Verified Causal Broadcast with Liquid Haskell

Patrick Redmond Gan Shen Niki Vazou Lindsey Kuper

UC Berkeley Programming Systems Seminar
24 October 2022

`github.com/lsd-ucsc/cbcast-lh`

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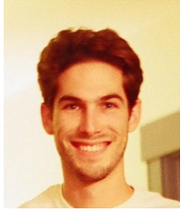

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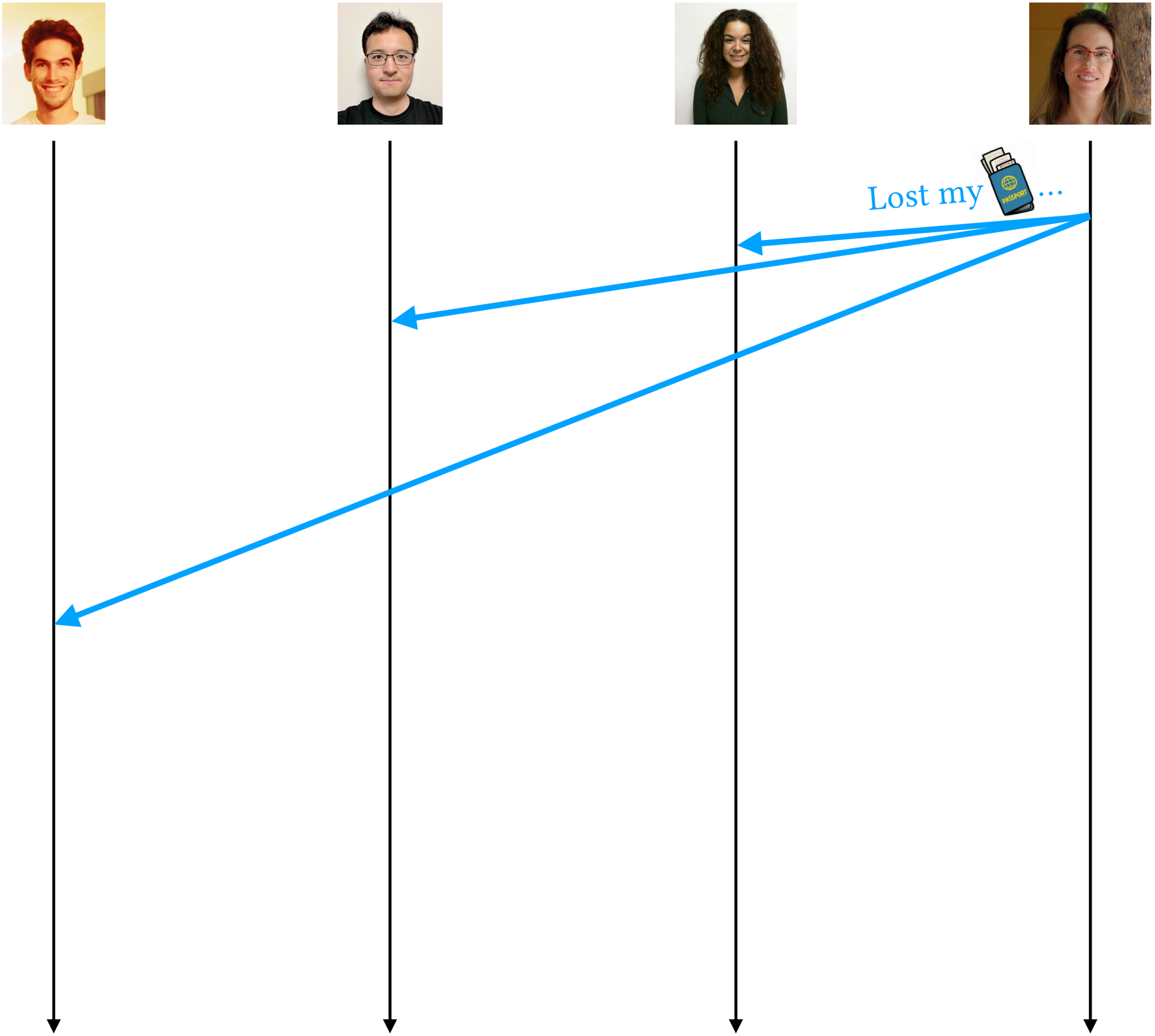
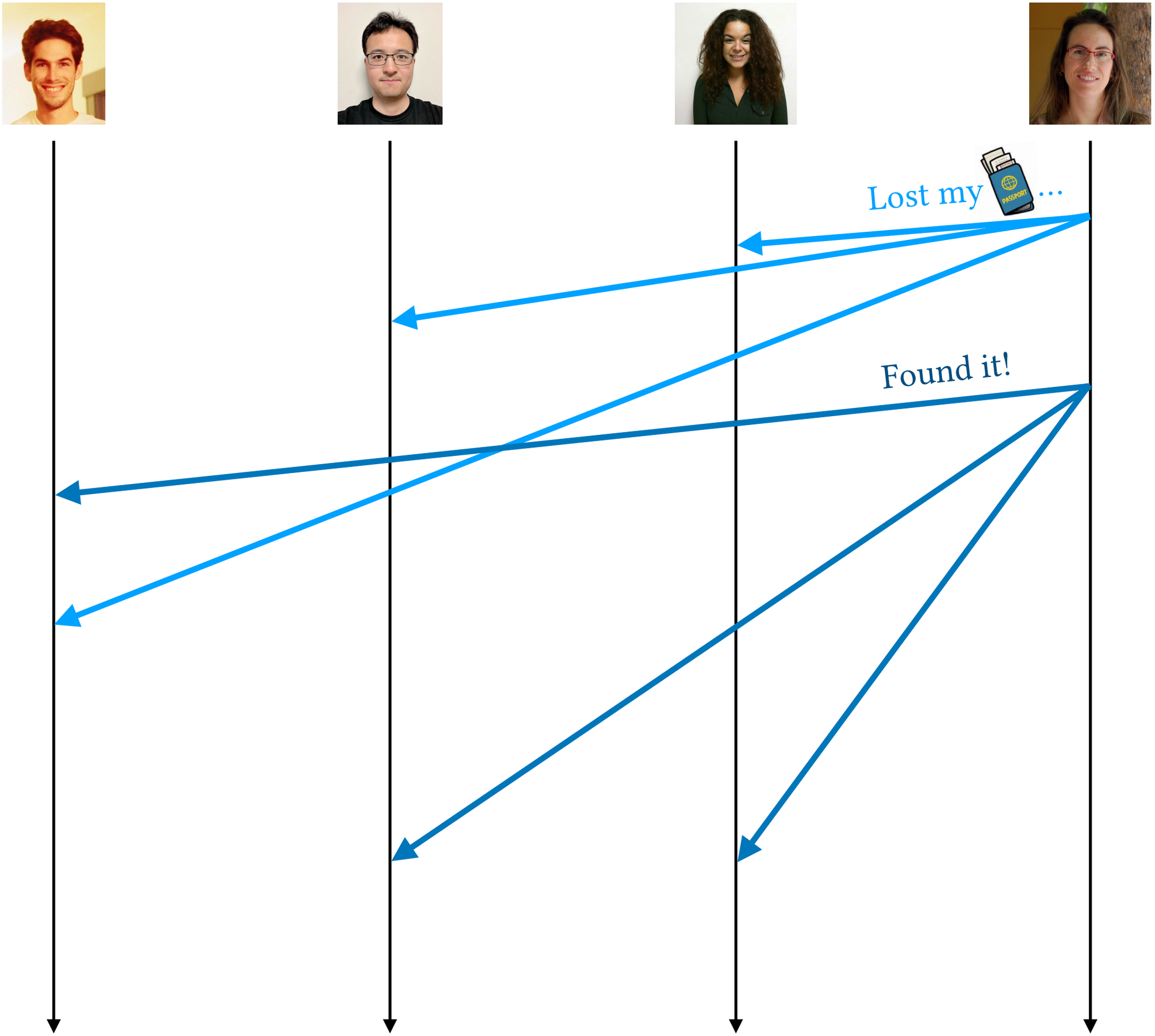

Lost my
PASSPORT
...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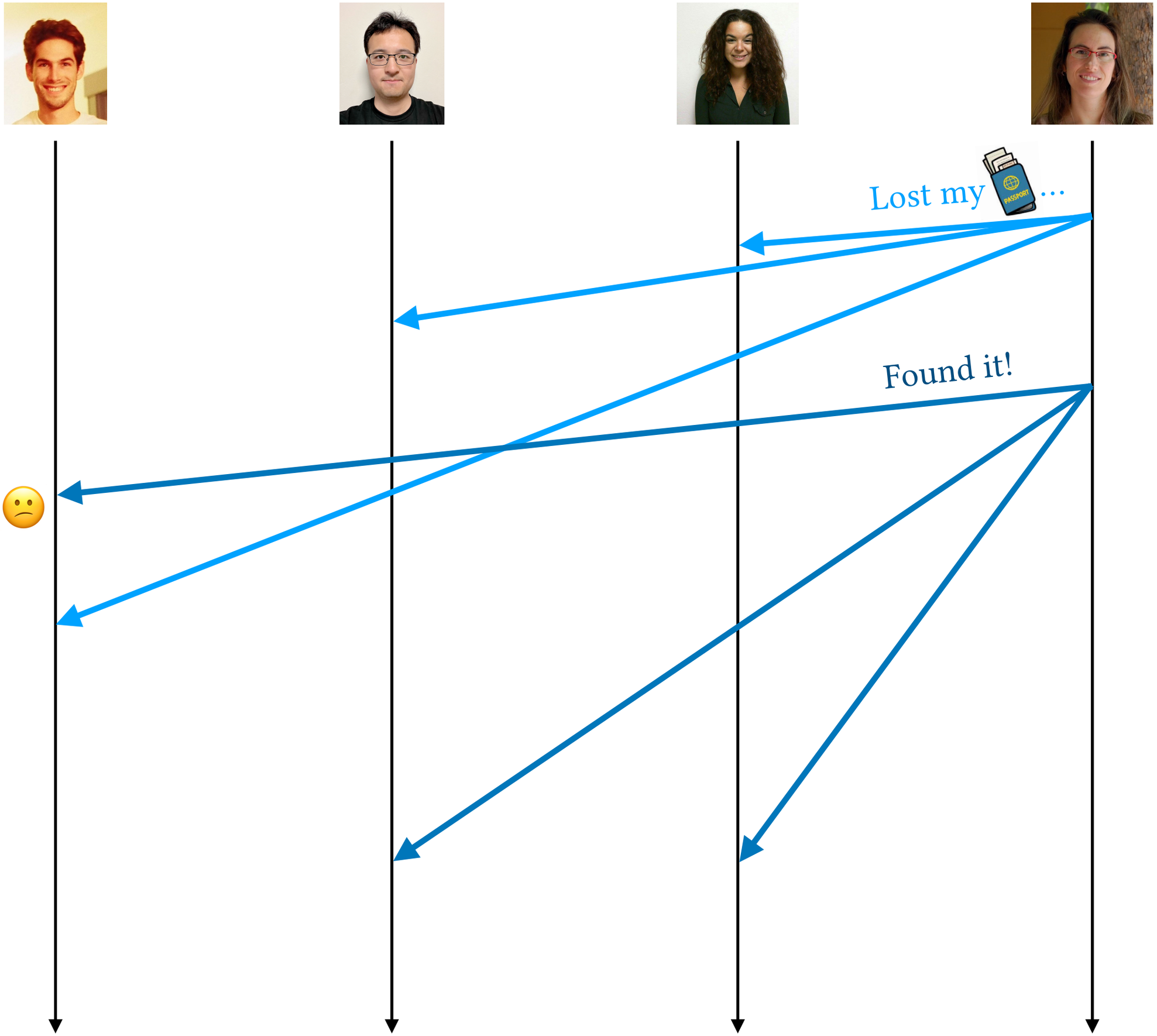
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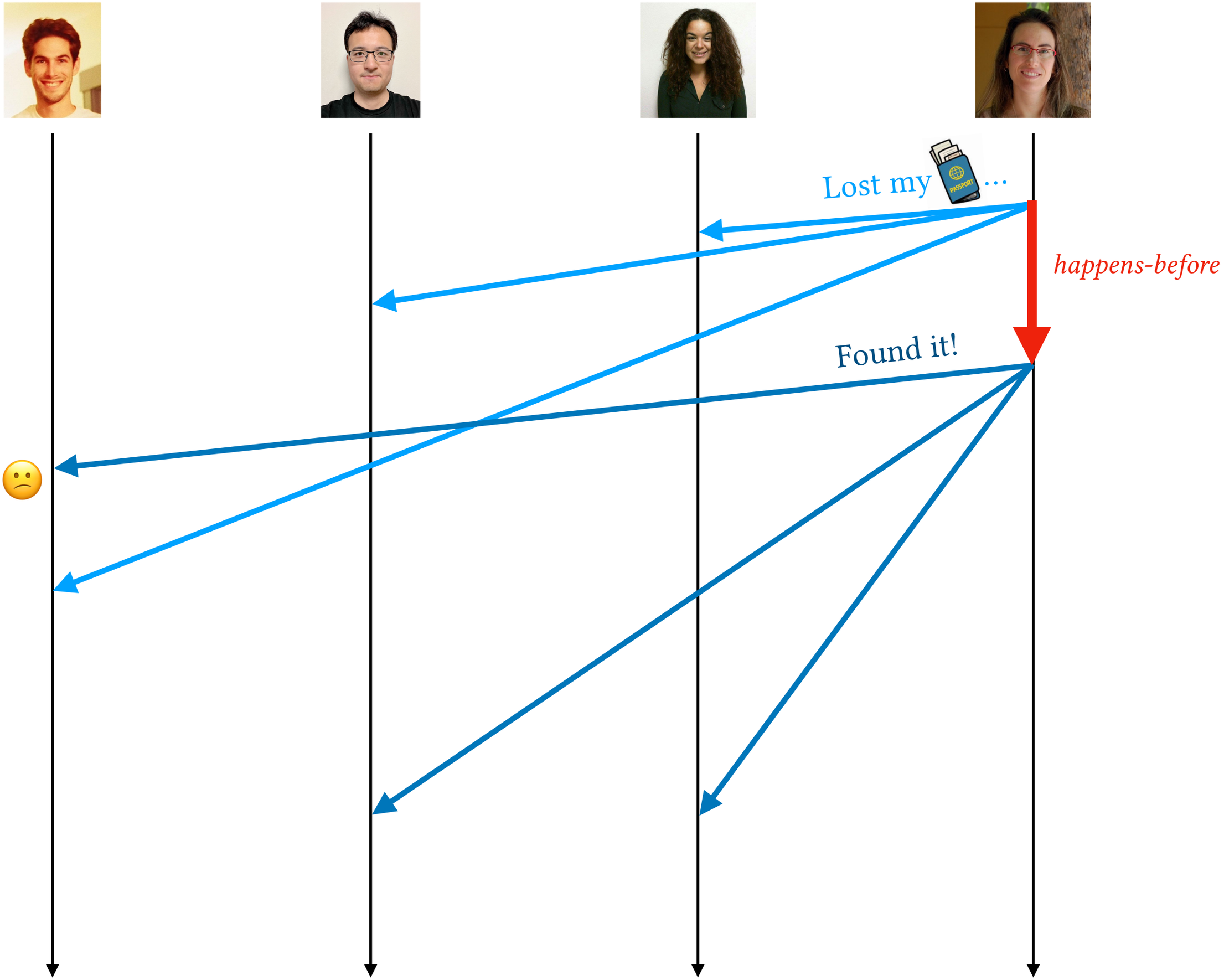
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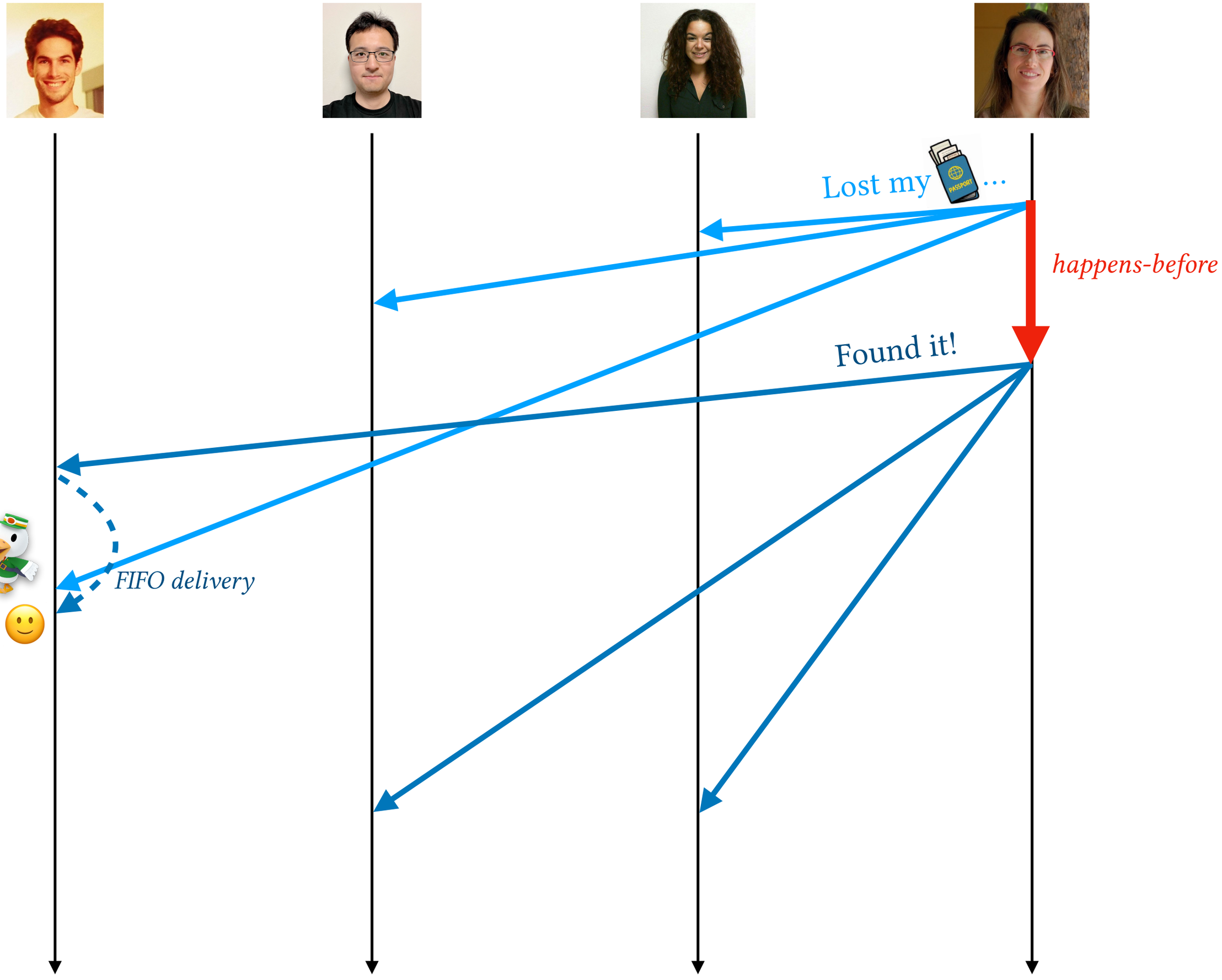
…
happens-before
Found it!




