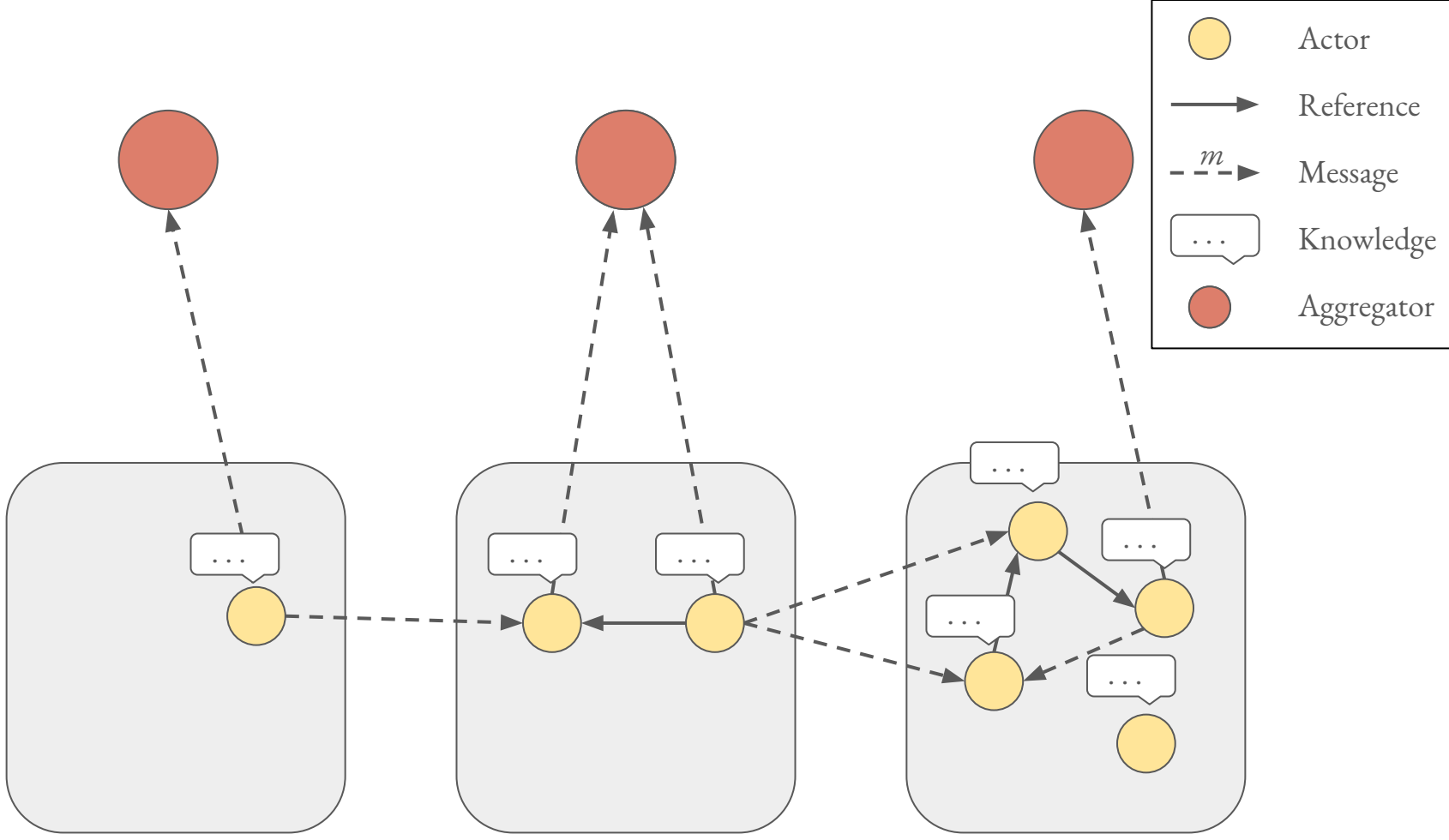


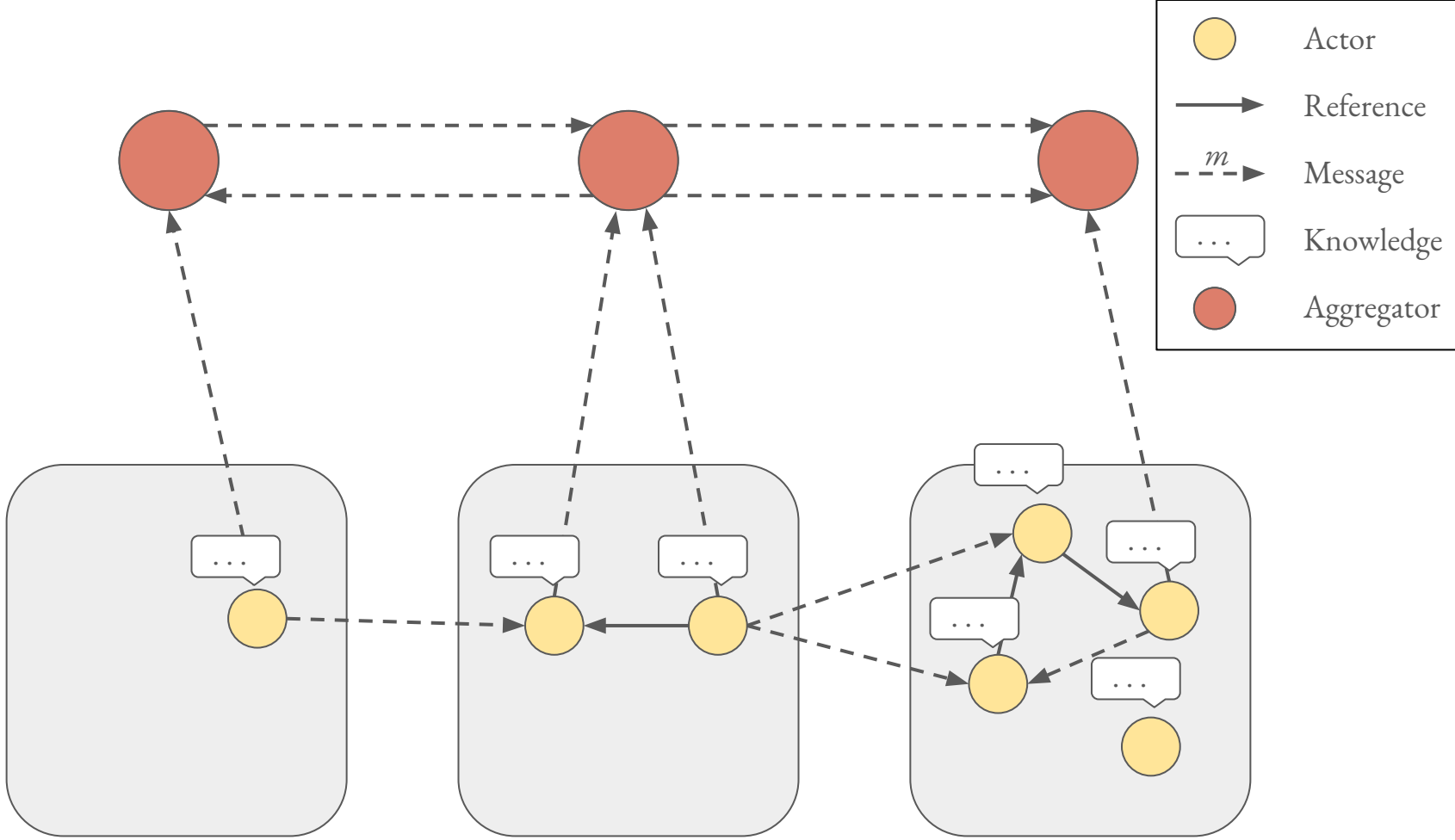

Actor
Reference
m
Message
Knowledge
Aggregator

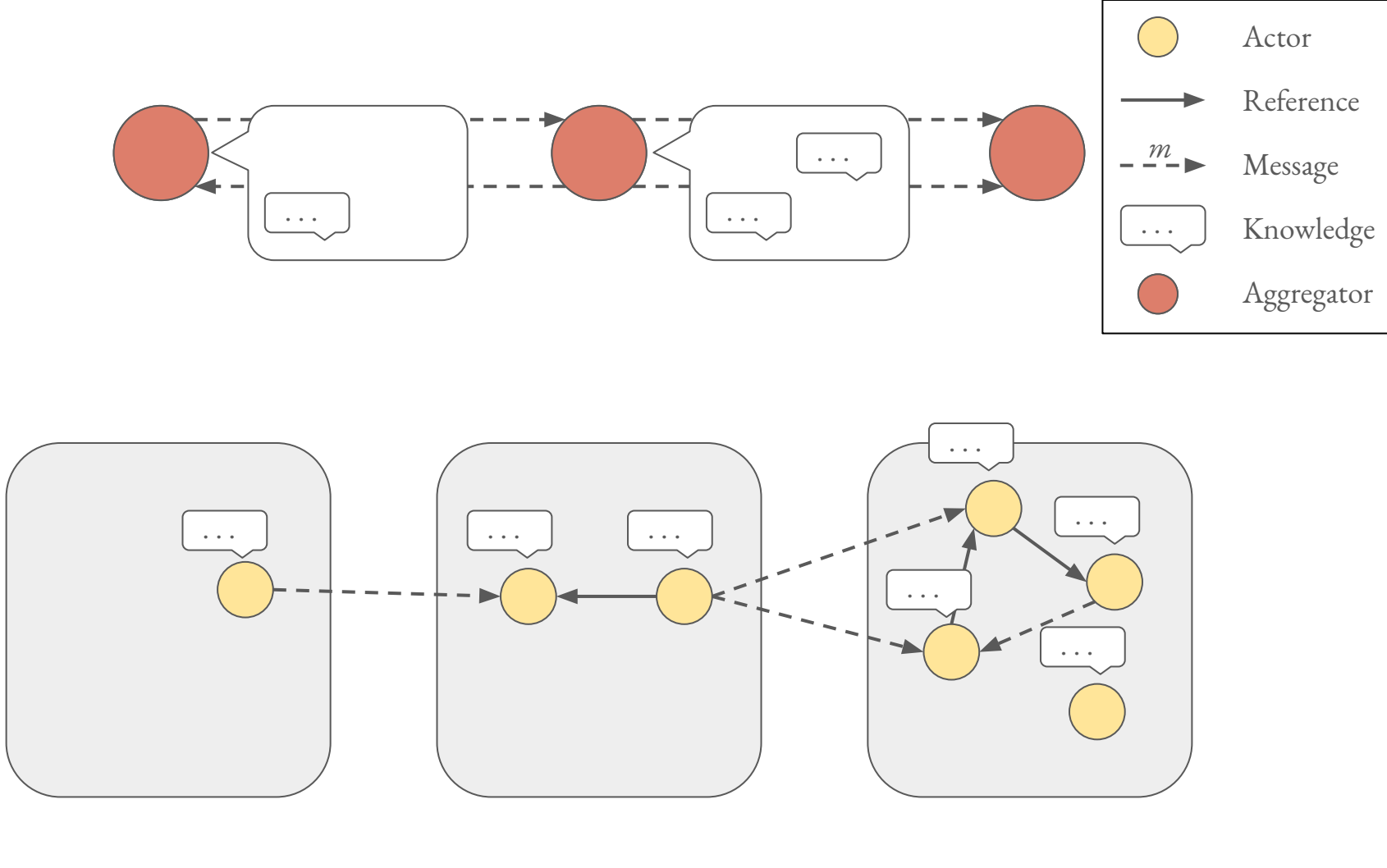


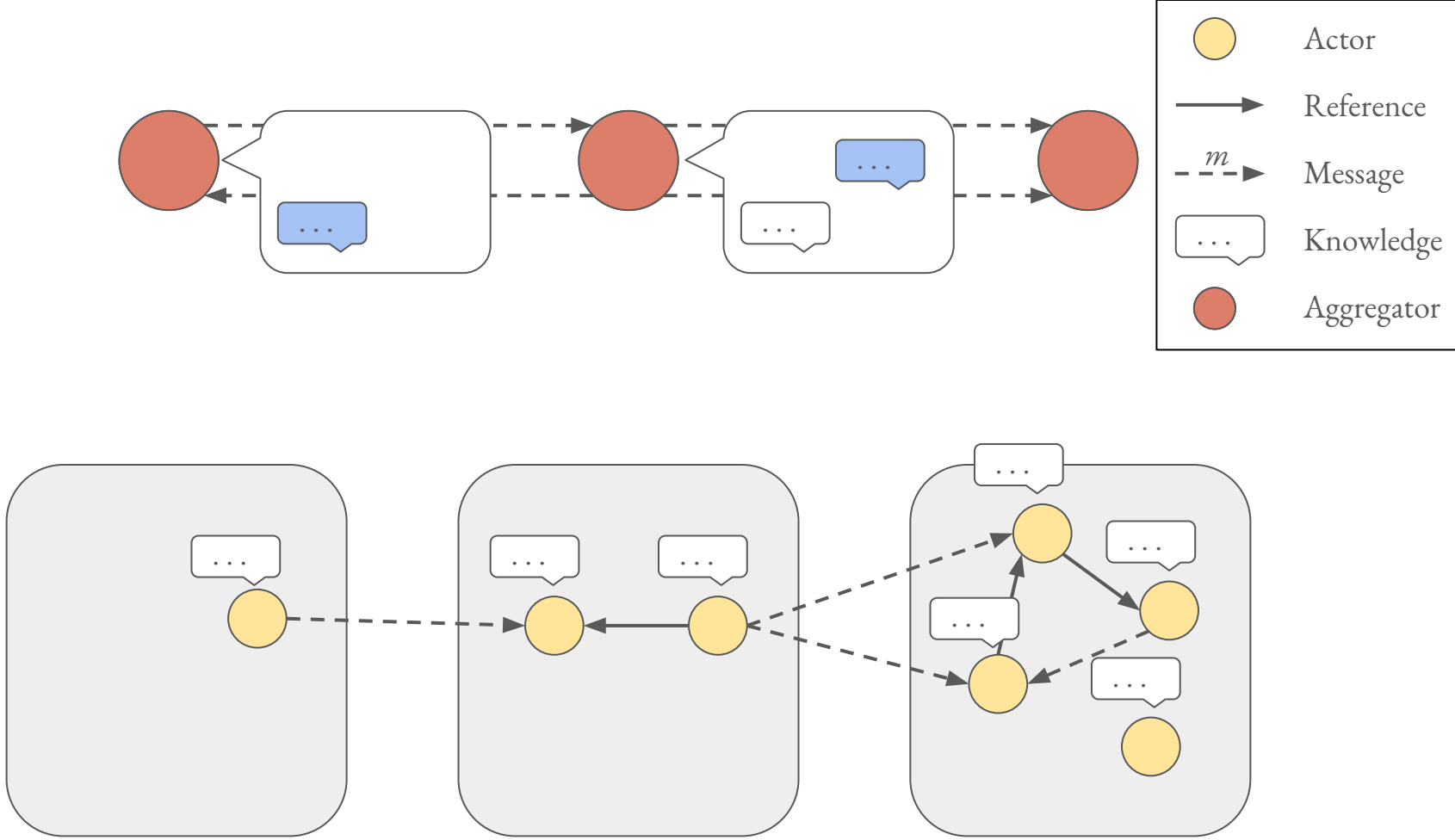

Actor
Reference
m
Message
Knowledge
Aggregator
self-destruct()

