Verified Causal Broadcast with Liquid Haskell

Patrick Redmond Gan Shen Niki Vazou Lindsey Kuper

Dagstuhl Seminar 23112:
Unifying Formal Methods for Trustworthy Distributed Systems
13 March 2023

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institute imdea software

github.com/lsd-ucsc/cbcast-lh

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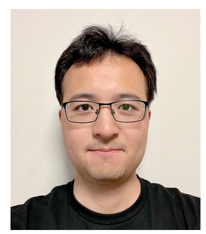

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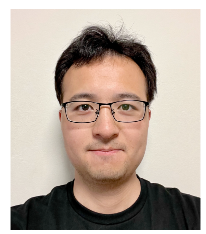

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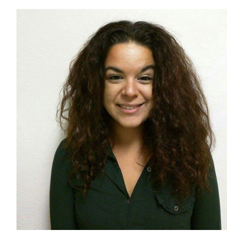

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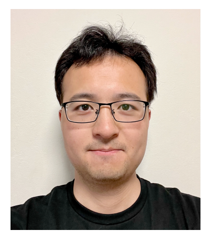

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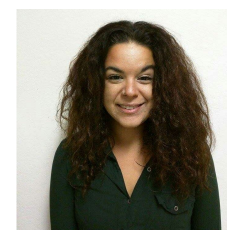

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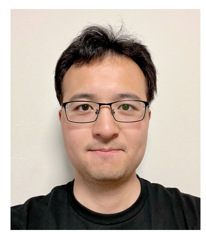

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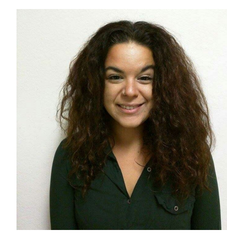

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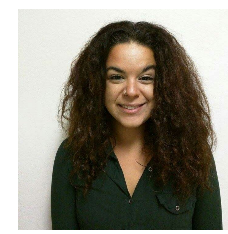

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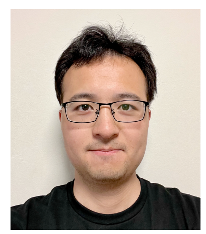

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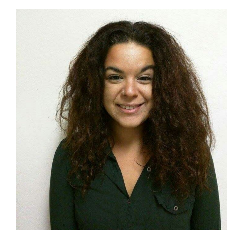

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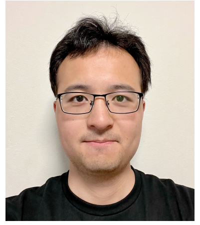

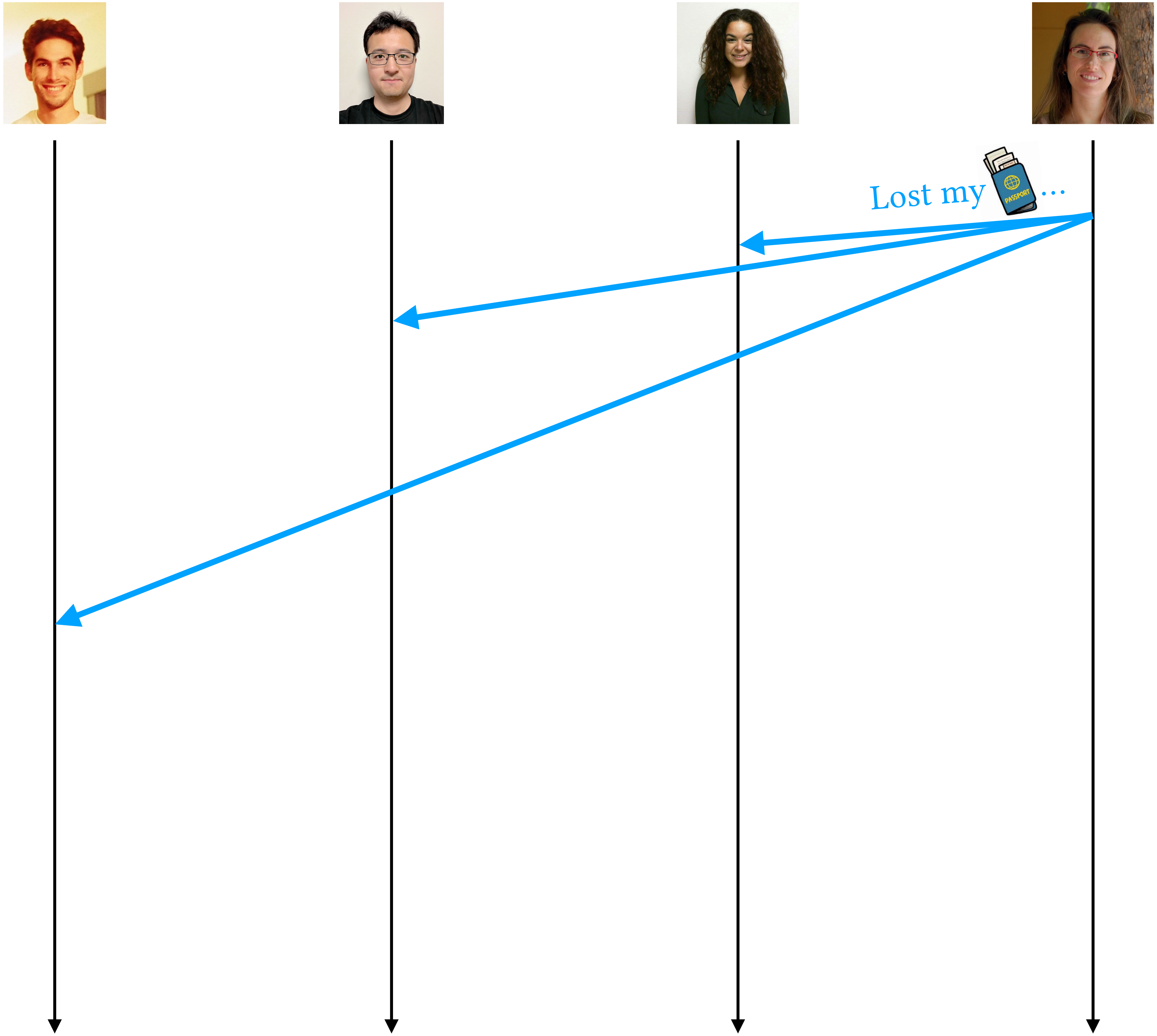
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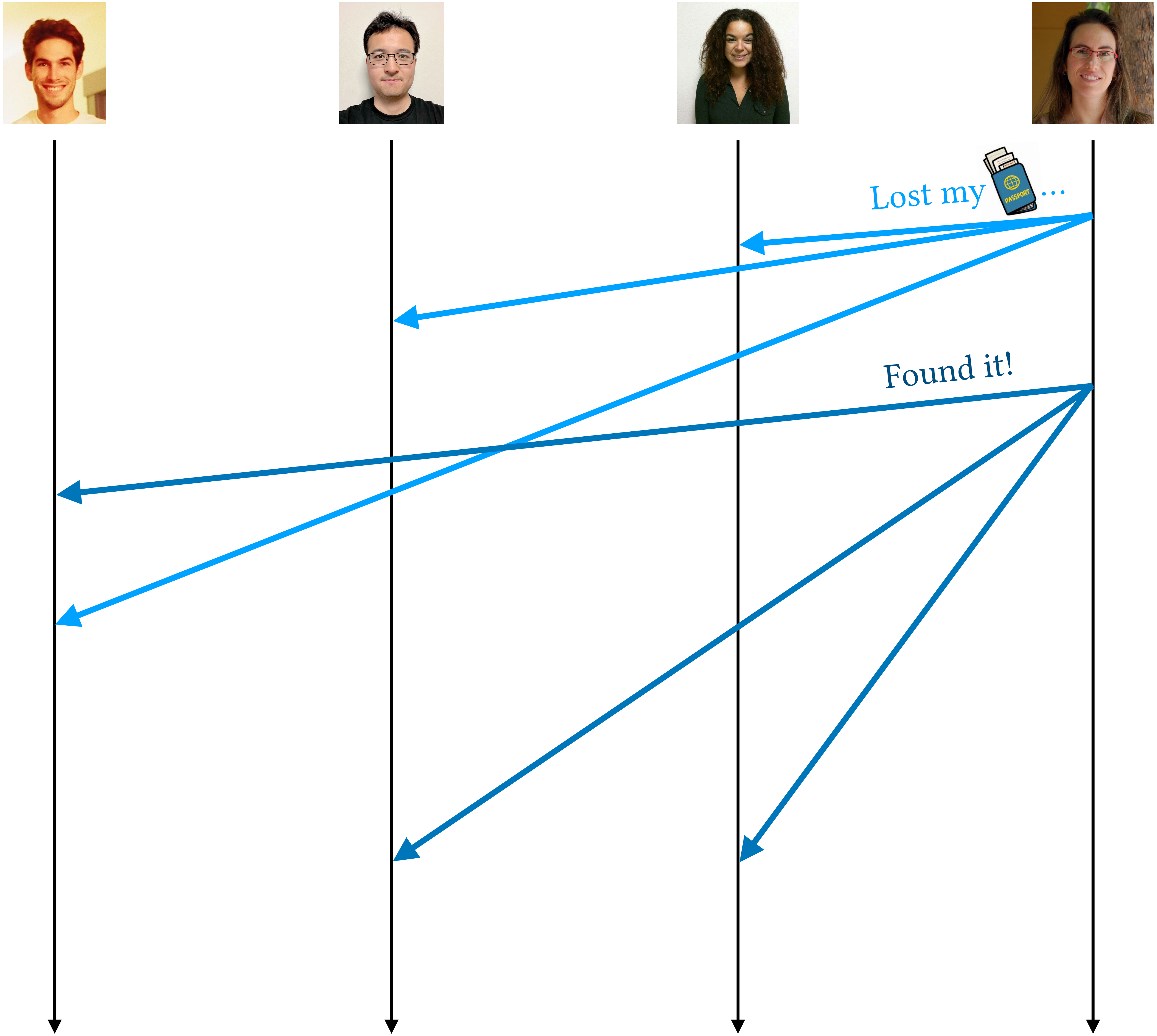
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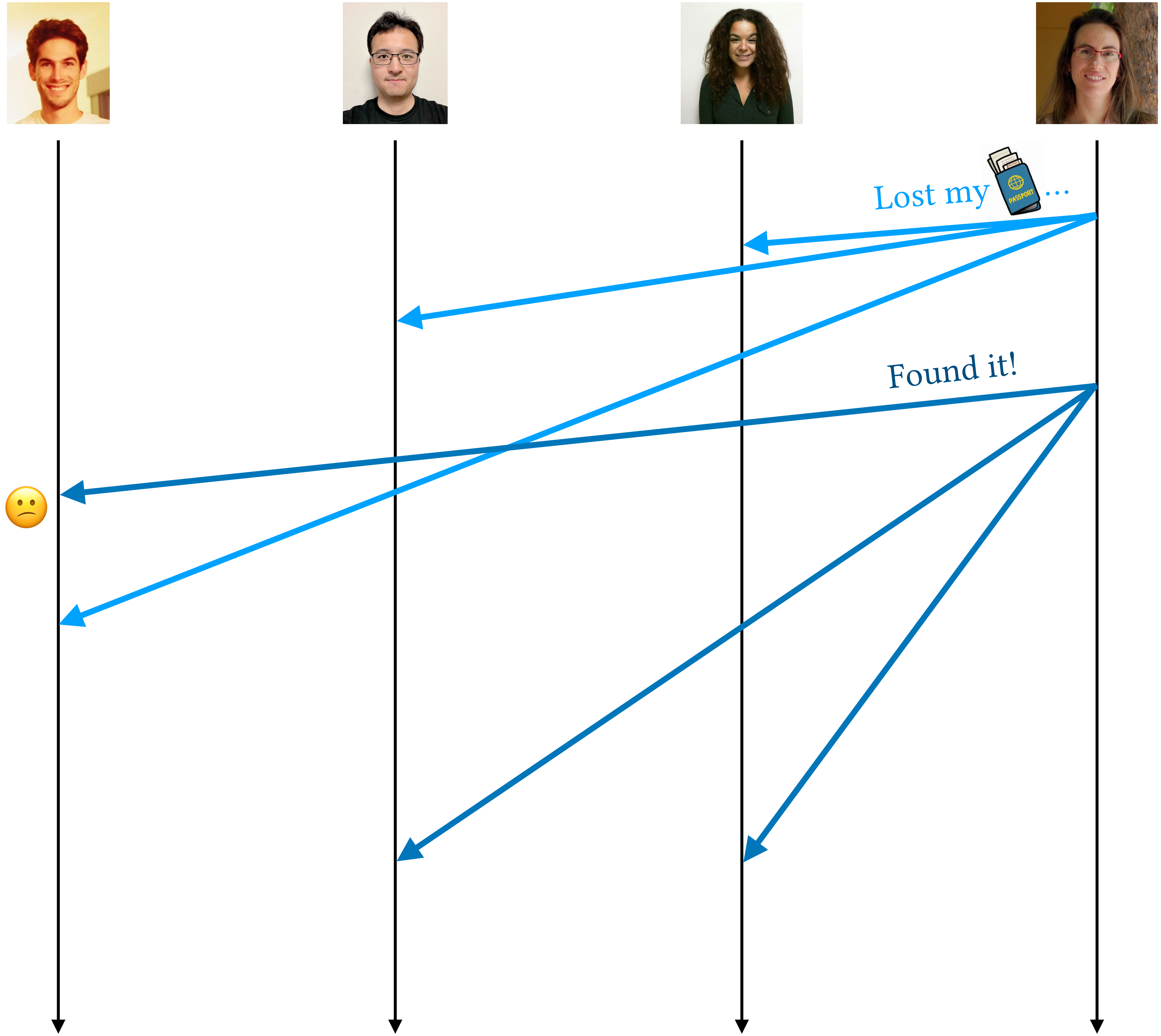
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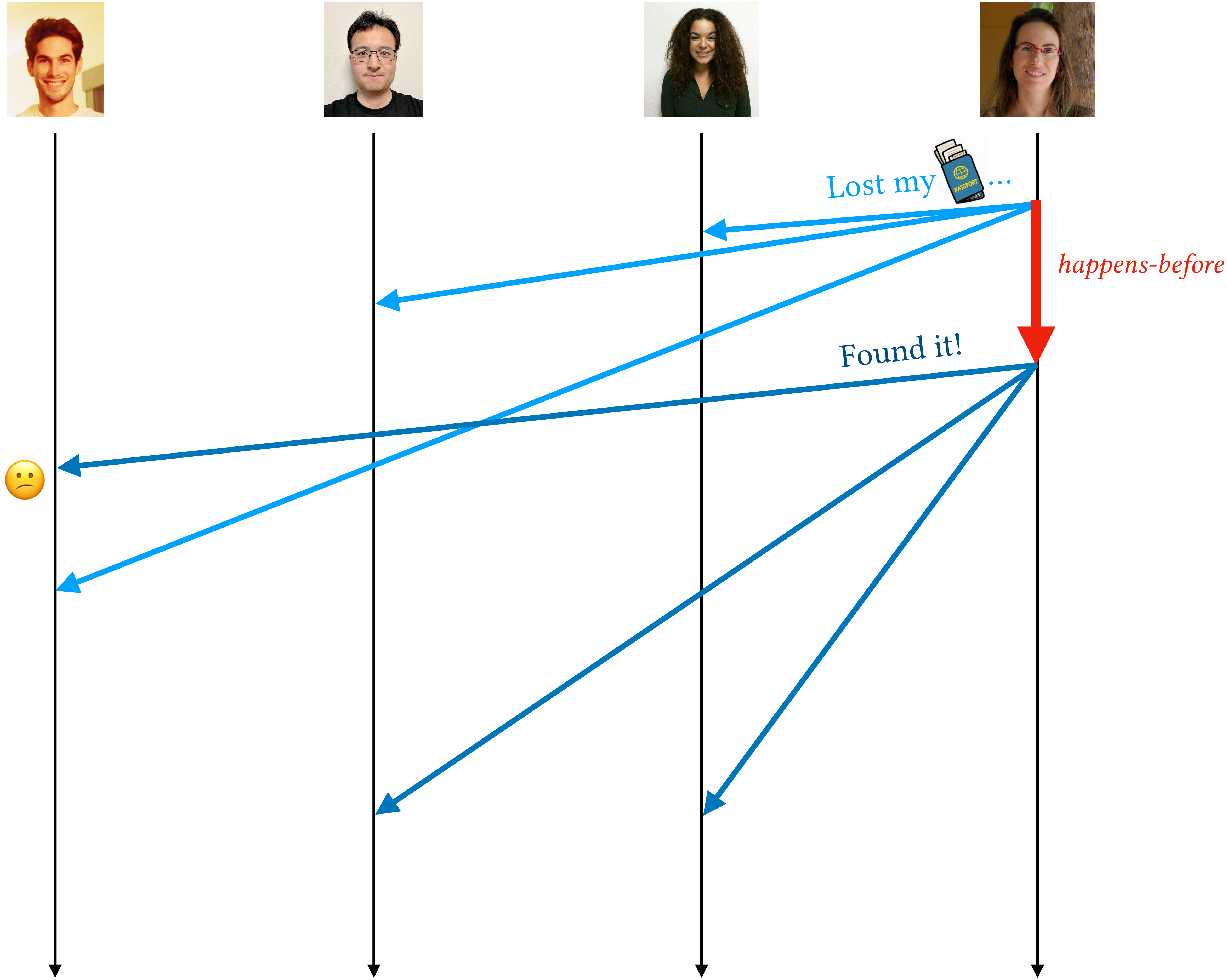
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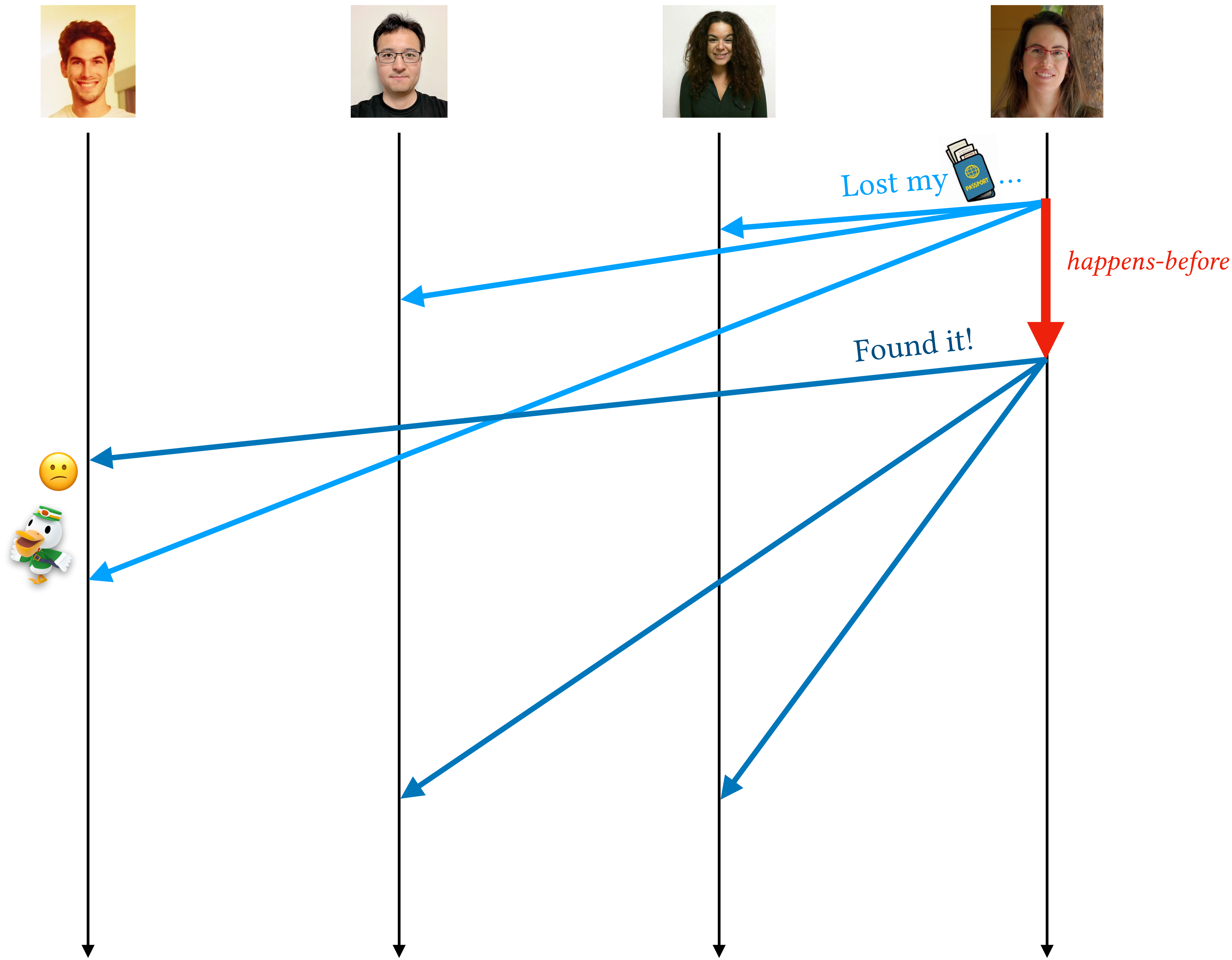
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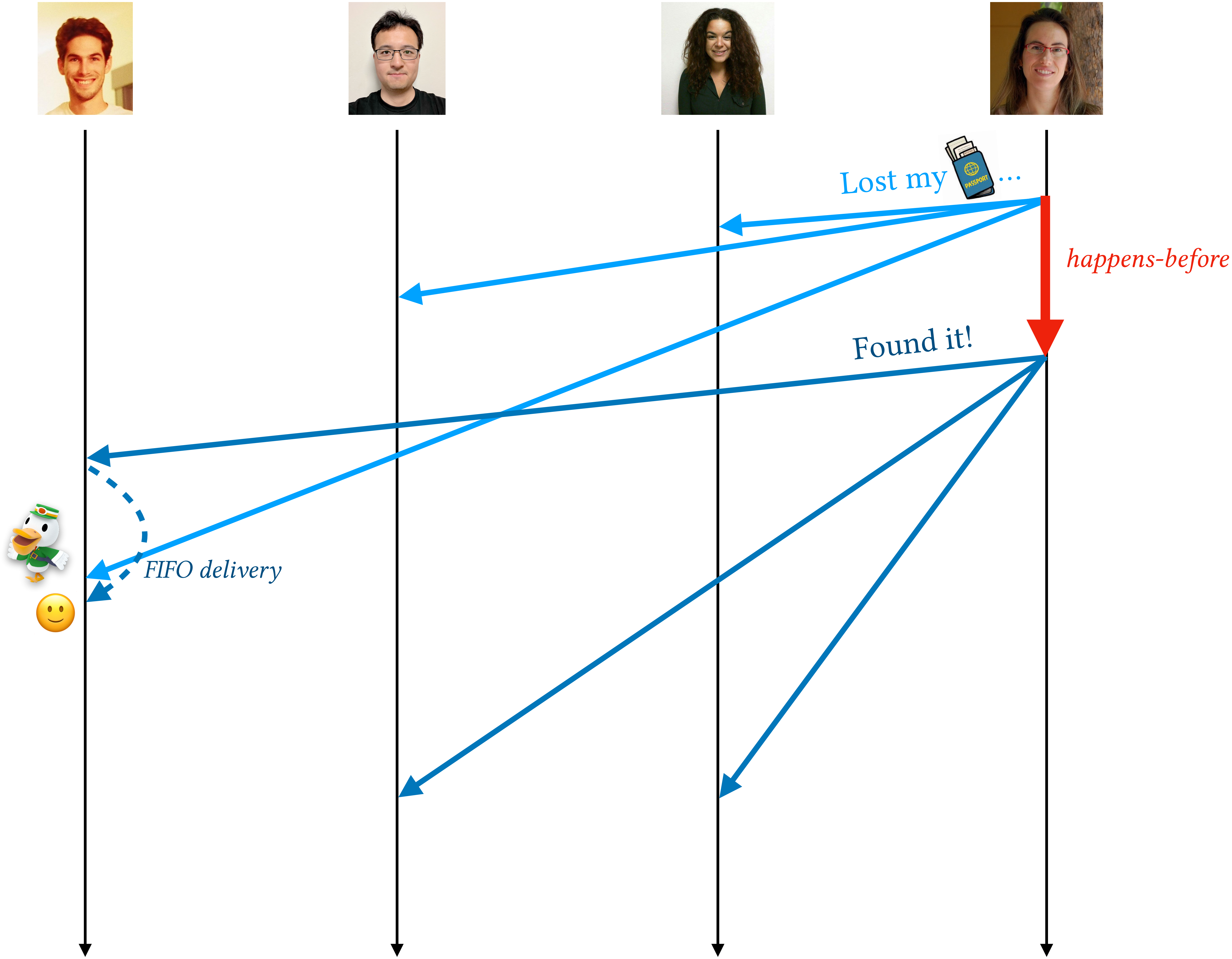