Lost my  ...

happens-before

Found it!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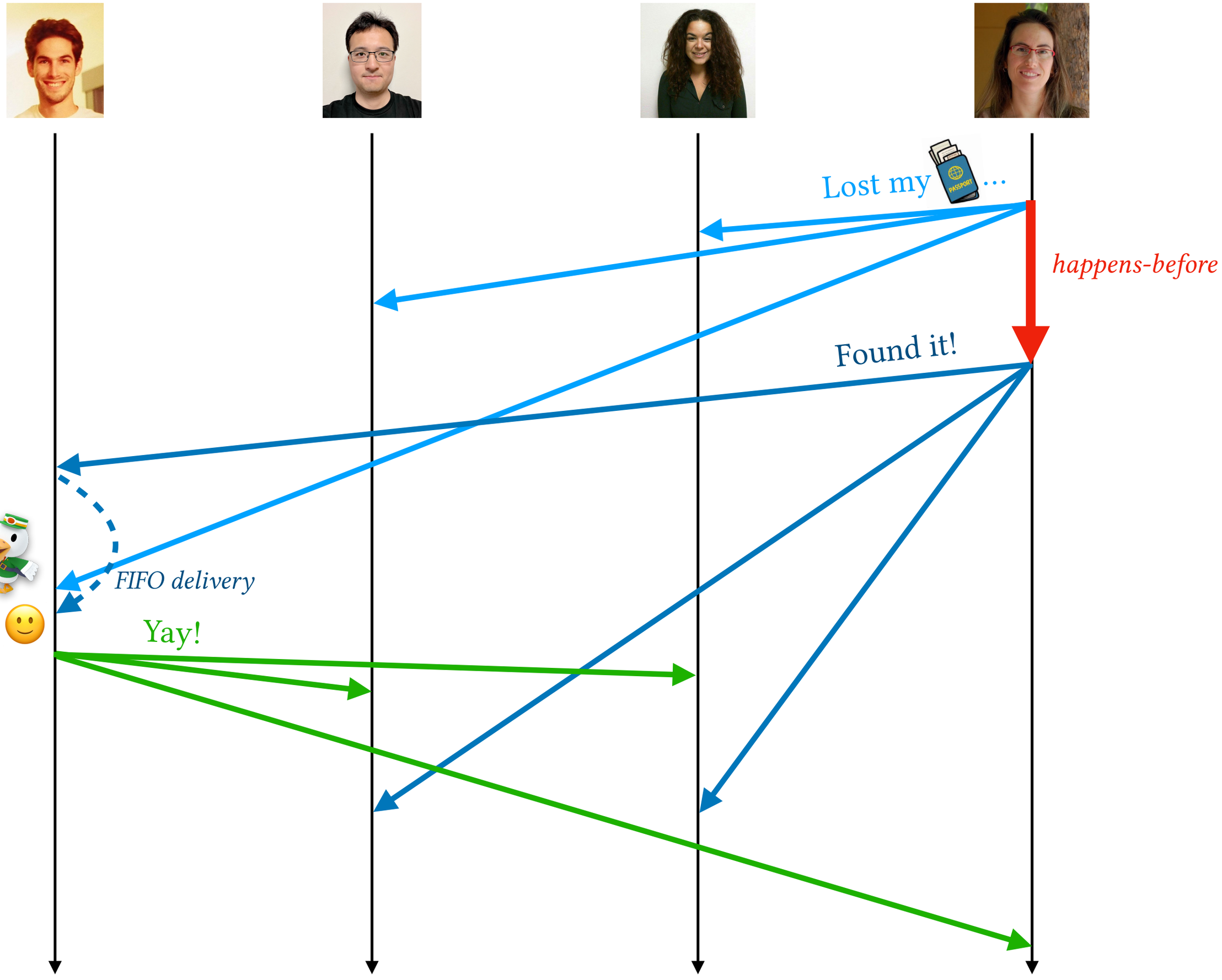
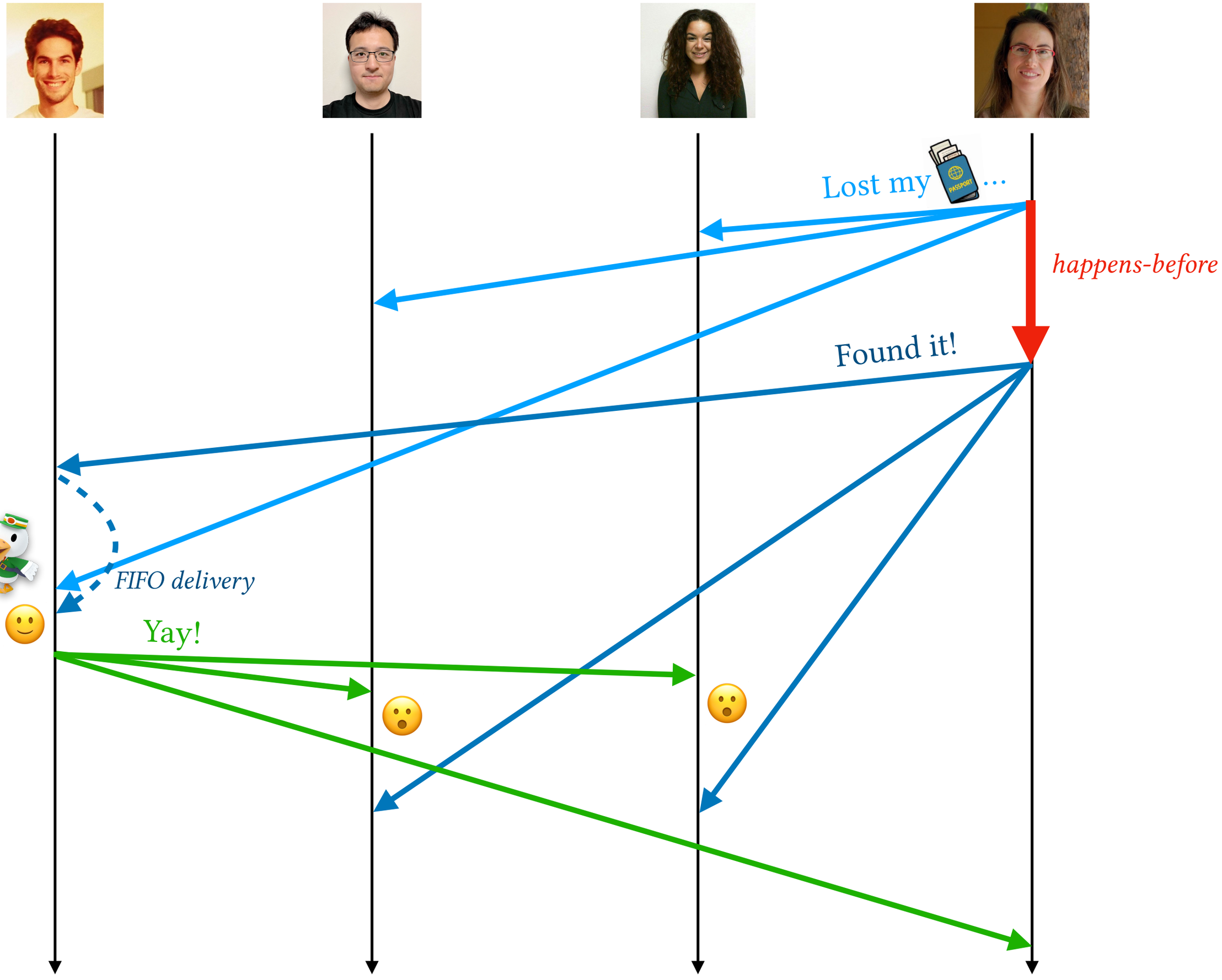
PASSPORT
happens-before
Found it!
FIFO delivery