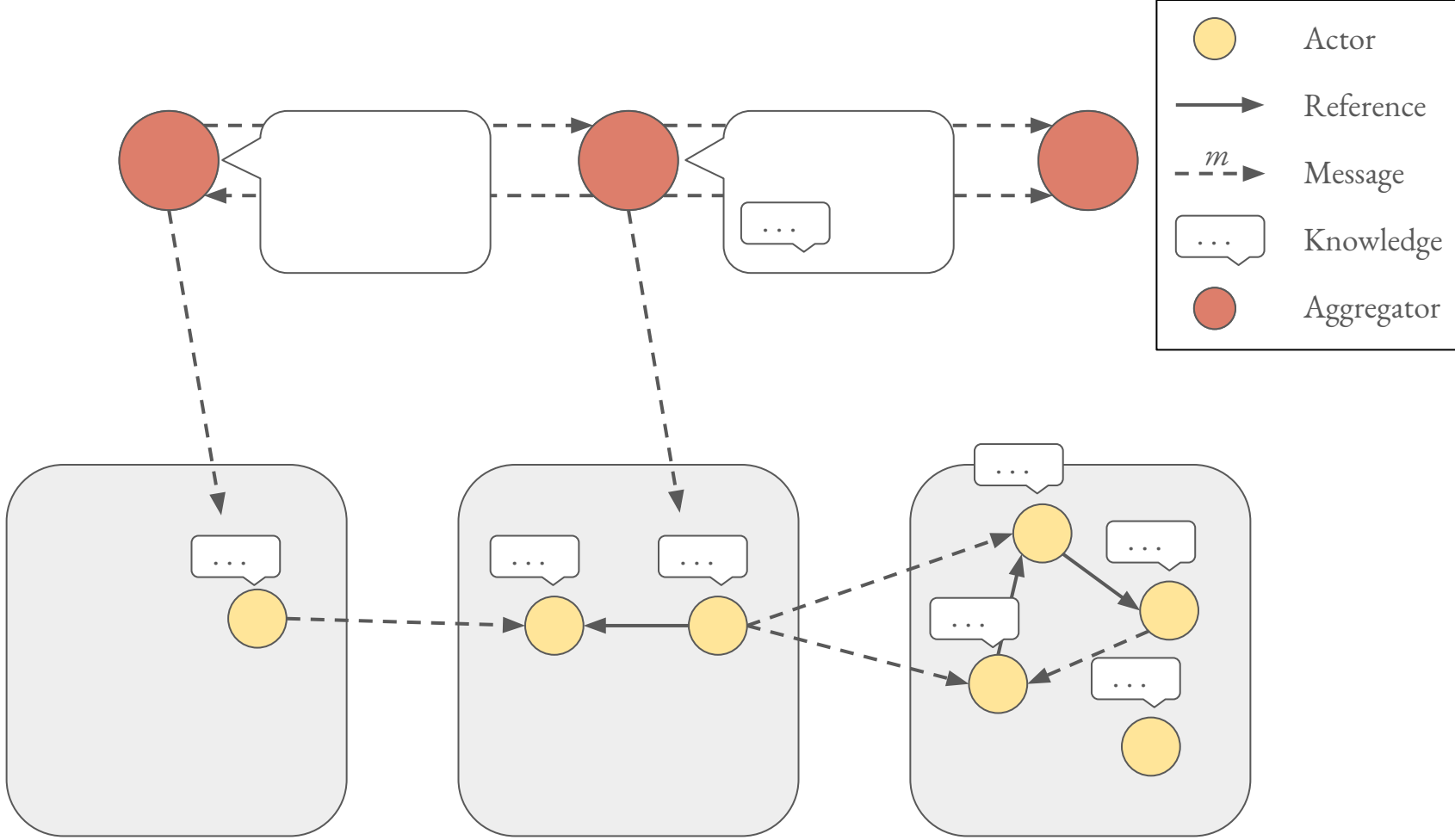

Actor
Reference
m
Message
Knowledge
Aggregator

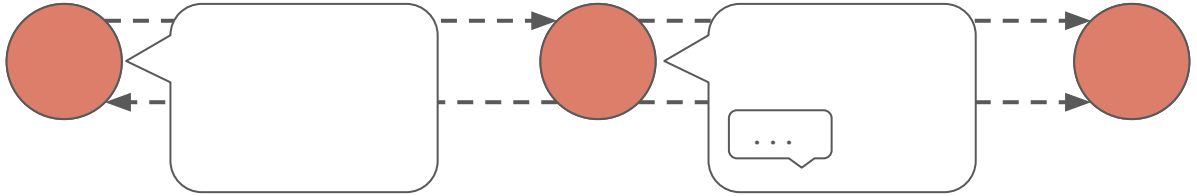

Actor
Reference
m
Message
Knowledge
Aggregator

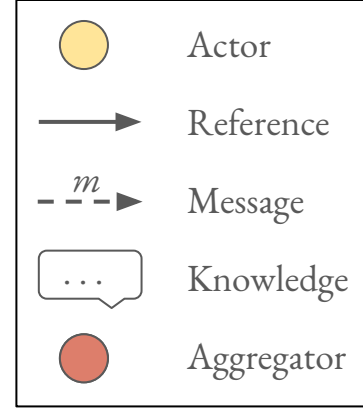

Actor
Reference
m
Message
Knowledge
Aggregator

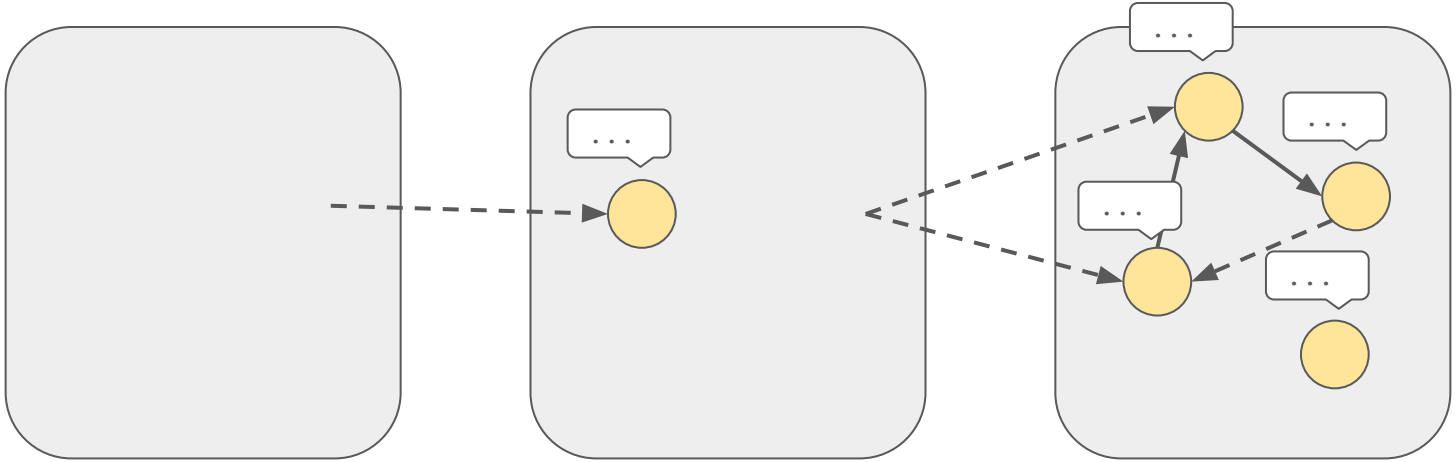

Actor
Reference
m
Message
Knowledge
Aggregator


Actor
Reference
m
Message
Knowledge
Aggregator


Actor
Reference
m
Message
Knowledge
Aggregator


...


Actor
Reference
m
Message
...
Knowledge
Aggregator


...
...
...
...
...

Detecting Terminated Actors

Detecting Terminated Actors

Q: How do you find an actor's **potential inverse acquaintances**?

Q: How do you know if an actor has **undelivered messages**?

Q: How do you know the snapshots are **consistent**?

Detecting Terminated Actors

Q: How do you find an actor's **potential inverse acquaintances**?

With contact tracing!

Q: How do you know if an actor has **undelivered messages**?

Q: How do you know the snapshots are **consistent**?

Detecting Terminated Actors

Q: How do you find an actor's **potential inverse acquaintances**?

With contact tracing!

Q: How do you know if an actor has **undelivered messages**?

With message counts!

Q: How do you know the snapshots are **consistent**?

Detecting Terminated Actors

Q: How do you find an actor's **potential inverse acquaintances**?

With contact tracing!

Q: How do you know if an actor has **undelivered messages**?

With message counts!

Q: How do you know the snapshots are **consistent**?

Magic!

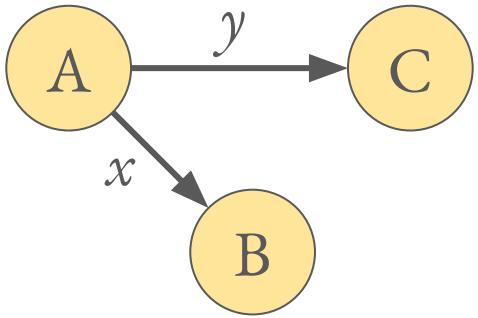
Part III: Contact Tracing

Contact Tracing

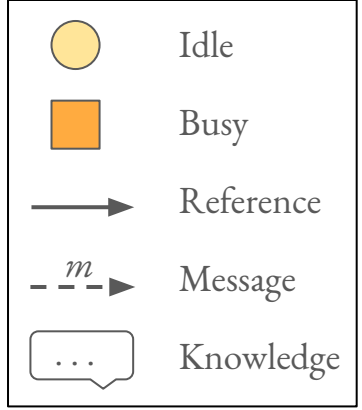
- Actors must use *reference objects* (**refobs**) instead of ordinary references
- Refobs are denoted (x : A ⁻◦ B), where x is a globally unique **token**
- Can only be used by the **owner** A to send messages to the **target** B
- Must be **deactivated** when no longer needed
- Actor gets a refob when it spawns a child
- If A has (x : A ⁻◦ B) and (y : A ⁻◦ C) then A can create (z : C ⁻◦ B)

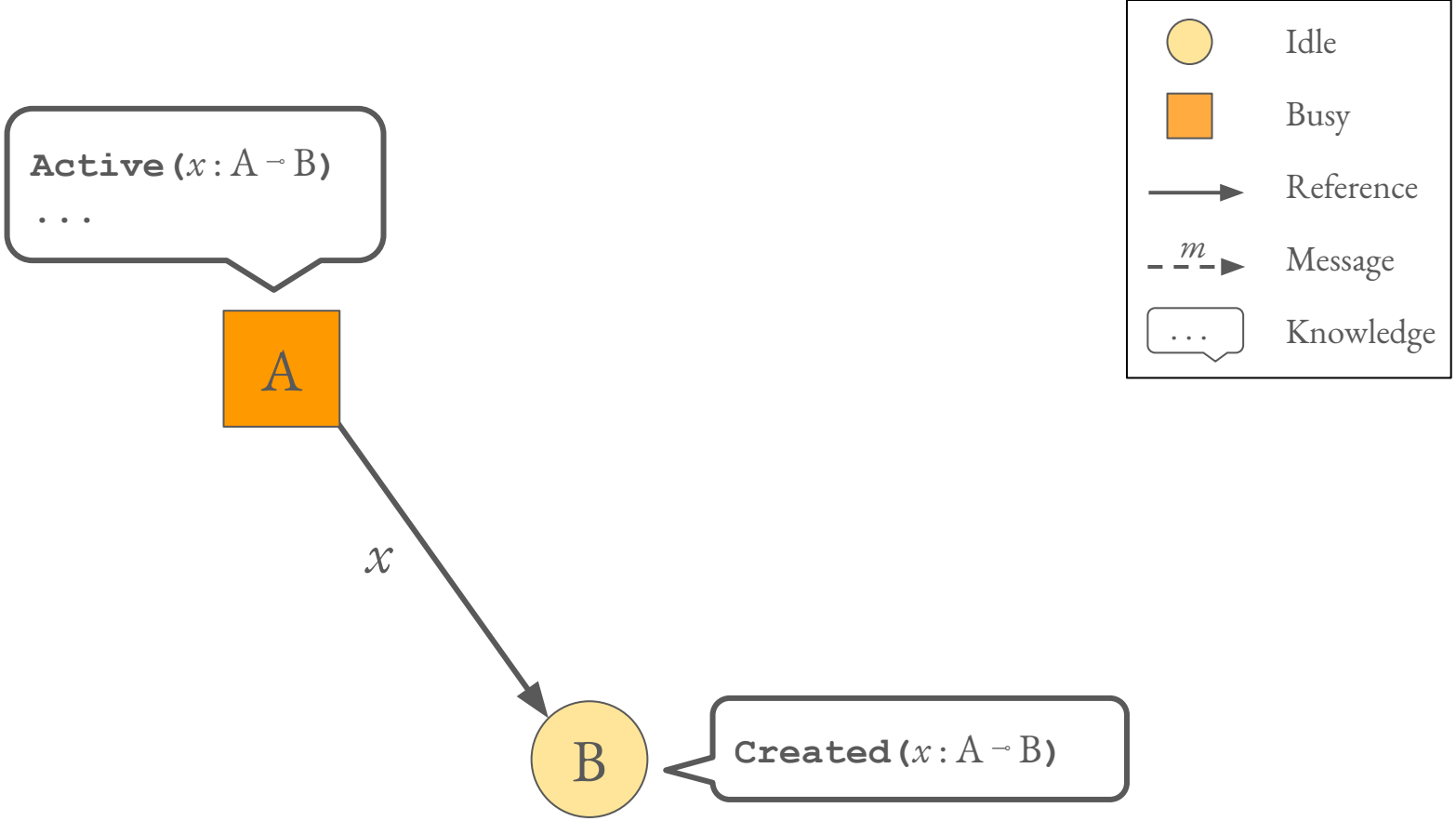
Contact Tracing

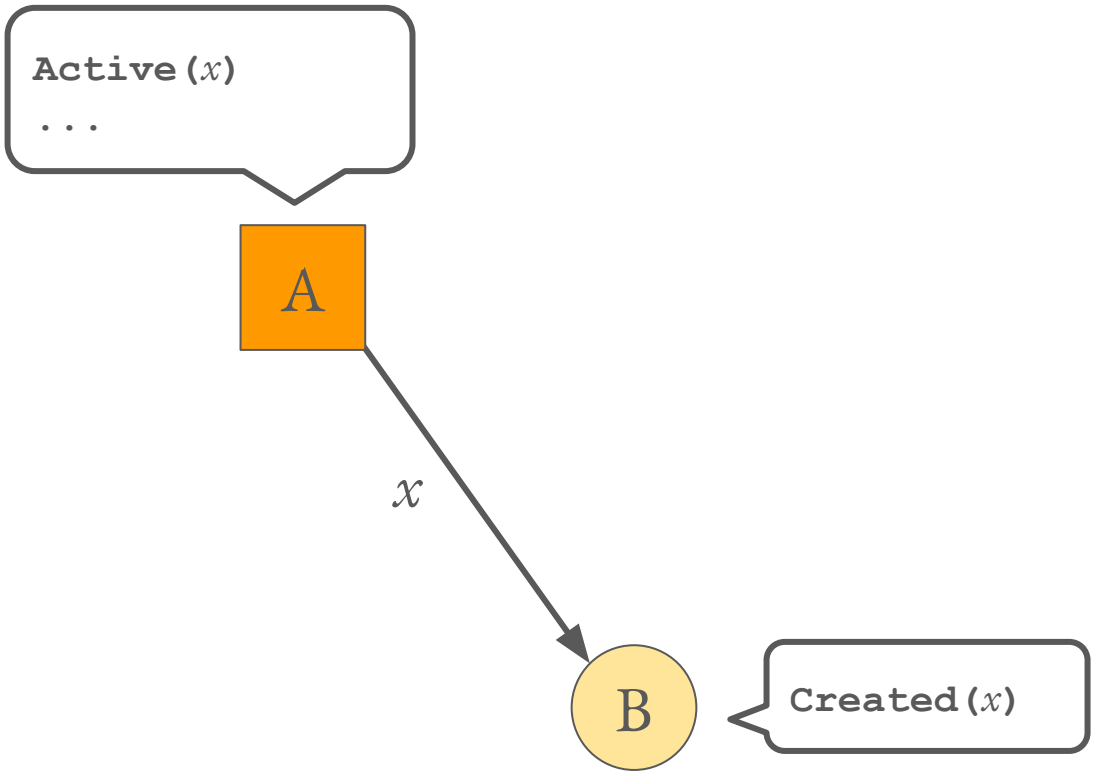
- Actors must use *reference objects* (**refobs**) instead of ordinary references
- Refobs are denoted ($x : \mathrm{A} \multimap \mathrm{B}$), where x is a globally unique **token**
- Can only be used by the **owner** A to send messages to the **target** B
- Must be **deactivated** when no longer needed
- Actor gets a refob when it spawns a child
- If A has ($x : \mathrm{A} \multimap \mathrm{B}$) and ($y : \mathrm{A} \multimap \mathrm{C}$) then A can create ($z : \mathrm{C} \multimap \mathrm{B}$)