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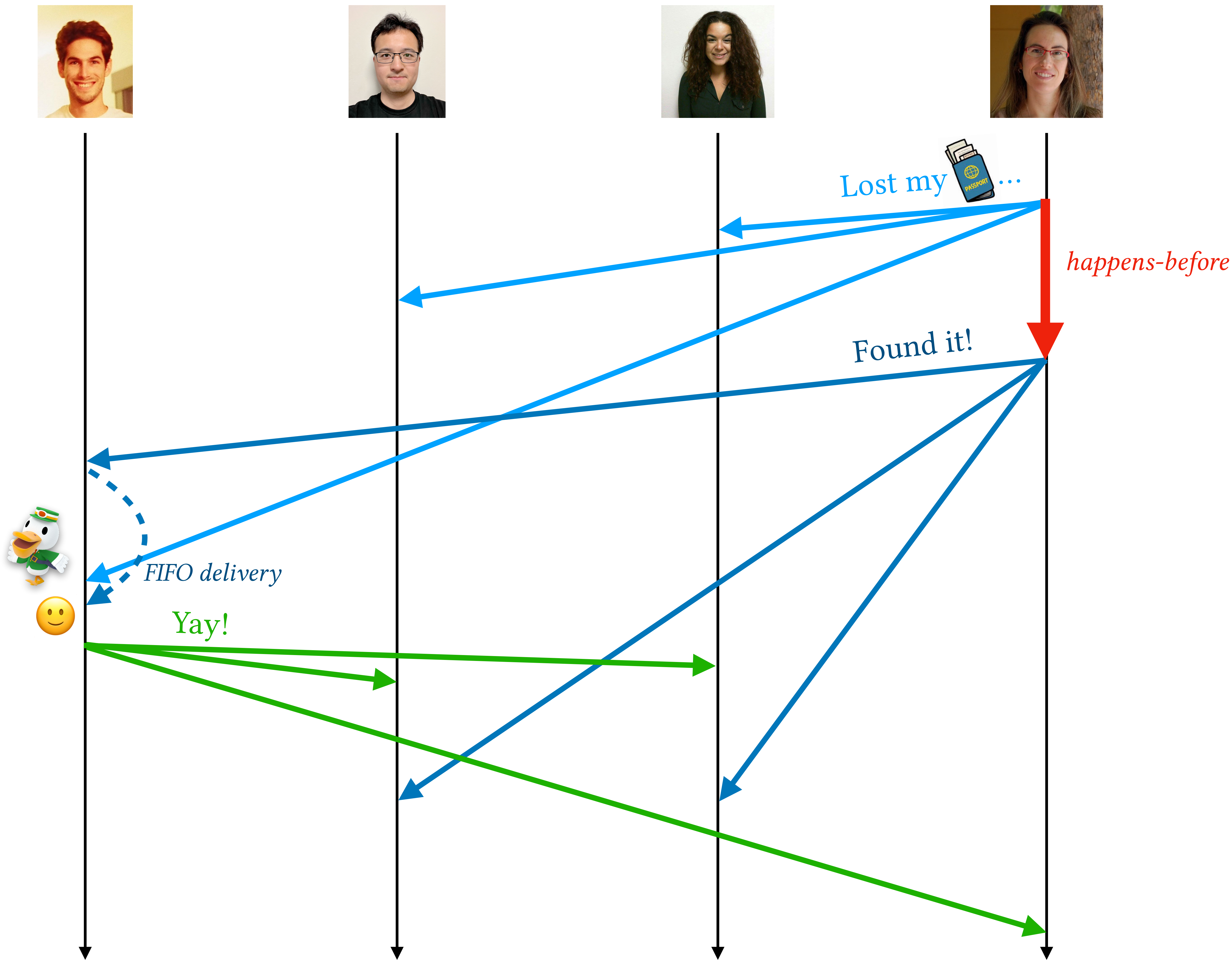
FIFO delivery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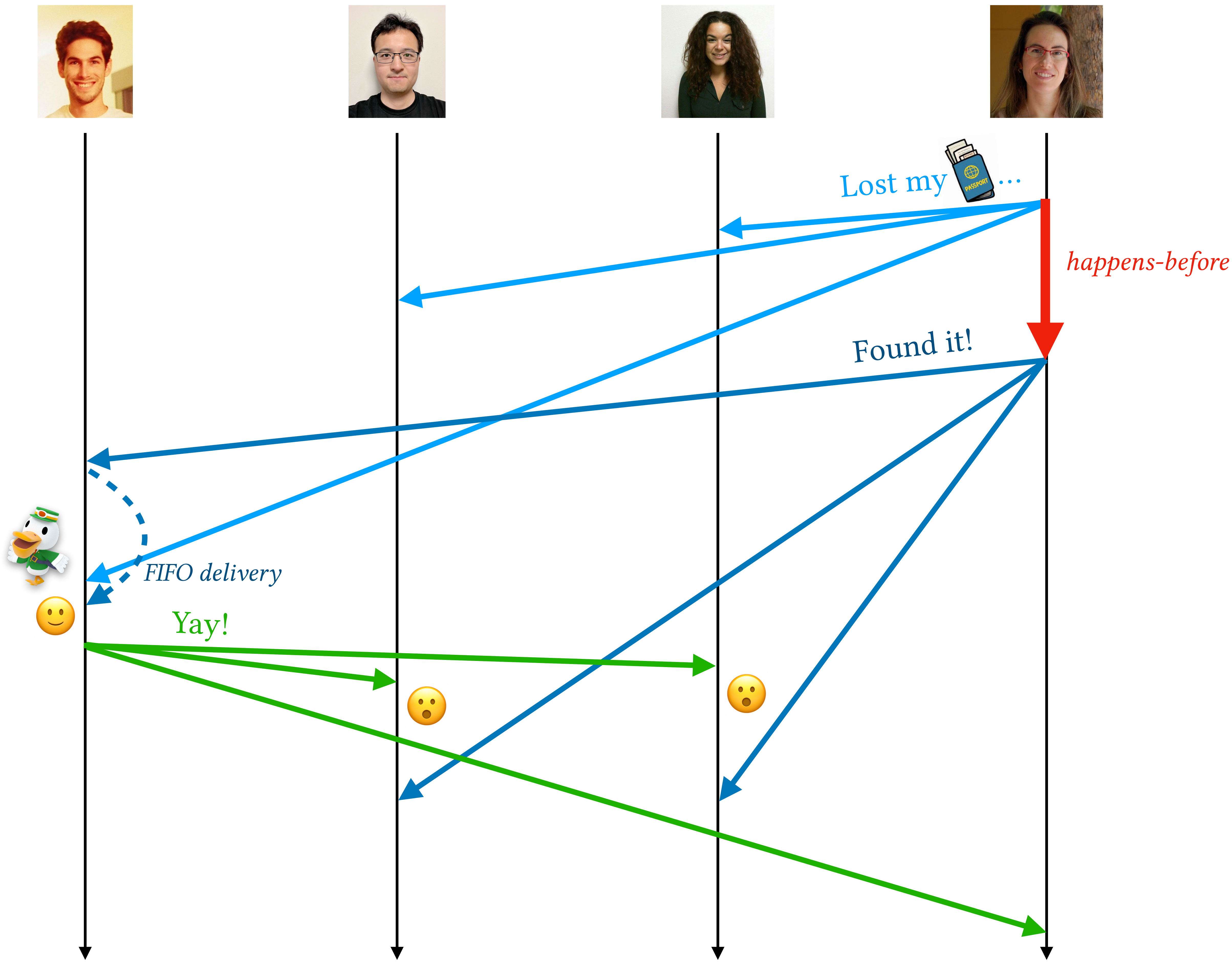