Lost my ...
happens-before
Found it!
FIFO delivery
Yay!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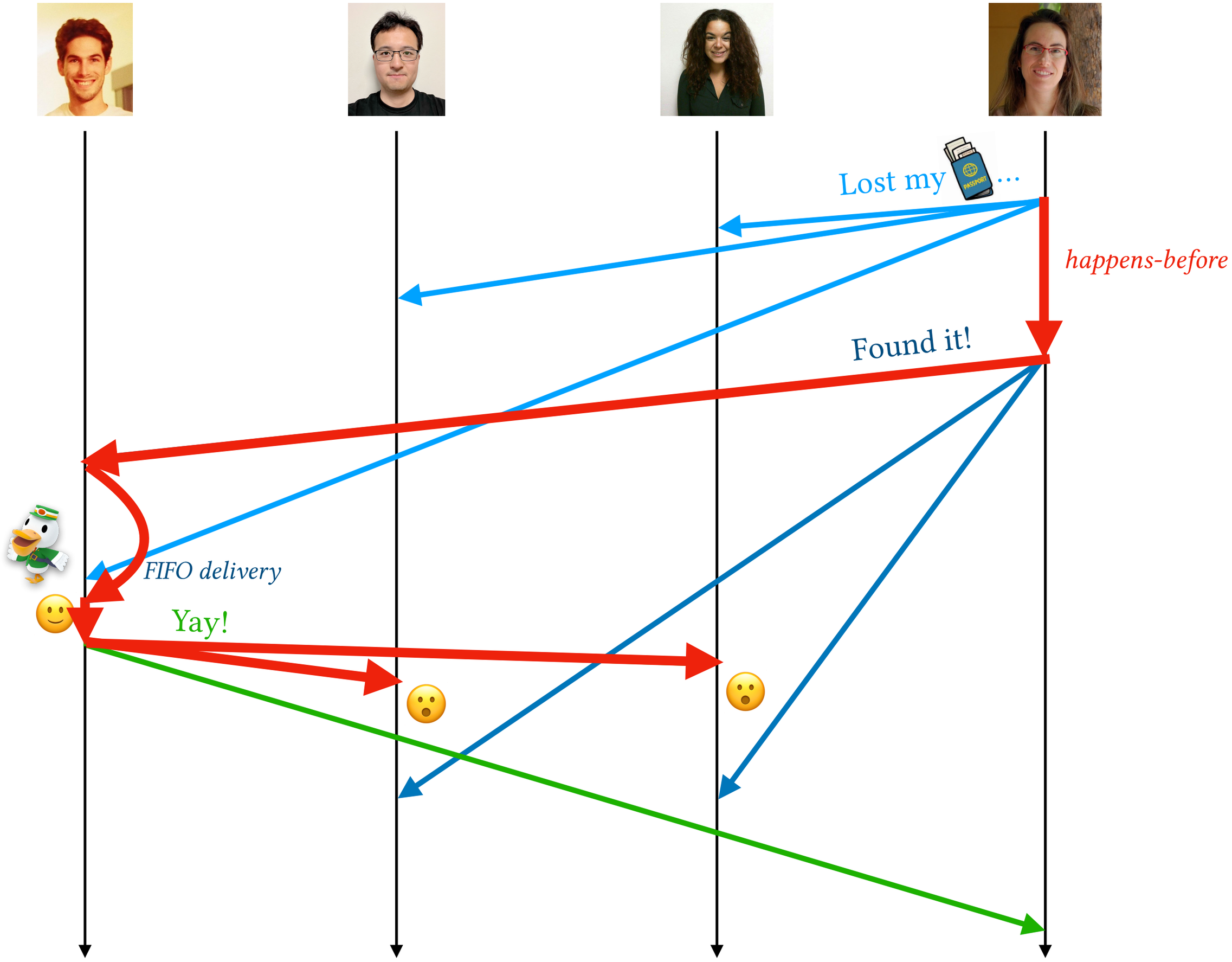
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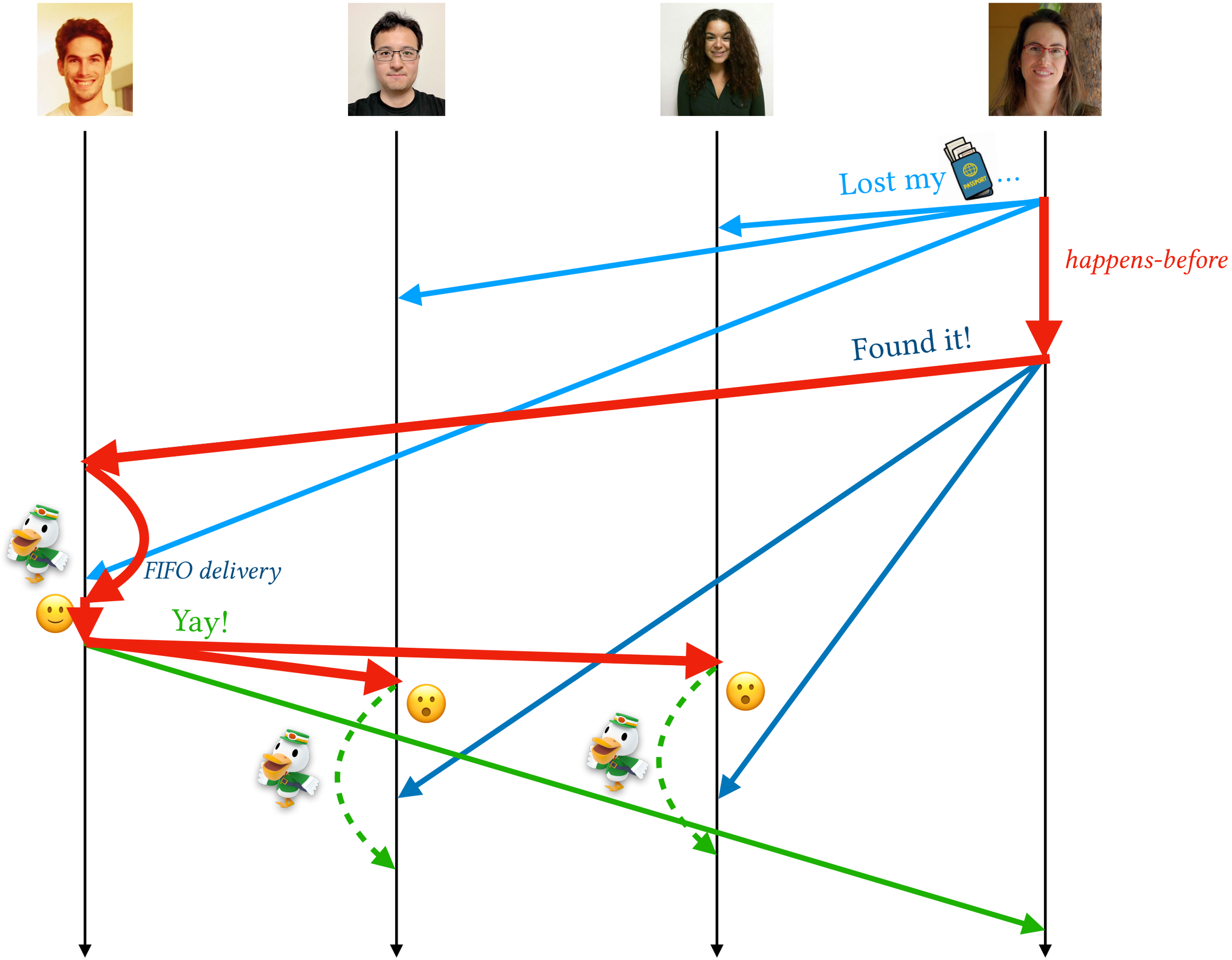
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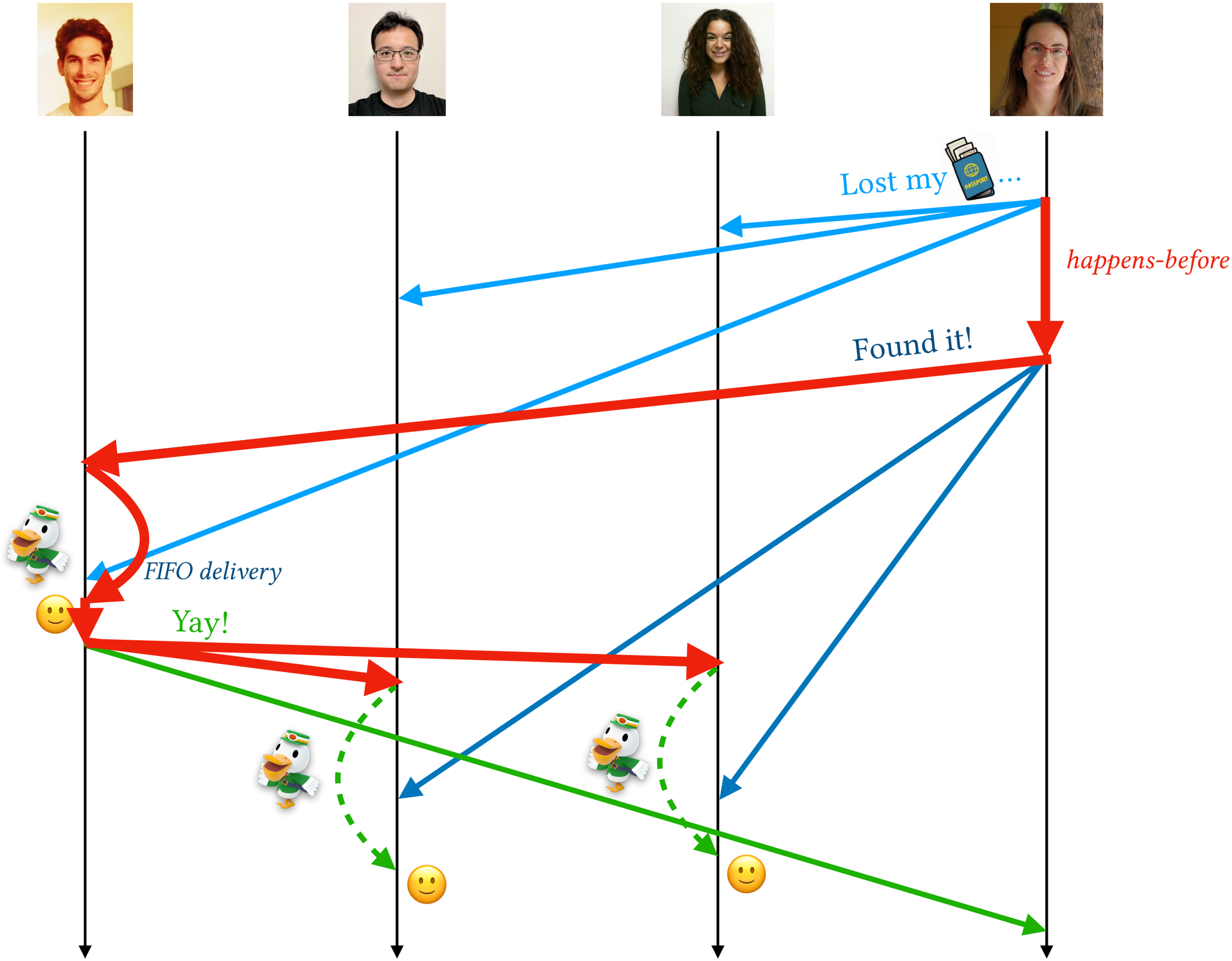
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Yay!




Causal broadcast with vector clocks [Birman et al., 1991]

[0,0,0,0]

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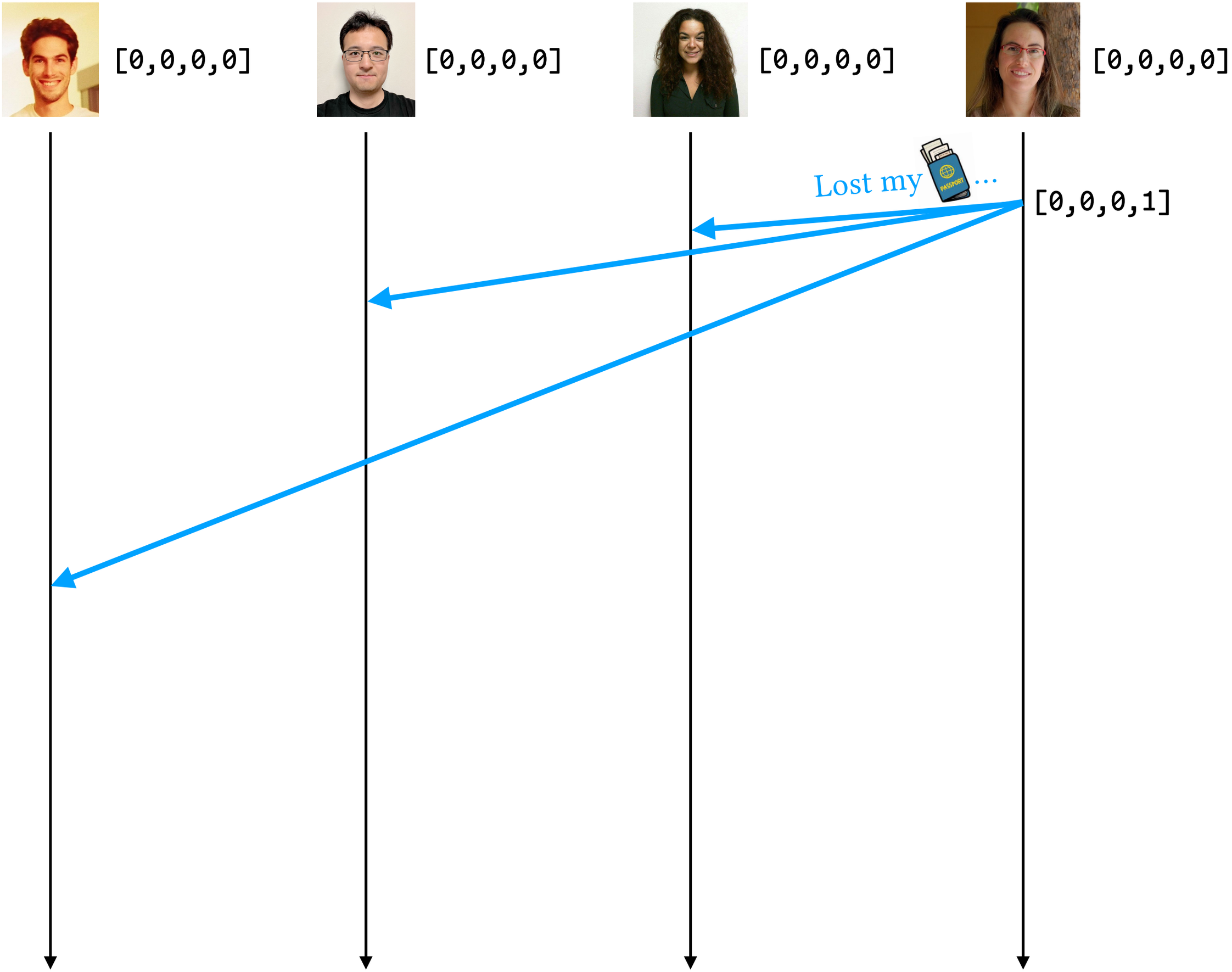

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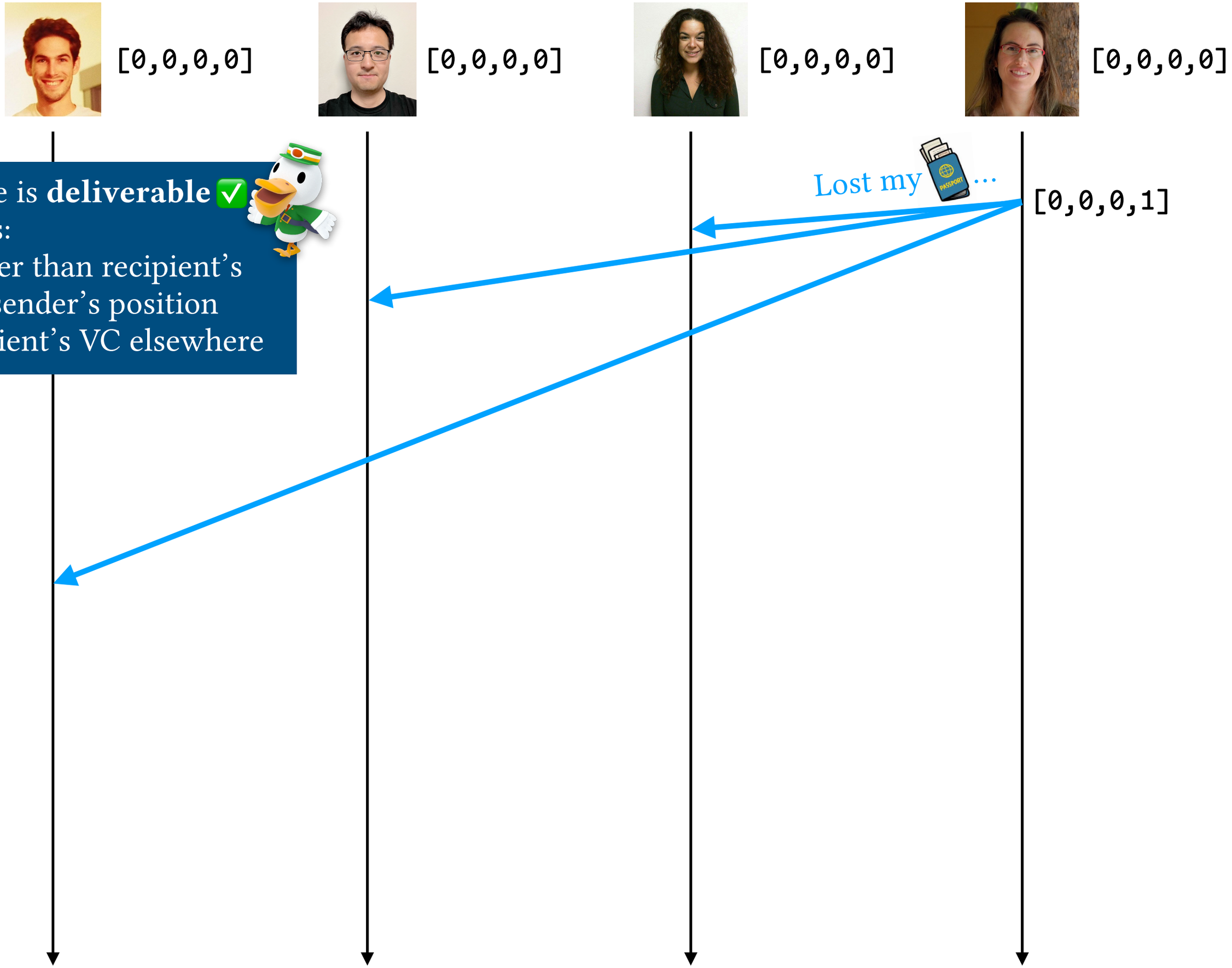

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[0,0,0,0] [0,0,0,0] [0,0,0,0] [0,0,0,0]

A message is **deliverable** ✅ if its VC is:

- 1 greater than recipient's VC in sender's position
- ≤ recipient's VC elsewhere

Lost my  …

[0,0,0,1]

✅

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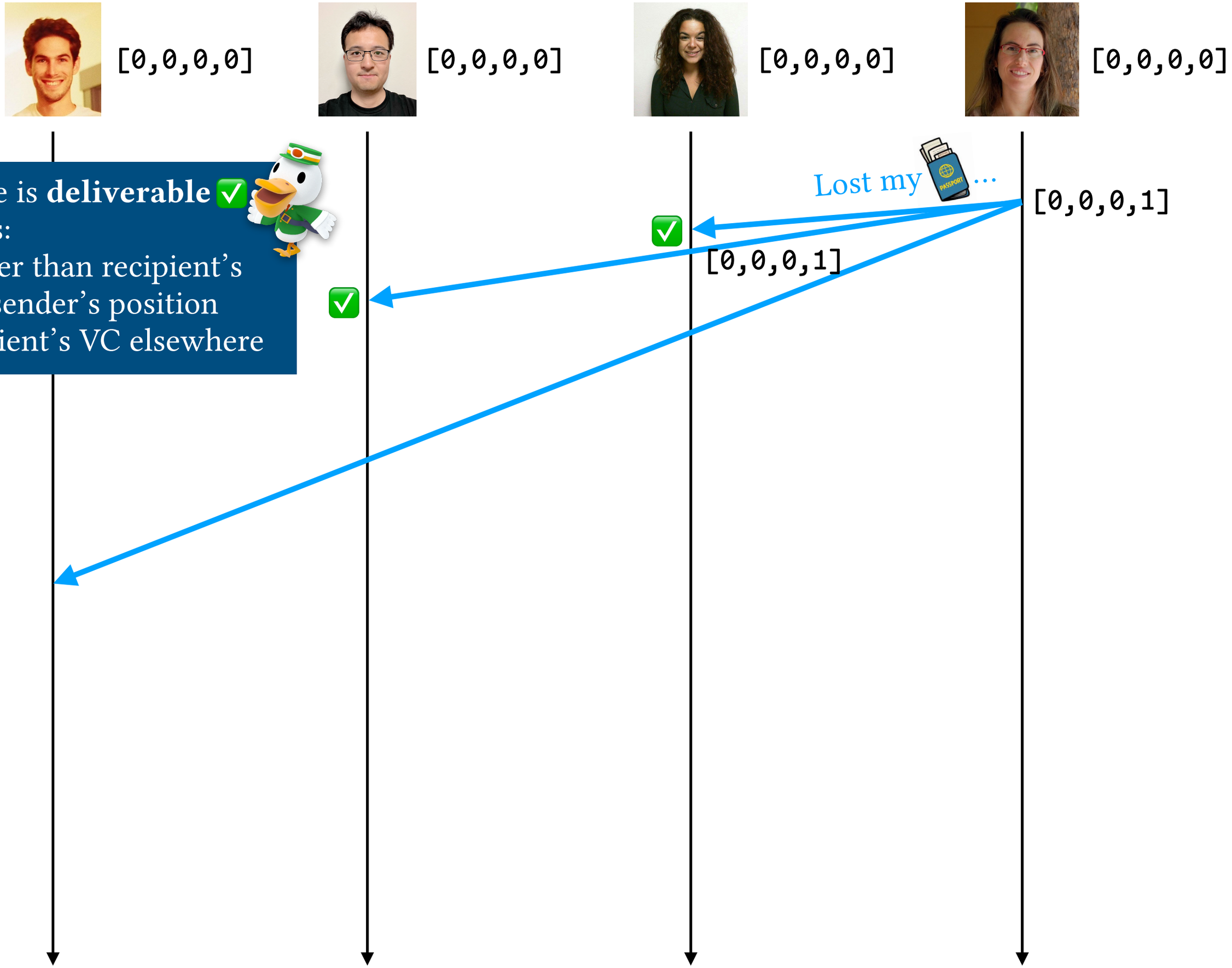

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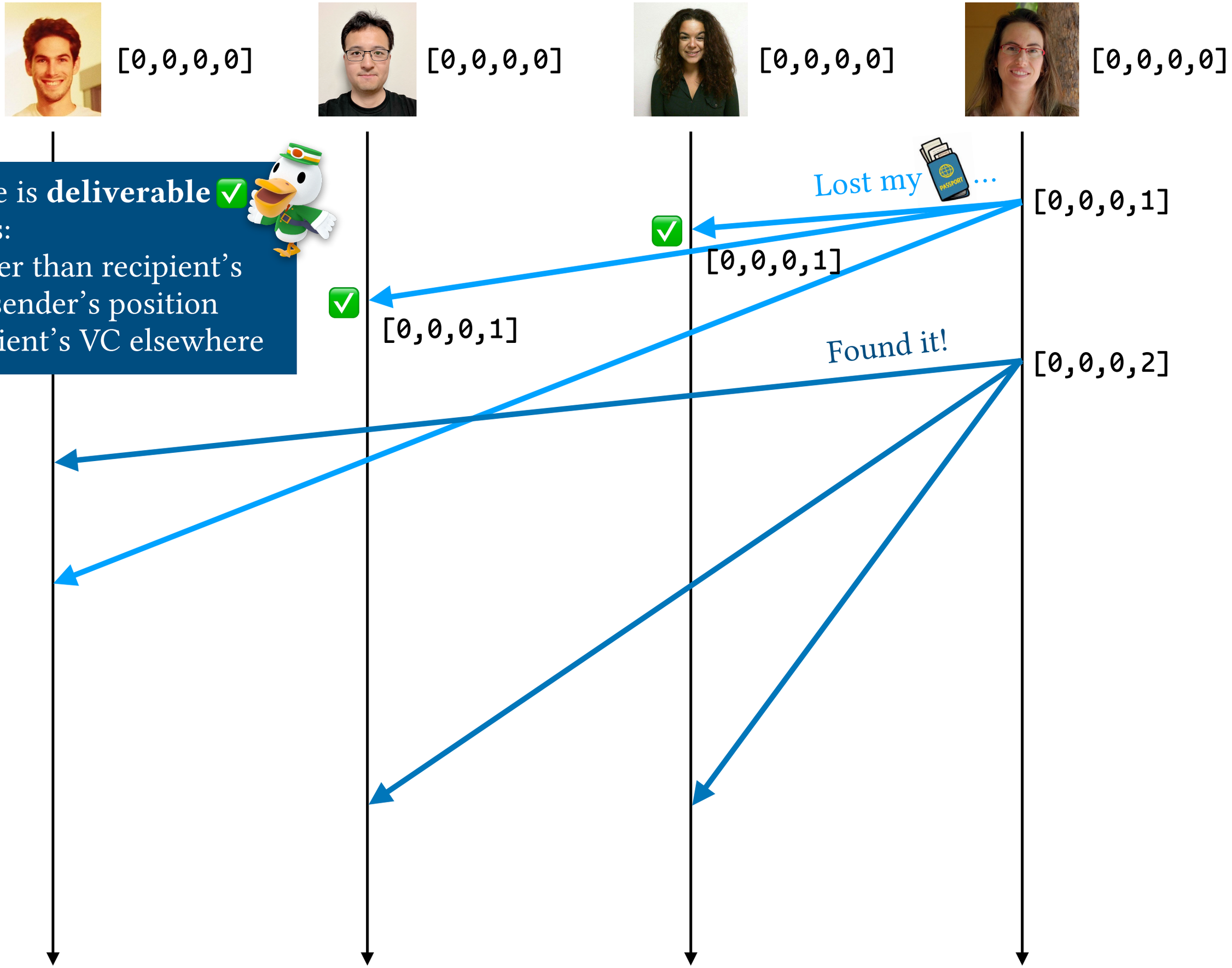

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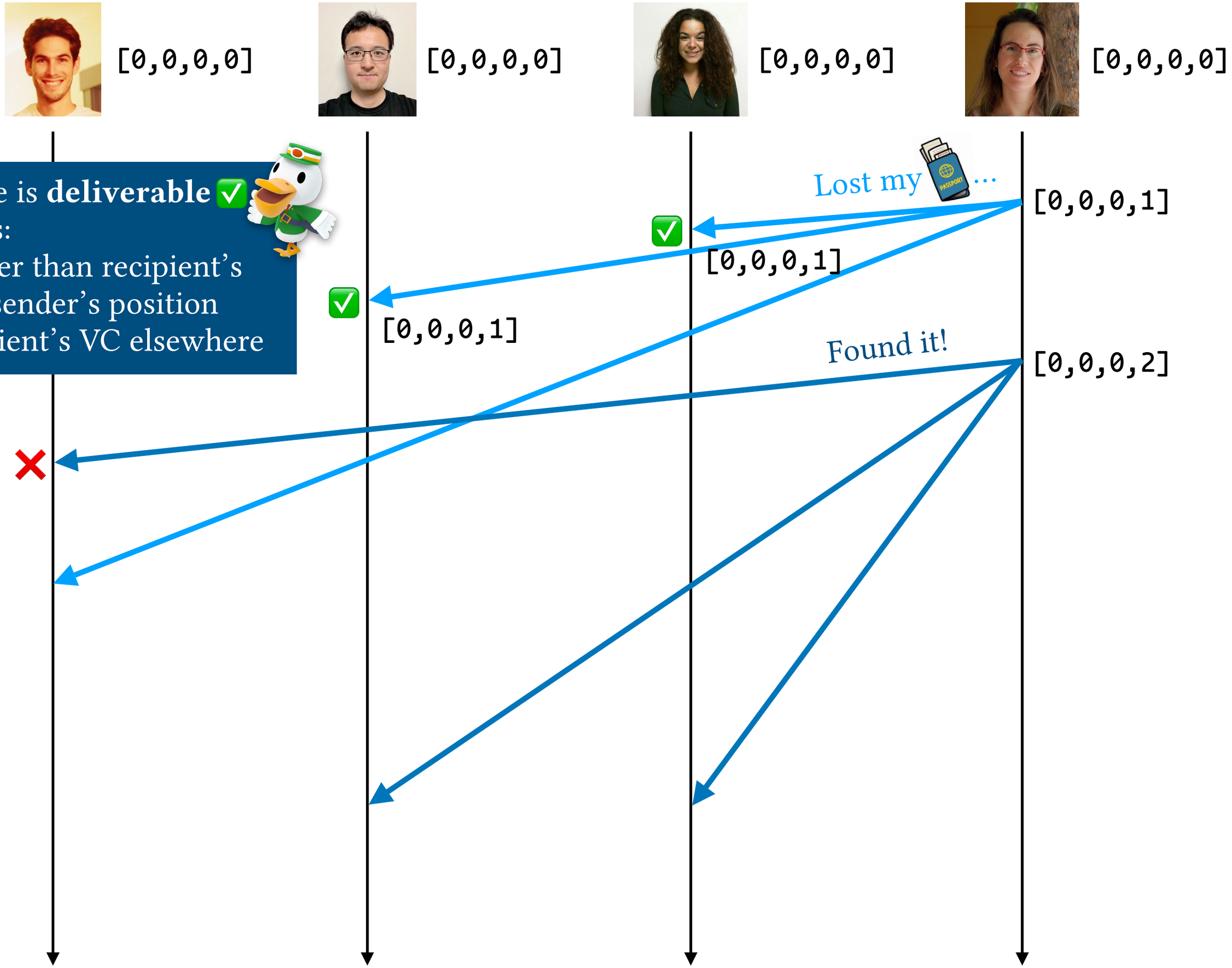

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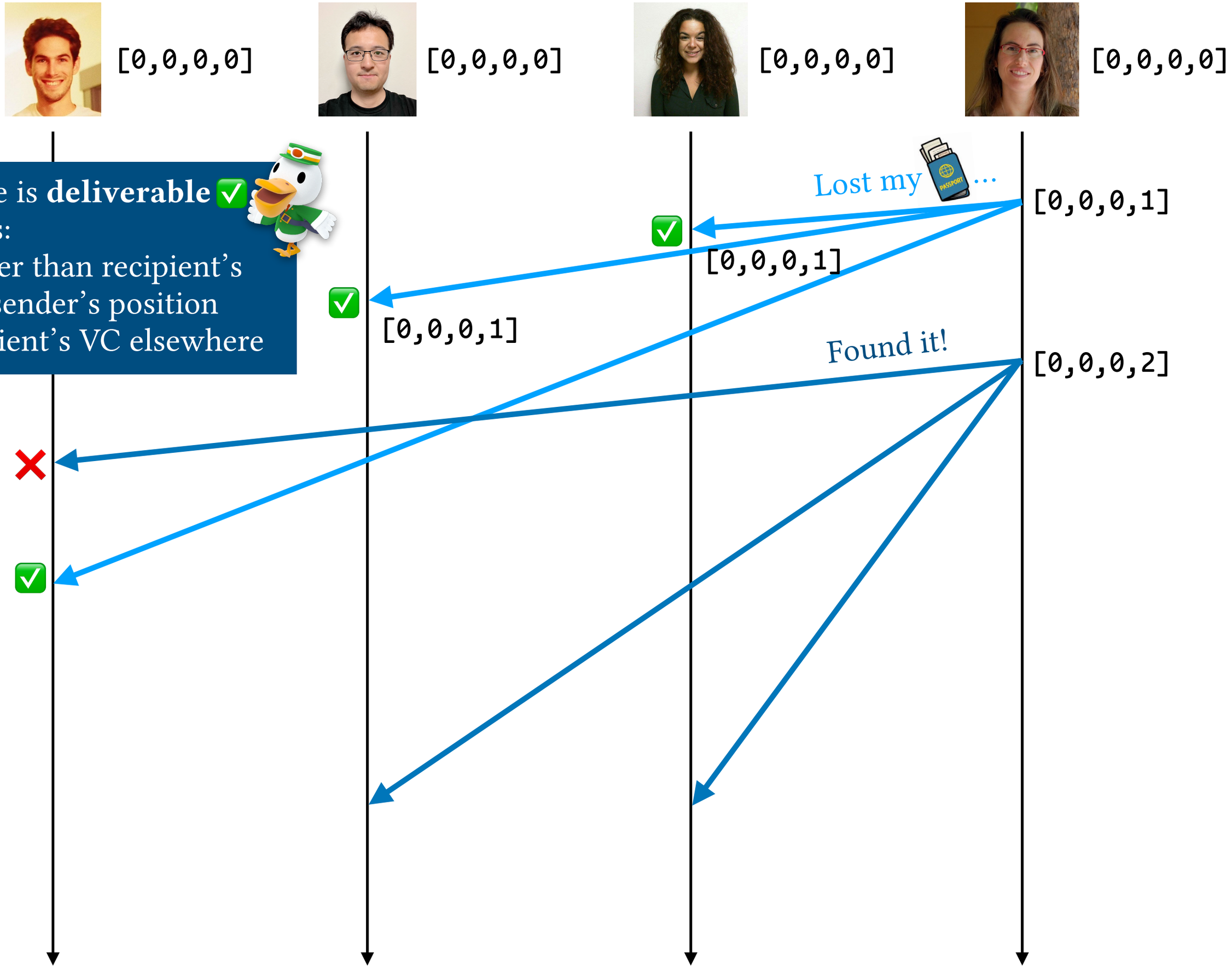

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Lost my  …

[0,0,0,1]

[0,0,0,1]