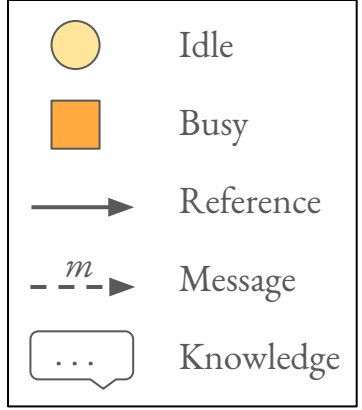


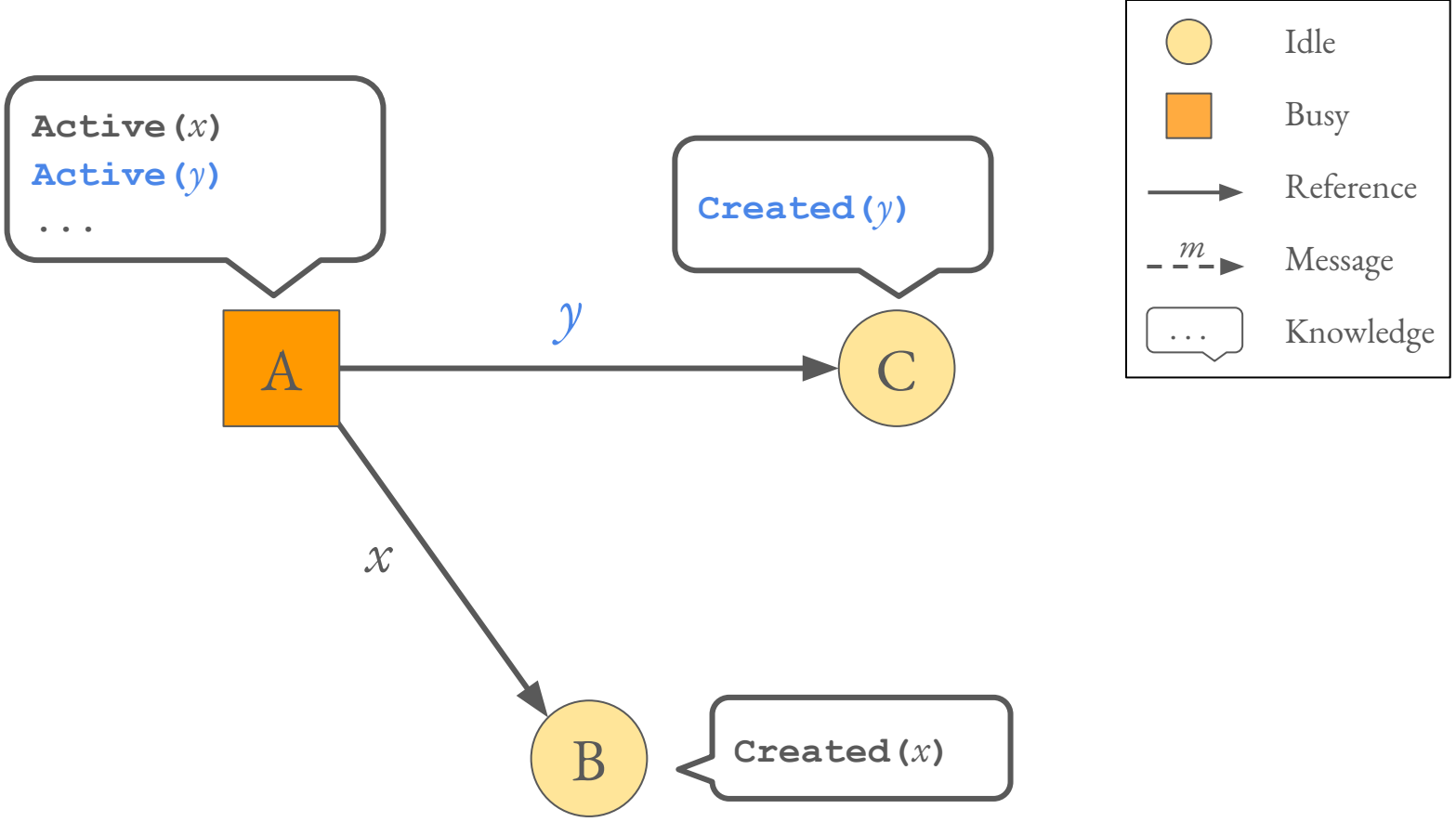

A

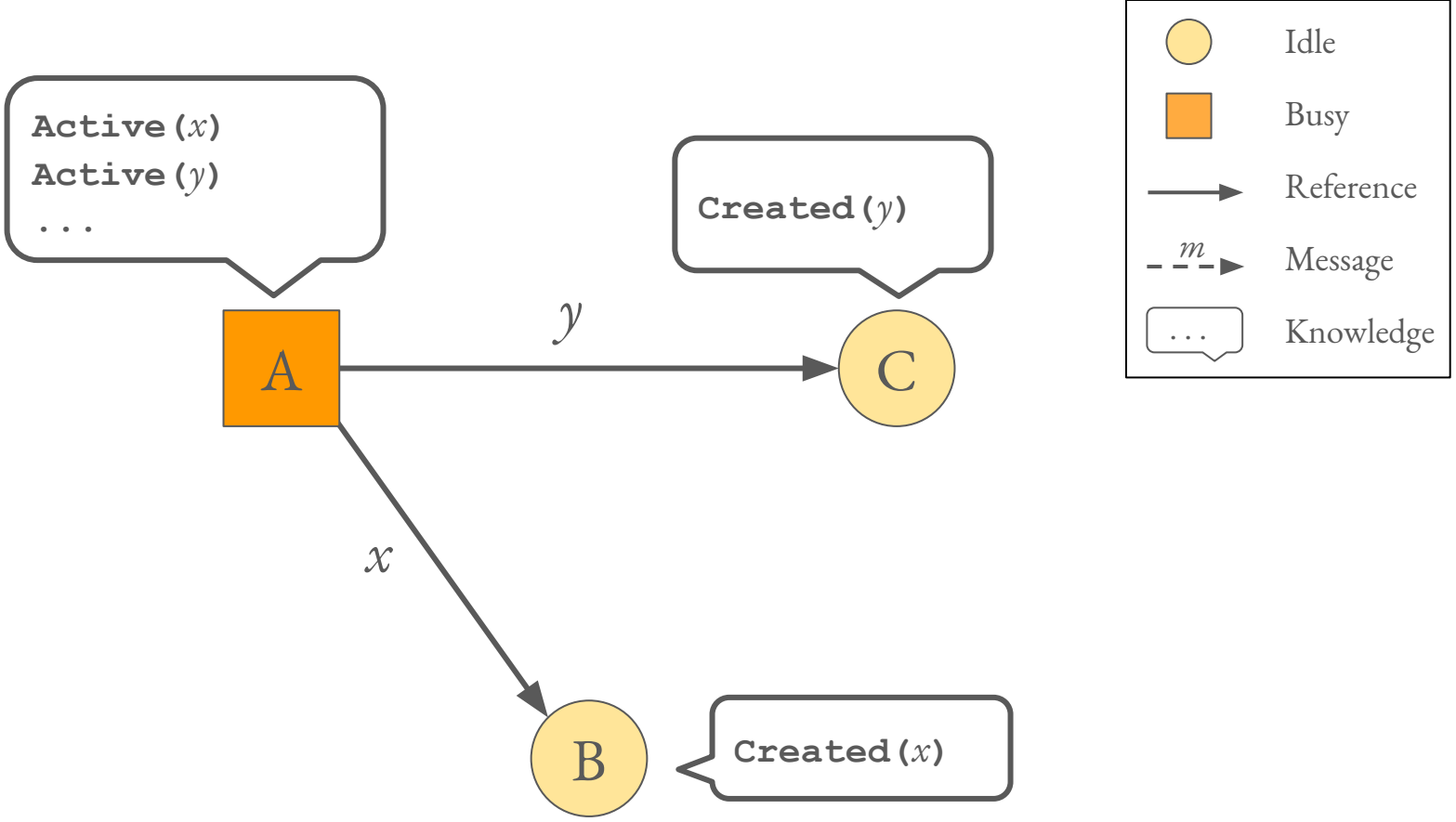

Idle
Busy
Reference
m
Message
Knowledge

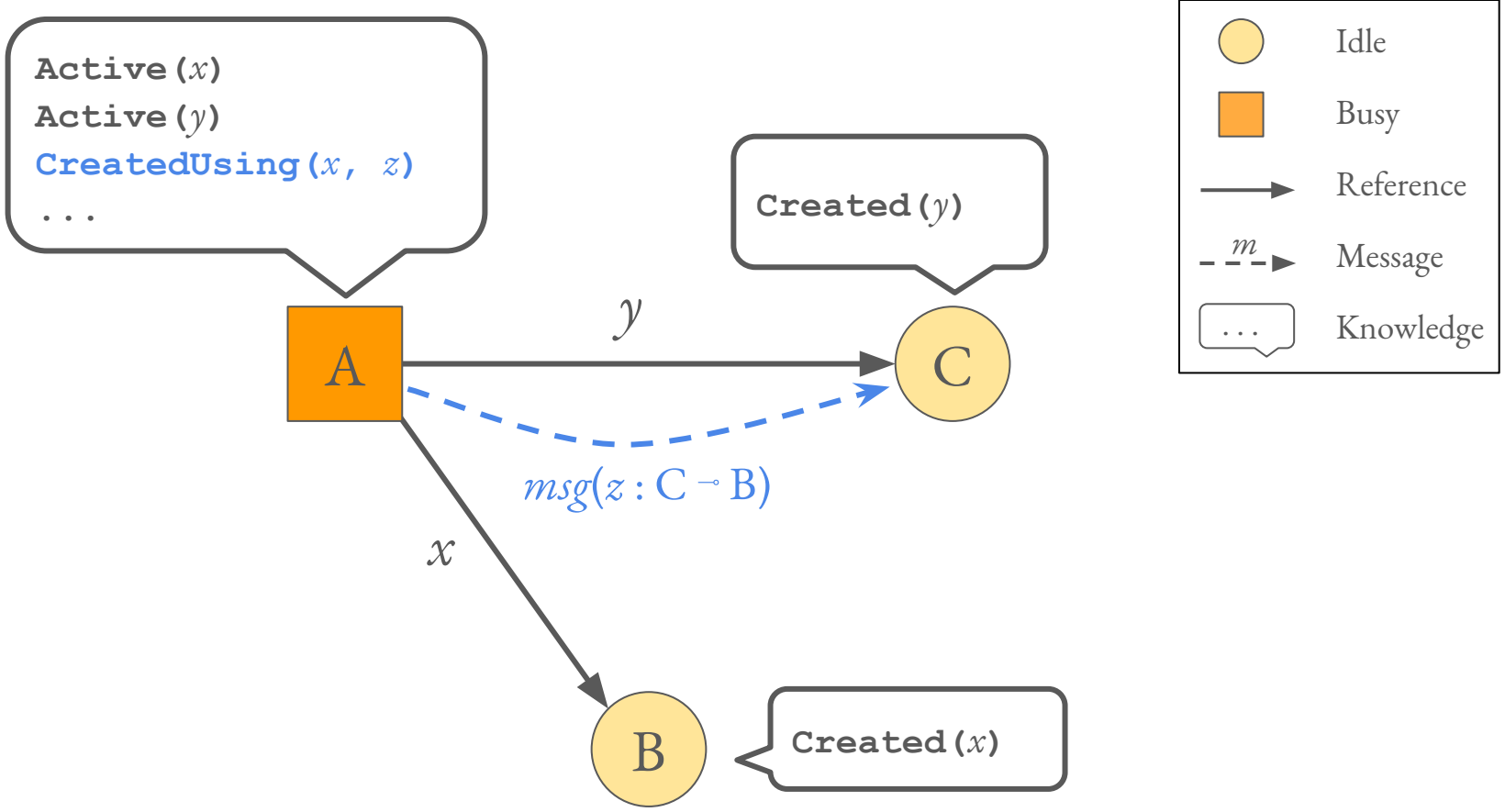

Active(x : A ⊸ B)
. . .
A
x
B
Created(x : A ⊸ B)
Idle
Busy
Reference
m
Message
. . .
Knowledge

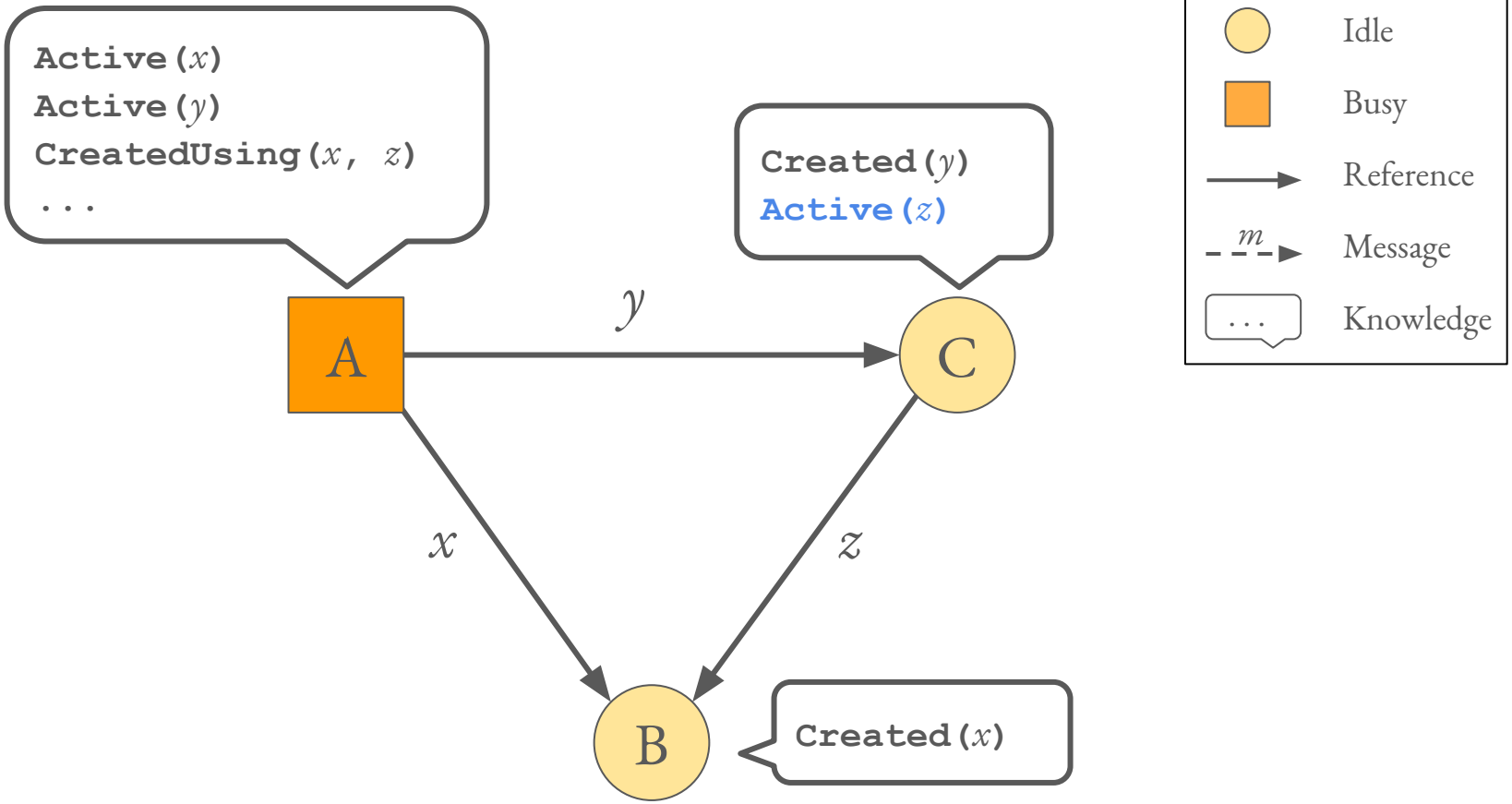

Active(x)
...
A
x
B
Created(x)

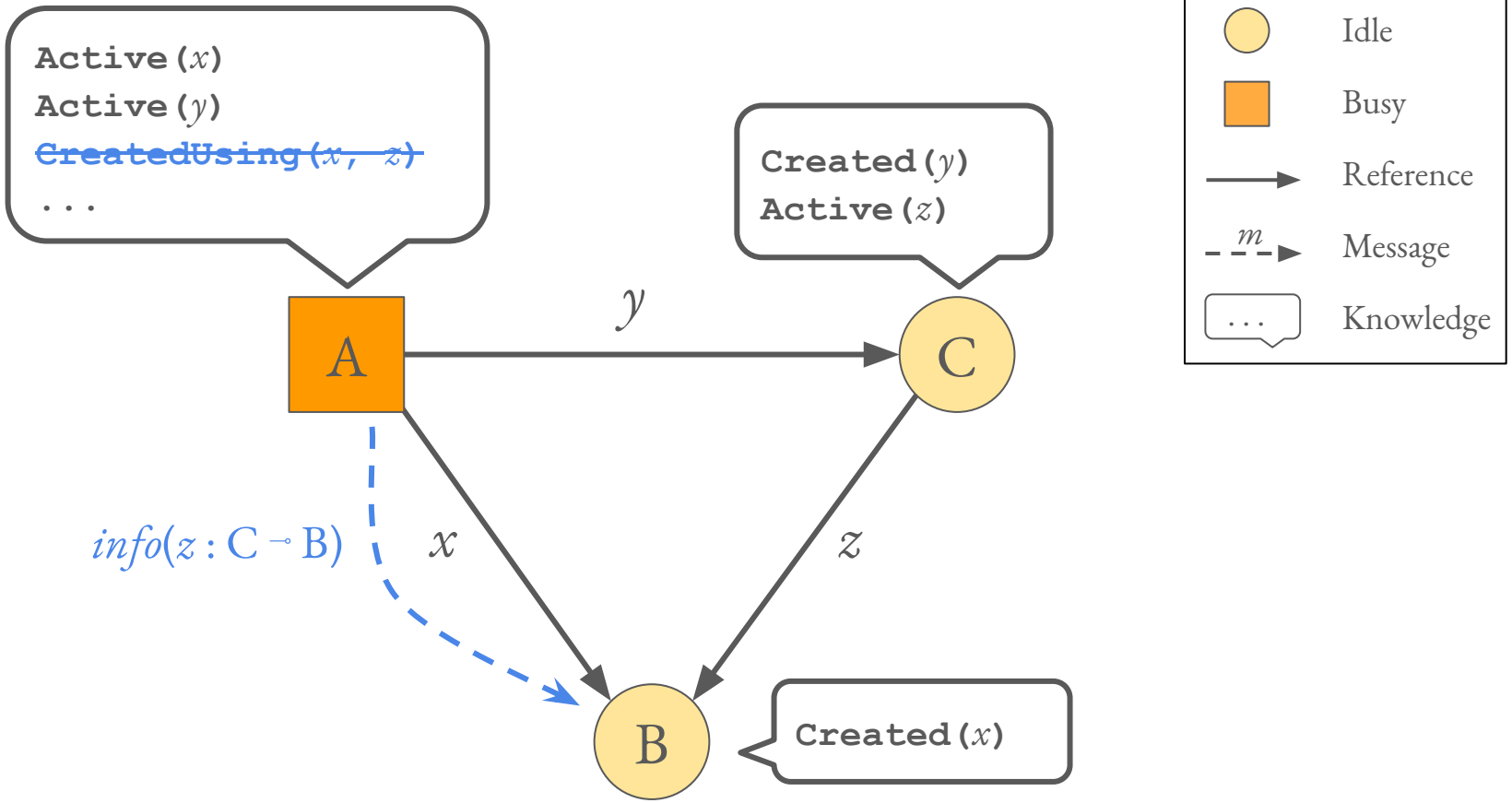

Idle
Busy
Reference
m
Message
...
Knowledge

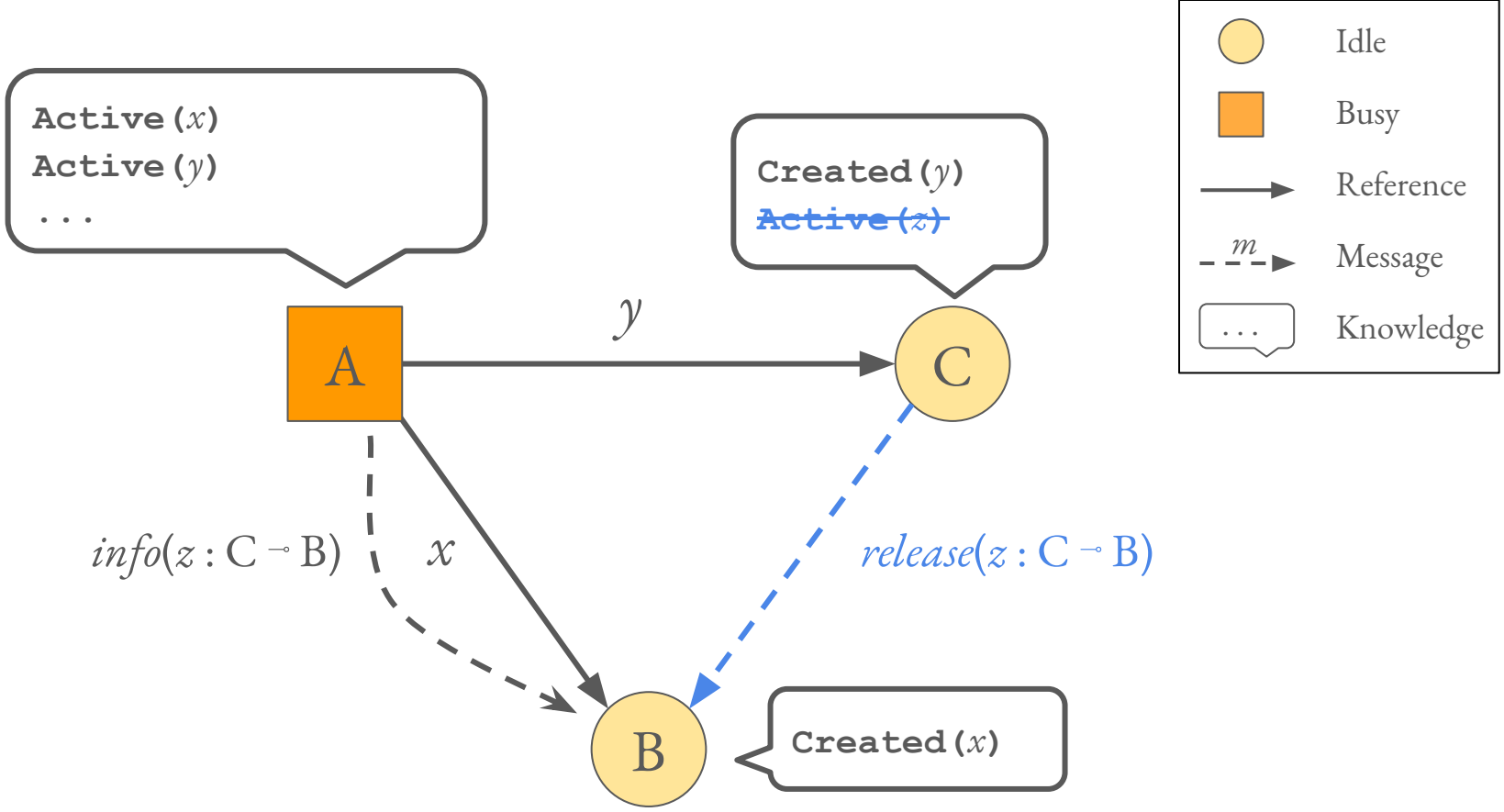

Active(x)
Active(y)
. . .
Created(y)
A
y
C
x
B
Created(x)
Idle
Busy
Reference
m
Message
. . .
Knowledge