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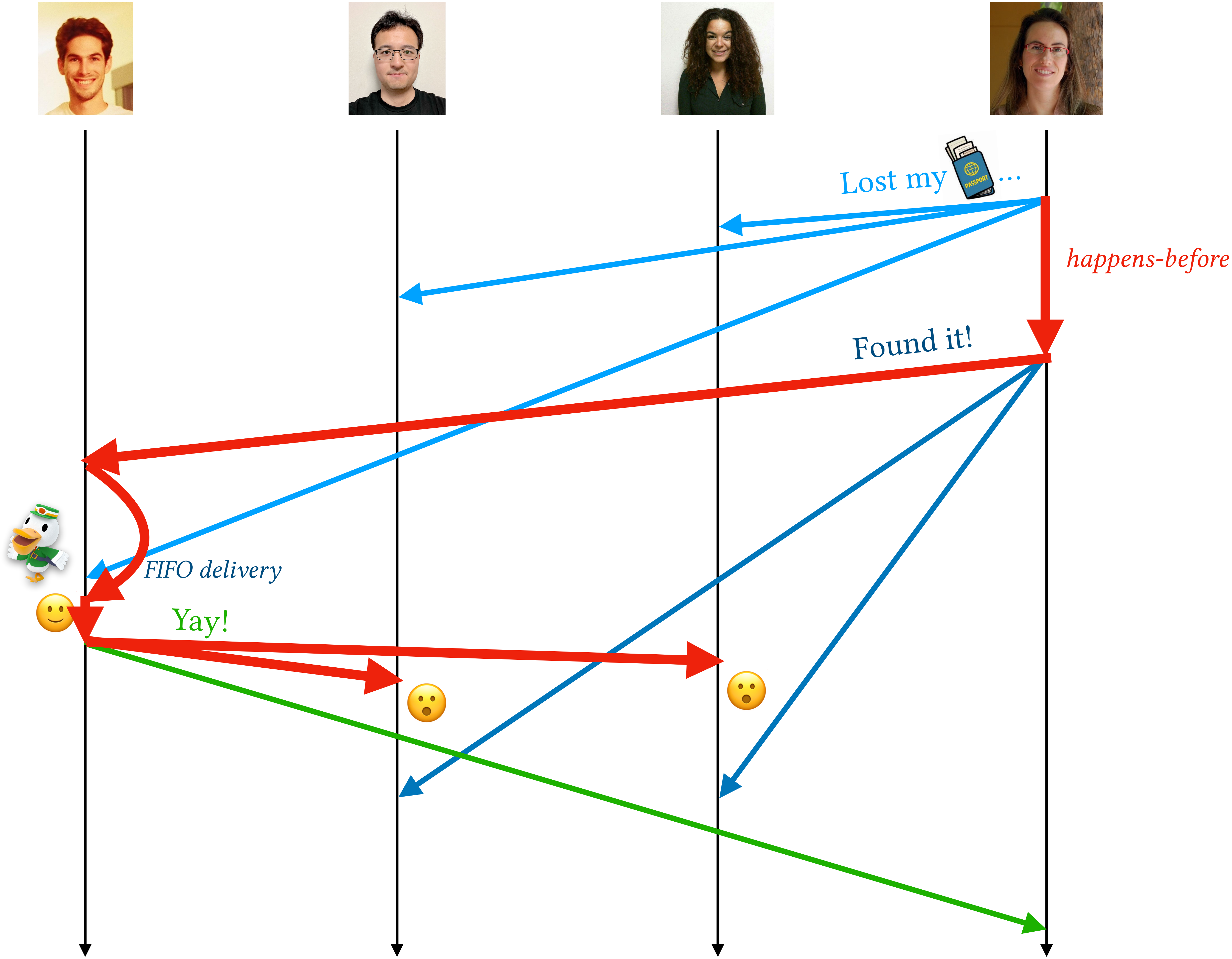
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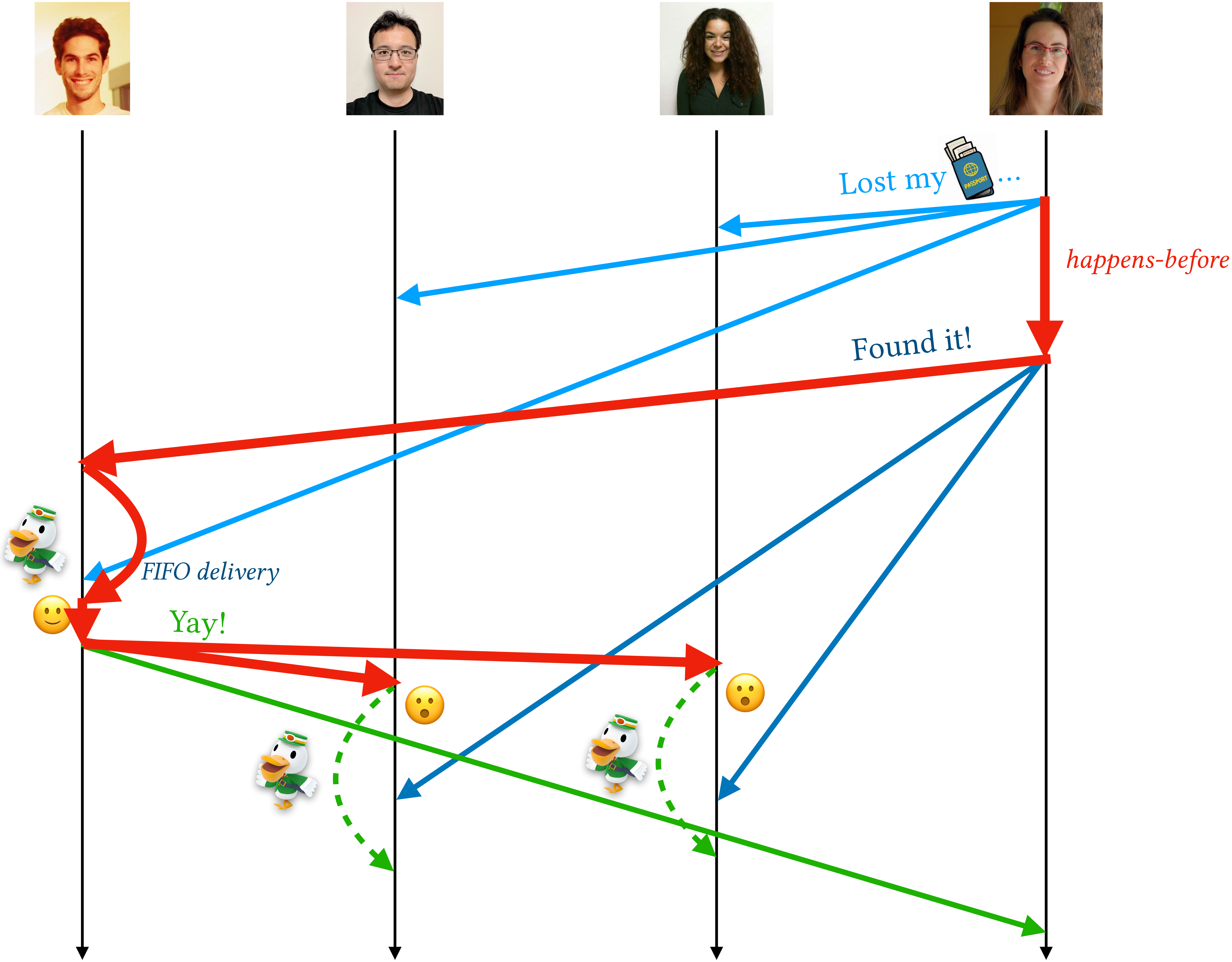
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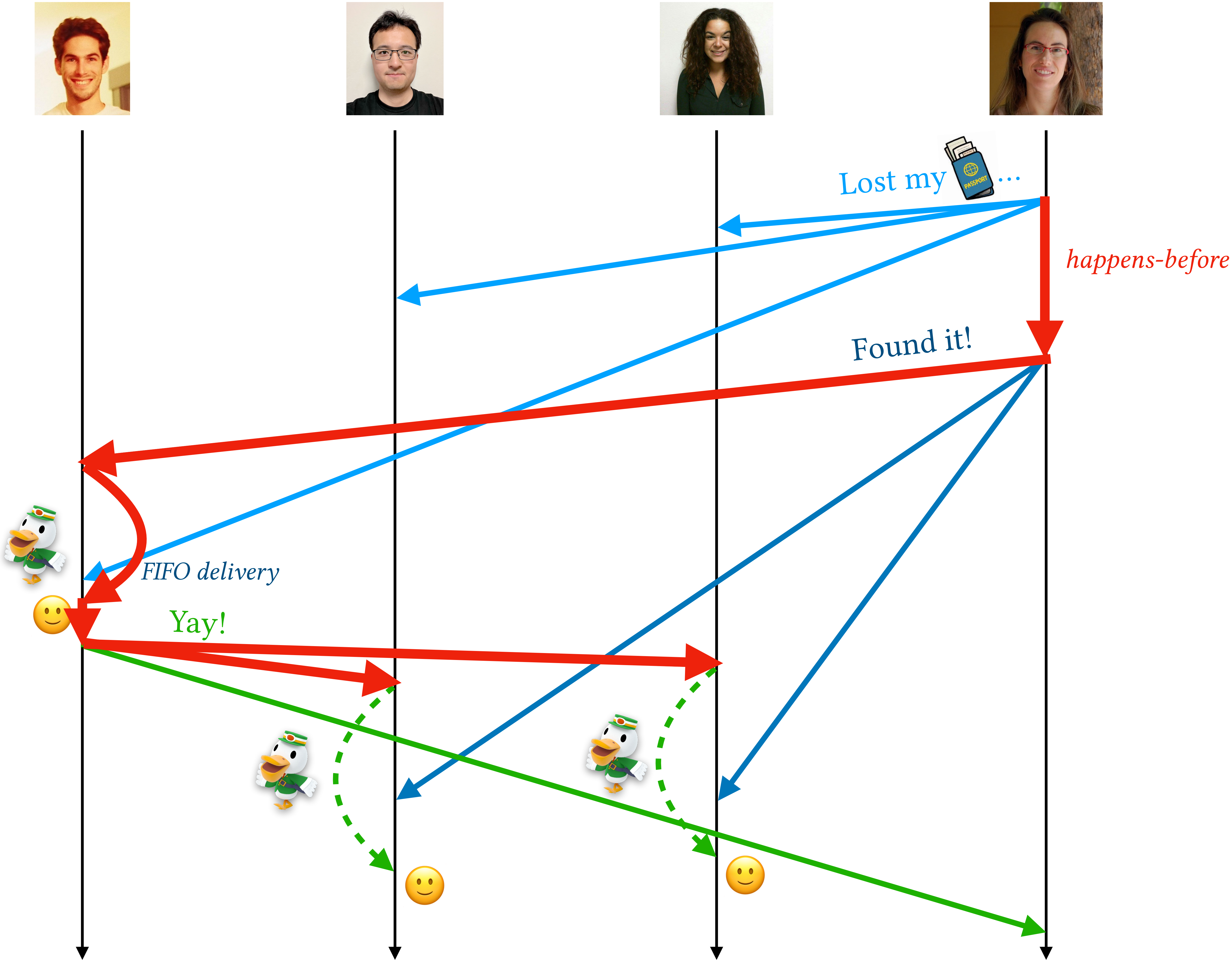
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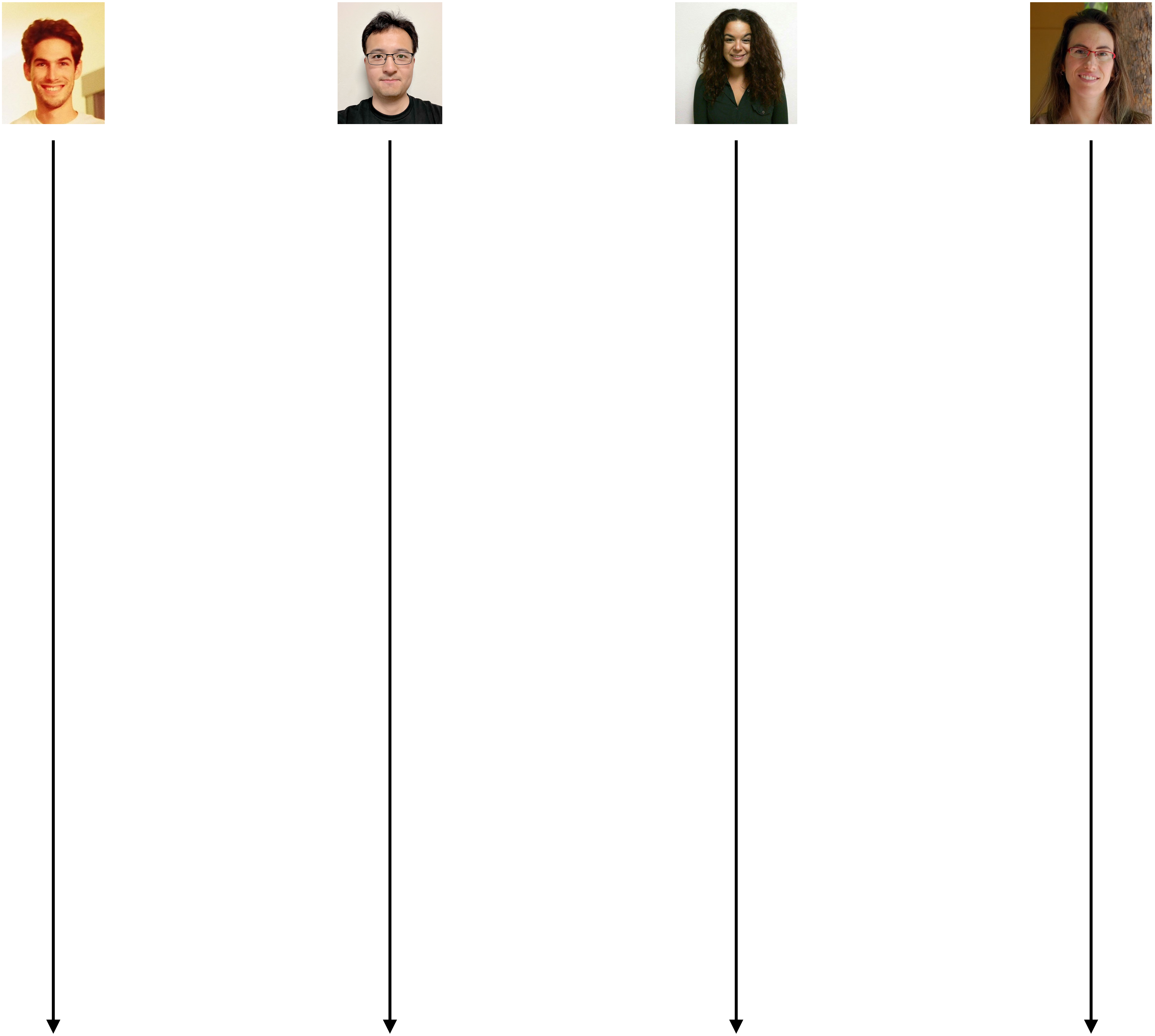
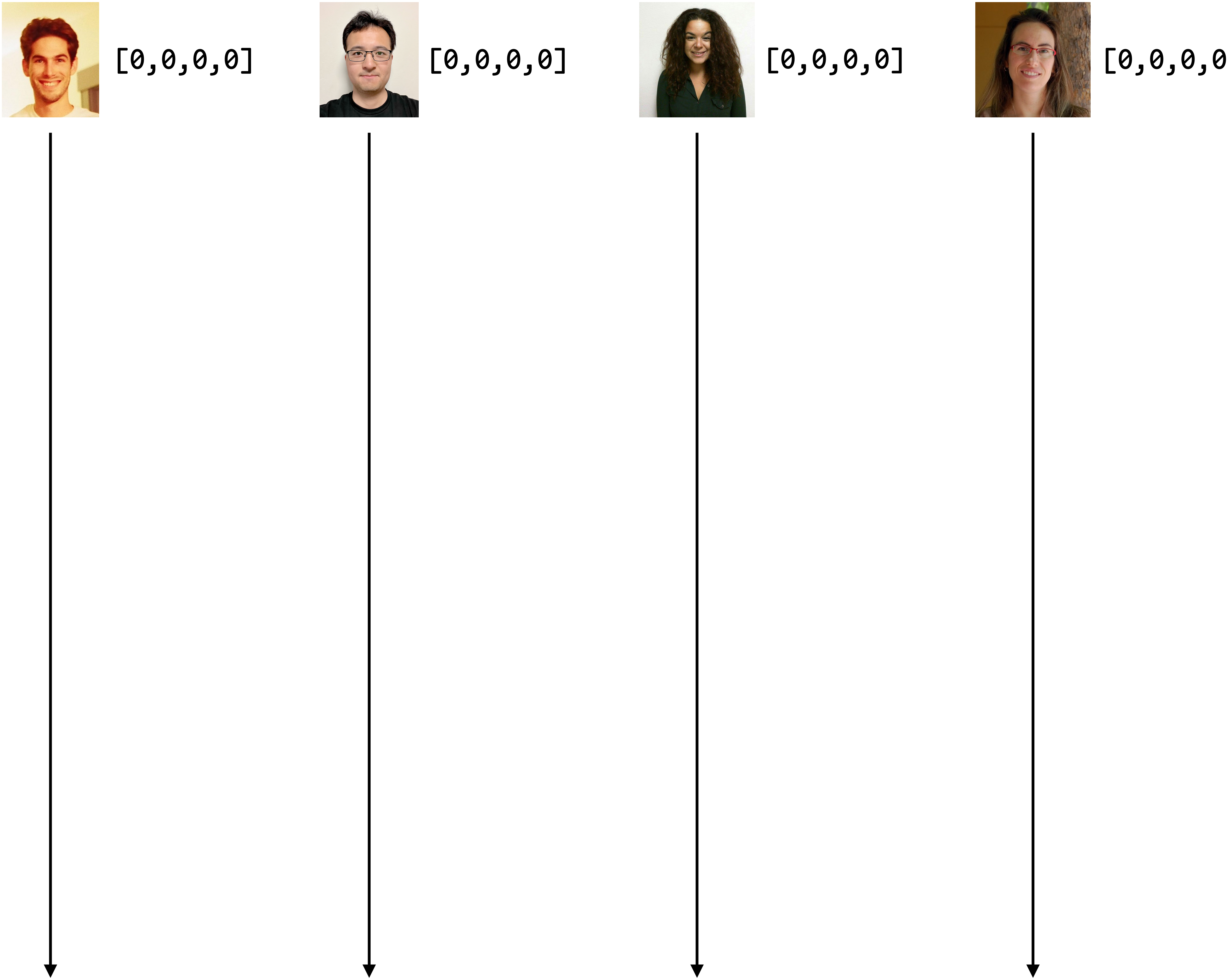


Causal broadcast with vector clocks [Birman et al., 1991]