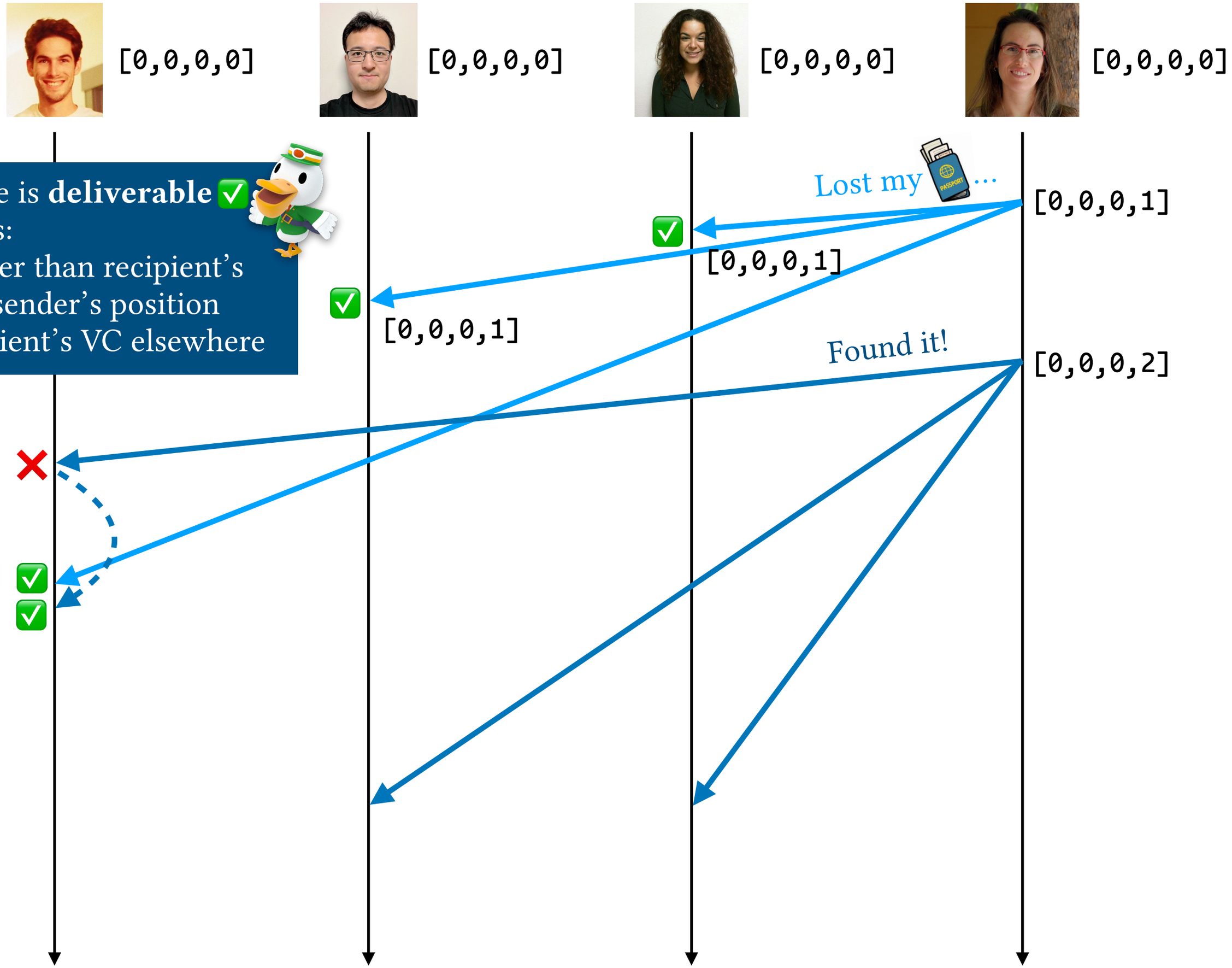
[0,0,0,1]

Found it!

[0,0,0,2]

[0,0,0,1]

Causal broadcast with vector clocks [Birman et al., 1991]



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Lost my  …

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✅ [0,0,0,1]

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Found it!

[0,0,0,2]

❌

[0,0,0,1] ✅
[0,0,0,2] ✅
[1,0,0,2]

Yay!

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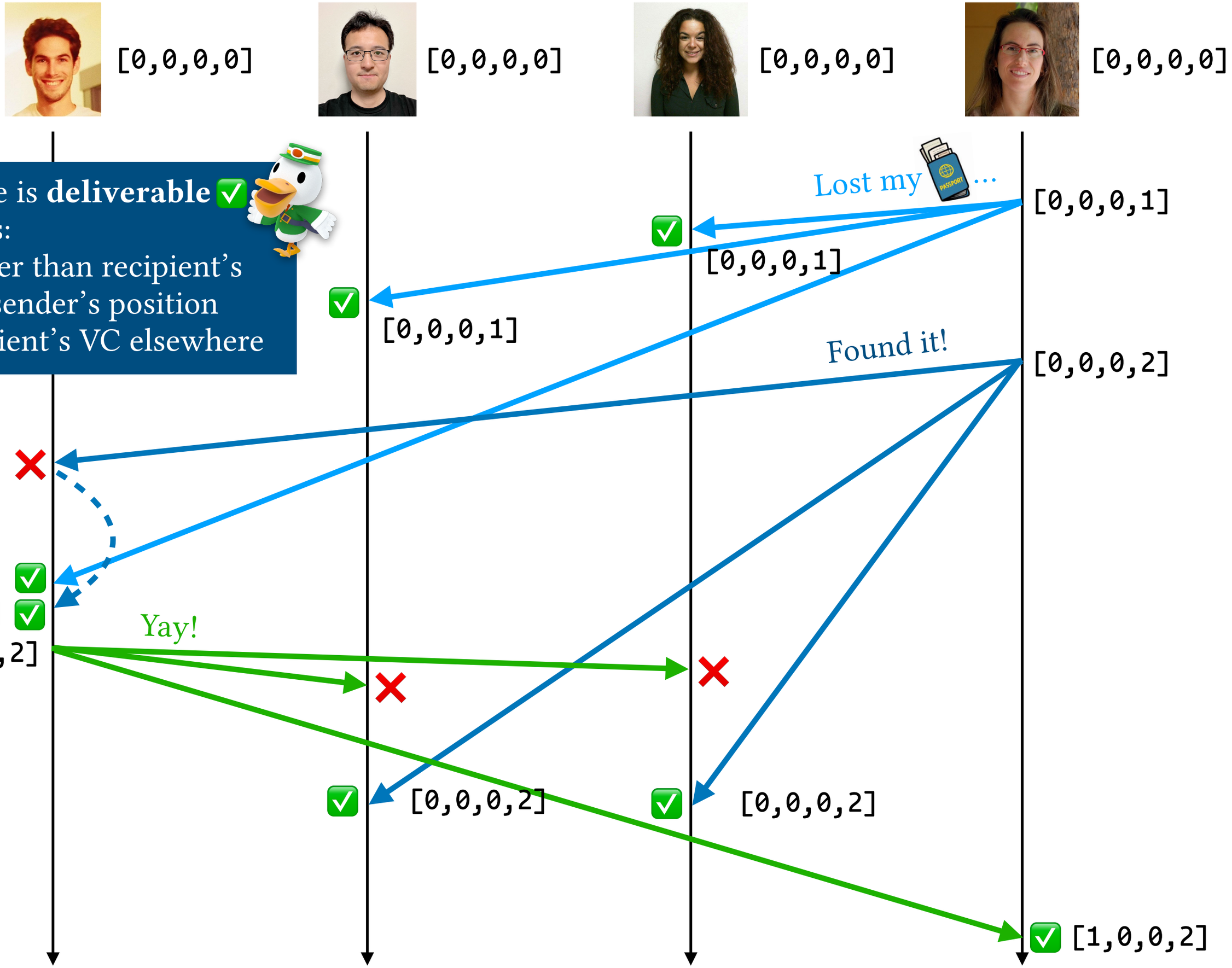

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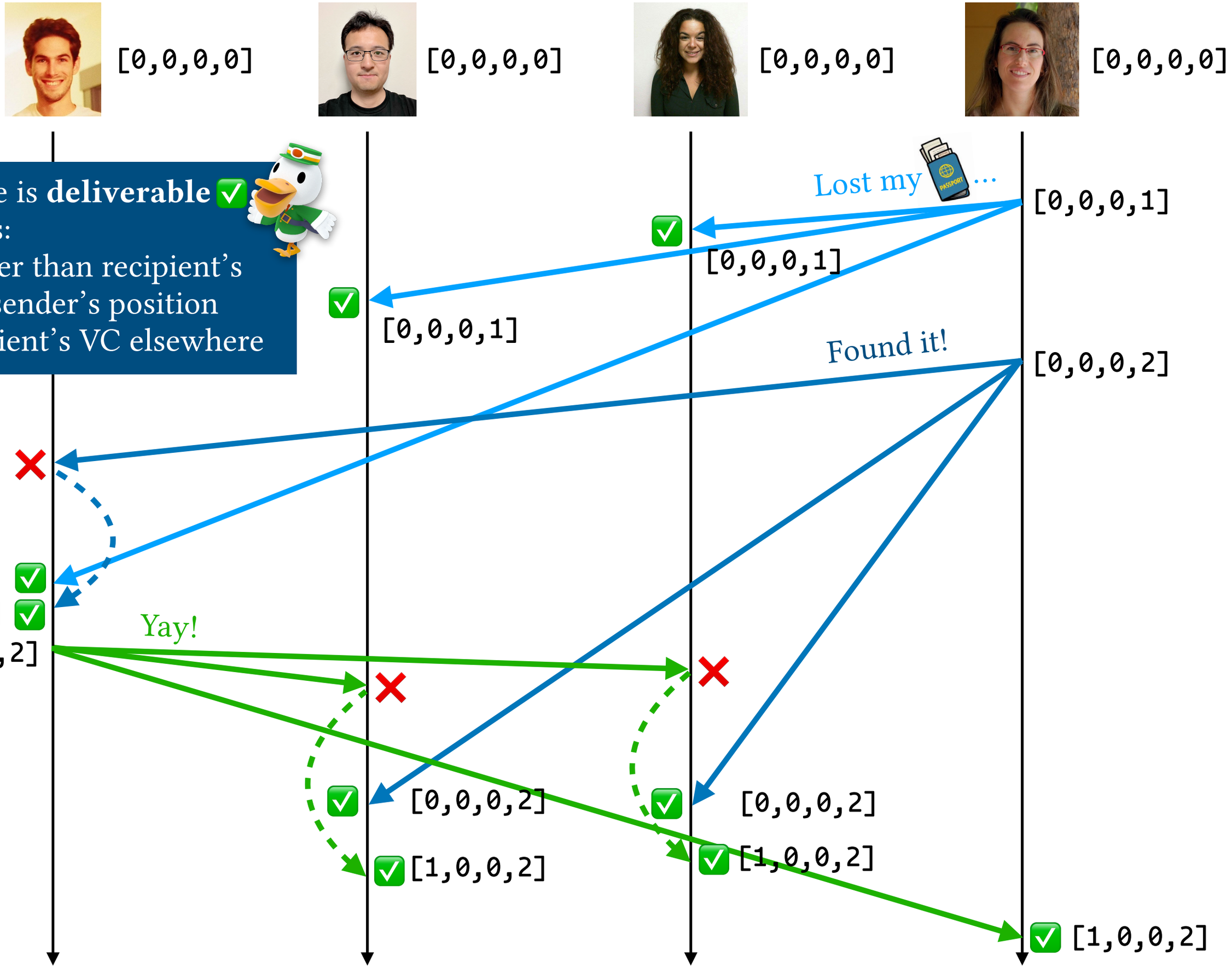

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...using **language-integrated** verification tools (*i.e.*, **types!**)

Refinement types

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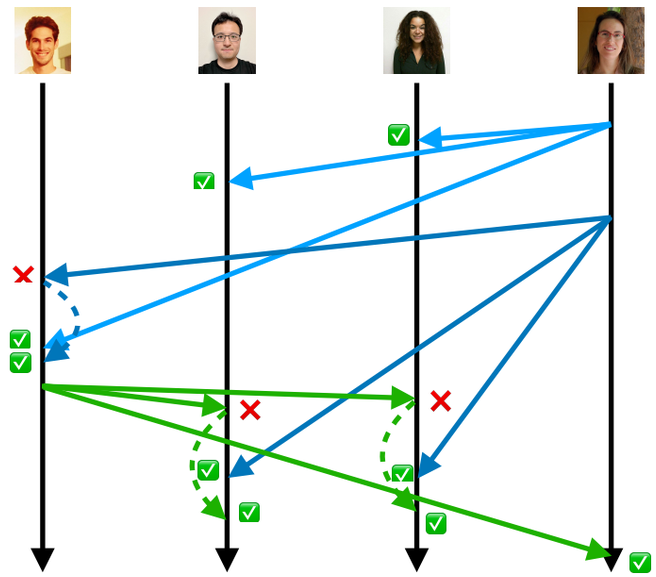
Refinement *reflection*

(Local) causal delivery as a refinement type

verification code

's process history (`pHist`):

```
[(Deliver  “Lost my  ”),
 (Deliver  “Found it!”),
 (Broadcast “Yay!”),
 …]
```