Active(x)
Active(y)
...
Created(y)
A
y
C
x
B
Created(x)
Idle
Busy
Reference
m
Message
...
Knowledge

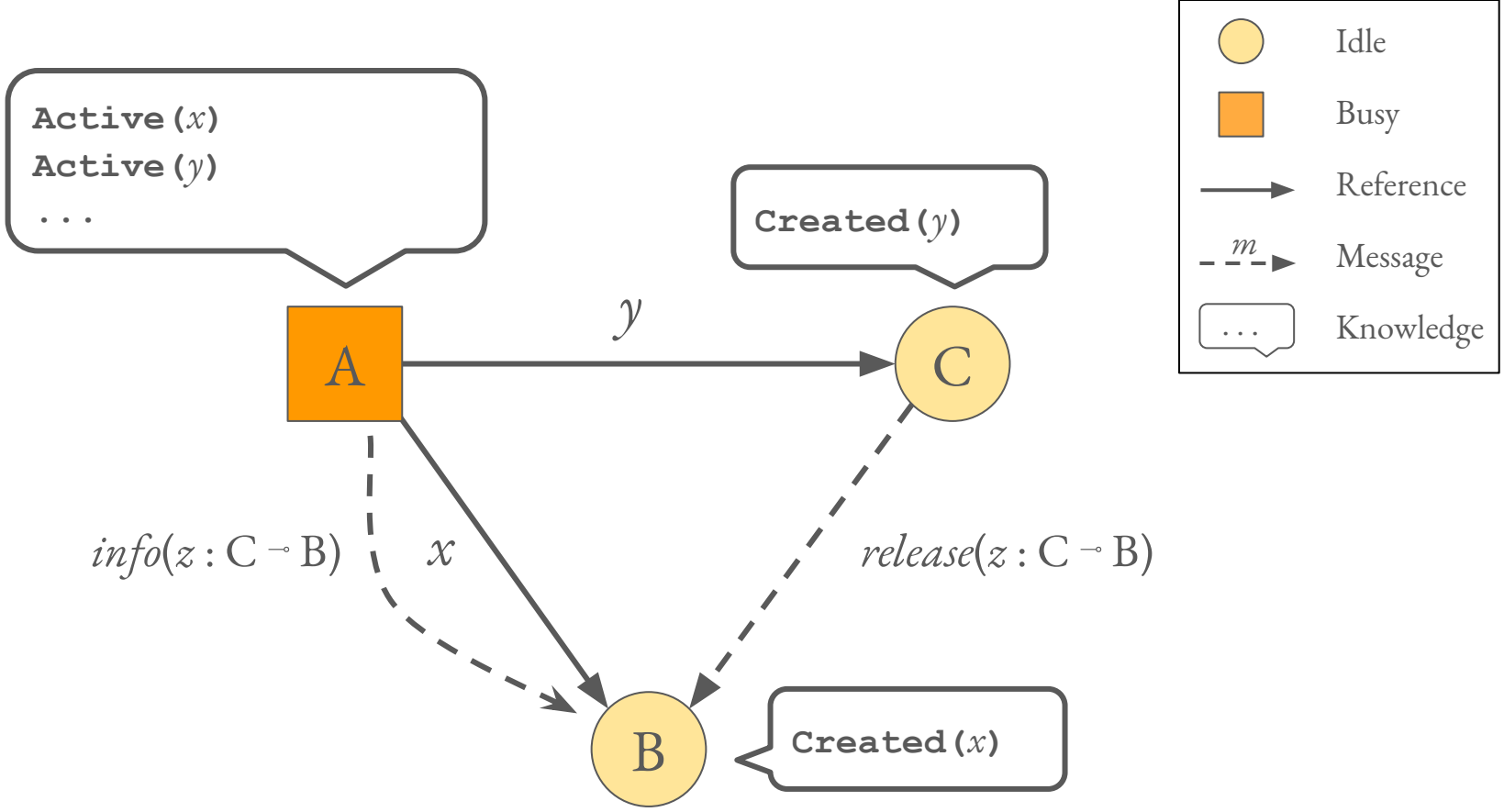

Active(x)
Active(y)
CreatedUsing(x, z)
...
Created(y)
A
y
C
msg(z : C → B)
x
B
Created(x)
Idle
Busy
Reference
m
Message
...
Knowledge

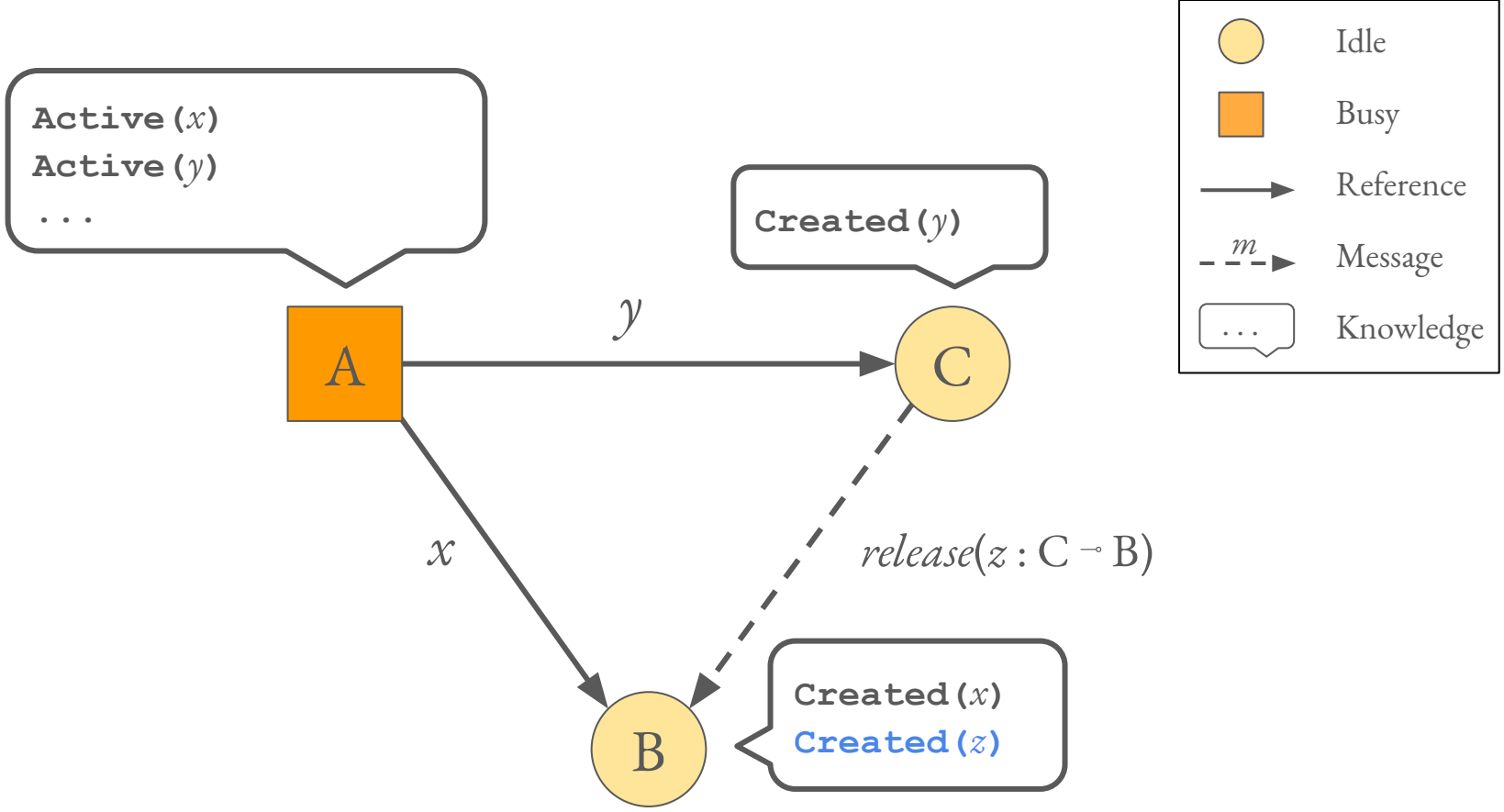

Active(x)
Active(y)
CreatedUsing(x, z)
...
Created(y)
Active(z)
A
C
B
y
x
z
Created(x)
Idle
Busy
Reference
m
Message
Knowledge

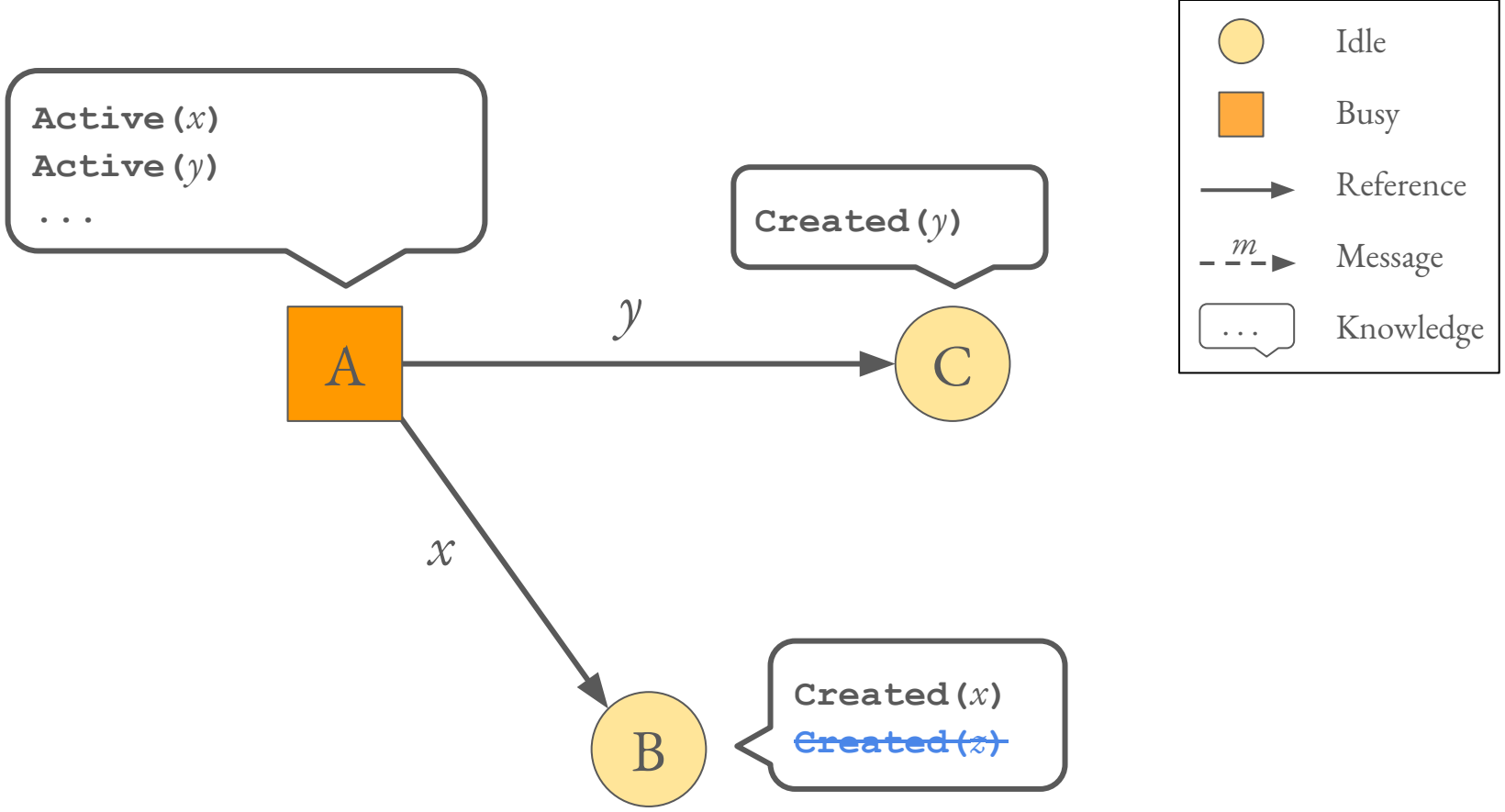

Active(x)
Active(y)
CreatedUsing(x, z)
...
Created(y)
Active(z)
A
C
B
y
x
z
info(z : C → B)
Created(x)
Idle
Busy
Reference
m
Message
Knowledge


Active(x)
Active(y)
...
Created(y)
Active(z)
A
y
C
info(z : C ⊸ B)
x
release(z : C ⊸ B)
B
Created(x)
Idle
Busy
Reference
m
Message
...
Knowledge

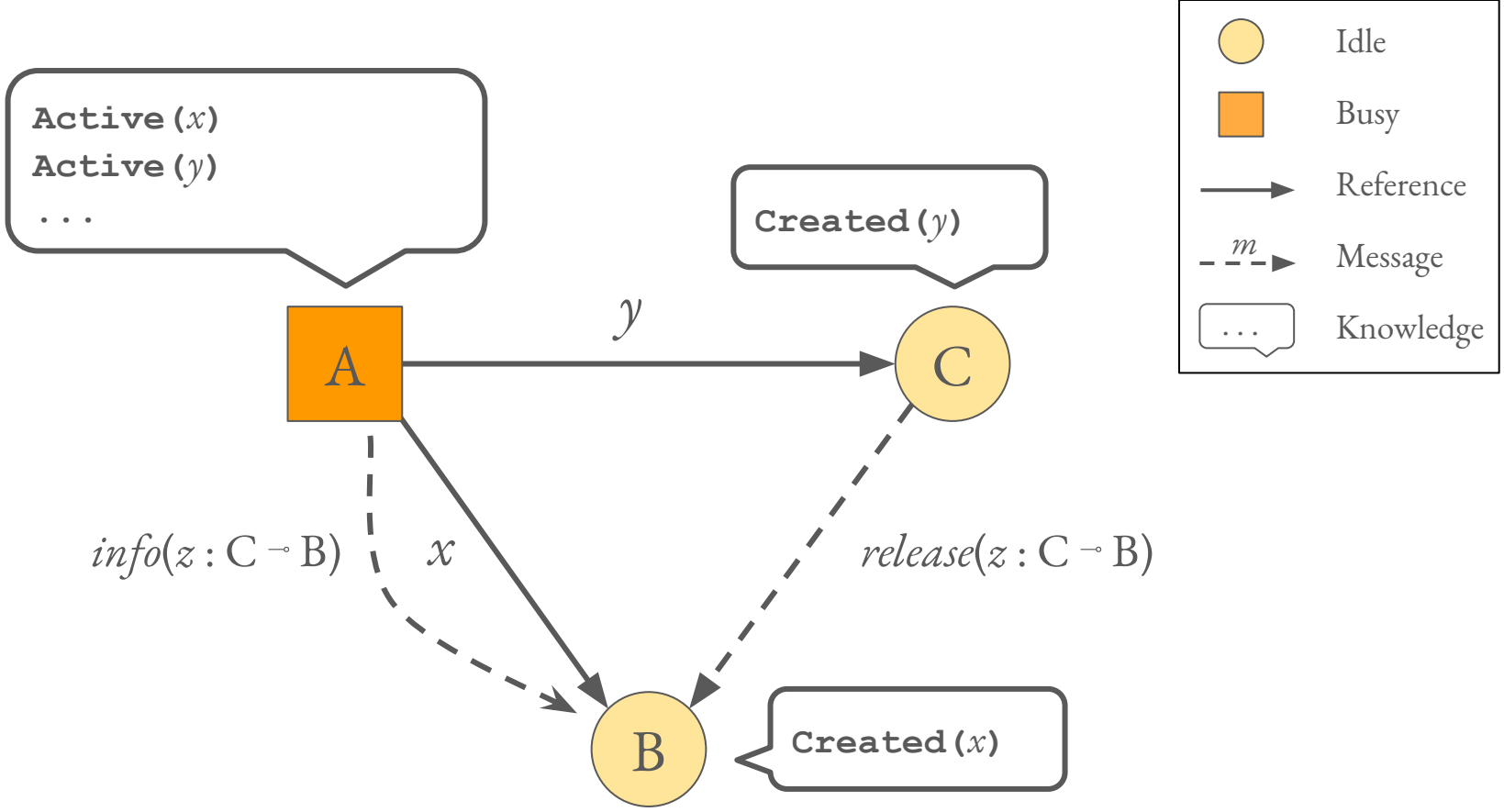
Case 1: *info* message arrives first

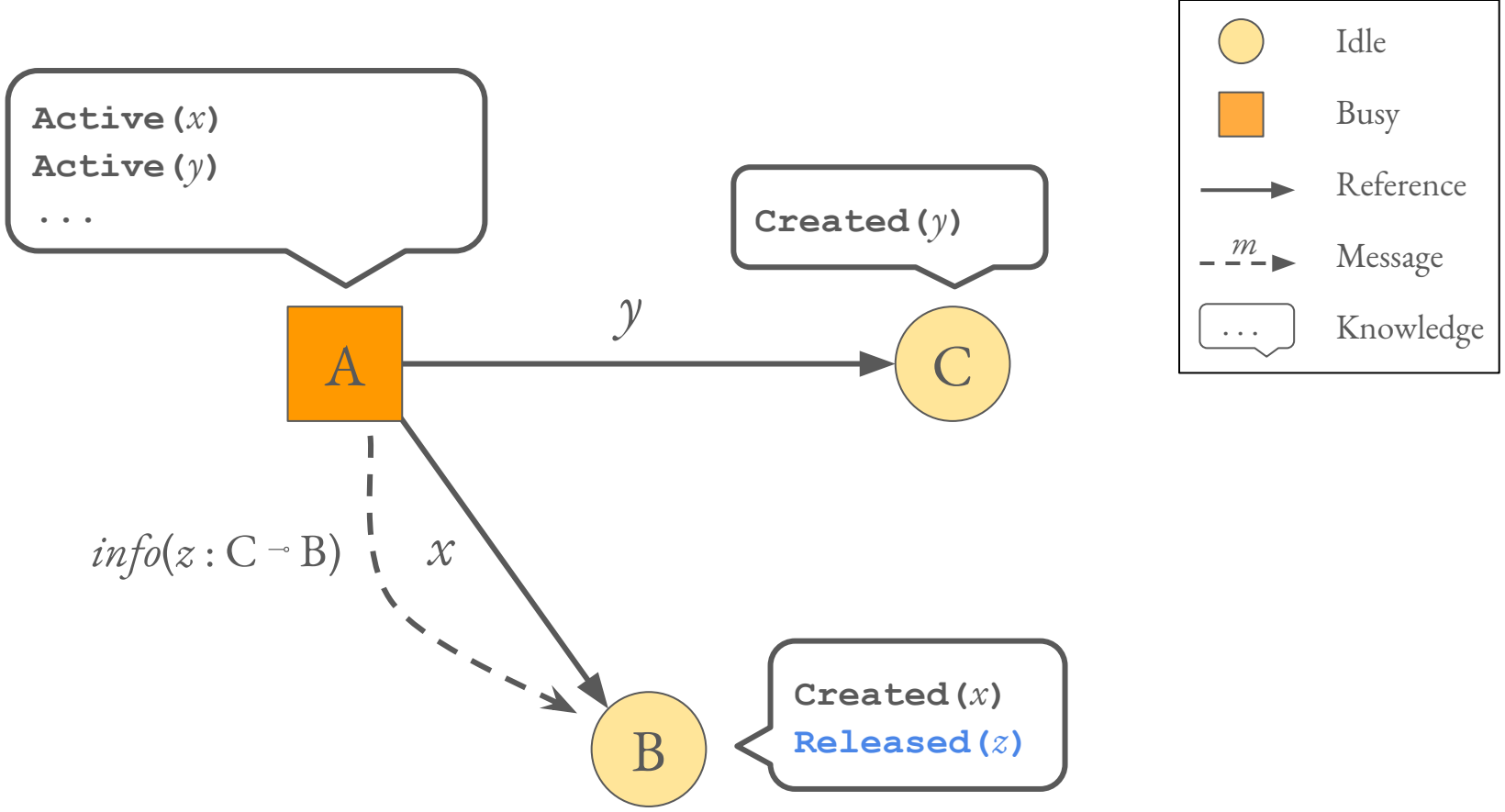

Active(x)
Active(y)
...
Created(y)
A
y
C
info(z : C ⊸ B)
x
release(z : C ⊸ B)
B
Created(x)
Idle
Busy
Reference
m
Message
...
Knowledge