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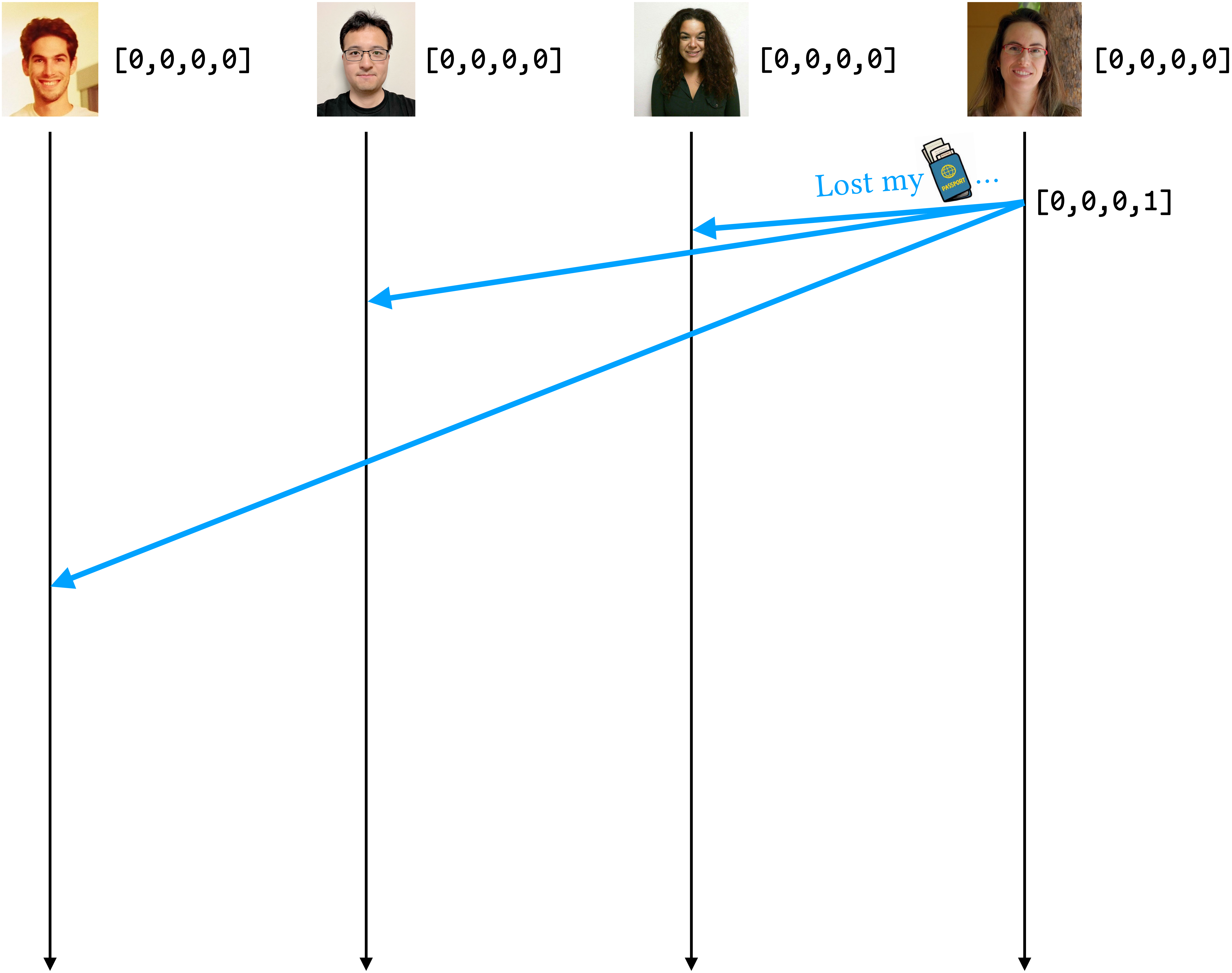

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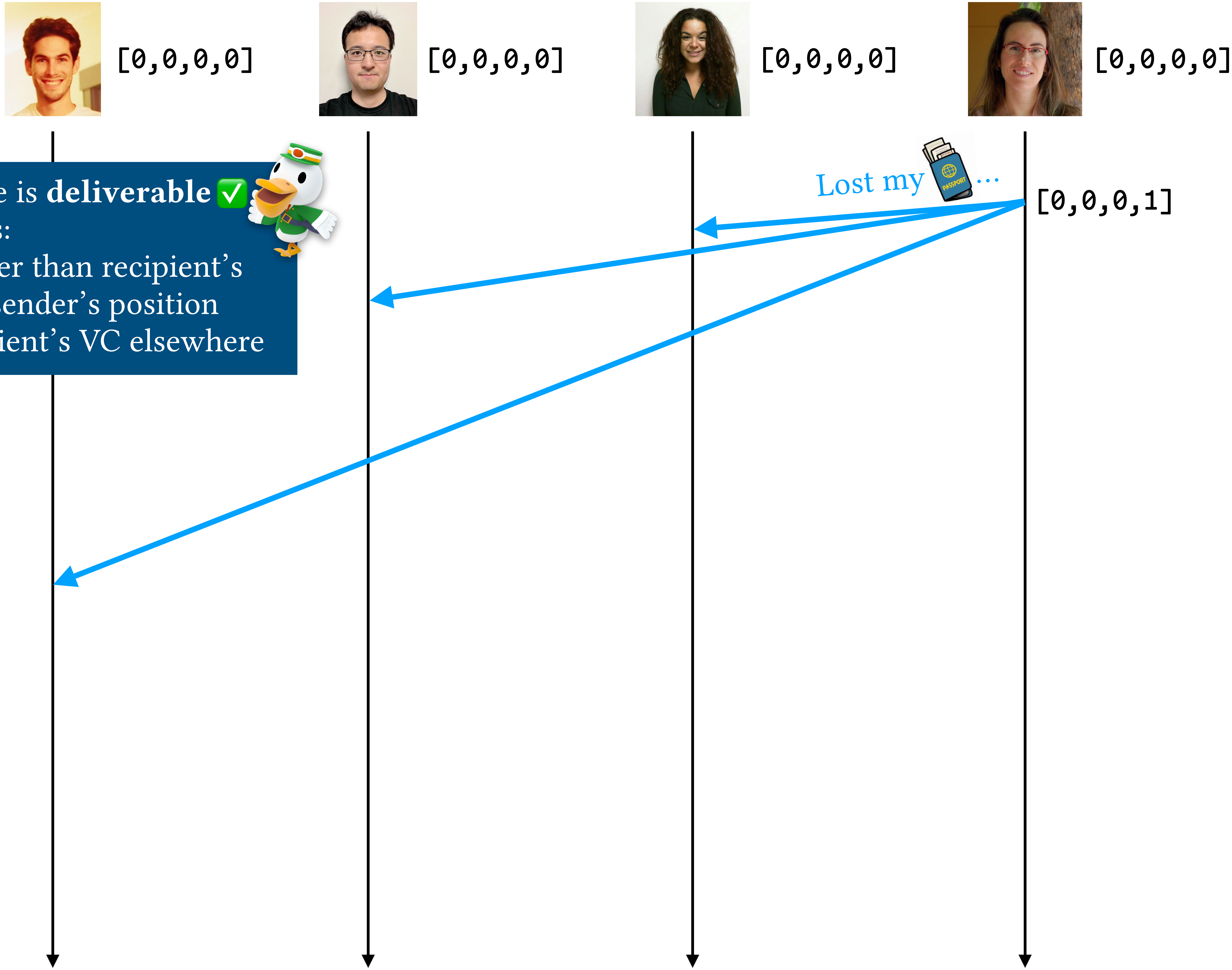

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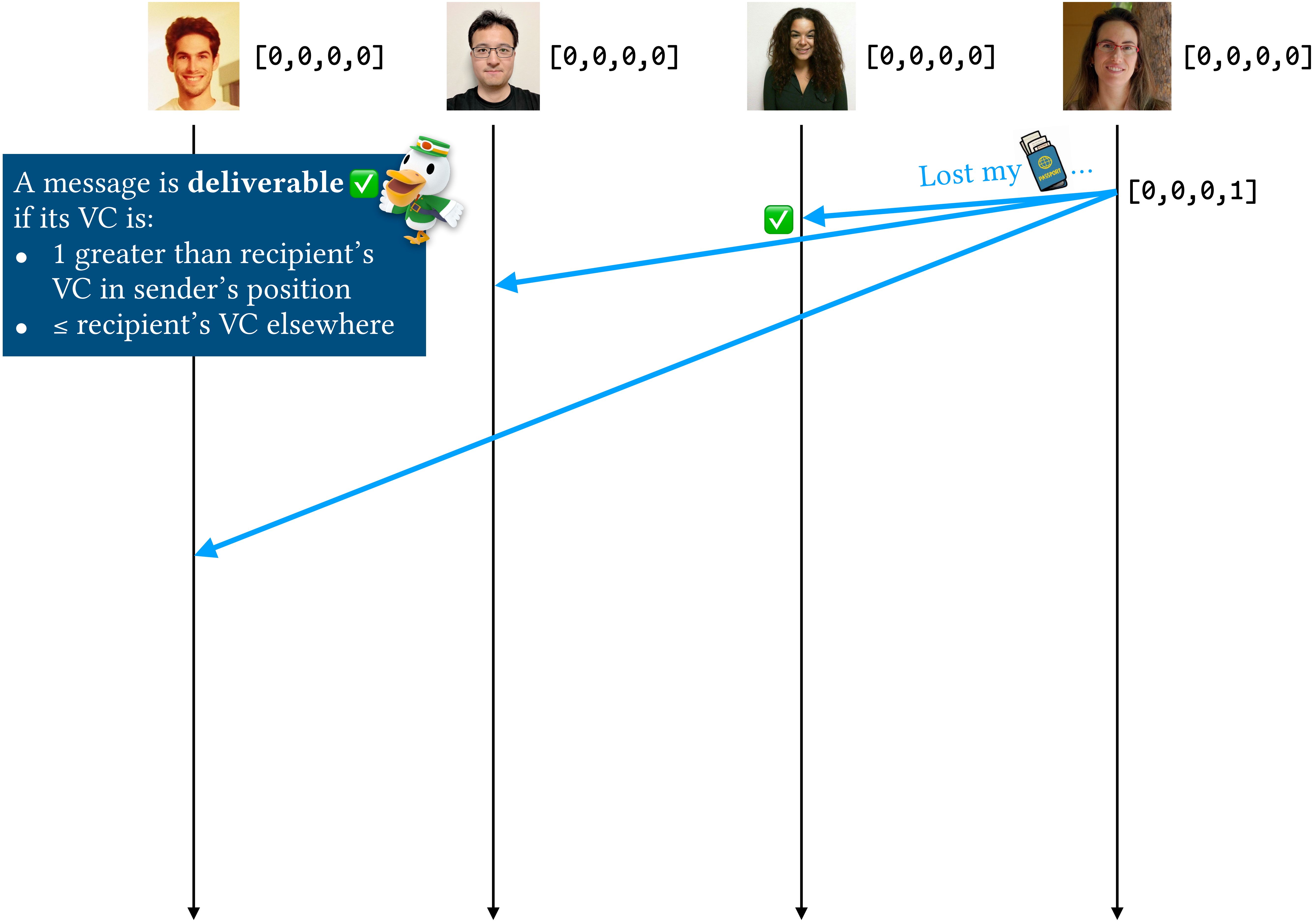

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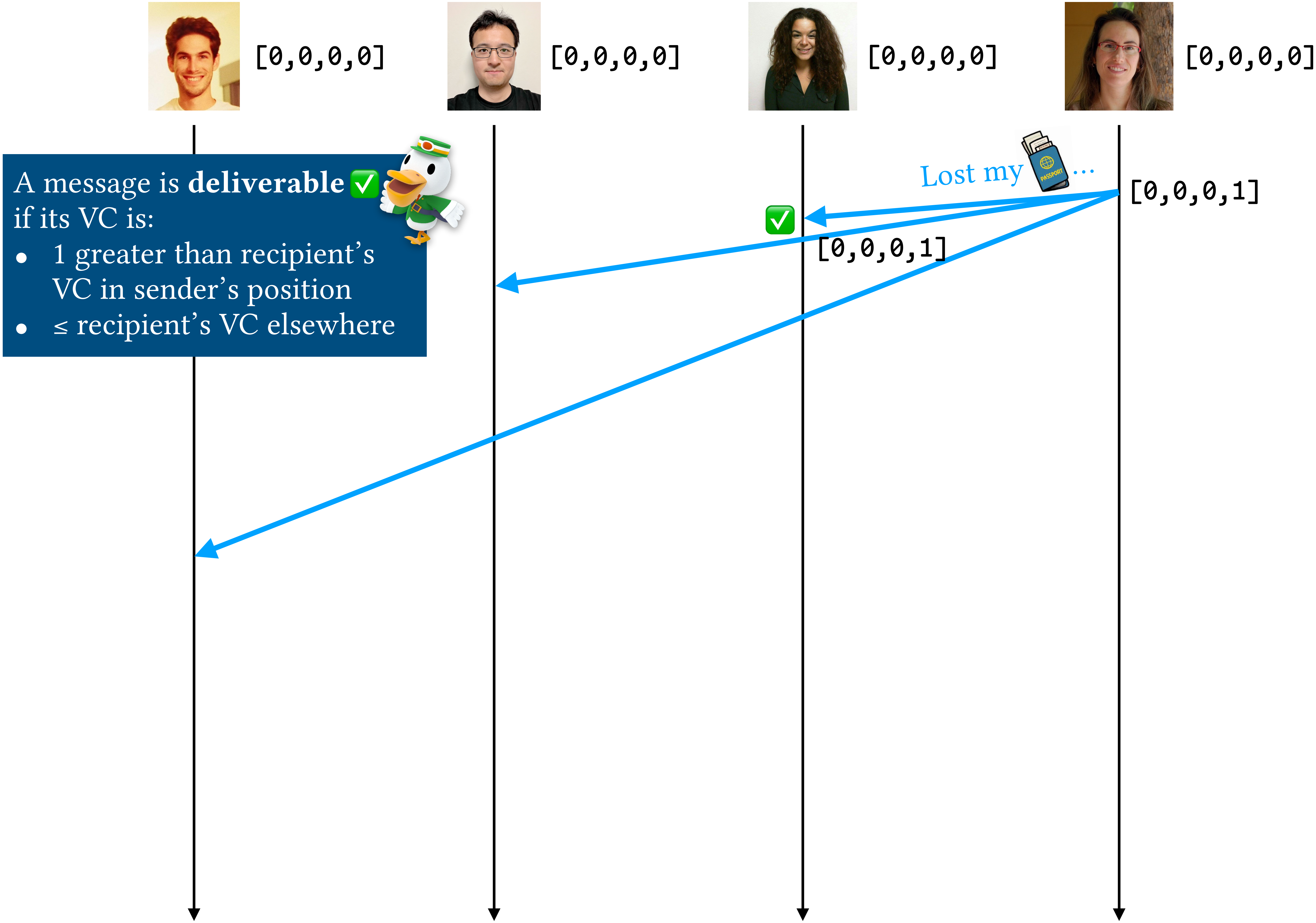

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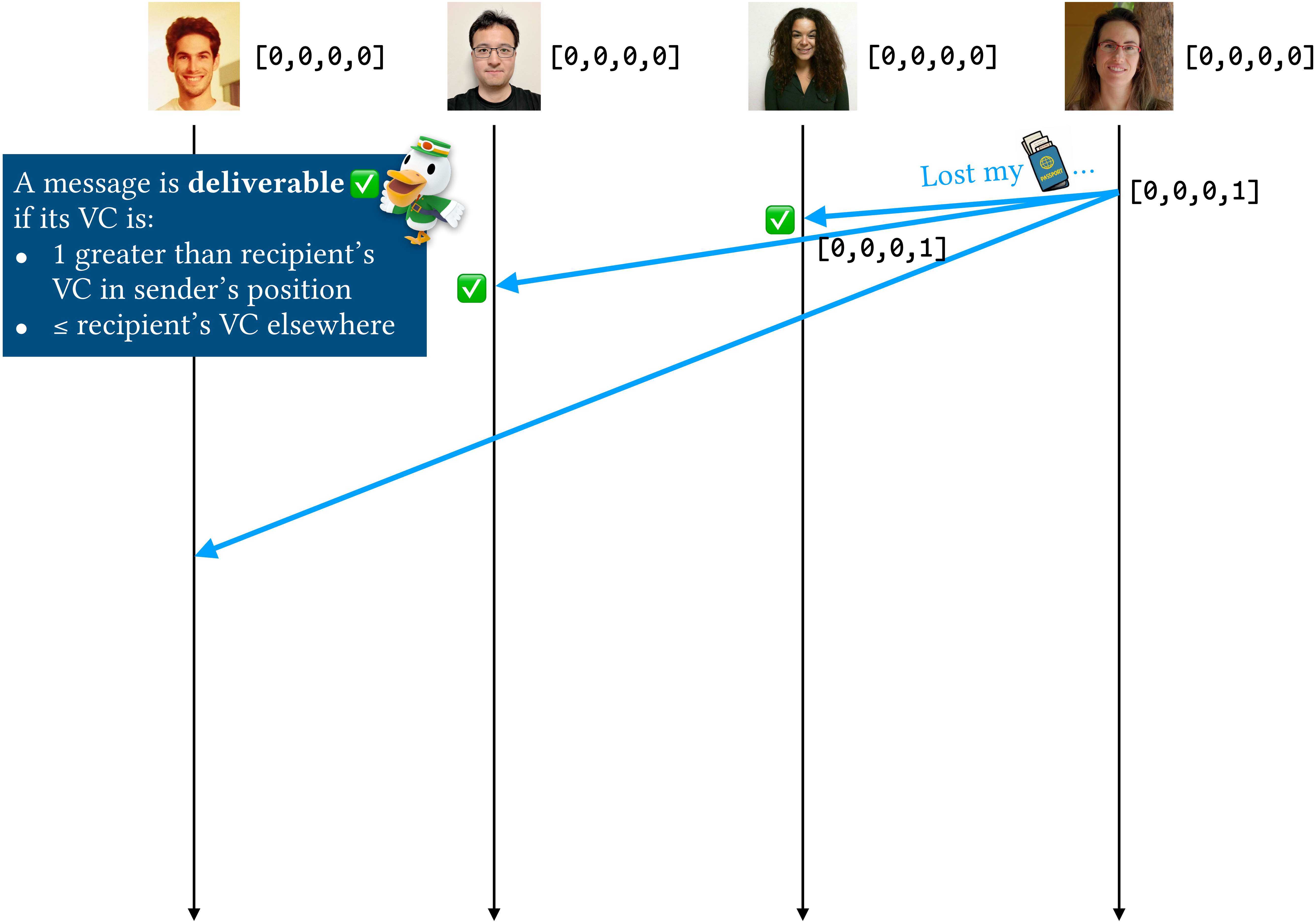