(Local) causal delivery as a refinement type

verification code

```
type LocalCausalDelivery P =
    =  { m1 : Message | elem (Deliver (pID P) m1) (pHist P) }
    -> { m2 : Message | elem (Deliver (pID P) m2) (pHist P)
                      && vcLess (mVC m1) (mVC m2) }
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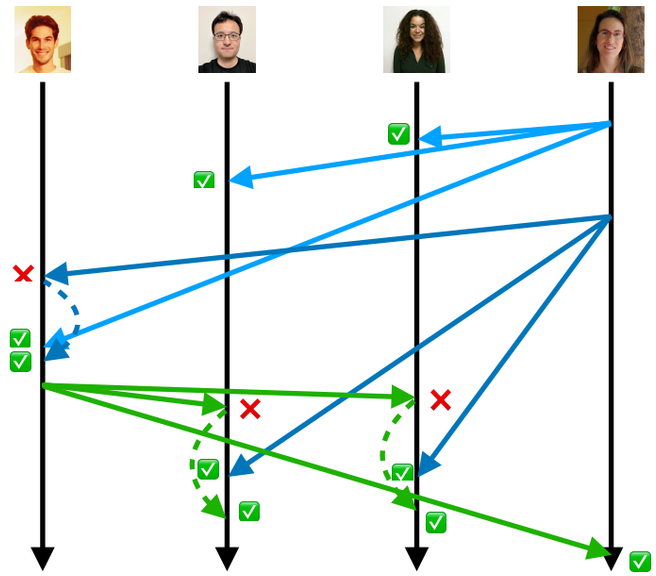

(Local) causal delivery as a refinement type

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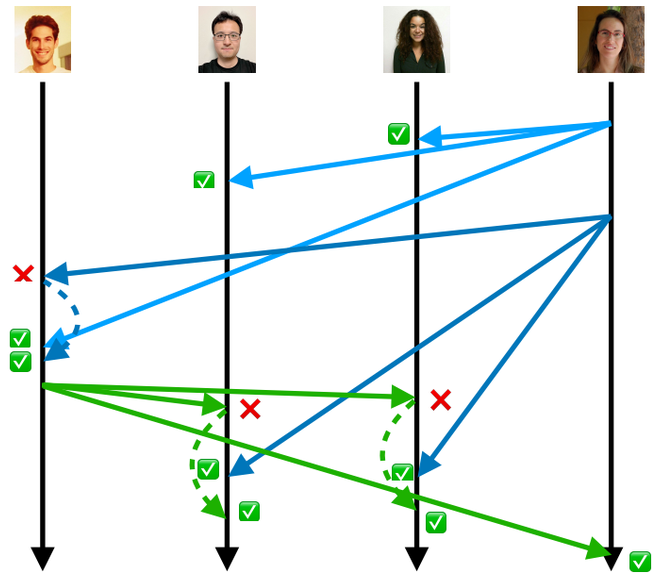

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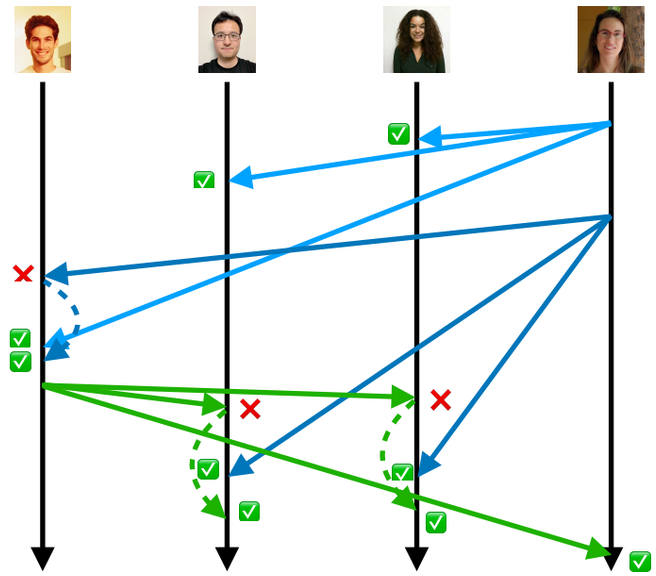

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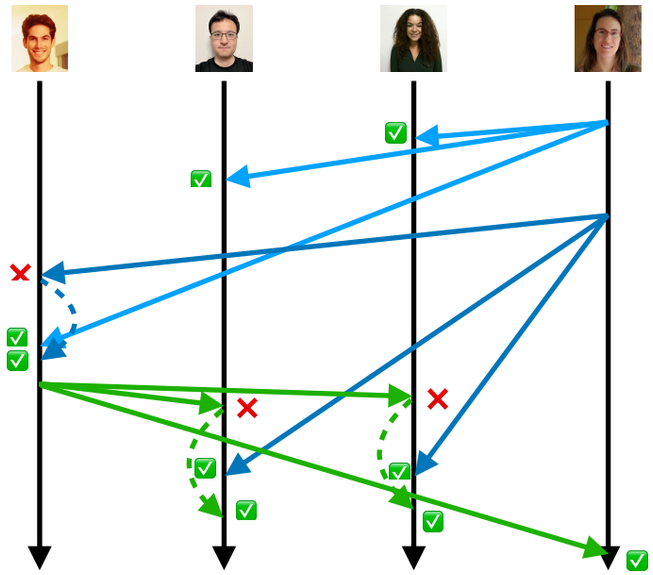

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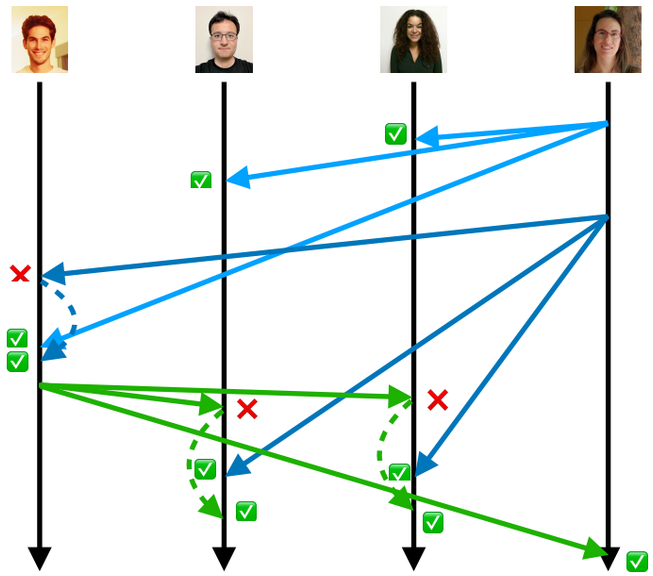

Running the protocol preserves (local) causal delivery

application code

verification code

Running the protocol preserves (local) causal delivery

```haskell
data Op r = OpBroadcast r | OpReceive (Message r) | OpDeliver

step :: Op r -> Process -> Process
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Running the protocol
for *one* step
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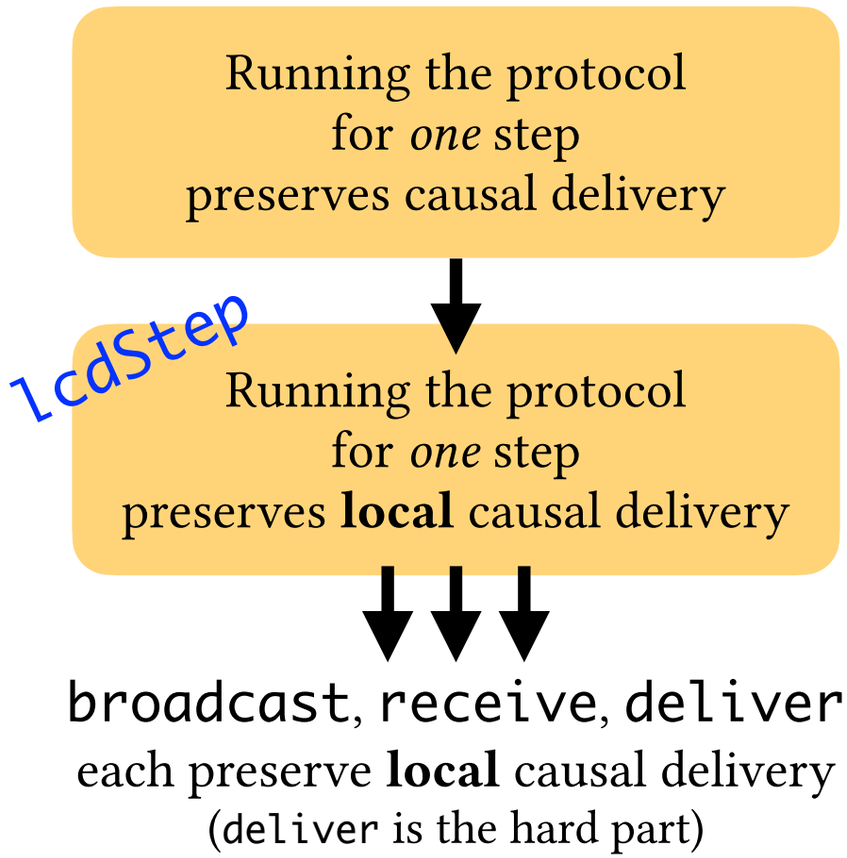
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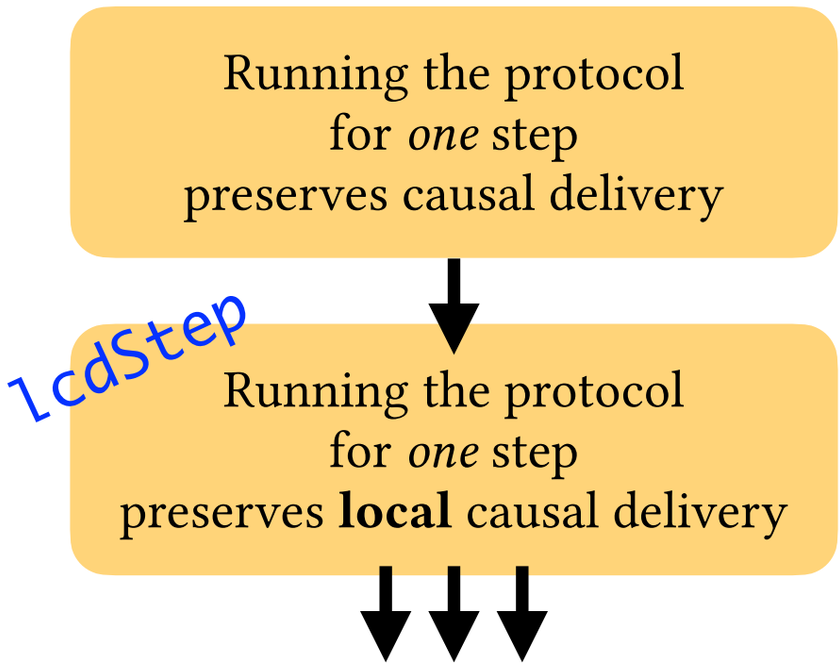

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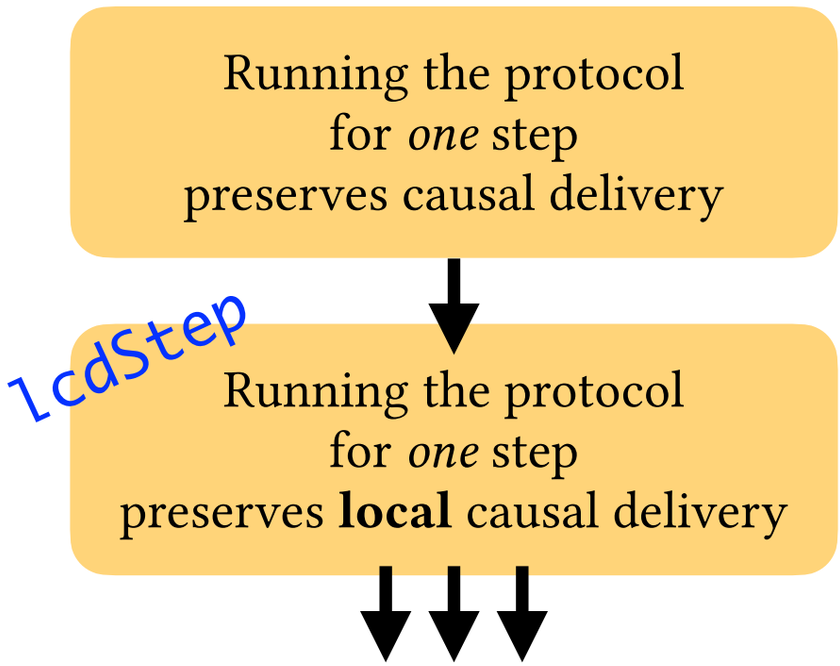

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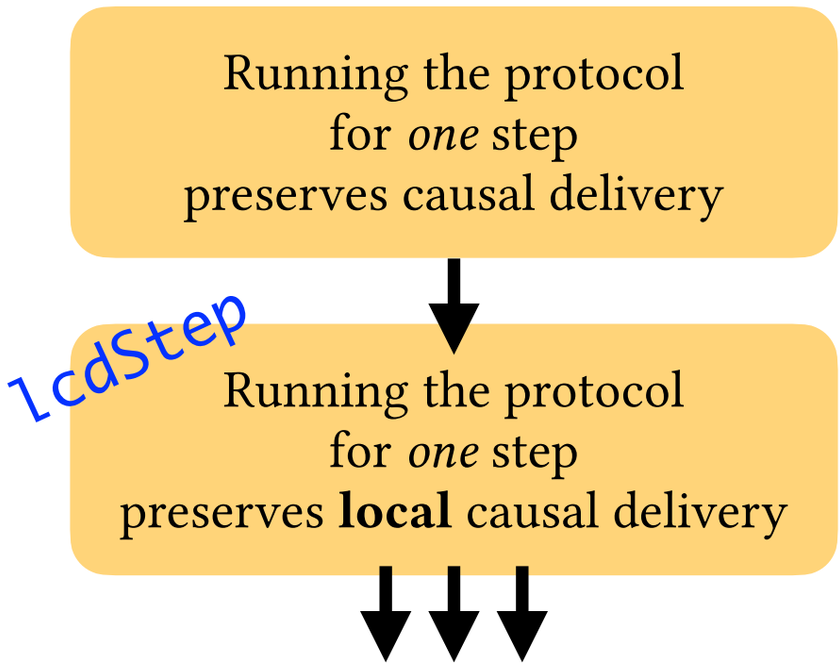

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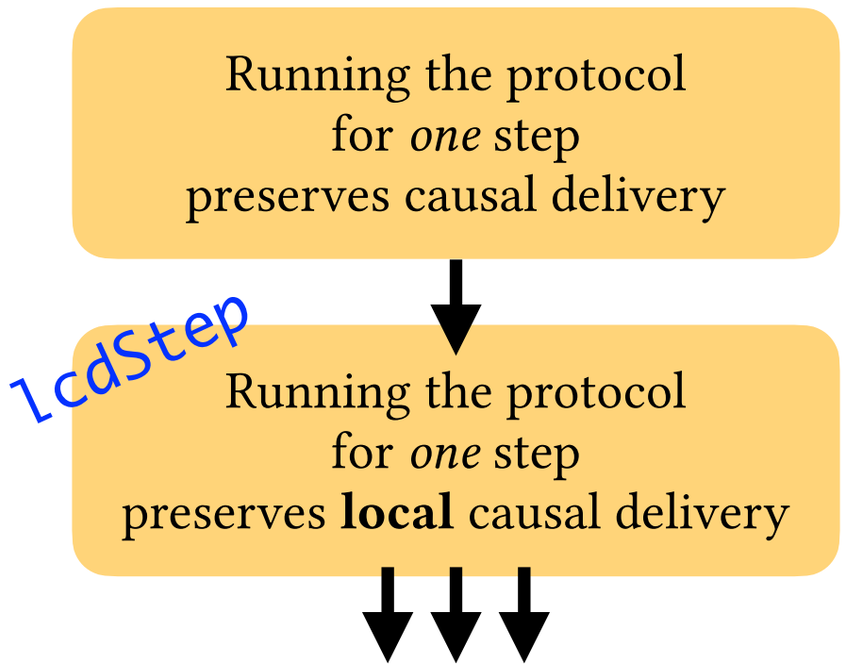