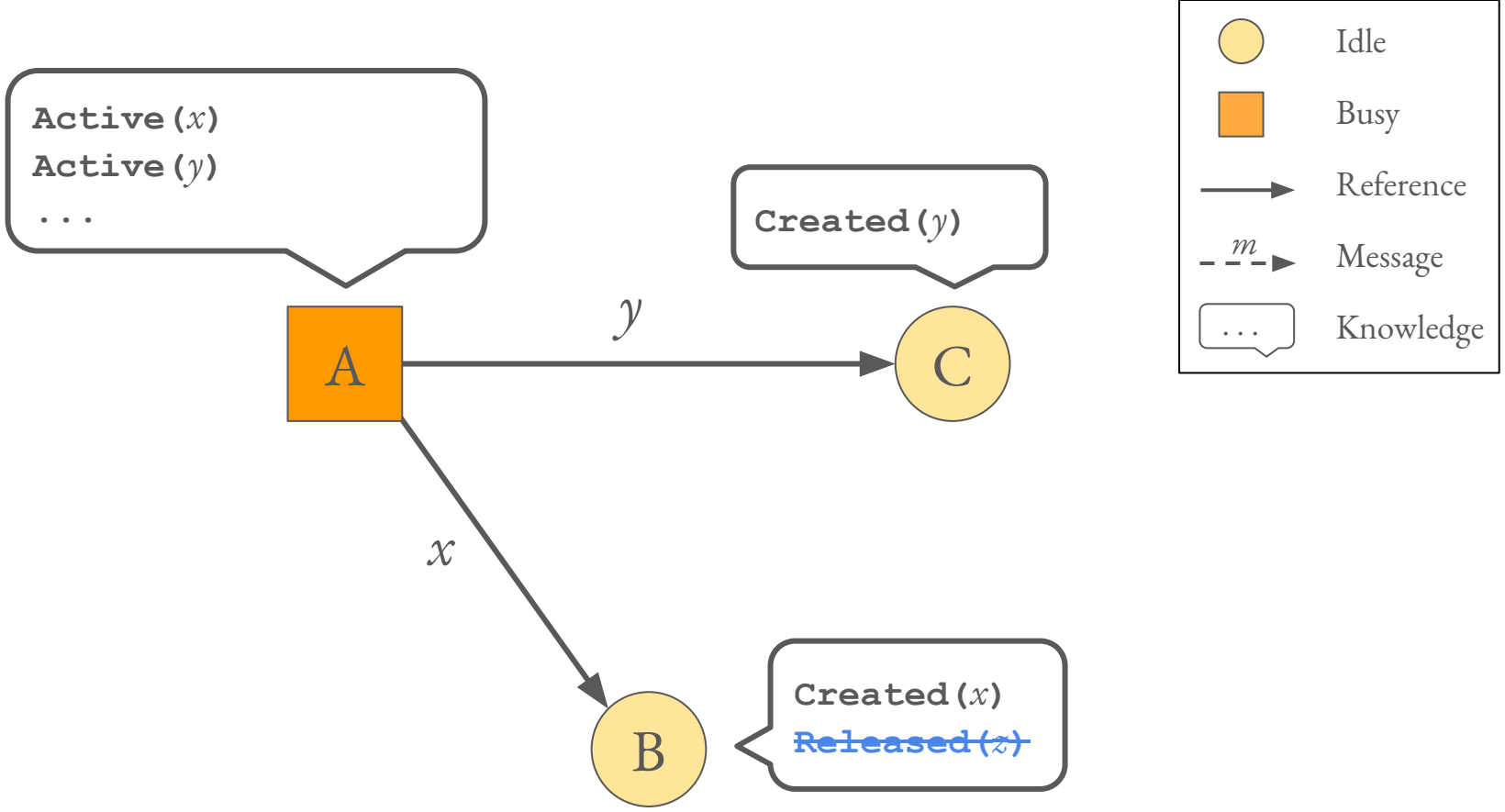

Active(x)
Active(y)
...
Created(y)
A
y
C
x
release(z : C ⊸ B)
B
Created(x)
Created(z)
Idle
Busy
Reference
m
Message
...
Knowledge


Active(x)
Active(y)
...
Created(y)
A
y
C
x
B
Created(x)
Created(z)
Idle
Busy
Reference
m
Message
...
Knowledge

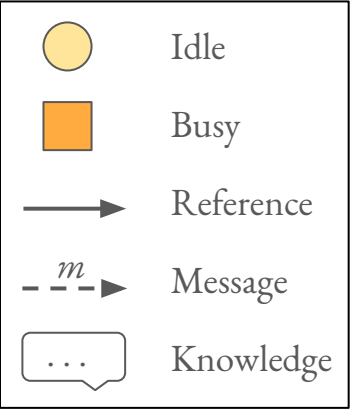
Case 2: *release* message arrives first


Active(x)
Active(y)
...
Created(y)
A
y
C
info(z : C ⊸ B)
x
release(z : C ⊸ B)
B
Created(x)
Idle
Busy
Reference
m
Message
...
Knowledge

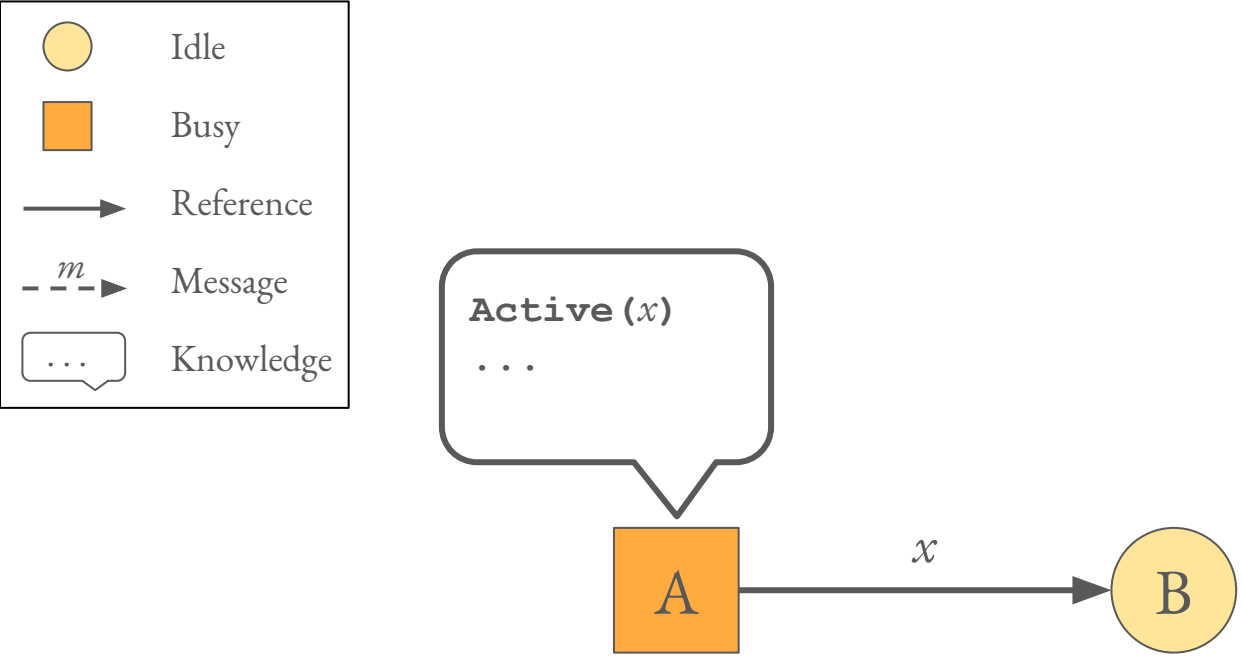

Active(x)
Active(y)
...
Created(y)
A
y
C
info(z : C ⊸ B)
x
B
Created(x)
Released(z)
Idle
Busy
Reference
m
Message
...
Knowledge

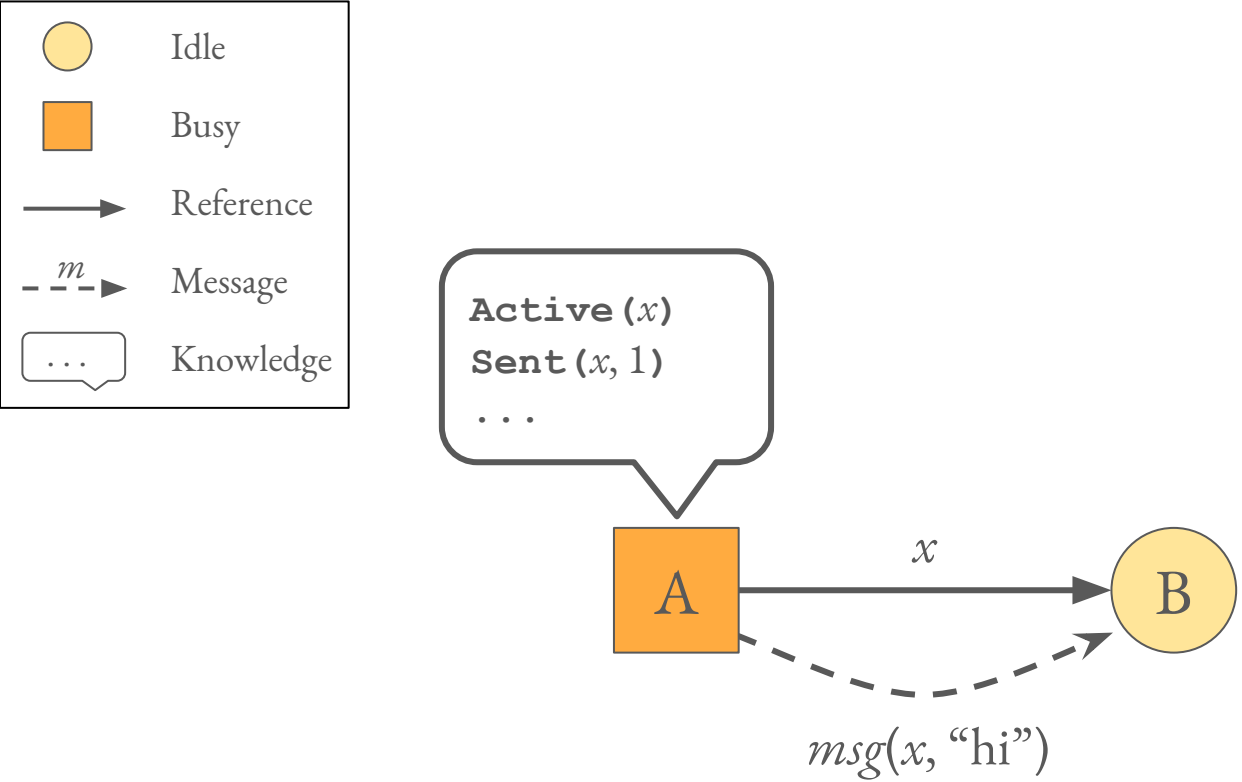

Active(x)
Active(y)
...
Created(y)
A
y
C
x
B
Created(x)
Released(z)
Idle
Busy
Reference
m
Message
...
Knowledge

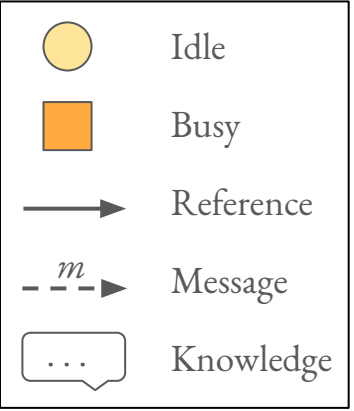
Part IV: Message Counts

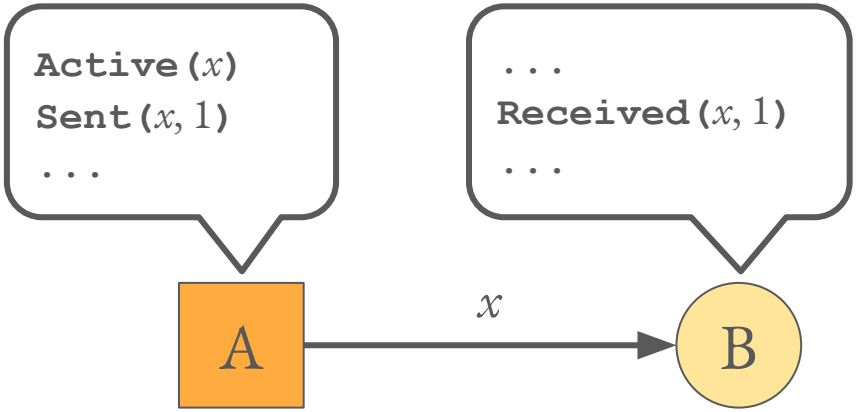

Idle
Busy
Reference
m
Message
Knowledge

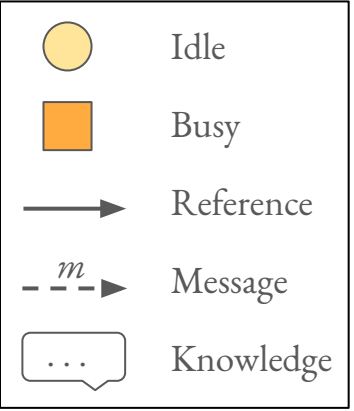

msg(x : A ⊸ B)
A
B

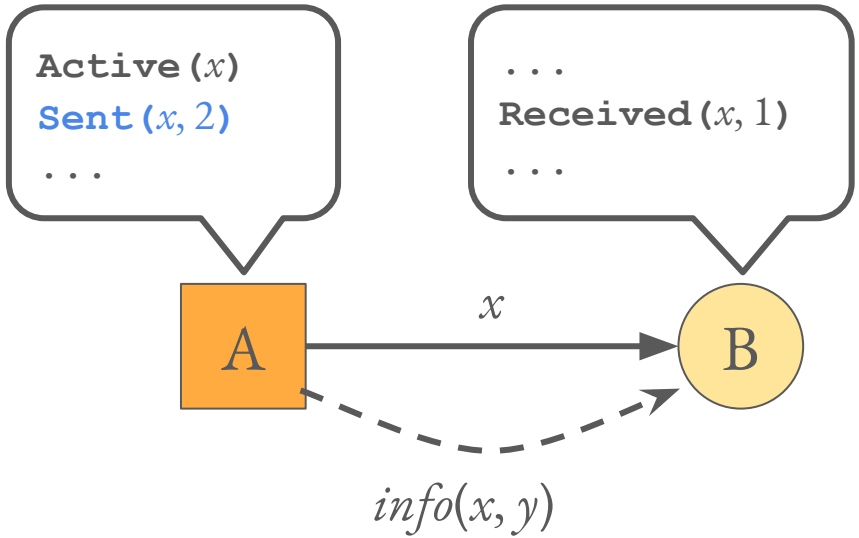

Idle
Busy
Reference
m
Message
Knowledge
Active(x)
. . .
A
x
B

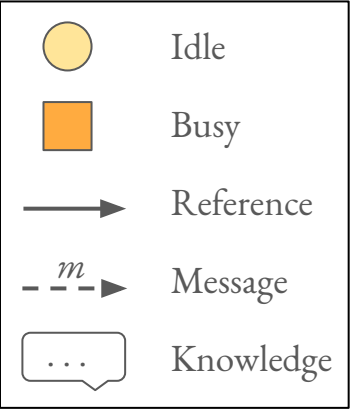

Idle
Busy
Reference
m
Message
Knowledge
Active(x)
Sent(x, 1)
. . .
A
x
B
msg(x, "hi")