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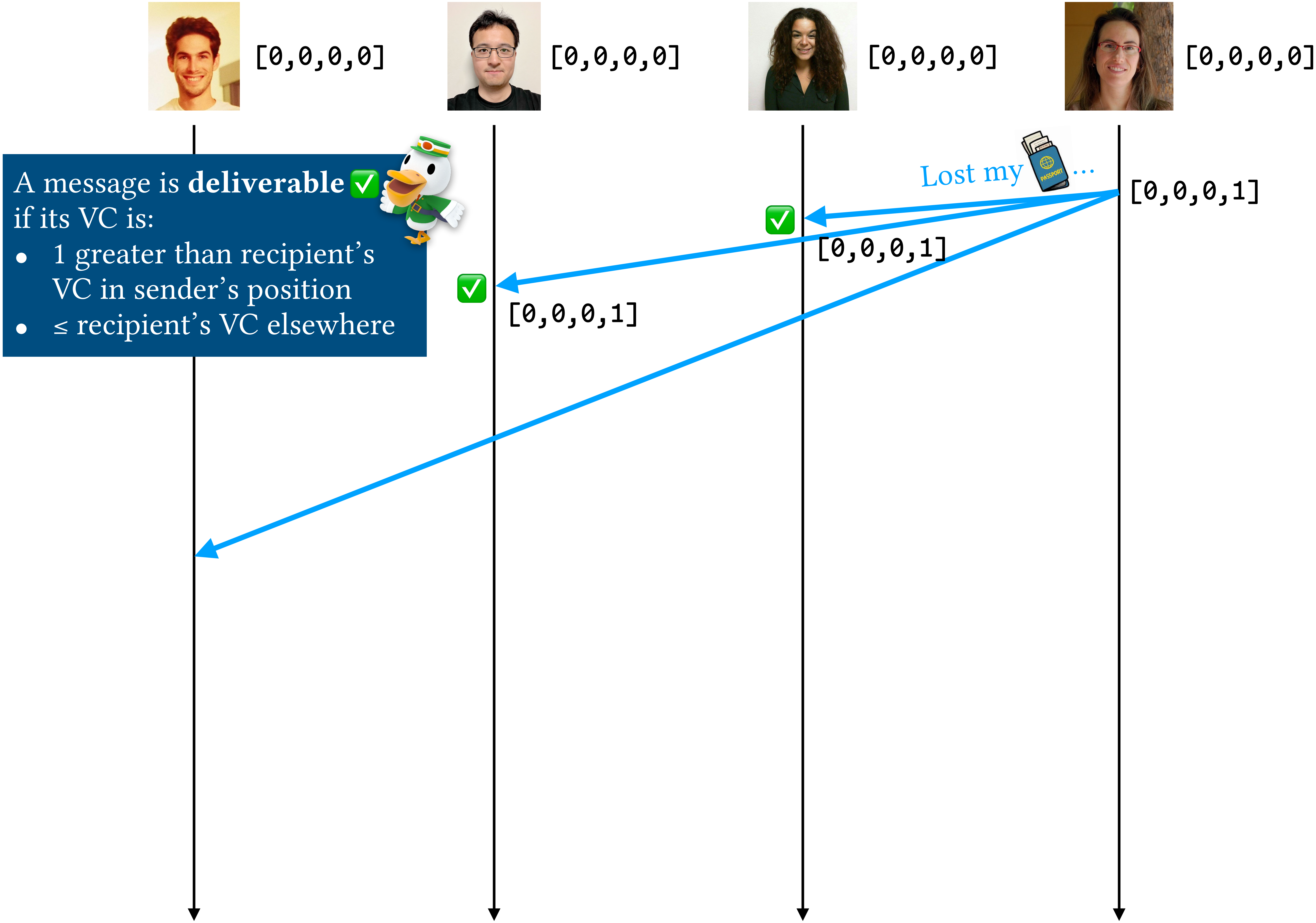

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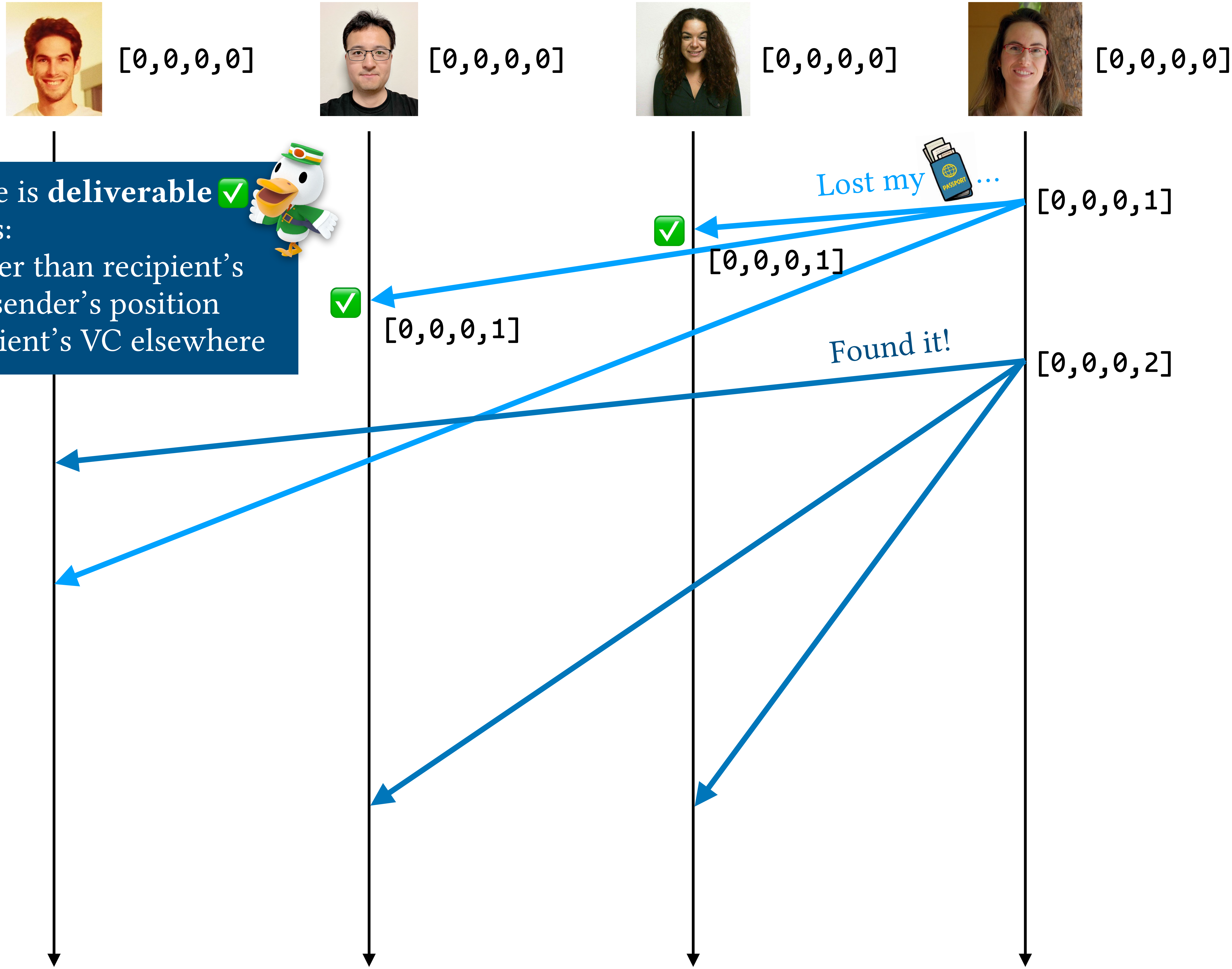

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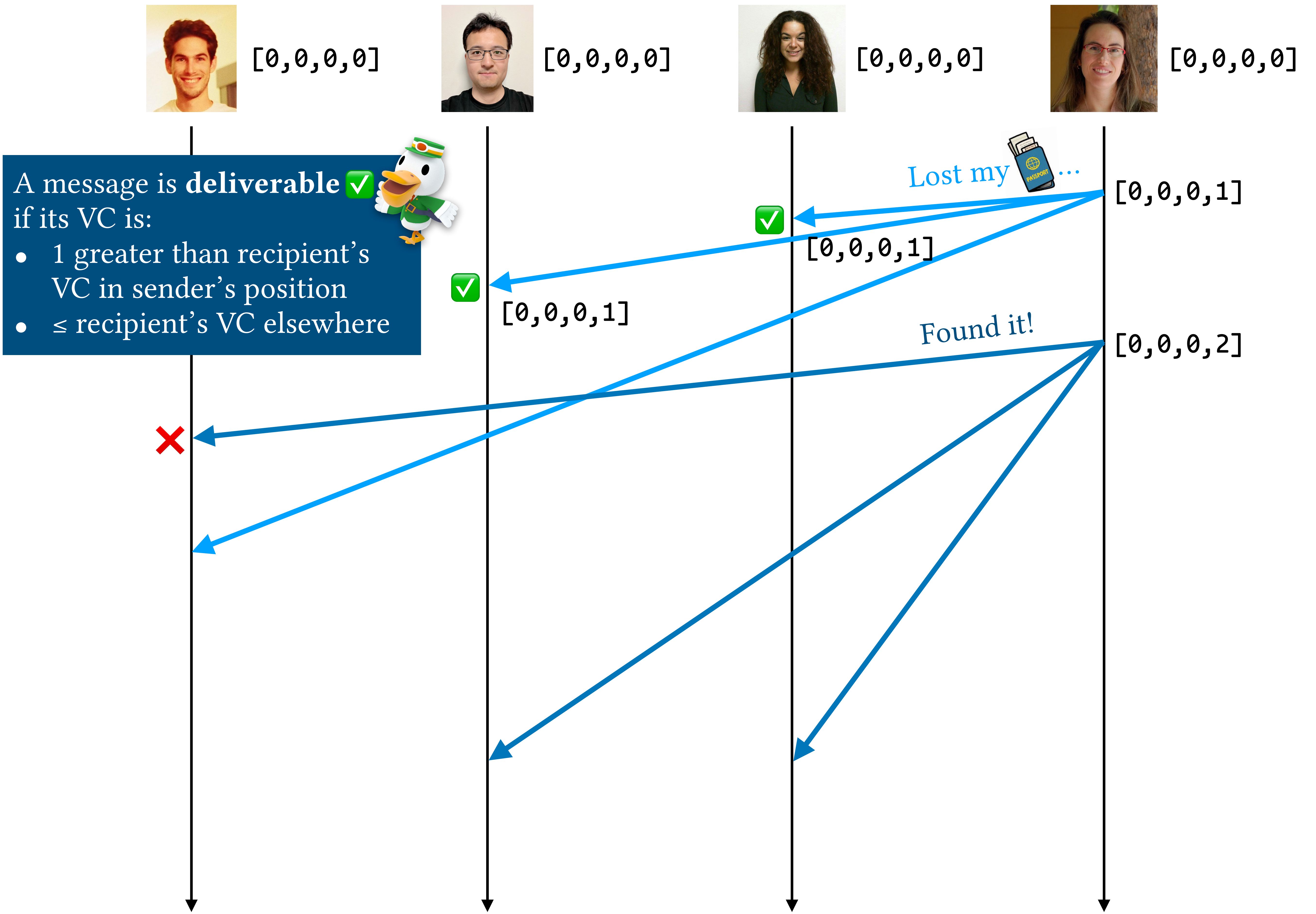

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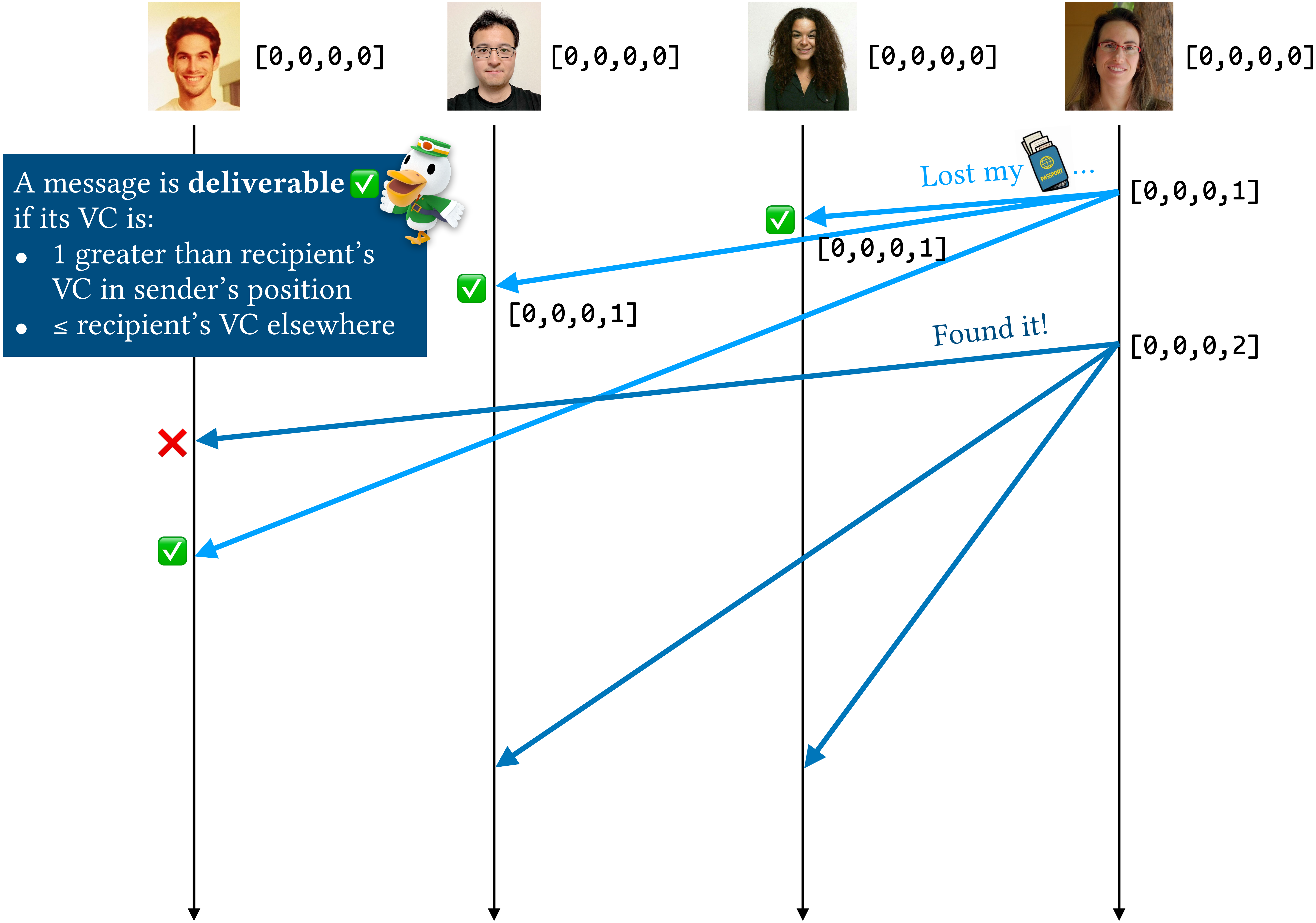

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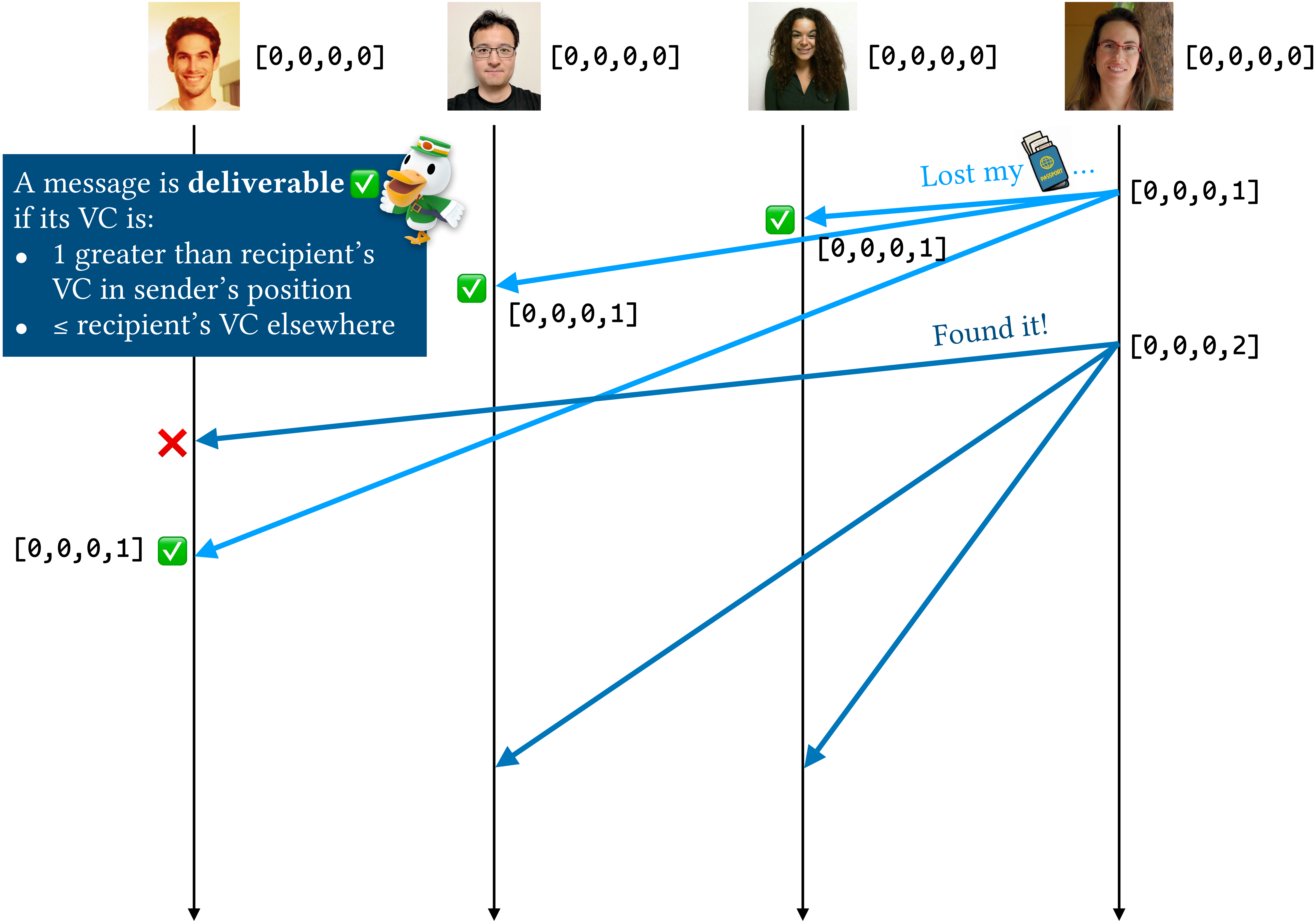