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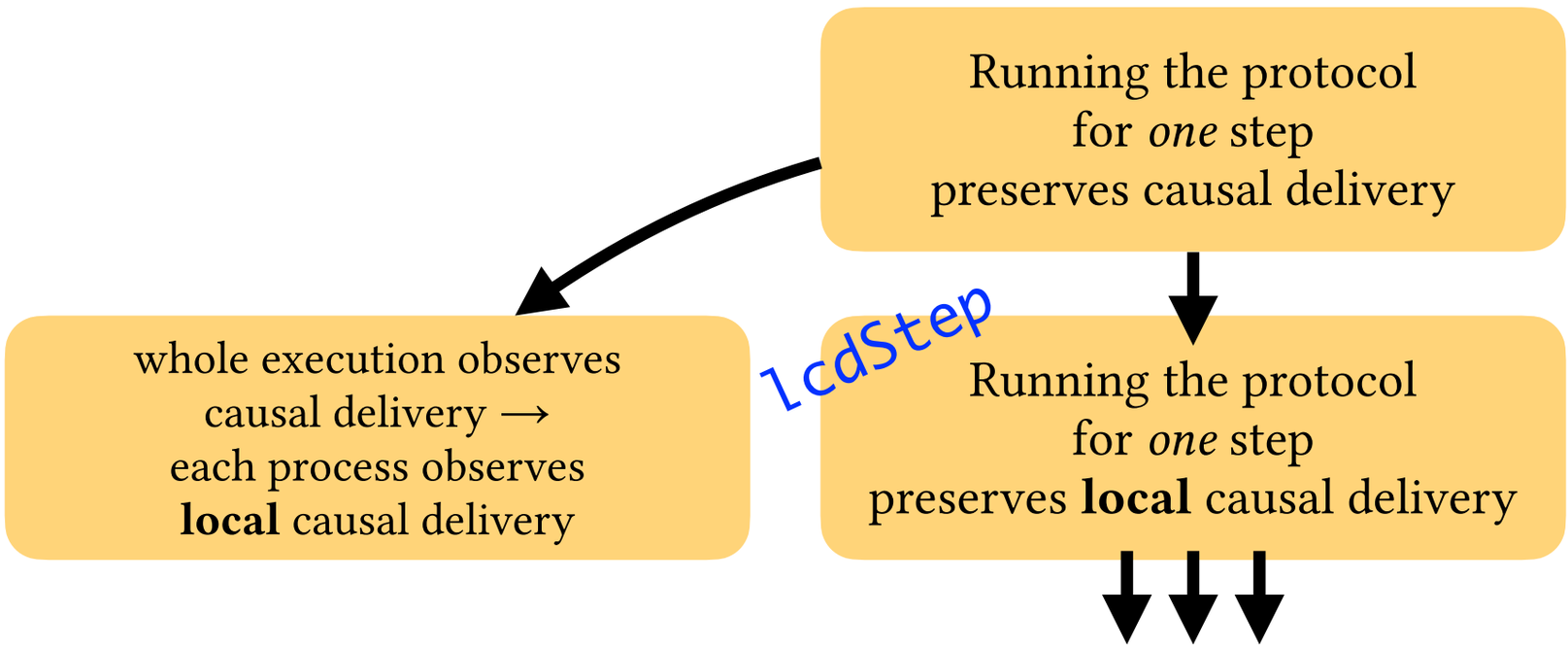

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Running the protocol
for *one* step
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whole execution observes
causal delivery ⟶
each process observes
local causal delivery

`lcdStep`

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vector clocks *reflect*
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Running the protocol
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(+ induction)

Running the protocol
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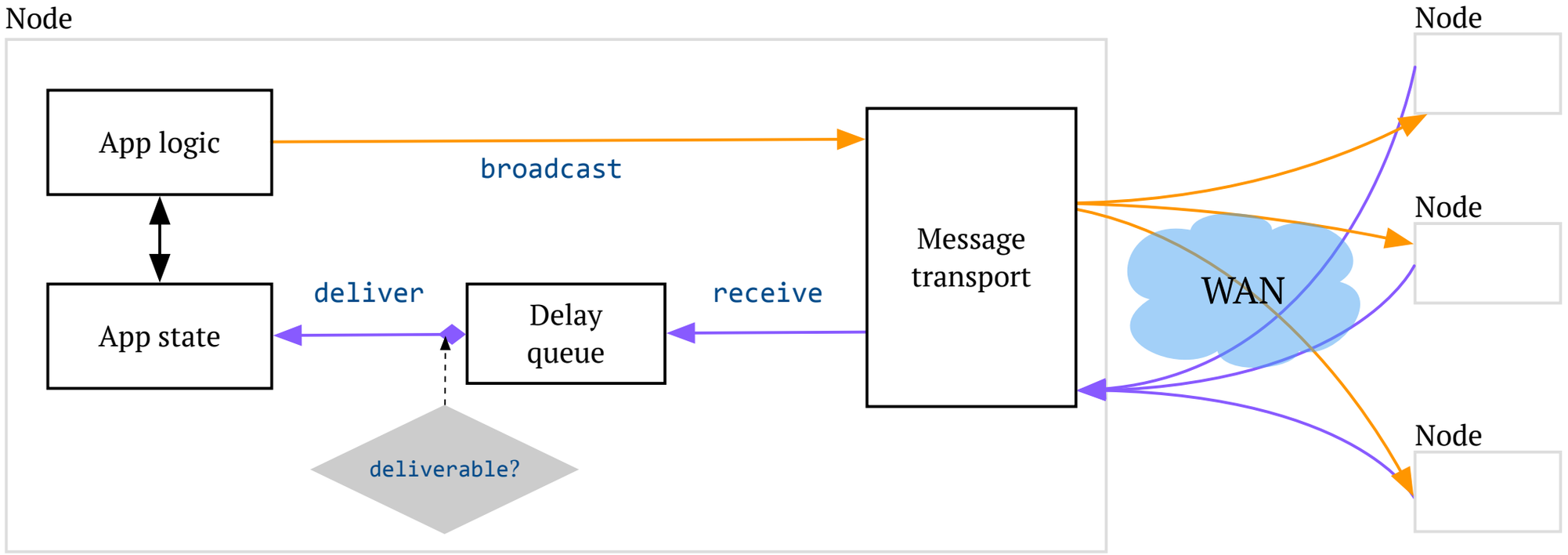
Building apps with causal broadcast



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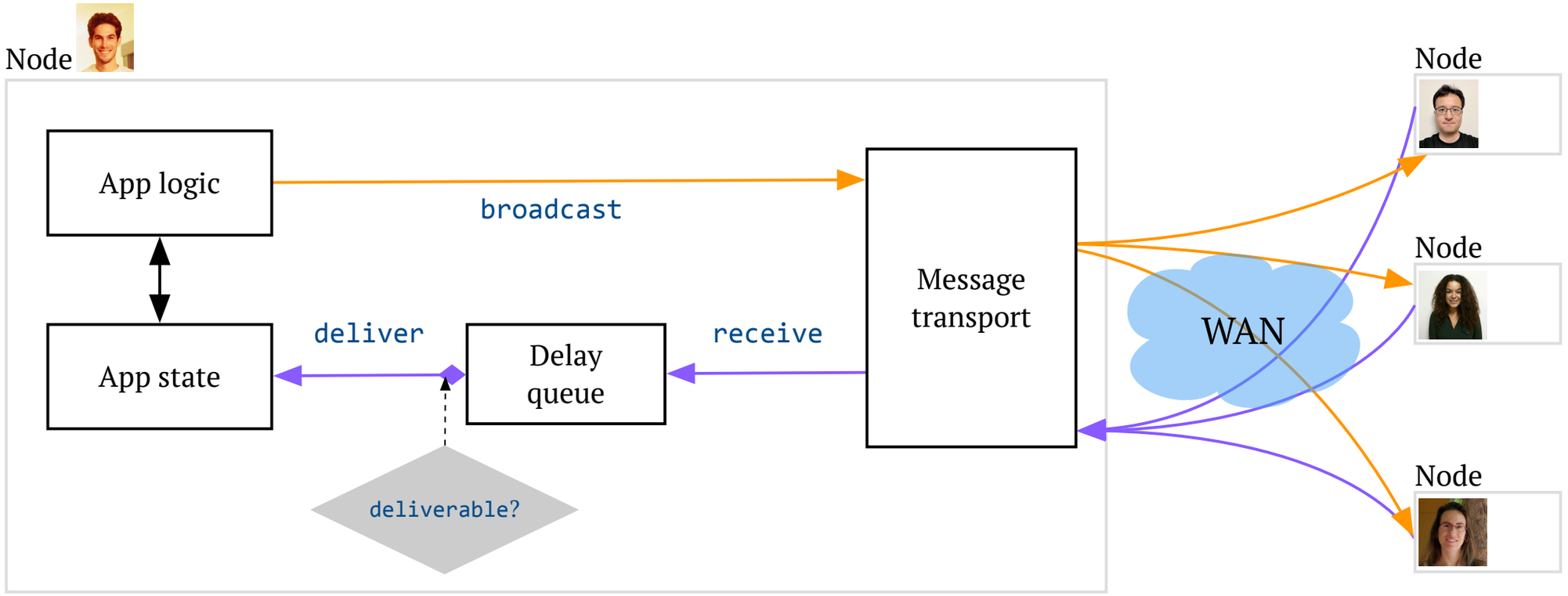

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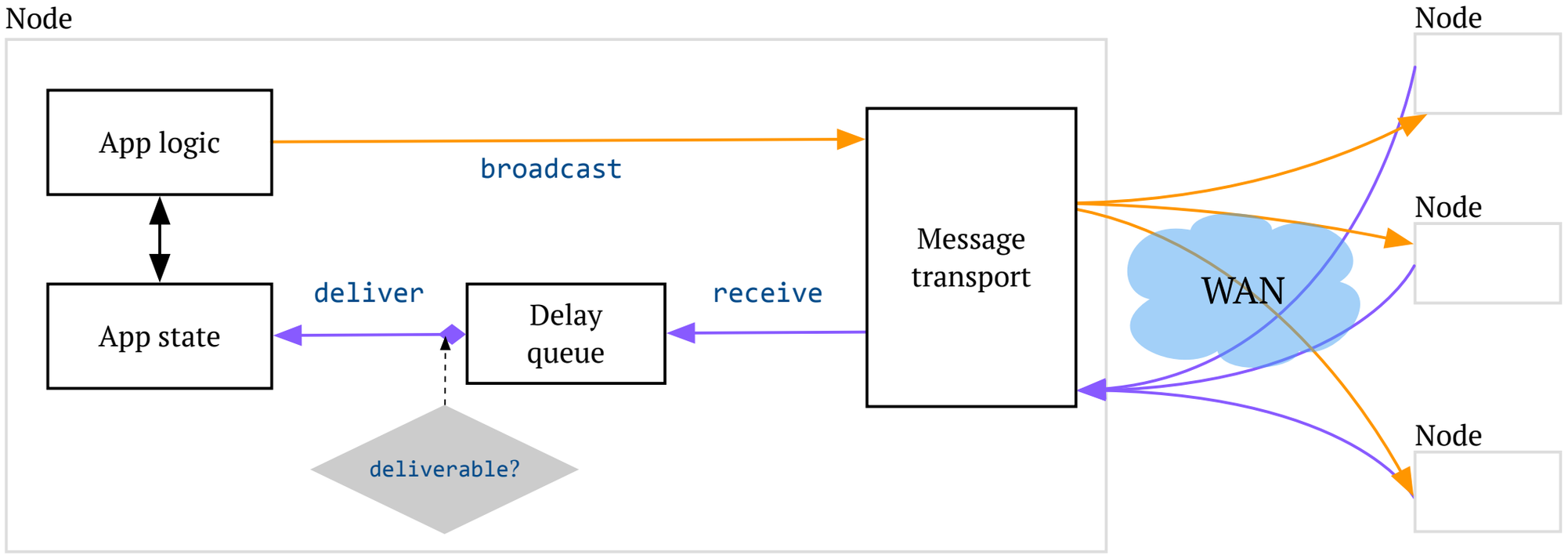

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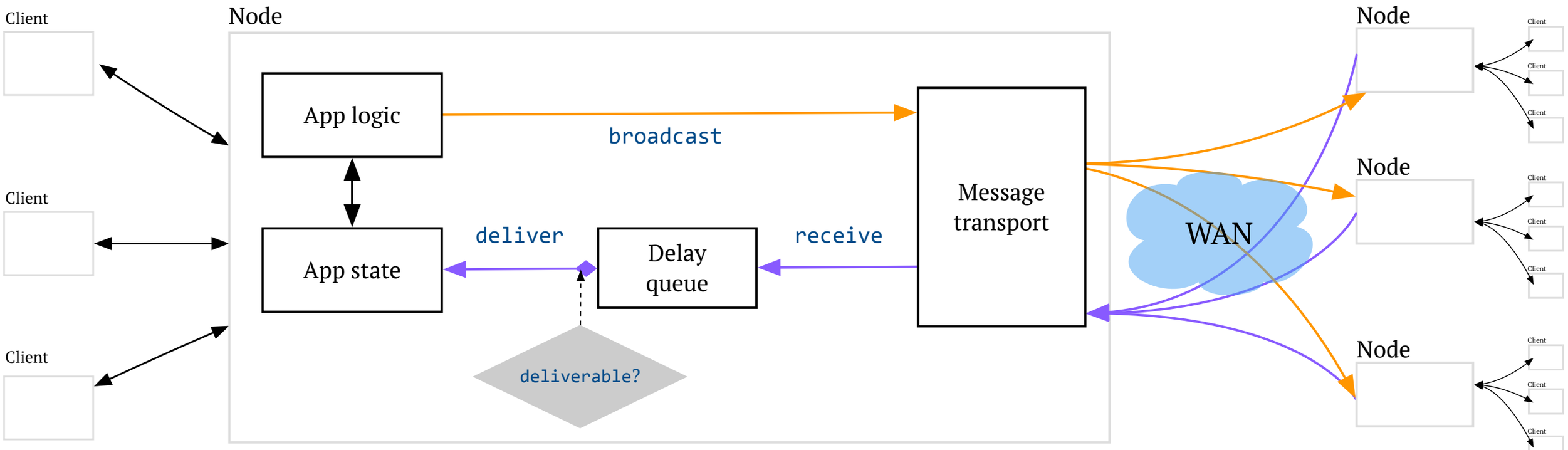

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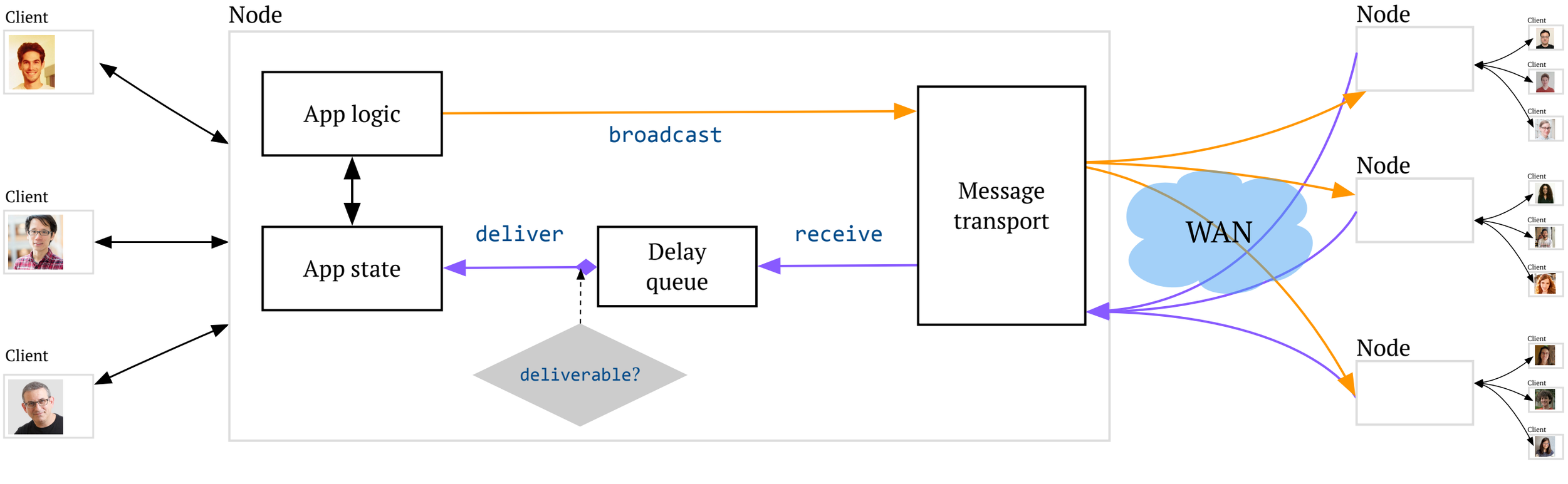