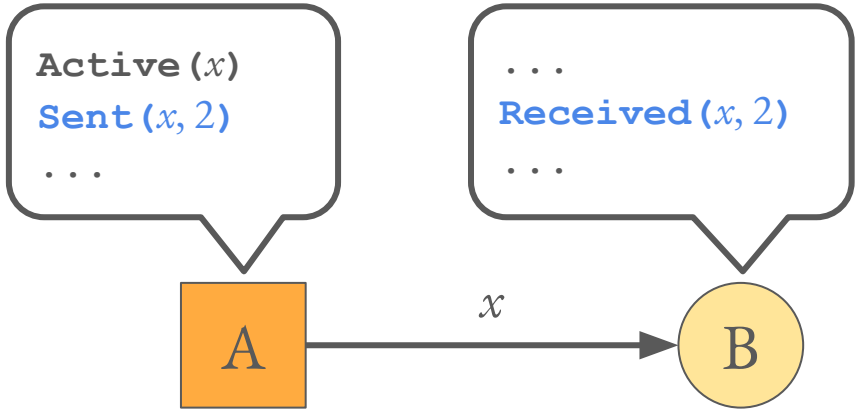

Idle
Busy
Reference
m
Message
. . .
Knowledge

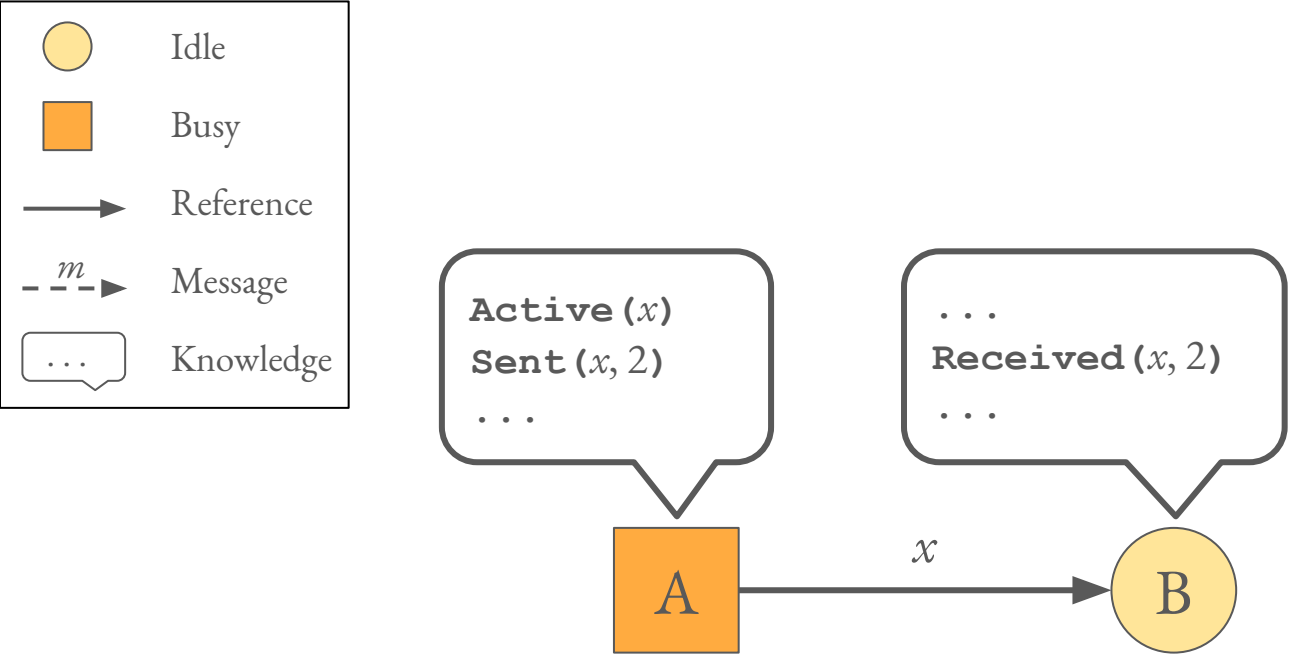

Active(x)
Sent(x, 1)
. . .
. . .
Received(x, 1)
. . .
A
x
B

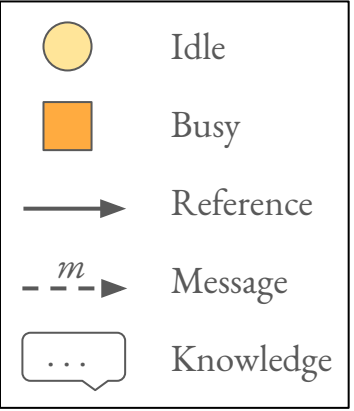

Idle
Busy
Reference
m
Message
Knowledge

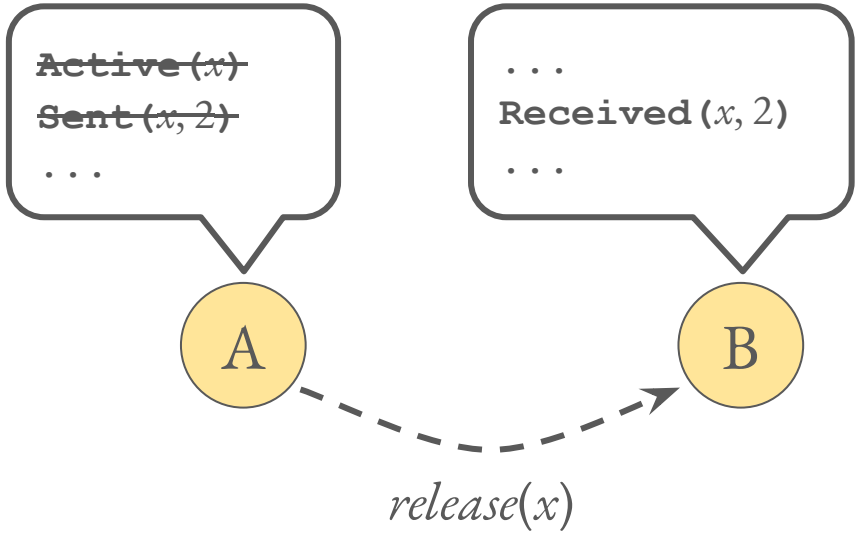

Active(x)
Sent(x, 2)
...
...
Received(x, 1)
...
A
x
B
info(x, y)

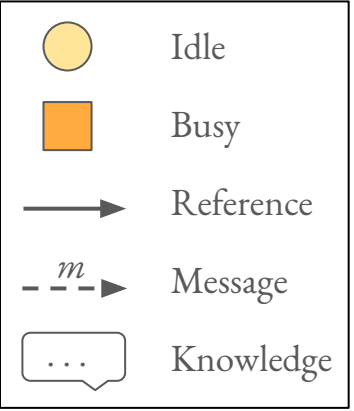

Idle
Busy
Reference
m
Message
Knowledge

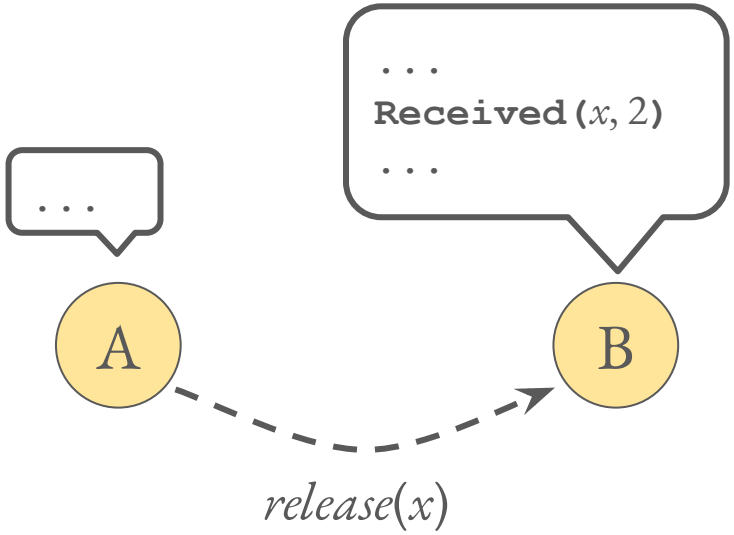

Active(x)
Sent(x, 2)
...
...
Received(x, 2)
...
A
x
B

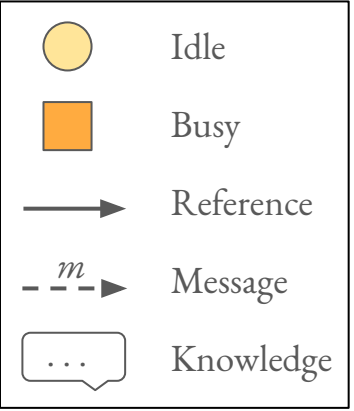

Idle
Busy
Reference
m
Message
. . .
Knowledge
Active(x)
Sent(x, 2)
. . .
. . .
Received(x, 2)
. . .
A
x
B

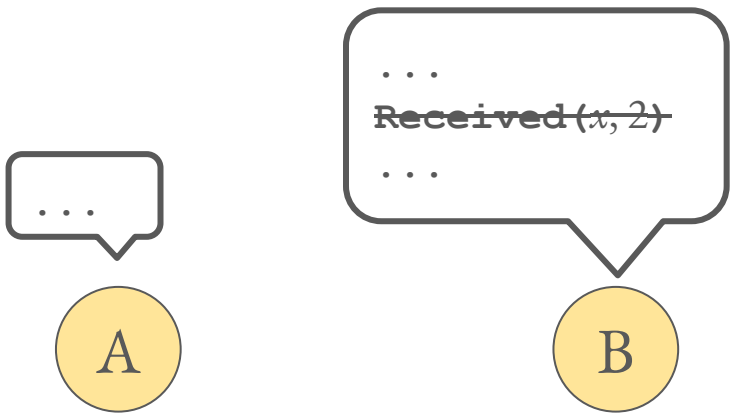

Idle
Busy
Reference
m
Message
. . .
Knowledge

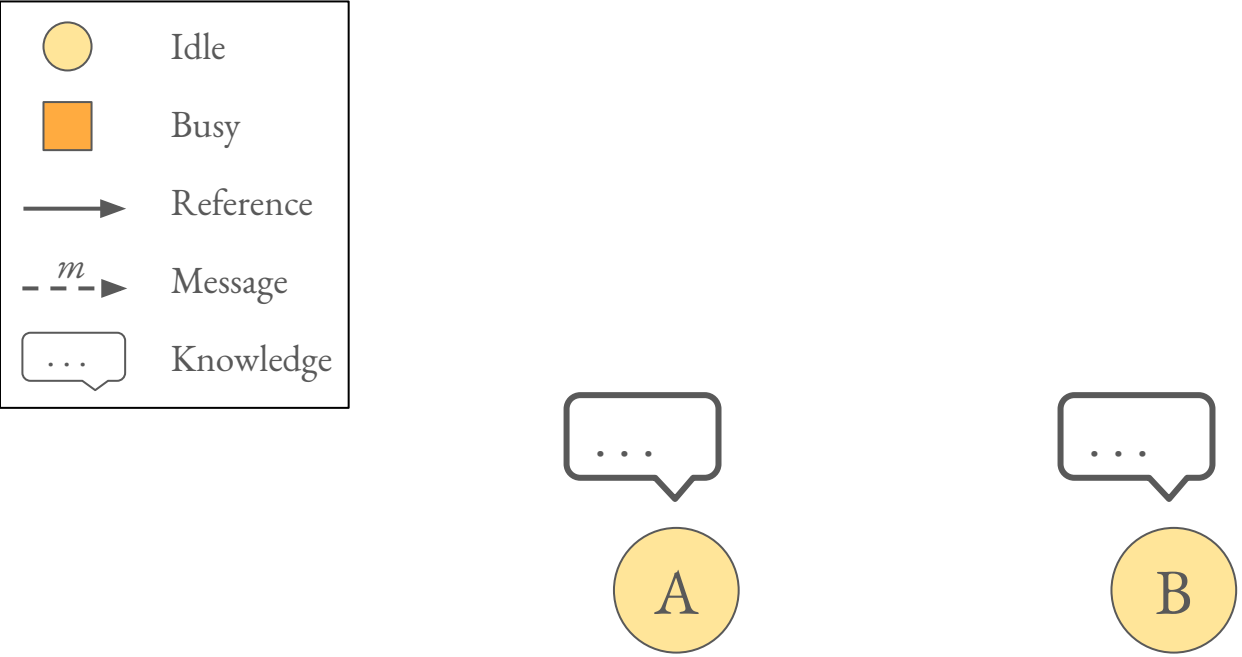

Active(x)
Sent(x, 2)
. . .
. . .
Received(x, 2)
. . .
A
B
release(x)


Idle
Busy
Reference
m
Message
. . .
Knowledge


. . .
Received(x, 2)
. . .
. . .
A
B
release(x)


Idle
Busy
Reference
m
Message
Knowledge


. . .
A
. . .
Received (x, 2)
. . .
B


Idle
Busy
Reference
m
Message
Knowledge
A
B

Part V: Termination Detection

“Appear to be terminated”?

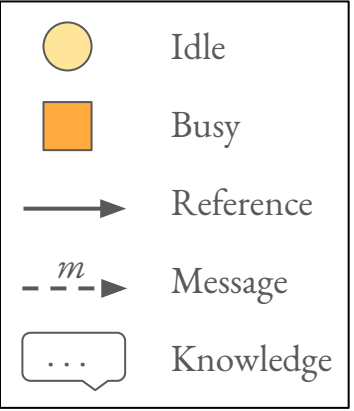
“Appear to be terminated”?

An actor is **terminated** if it is blocked…
and its potential inverse acquaintances are blocked…
and their potential inverse acquaintances are blocked…
and so on.

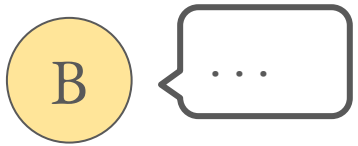
“Appear to be terminated”?

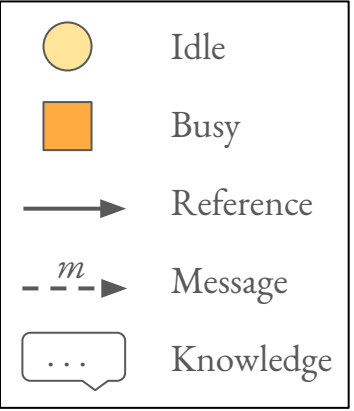
Let *S* be a set of snapshots.

Assume B is the first actor in *S* to take a snapshot.



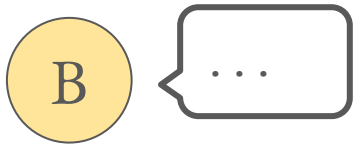
“Appear to be terminated”?

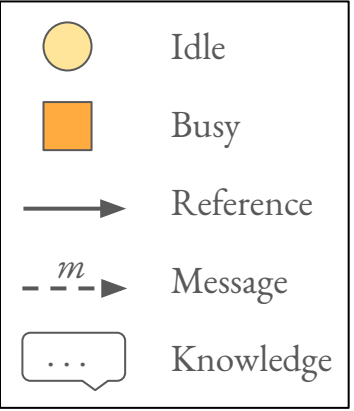




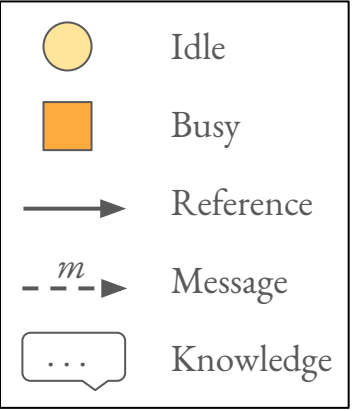
“Appear to be terminated”?

If B has no facts **`Created`**`(`x : A → B`)` then it has no potential inverse acquaintances (see paper).



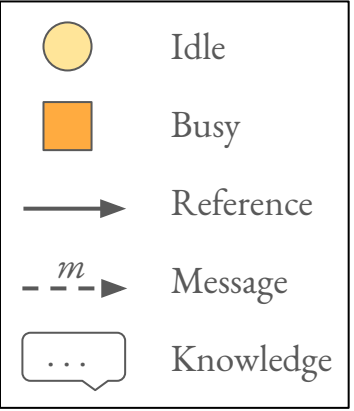


“Appear to be terminated”?



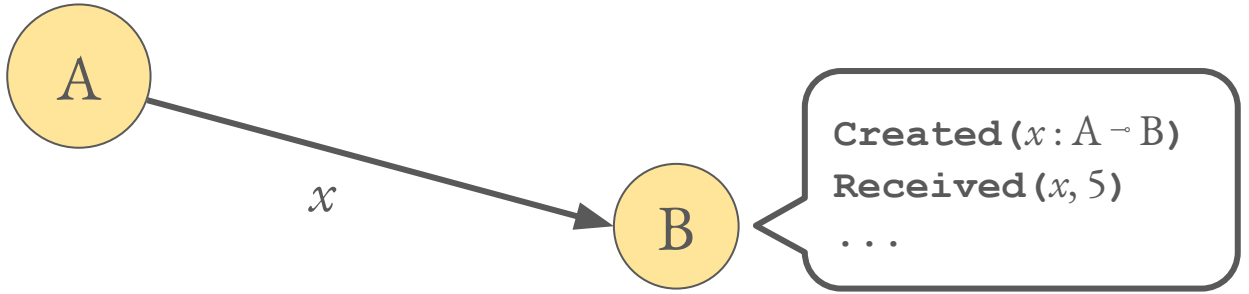
“Appear to be terminated”?

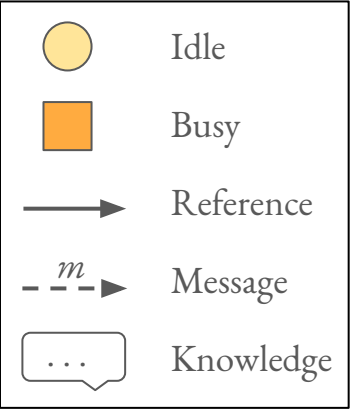
To find out if B is terminated, we need a snapshot from A.



“Appear to be terminated”?