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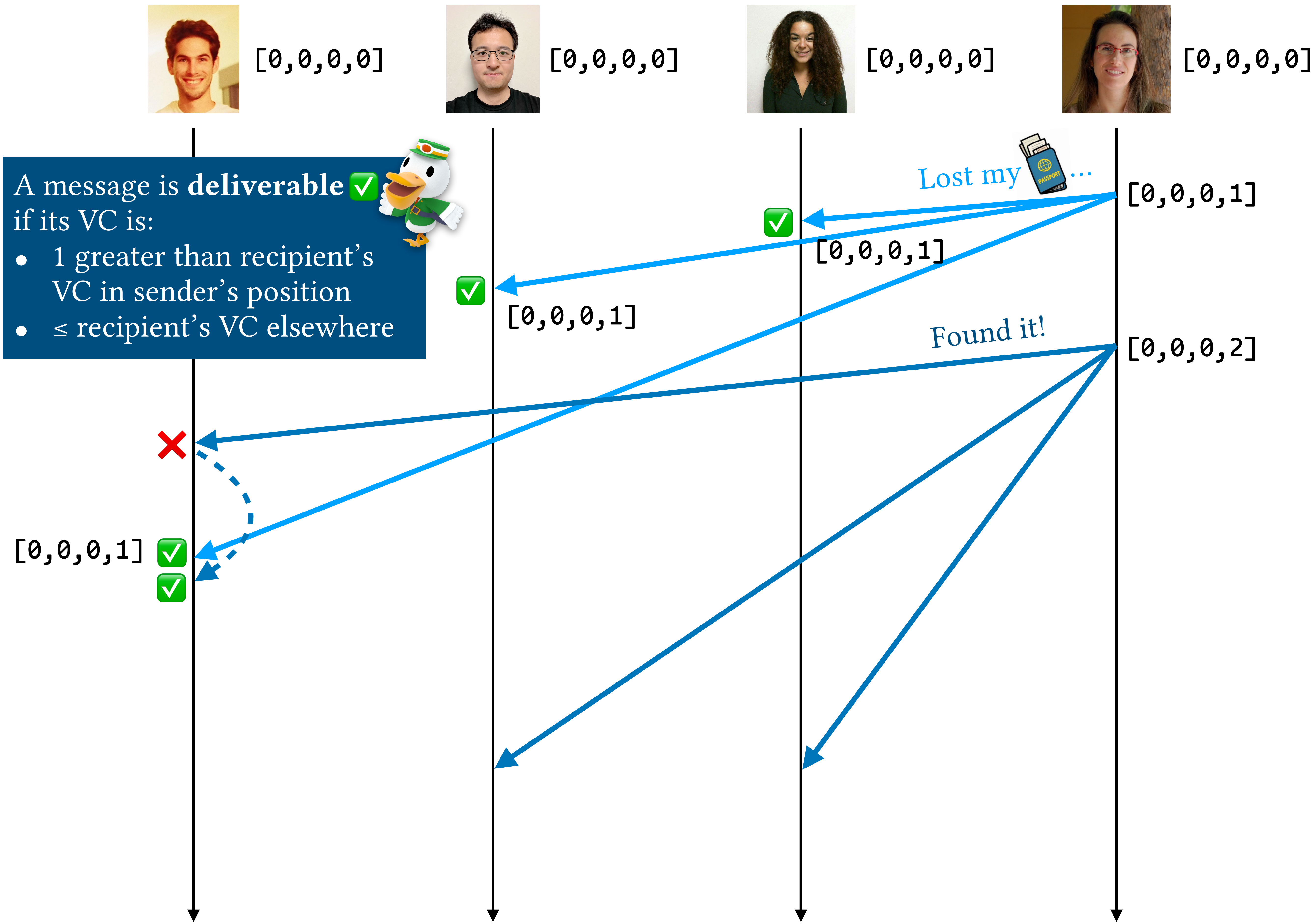

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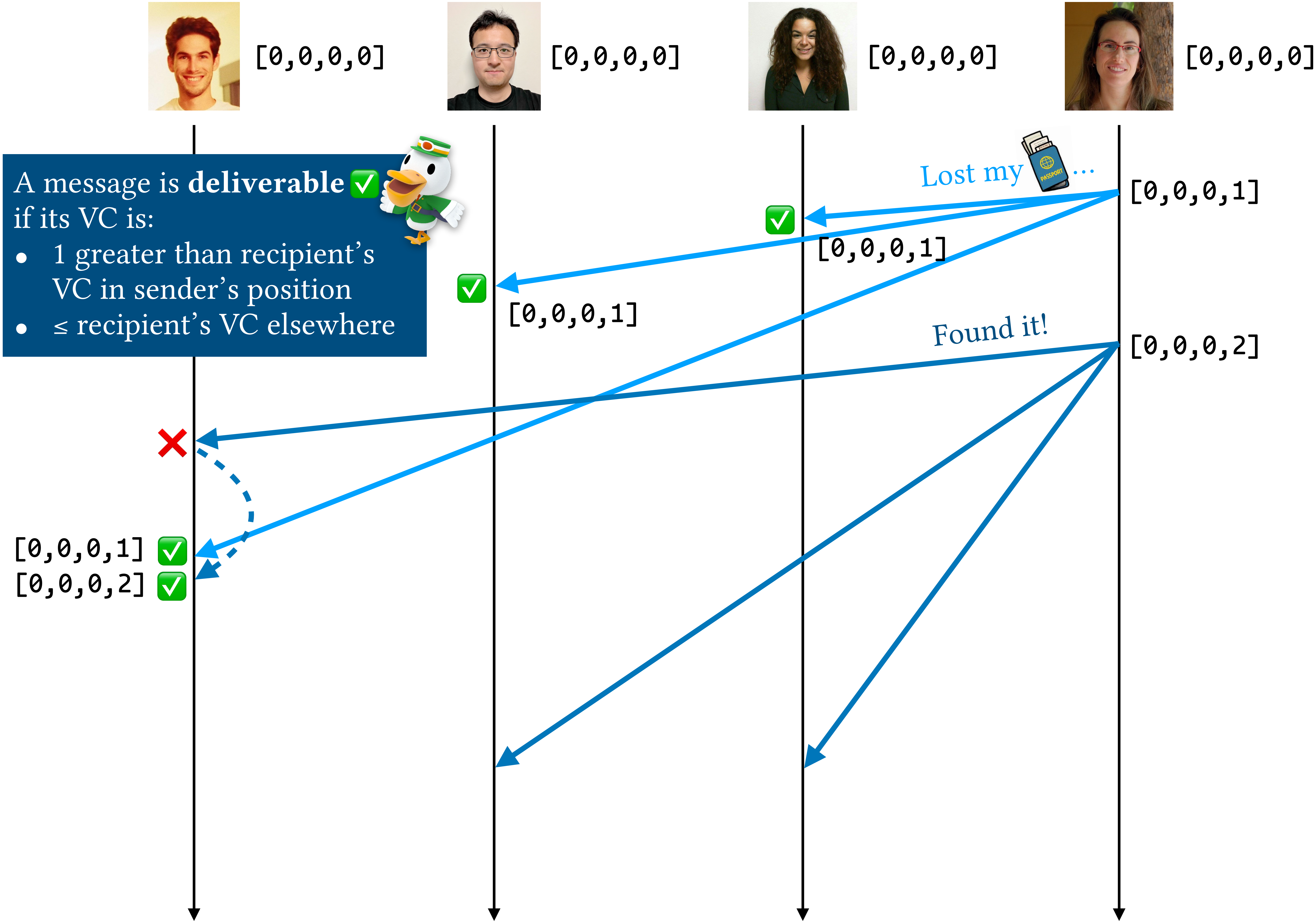

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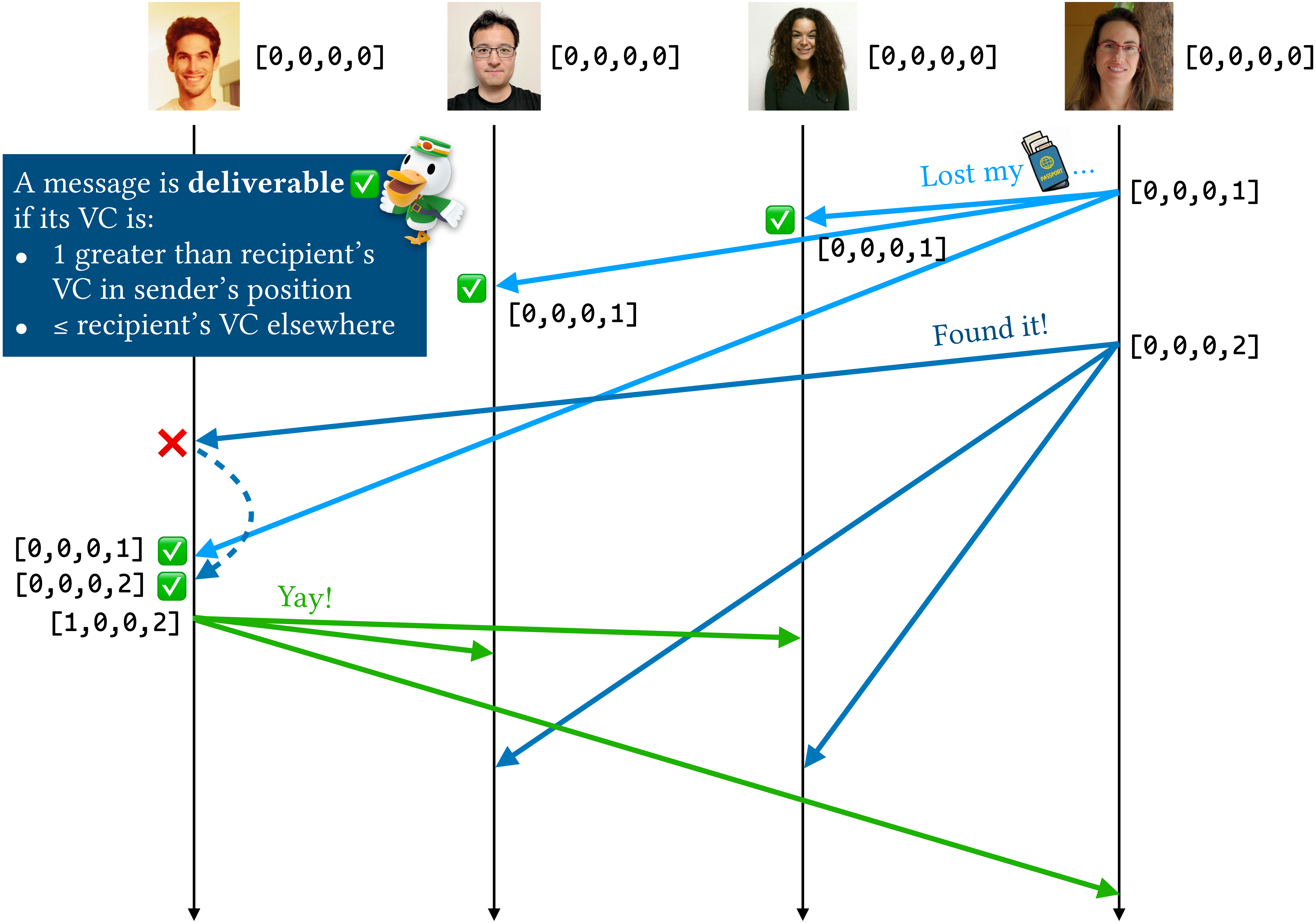

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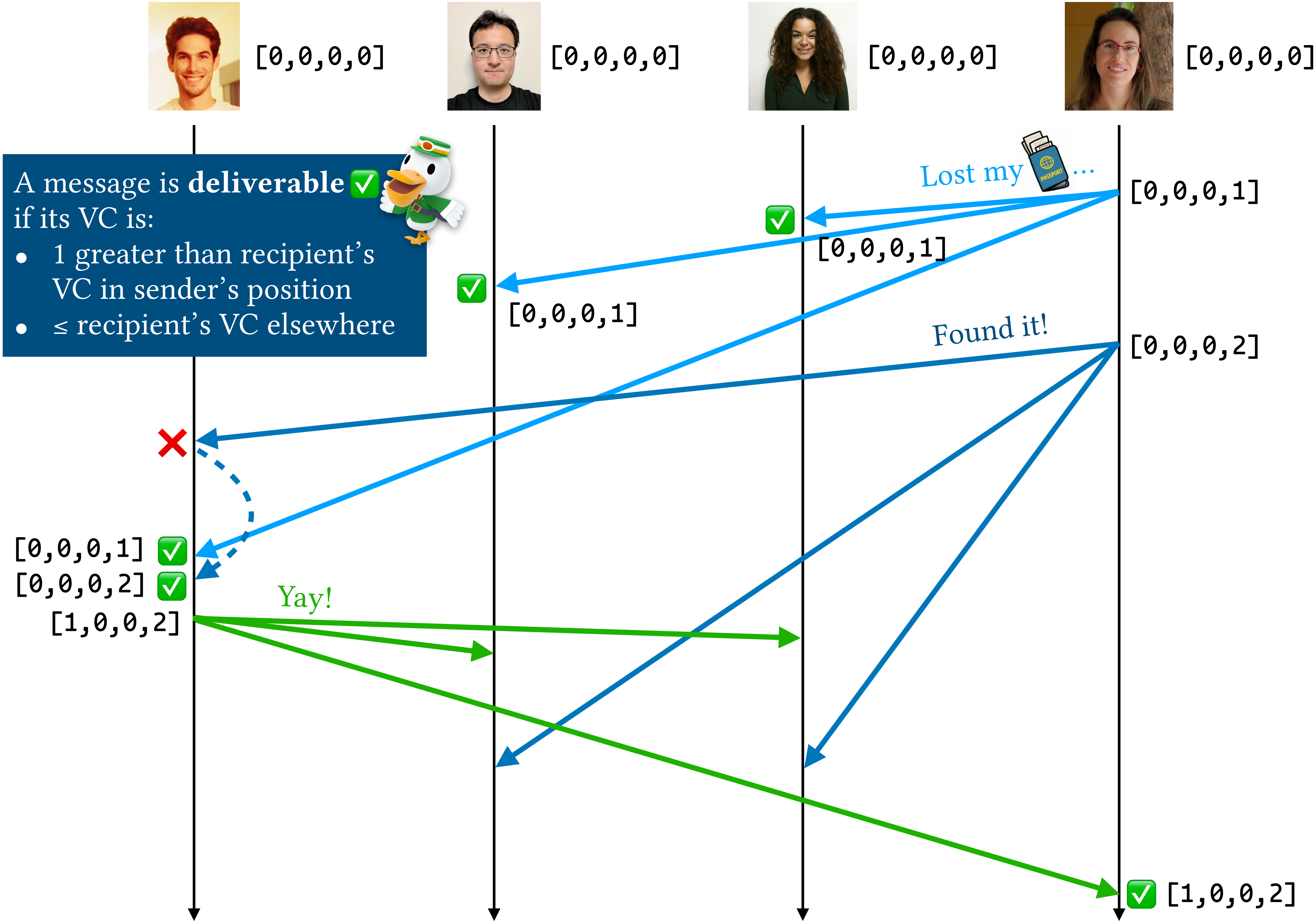