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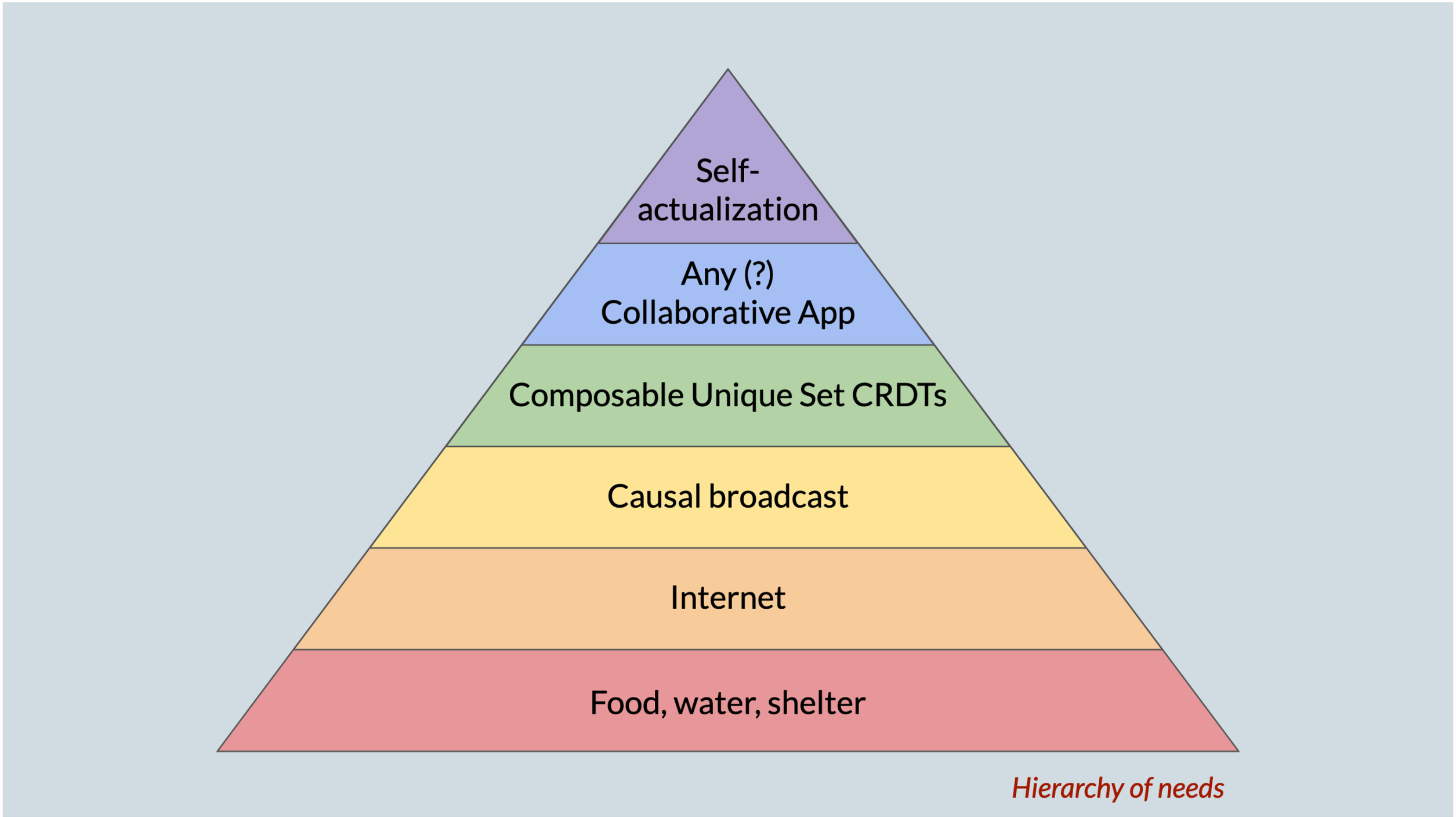

Credit: Matthew Weidner

Programmers should be able to...

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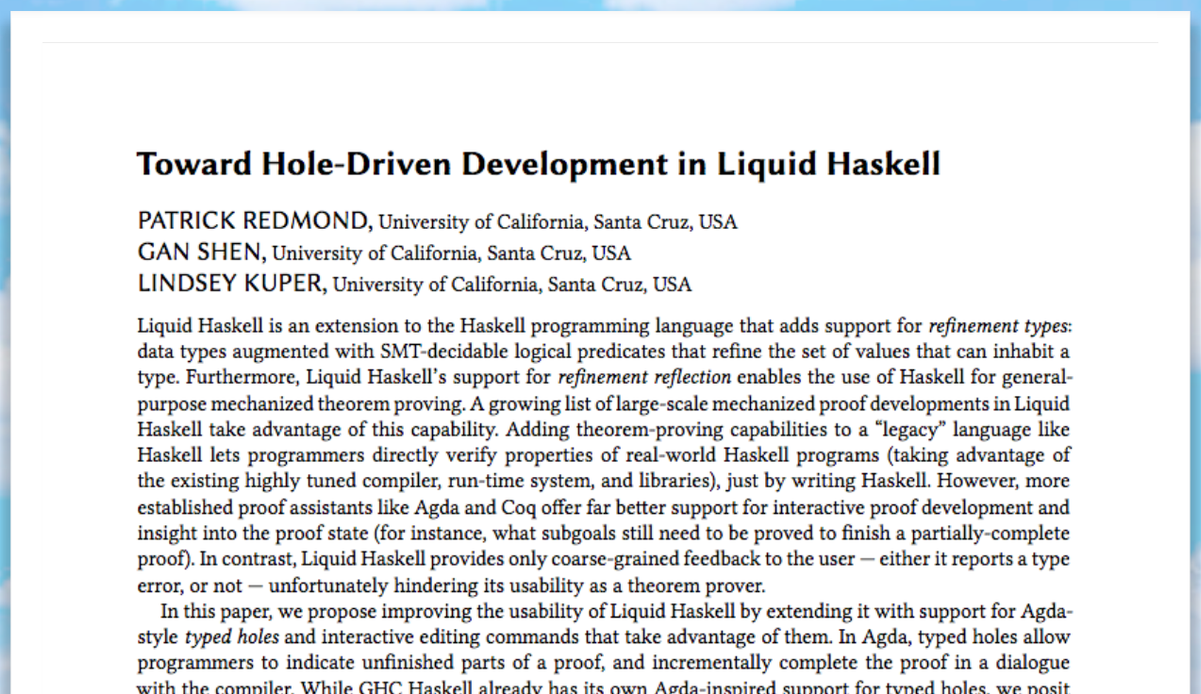


Toward Hole-Driven Development in Liquid Haskell

PATRICK REDMOND, University of California, Santa Cruz, USA
GAN SHEN, University of California, Santa Cruz, USA
LINDSEY KUPER, University of California, Santa Cruz, USA

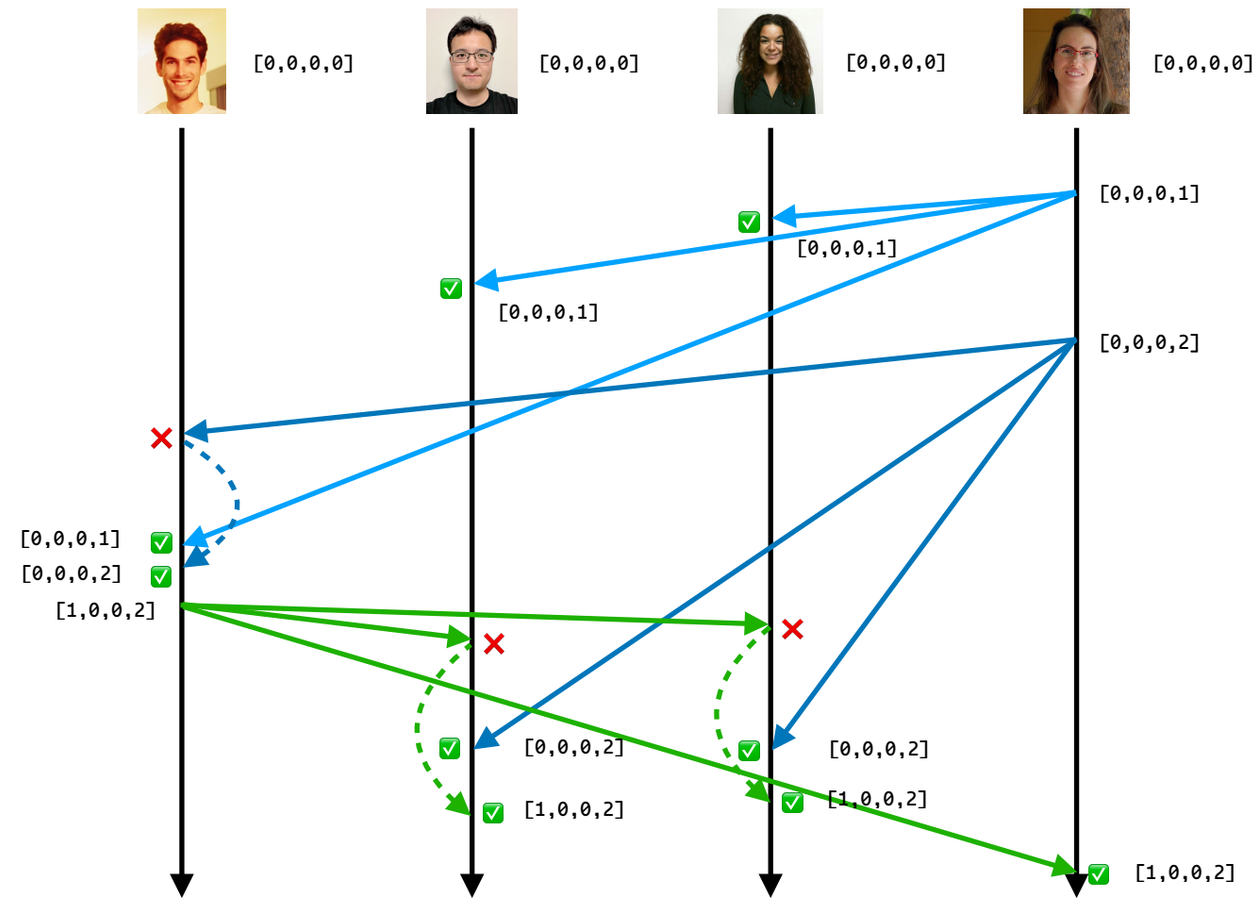
Liquid Haskell is an extension to the Haskell programming language that adds support for *refinement types*: data types augmented with SMT-decidable logical predicates that refine the set of values that can inhabit a type. Furthermore, Liquid Haskell's support for *refinement reflection* enables the use of Haskell for general-purpose mechanized theorem proving. A growing list of large-scale mechanized proof developments in Liquid Haskell take advantage of this capability. Adding theorem-proving capabilities to a "legacy" language like Haskell lets programmers directly verify properties of real-world Haskell programs (taking advantage of the existing highly tuned compiler, run-time system, and libraries), just by writing Haskell. However, more established proof assistants like Agda and Coq offer far better support for interactive proof development and insight into the proof state (for instance, what subgoals still need to be proved to finish a partially-complete proof). In contrast, Liquid Haskell provides only coarse-grained feedback to the user — either it reports a type error, or not — unfortunately hindering its usability as a theorem prover.

In this paper, we propose improving the usability of Liquid Haskell by extending it with support for Agda-style *typed holes* and interactive editing commands that take advantage of them. In Agda, typed holes allow programmers to indicate unfinished parts of a proof, and incrementally complete the proof in a dialogue

[HATRA 2021]

Thank you!

Languages, Systems, and Data Lab: lsd.ucsc.edu
Lindsey's research blog: decomposition.al



github.com/lsd-ucsc/cbcast-lh

Thank you!

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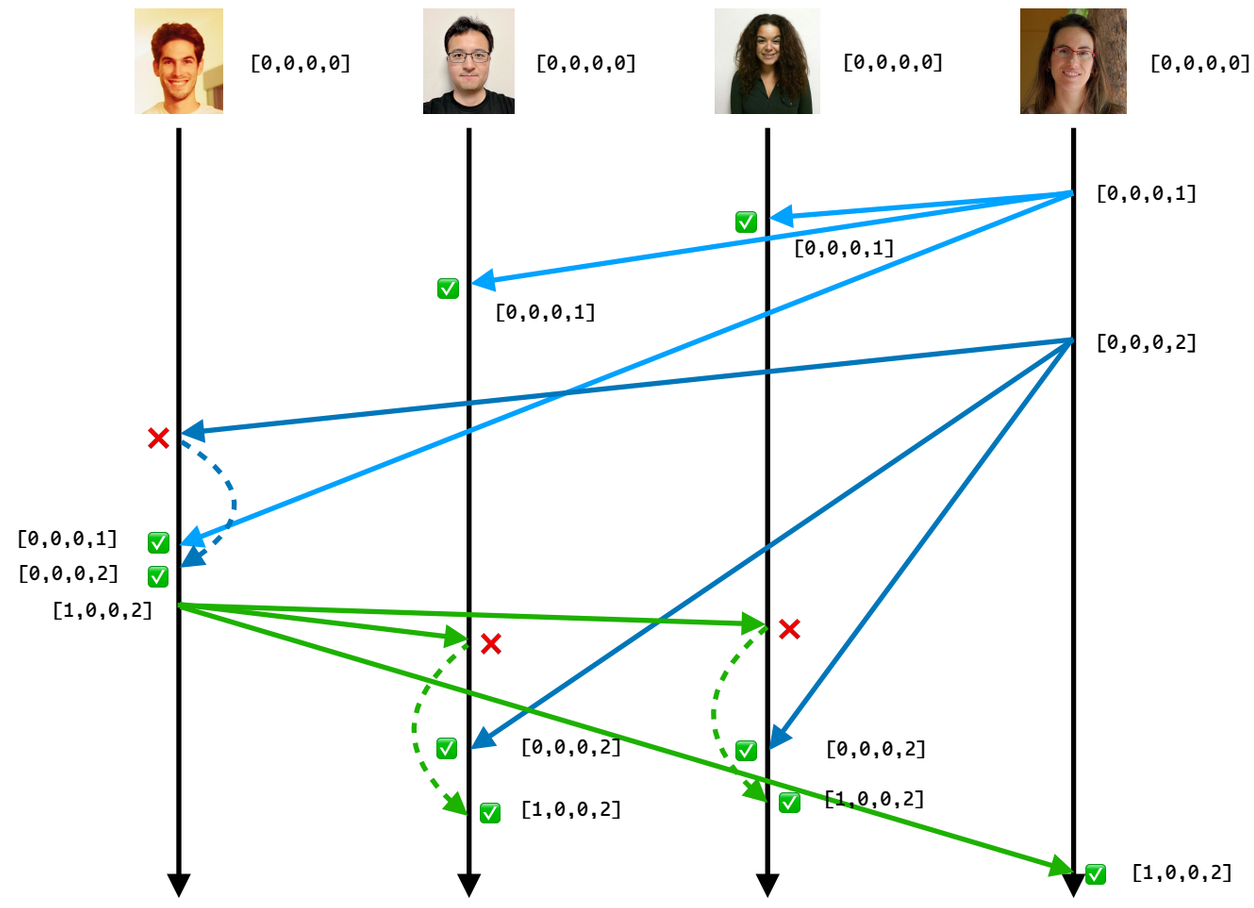

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