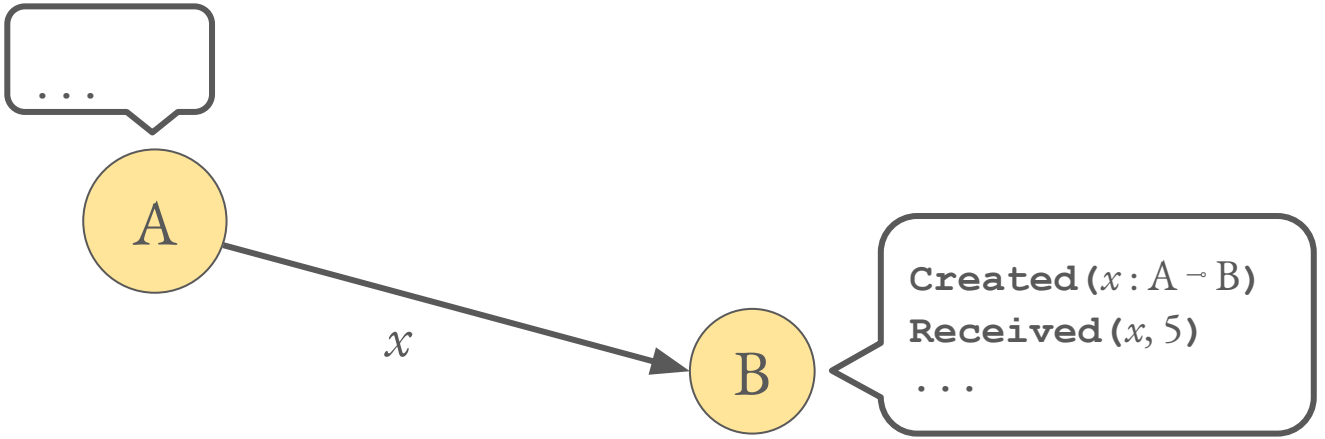
To find out if B is terminated, we need a snapshot from A.

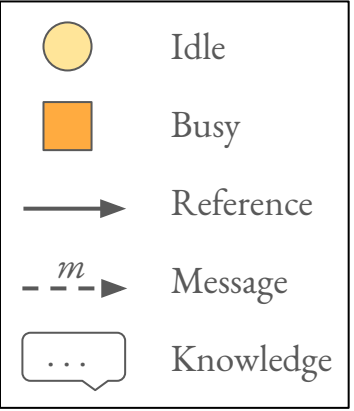




“Appear to be terminated”?

What if A’s snapshot doesn’t contain **`Active`**(*x*)?

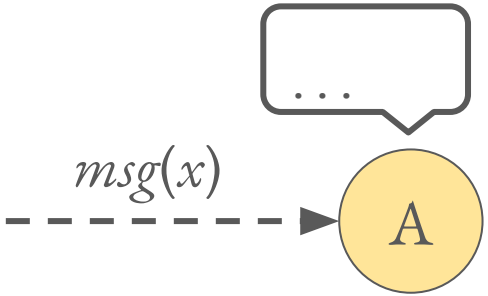


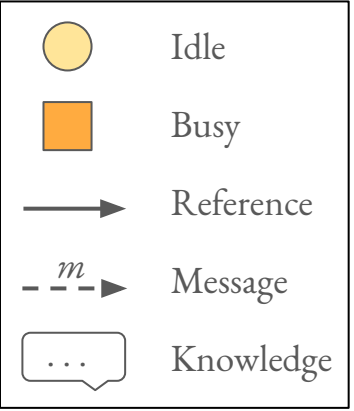


“Appear to be terminated”?

What if A’s snapshot doesn’t contain **`Active(`***x***`)`**?

Case 1: It hasn’t received *x* yet.



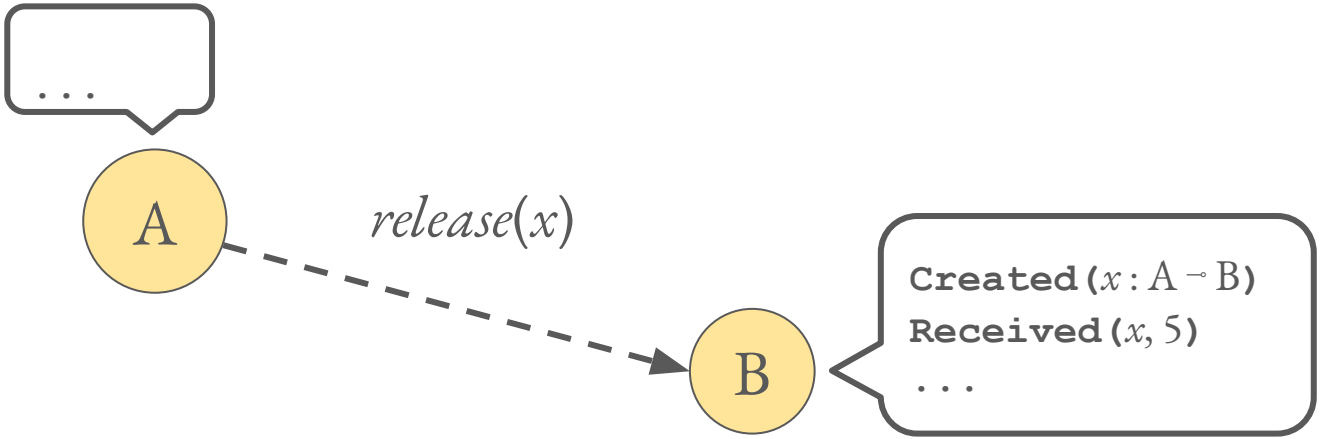


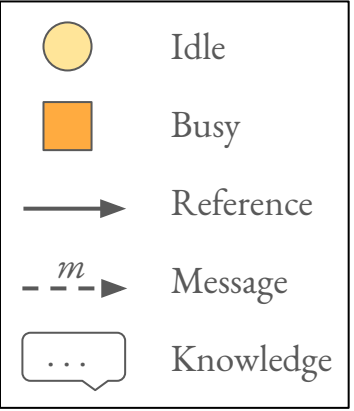
“Appear to be terminated”?

What if A’s snapshot doesn’t contain **`Active`**`(`x`)`?

Case 1: It hasn’t received x yet.

Case 2: It has released x already.





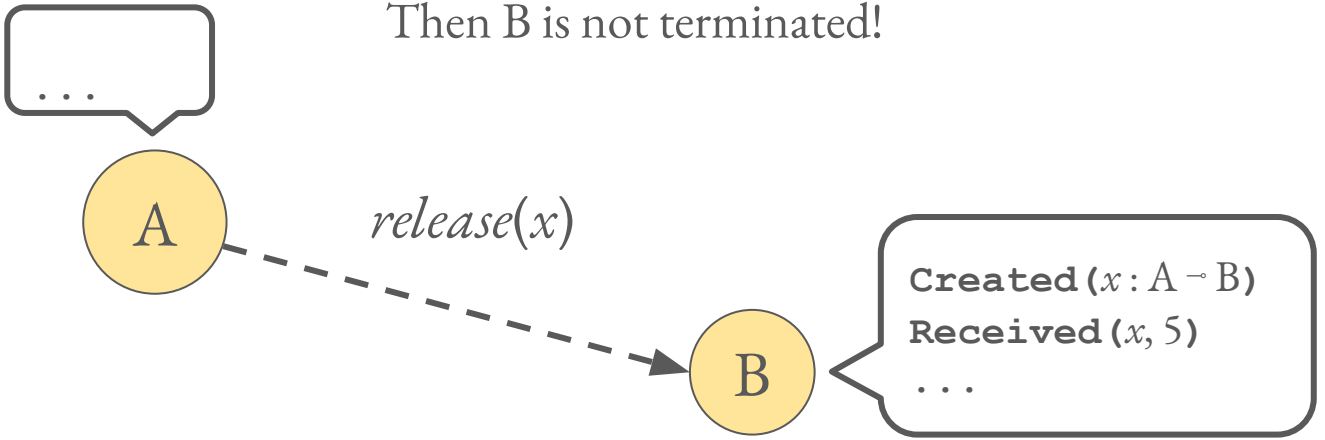
“Appear to be terminated”?

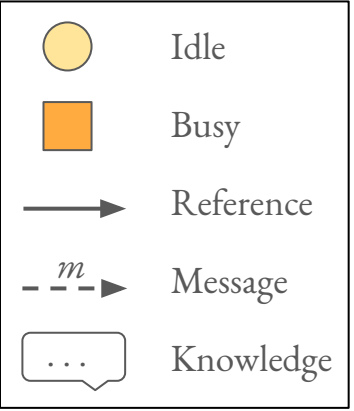
What if A’s snapshot doesn’t contain **`Active(`***x***`)`**?

Case 1: It hasn’t received *x* yet.

Case 2: It has released *x* already.

Then B is not terminated!

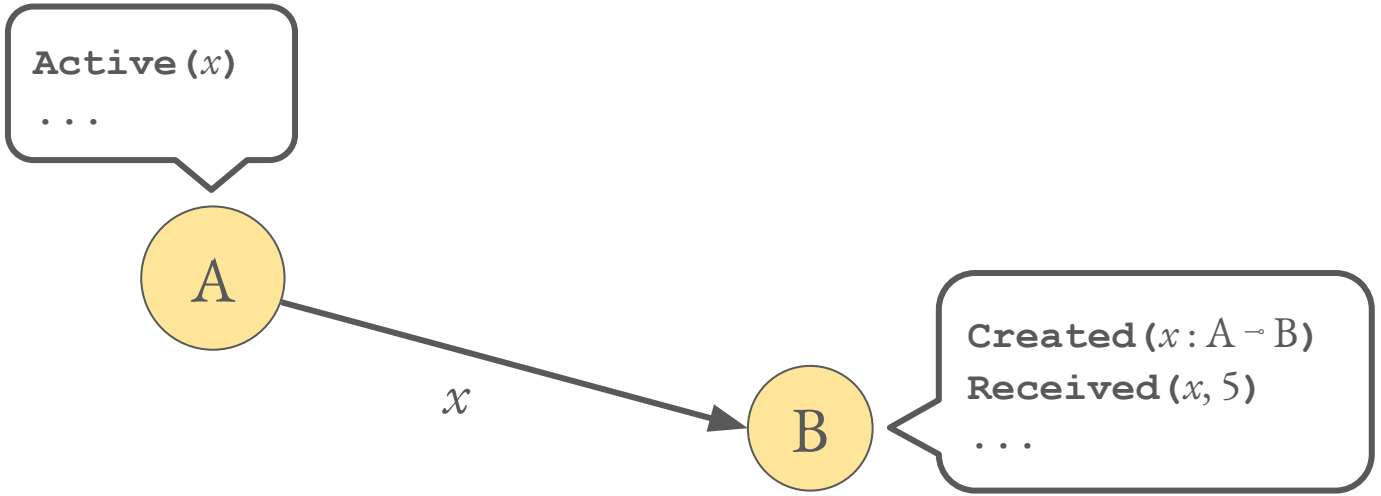


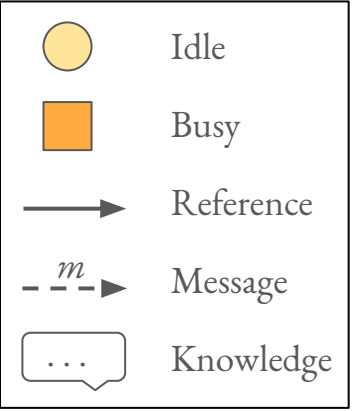


“Appear to be terminated”?

B is only terminated if...

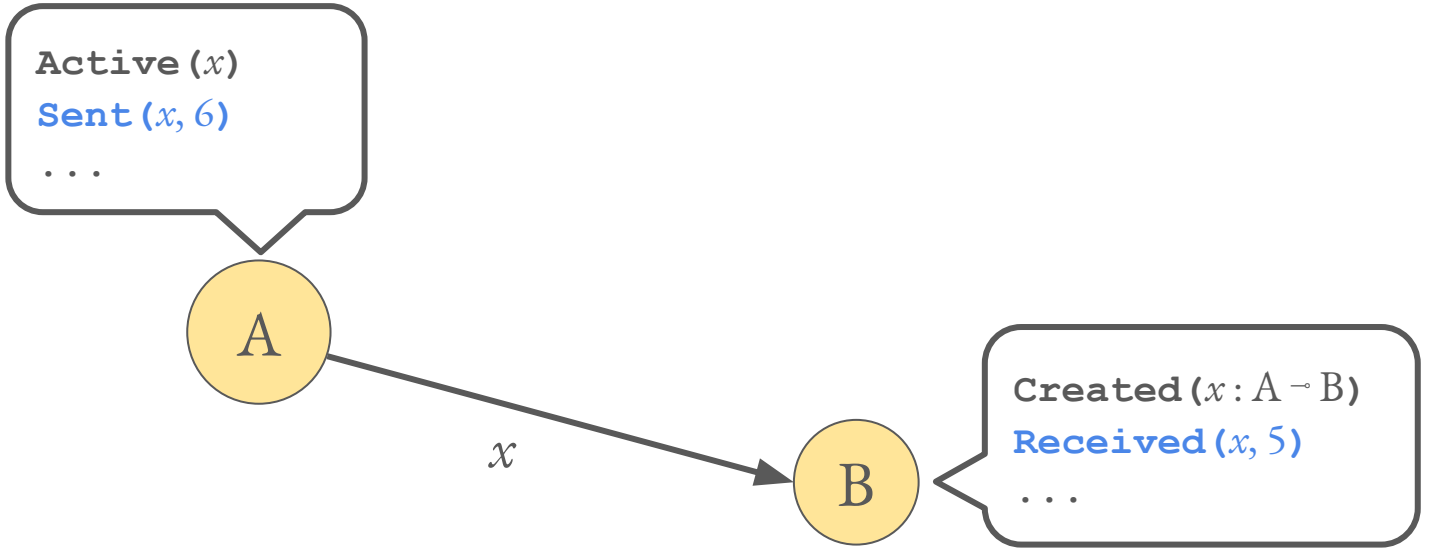
- A’s snapshot contains **`Active`**(x).

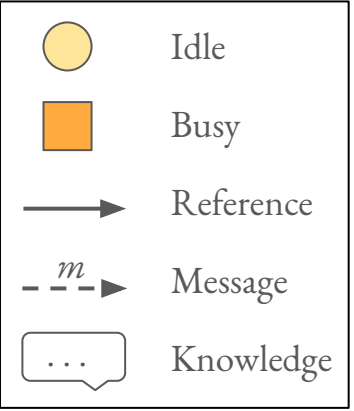




“Appear to be terminated”?

What if the message counts differ?



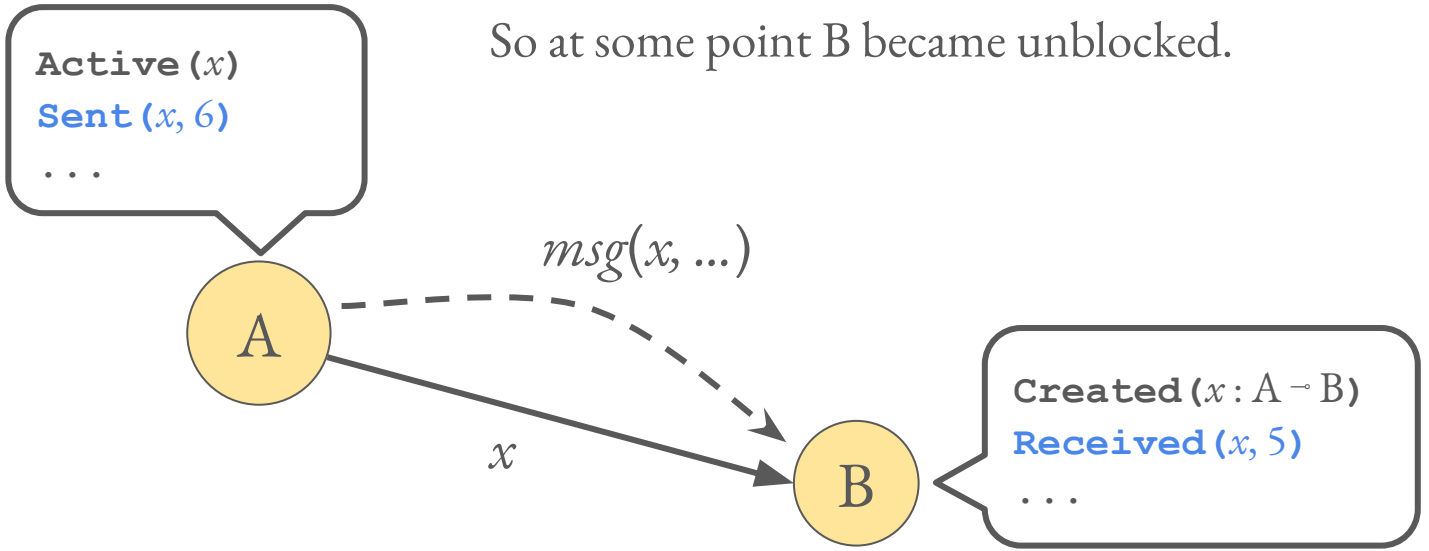


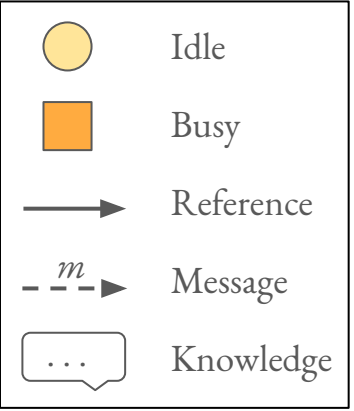
“Appear to be terminated”?

What if the message counts differ?

Recall B’s snapshot came first.

So at some point B became unblocked.