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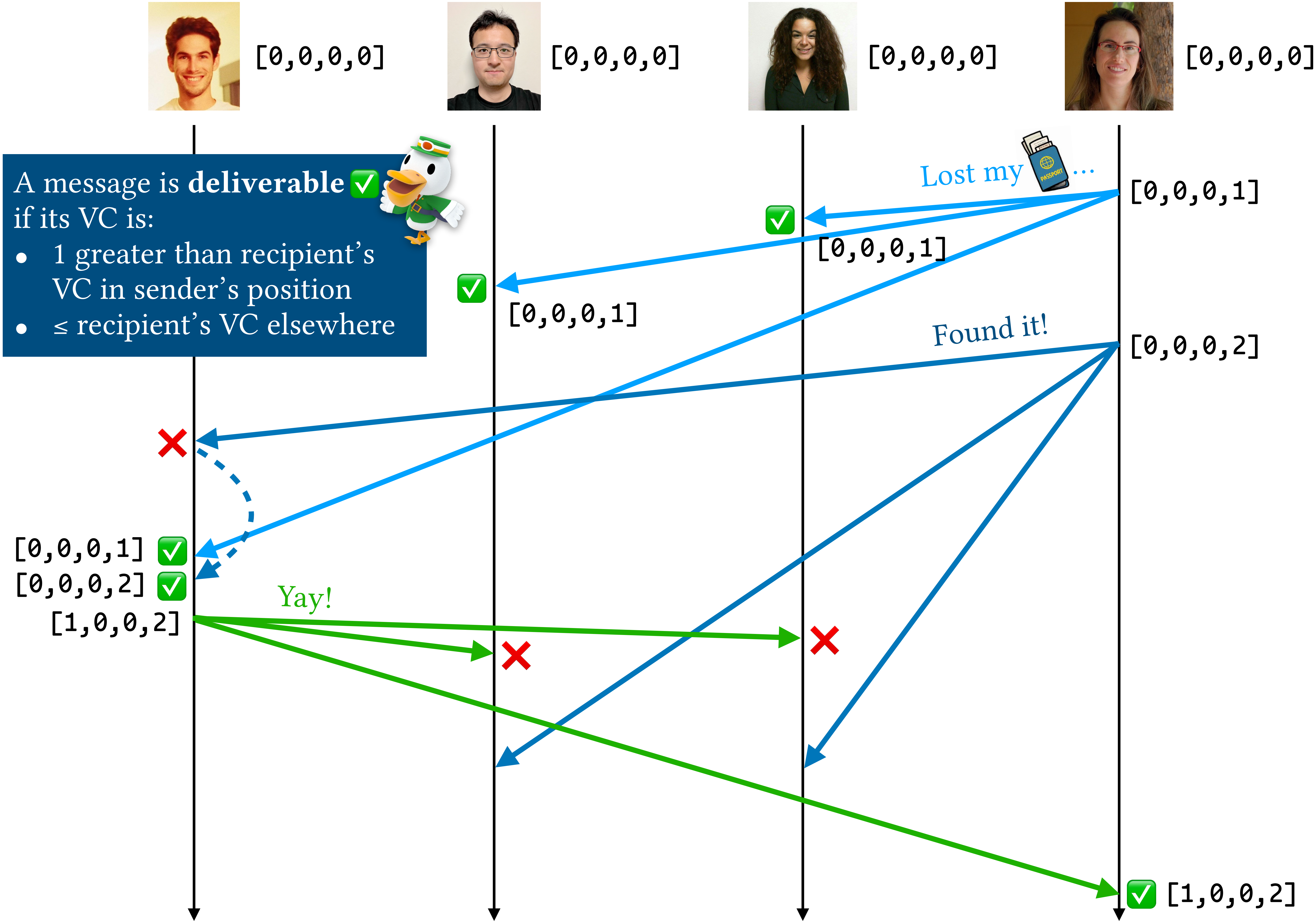

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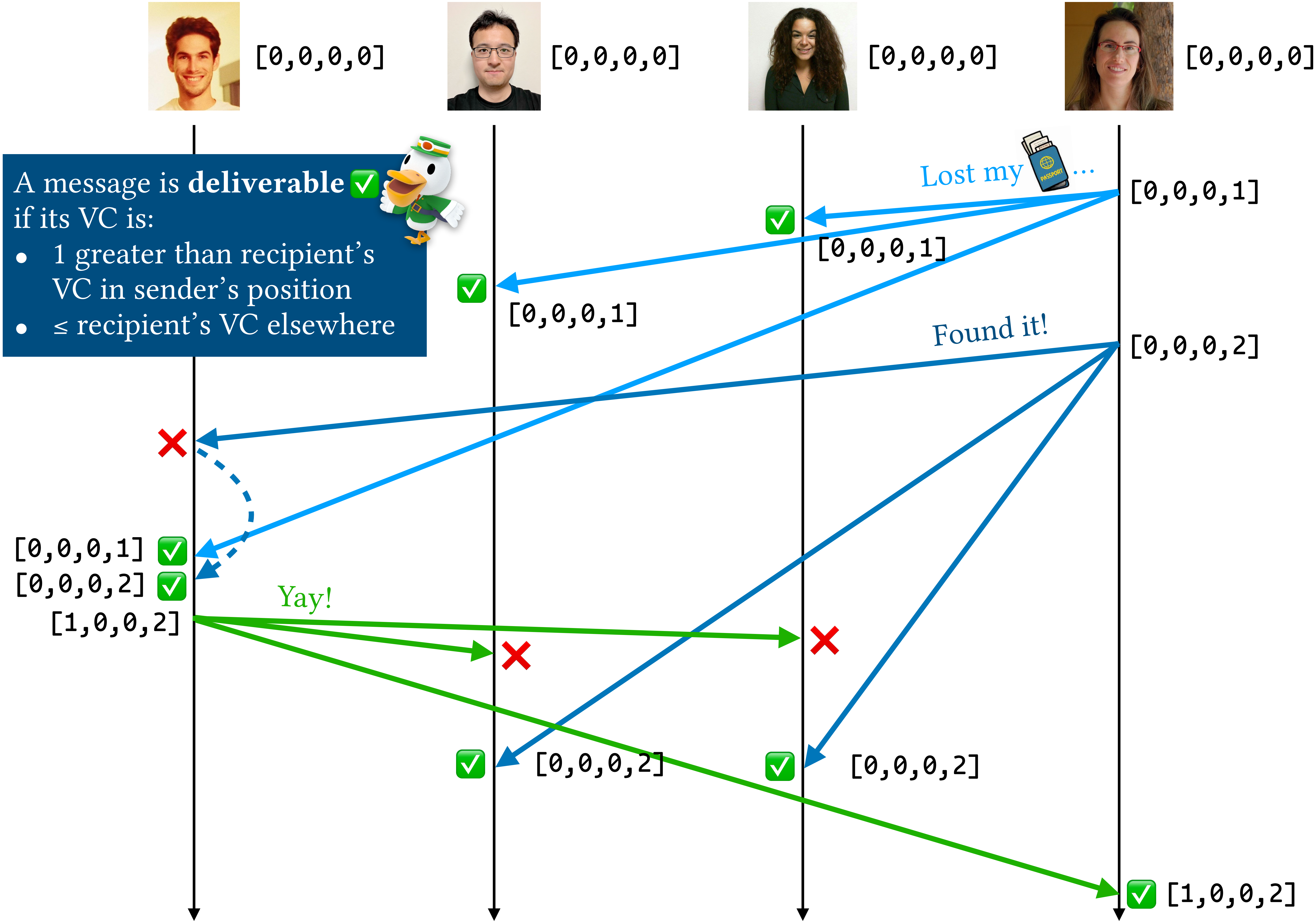

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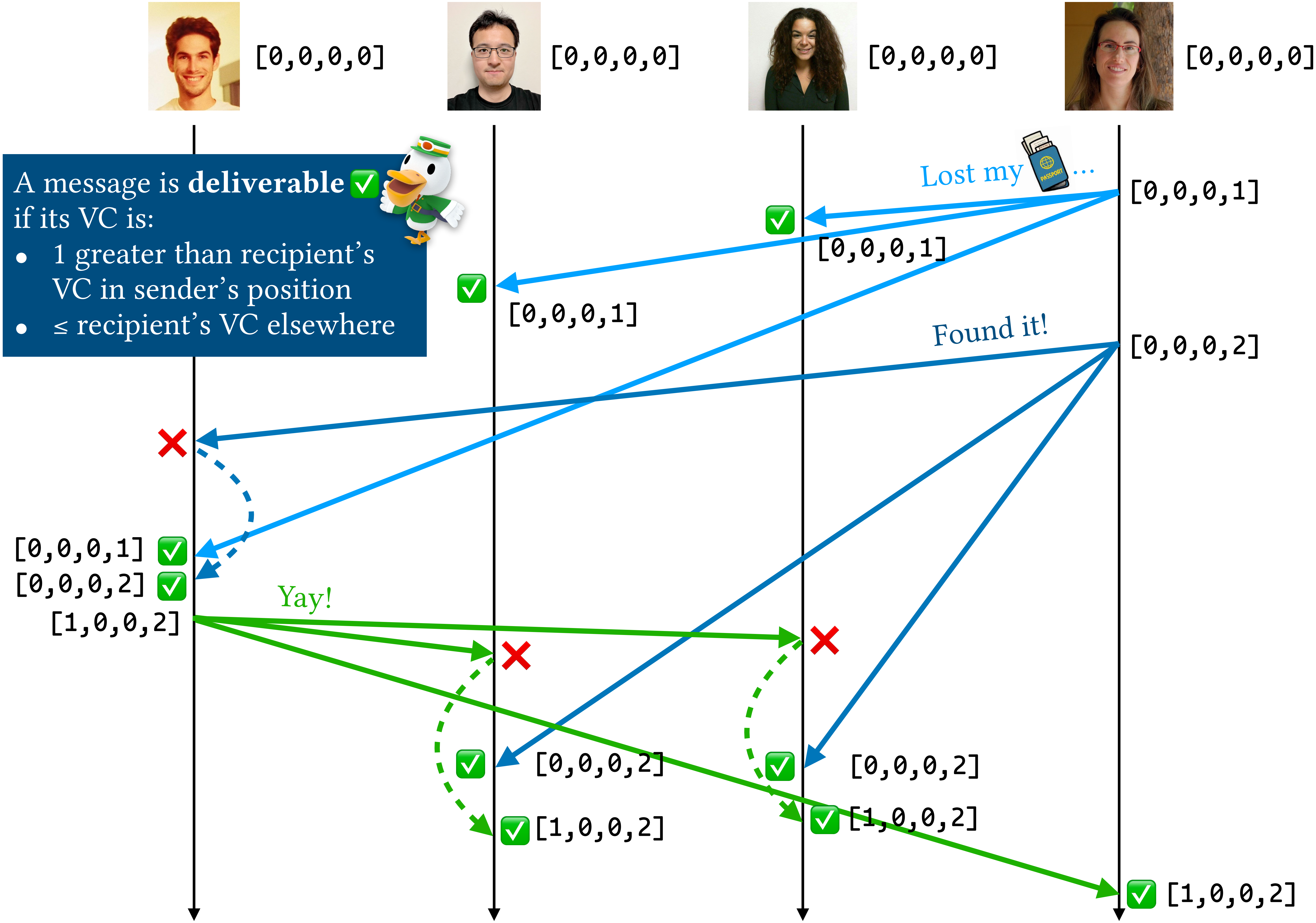

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type Commutative a A = x:a -> y:a -> { _:Proof | A x y == A y x }

vcMergeComm :: n:Nat -> Commutative (VCsized n) vcMerge
vcMergeComm _n []      []      = ()
vcMergeComm n  (_x:xs) (_y:ys) = vcMergeComm (n - 1) xs ys
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Refinement *reflection*

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type Nat = { v:Int | v >= 0 }
type VectorClock = [Nat]

type VCsized N = { vc:VectorClock | len vc == N }
type VCsameLength V = VCsized {len V}

vcMerge :: v:VectorClock -> VCsameLength {v} -> VCsameLength {v}
vcMerge = zipWith max
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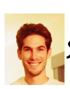
Refinement *reflection*

(Local) causal delivery as a refinement type

verification code

**'s process history (** `pHist` **):**

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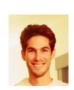
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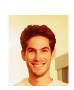
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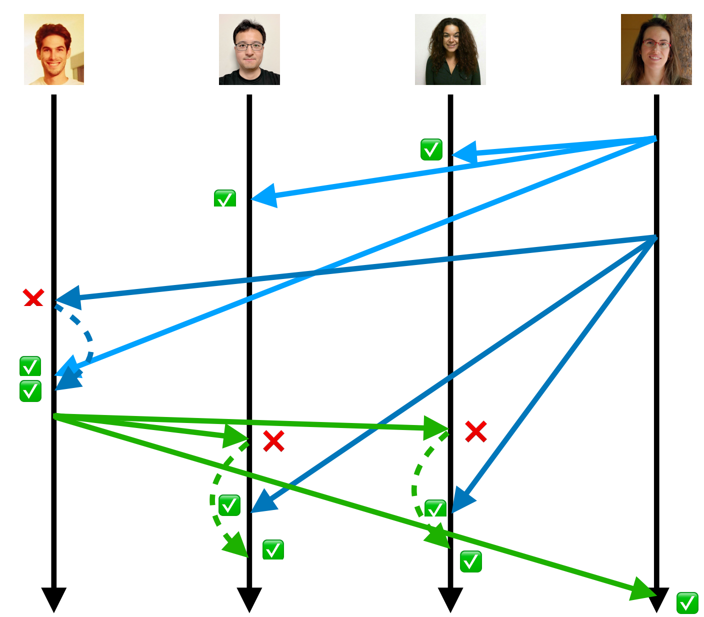

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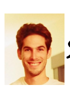
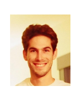
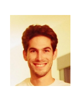
**'s process history (** `pHist` **):**

[(Deliver  “Lost my ”),
 (Deliver  “Found it!”),
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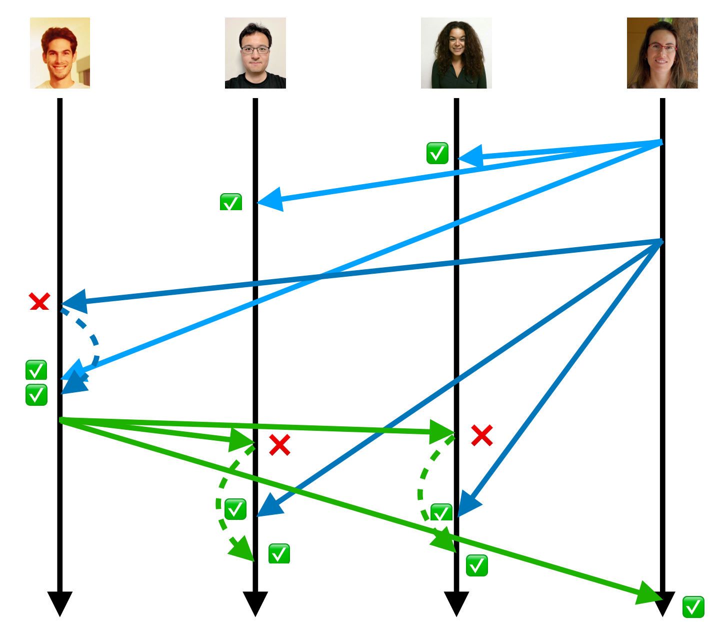

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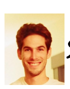
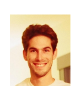
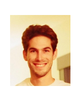
**'s process history (** `pHist` **):**

[(Deliver  "Lost my "),
 (Deliver  "Found it!"),
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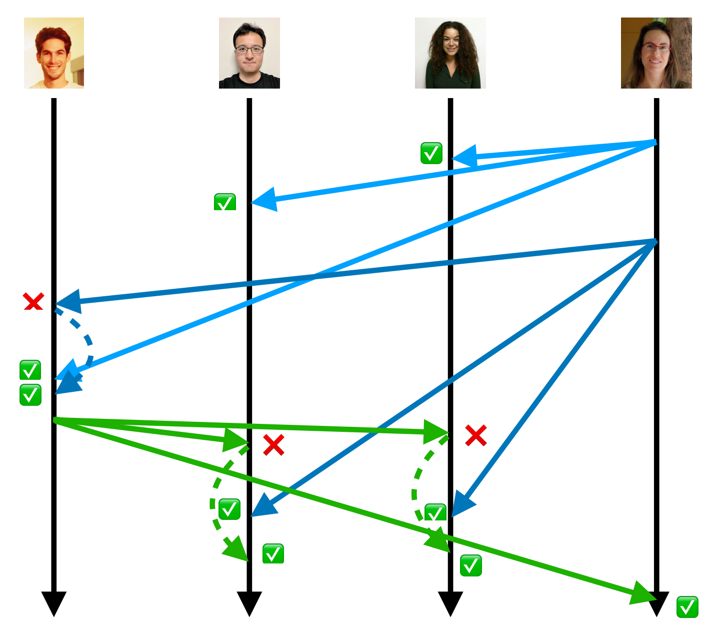

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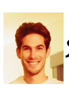
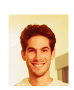
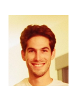
**’s process history (** pHist **):**

[(Deliver  “Lost my ”),
 (Deliver  “Found it!”),
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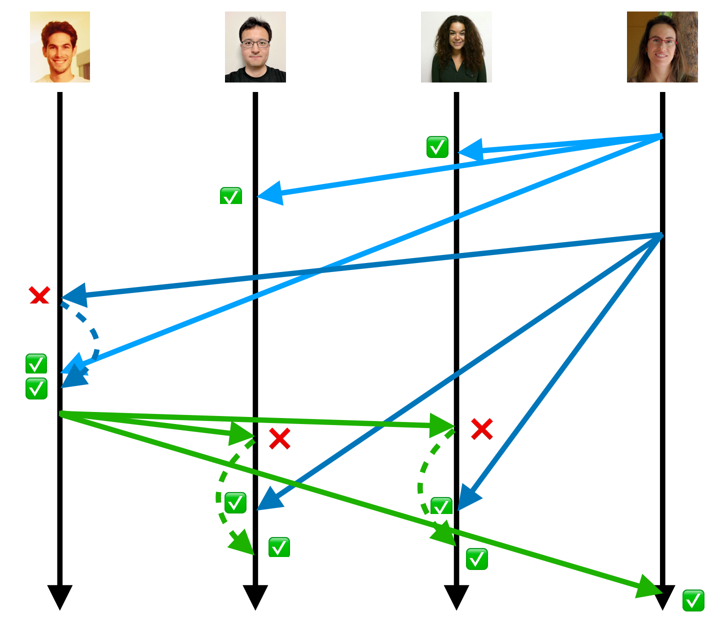

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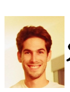
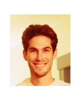
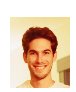
**’s process history (** `pHist` **):**