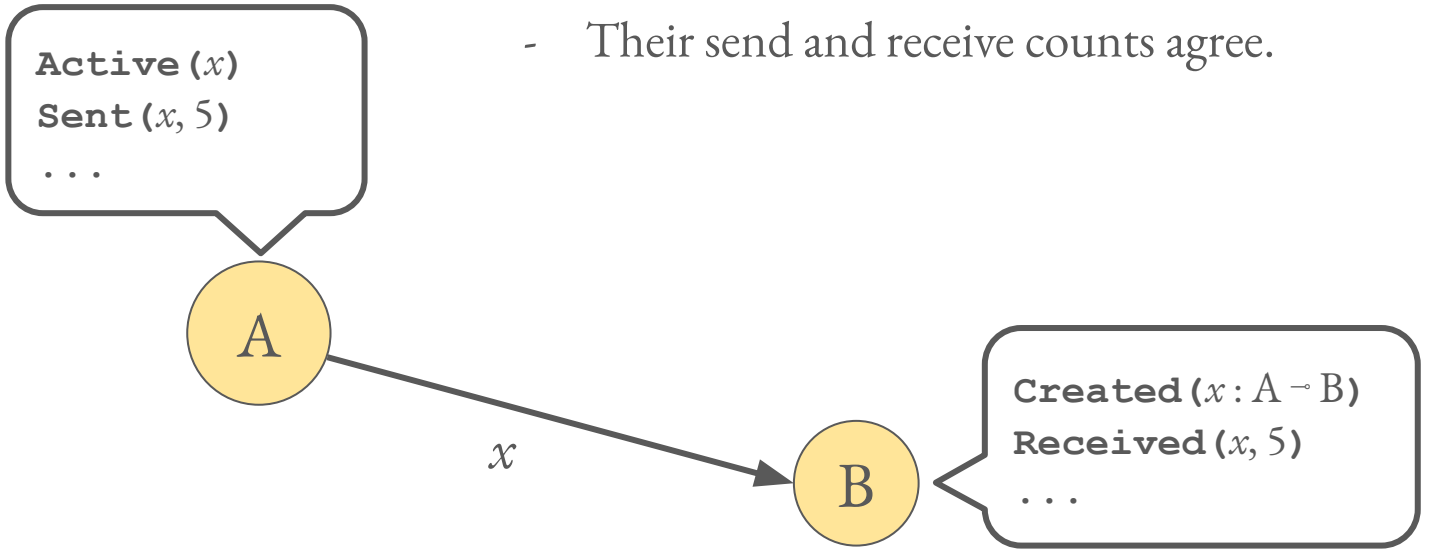


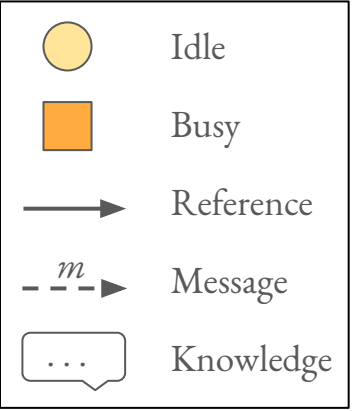


“Appear to be terminated”?

B is only terminated if...

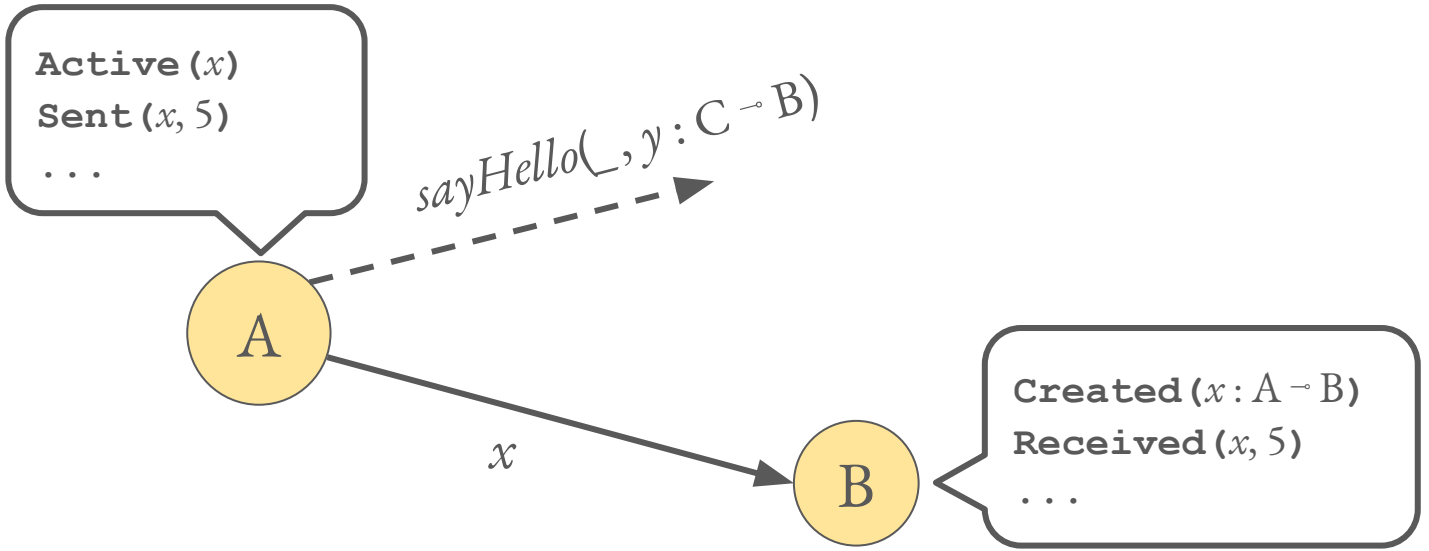
- A’s snapshot contains **`Active`**(x);
- Their send and receive counts agree.

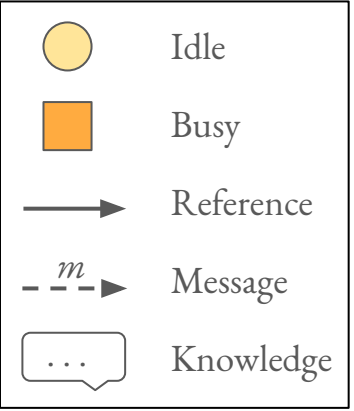




“Appear to be terminated”?

What if A created a new refob $y : C \multimap B$ before snapshot?

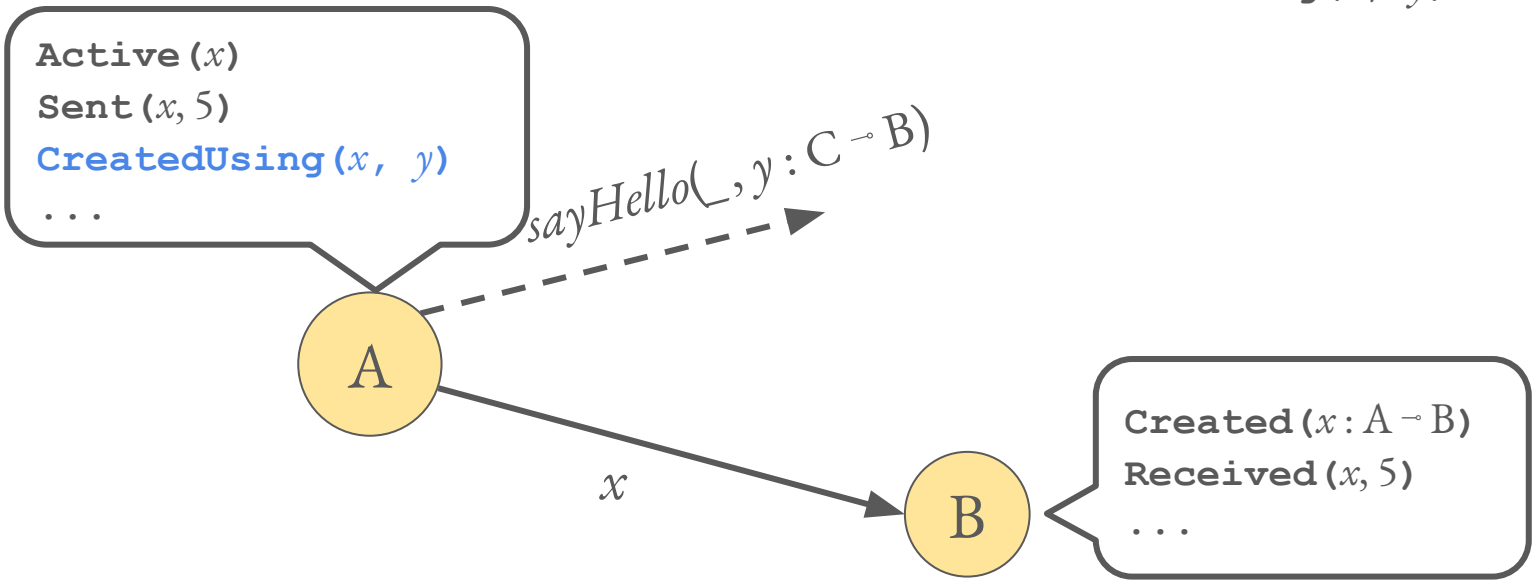


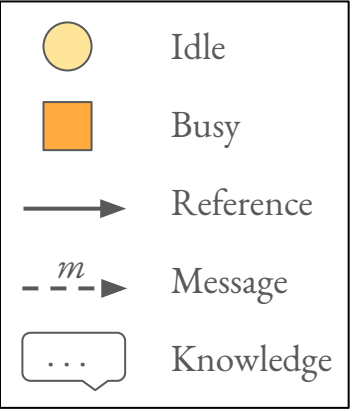


“Appear to be terminated”?

What if A created a new refob $y : C \multimap B$ before snapshot?

Then A created a fact **`CreatedUsing`**(x, y).



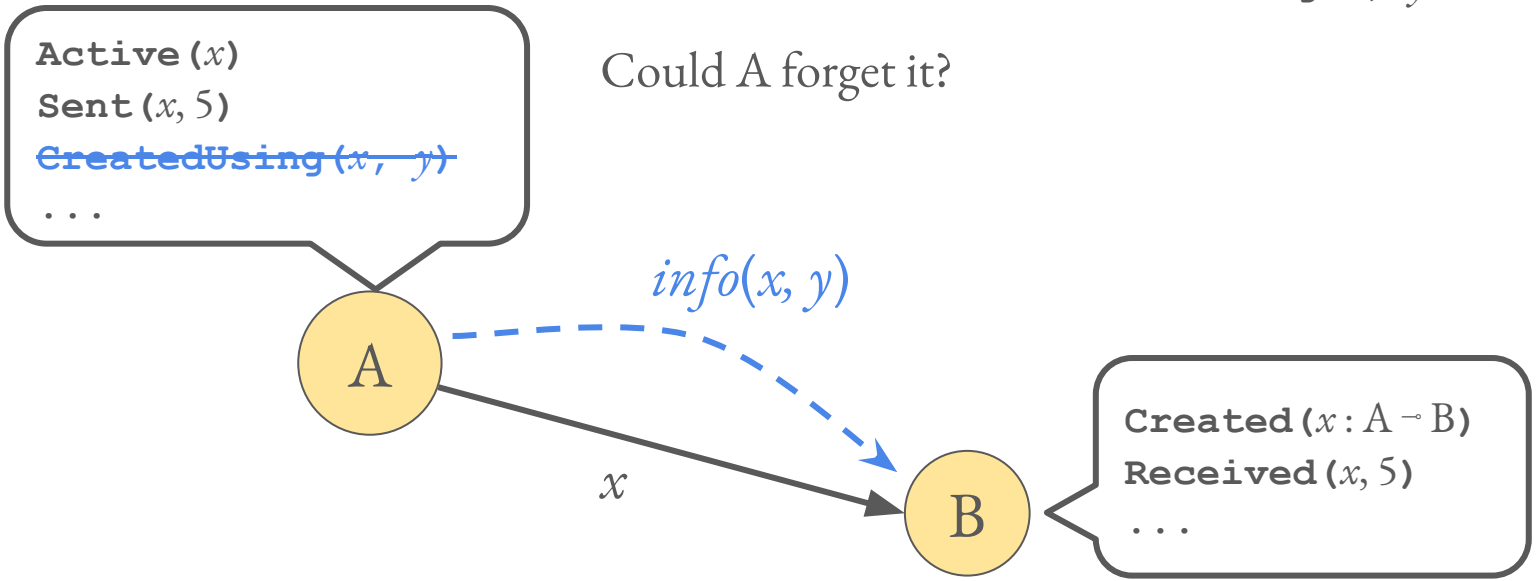


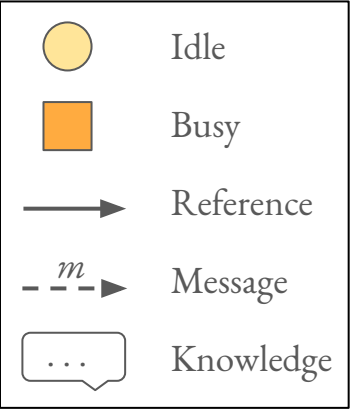
“Appear to be terminated”?

What if A created a new refob $y : C \multimap B$ before snapshot?

Then A created a fact `CreatedUsing(`x`, `y`)`.

Could A forget it?



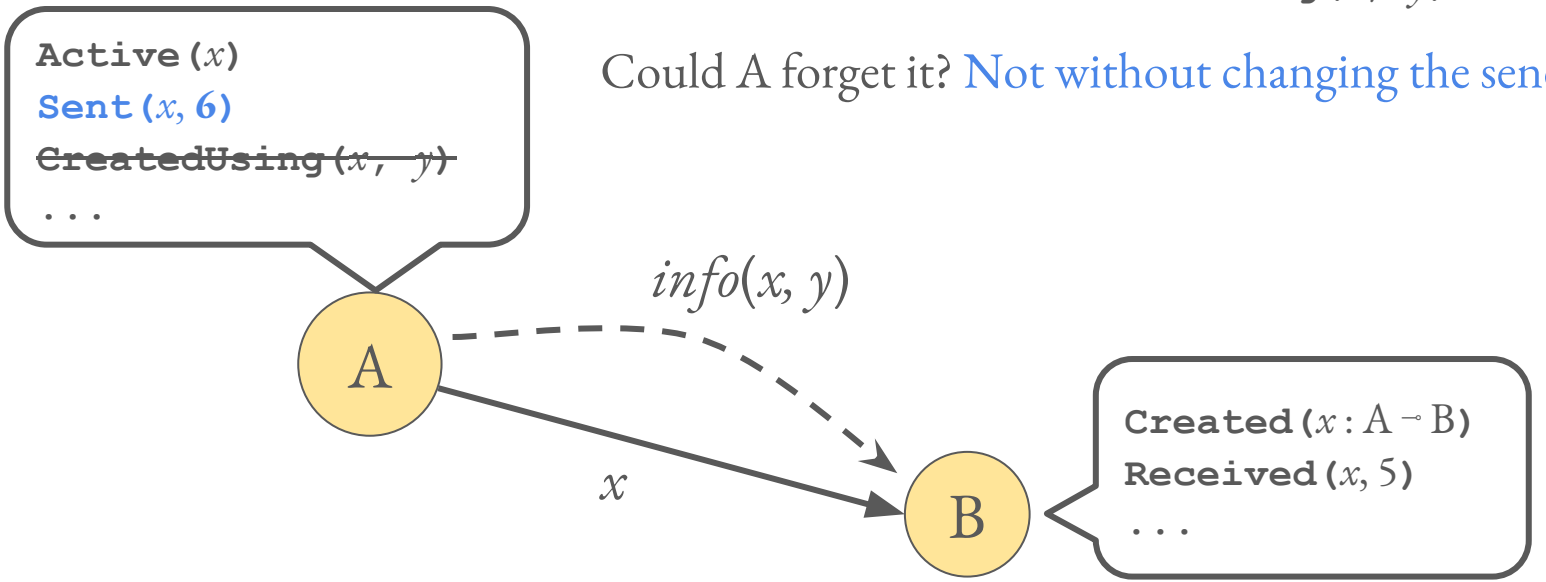


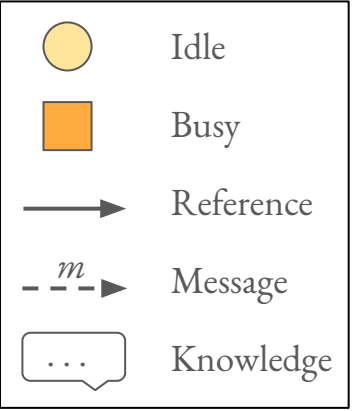
"Appear to be terminated"?

What if A created a new refob $y : C \multimap B$ before snapshot?

Then A created a fact `CreatedUsing(`x`, `y`)`.

Could A forget it? Not without changing the send count!



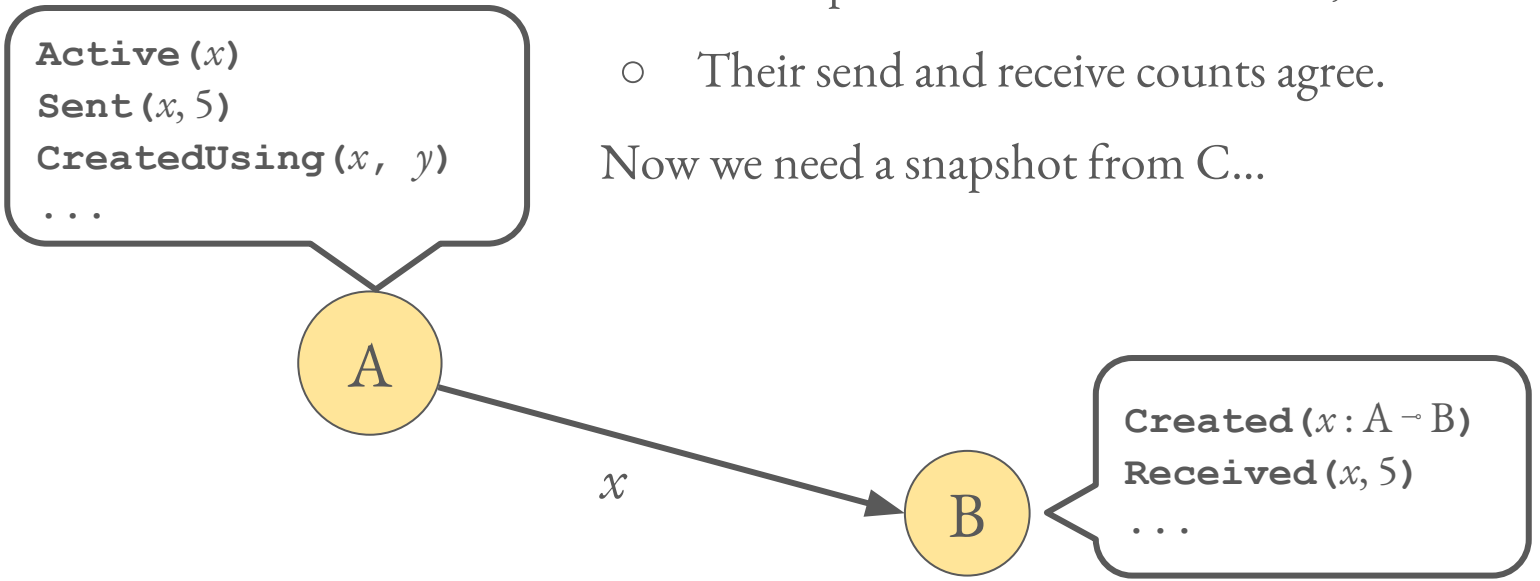


“Appear to be terminated”?

B is only terminated if...

- A’s snapshot contains **`Active`**`(`x`)`;
- Their send and receive counts agree.

Now we need a snapshot from C...



“Appear to be terminated”?

Assuming B is blocked, show that the next actor is also blocked.

“Appear to be terminated”?

Assuming B is blocked, show that the next actor
is also blocked.

Hence every actor that can potentially reach B is blocked!

Acknowledgments

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