[(Deliver  “Lost my ”),
 (Deliver  “Found it!”),
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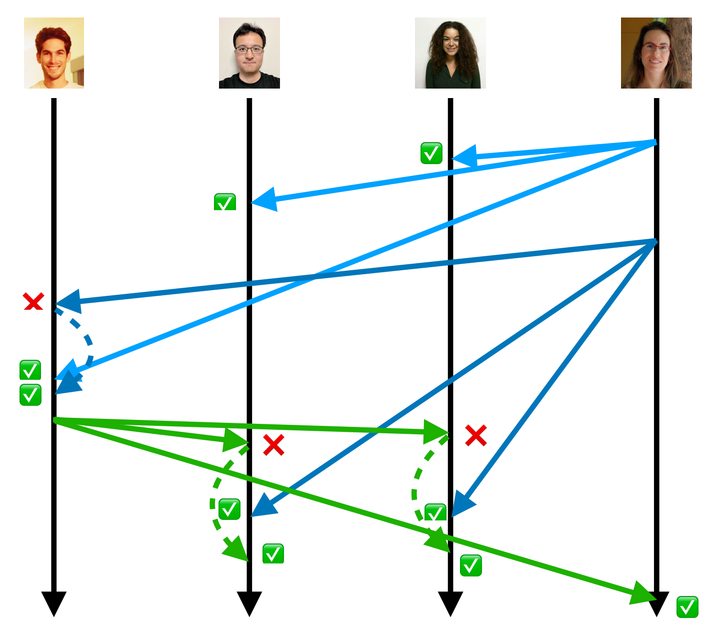

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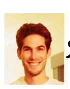
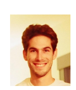
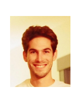
**’s process history (** `pHist` **):**

[(Deliver  “Lost my ”),
 (Deliver  “Found it!”),
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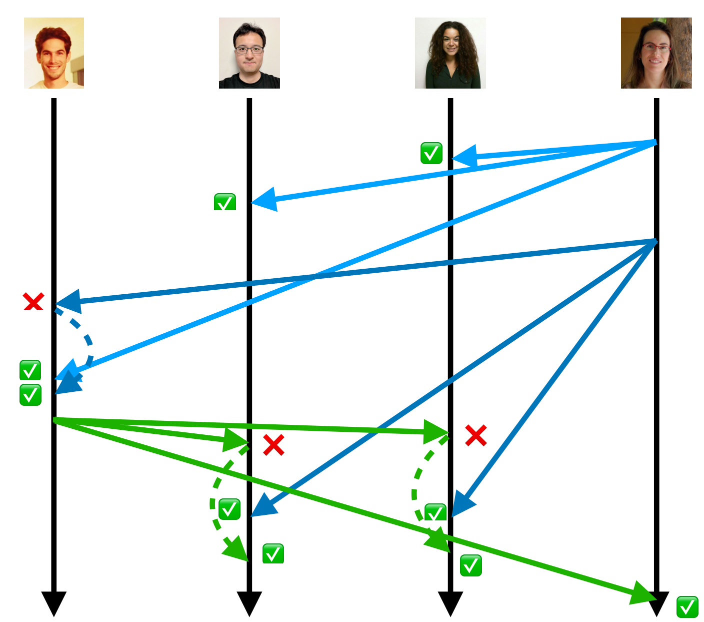

Running the protocol preserves (local) causal delivery

application code

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step :: Op r -> Process -> Process
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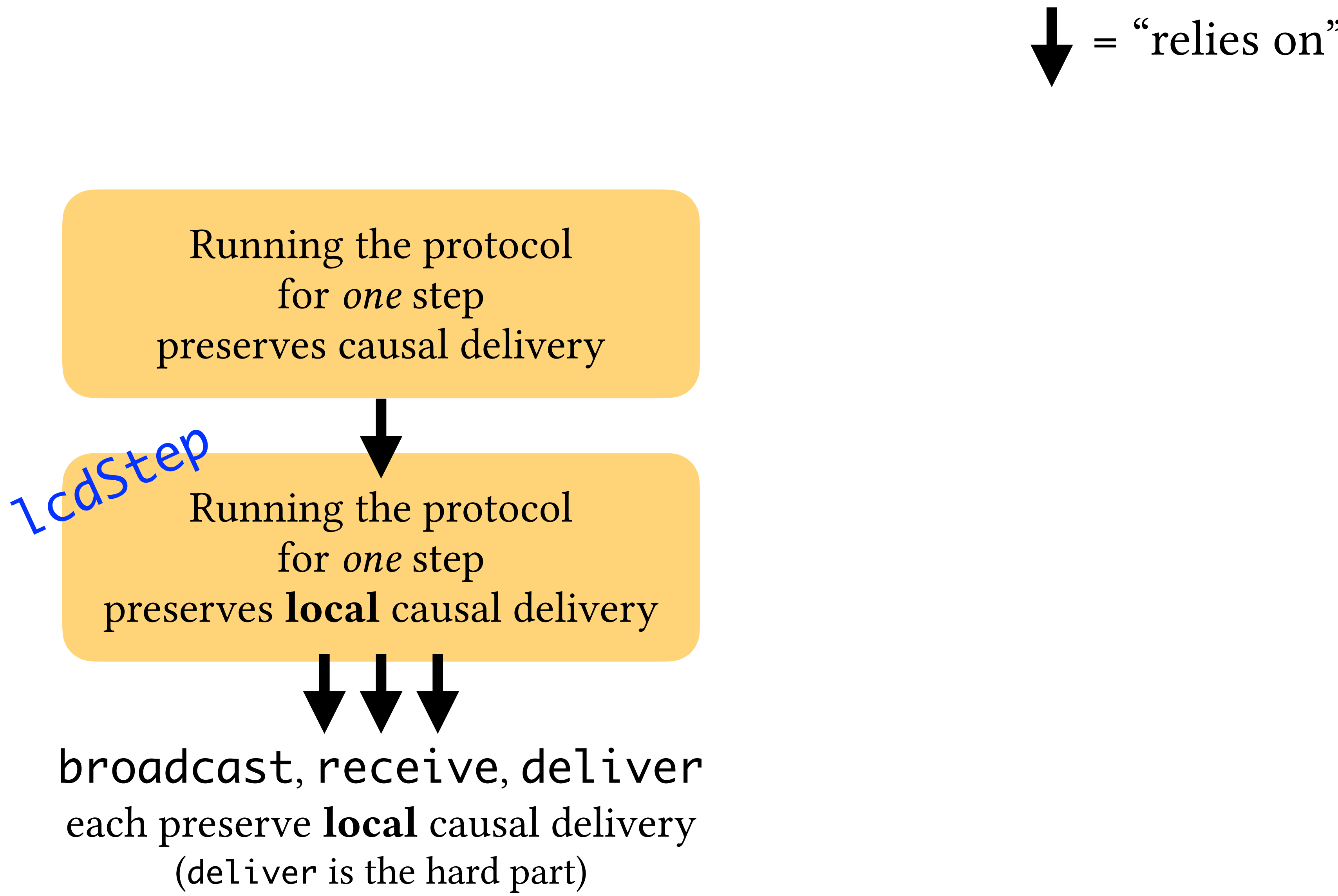

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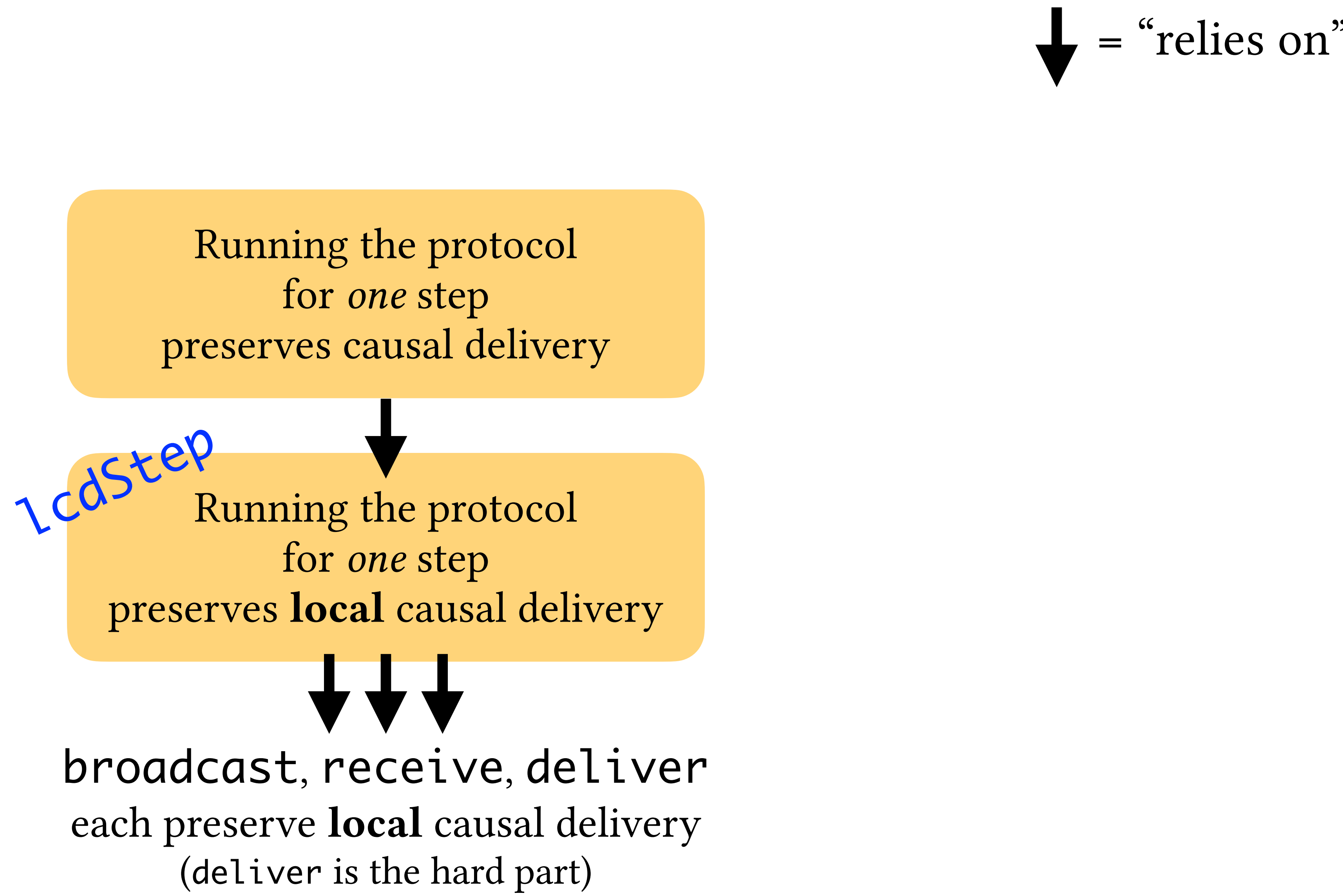

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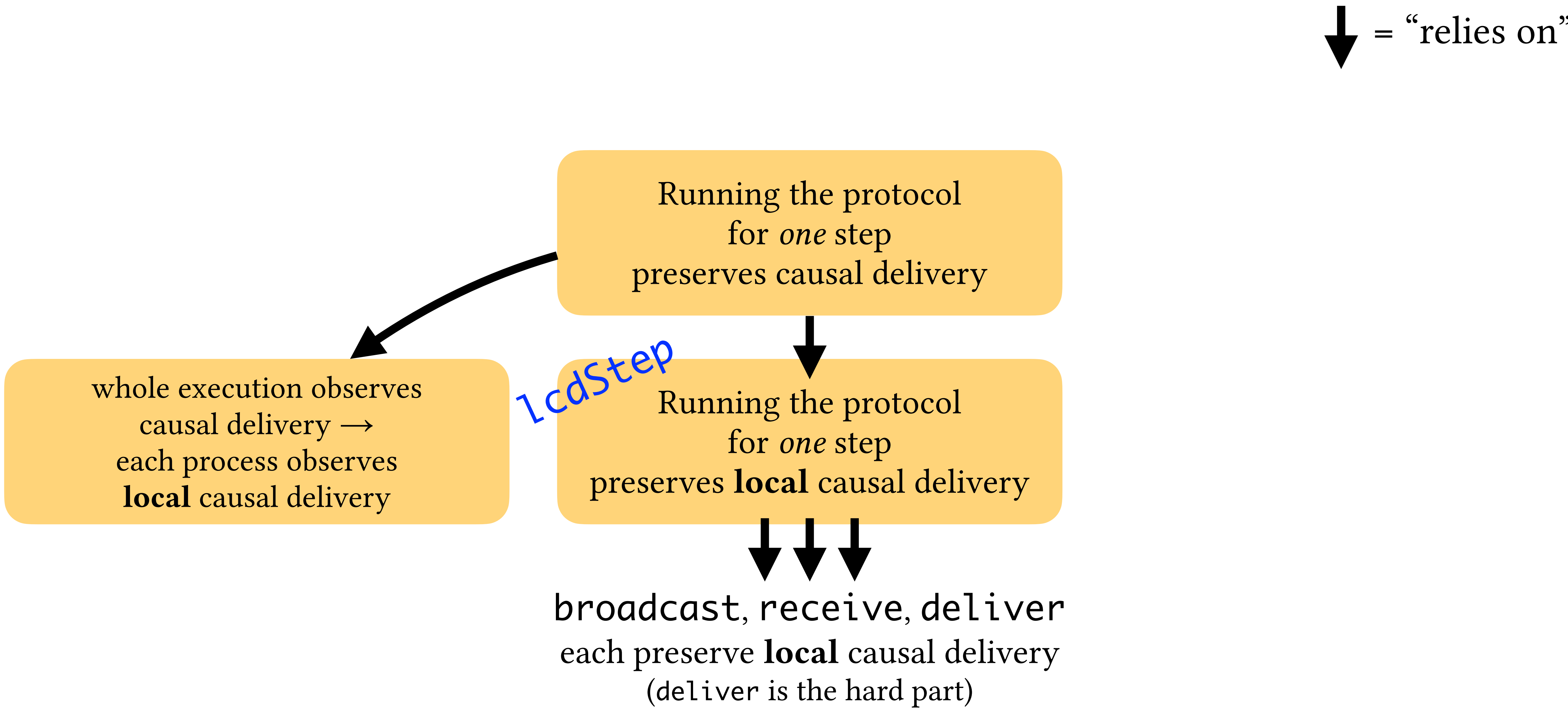

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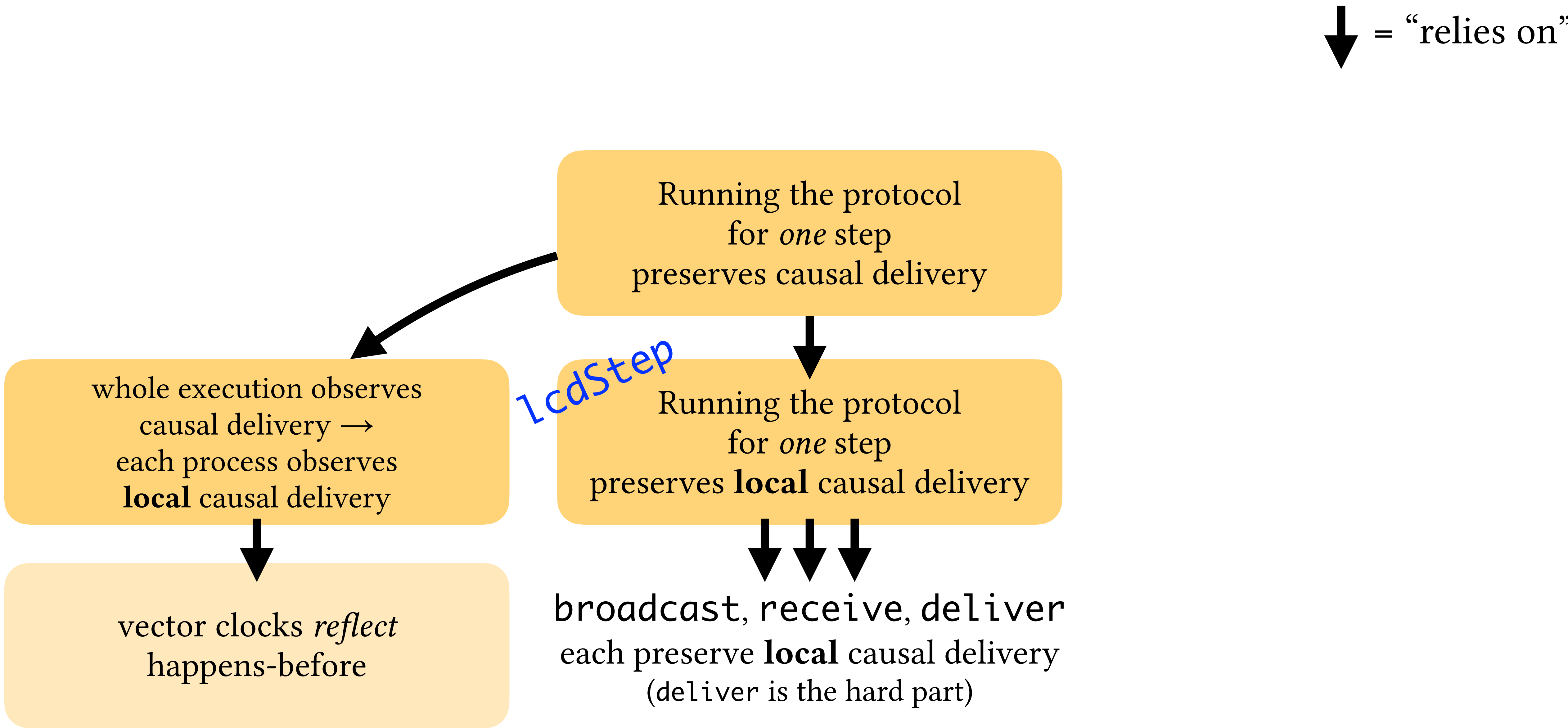

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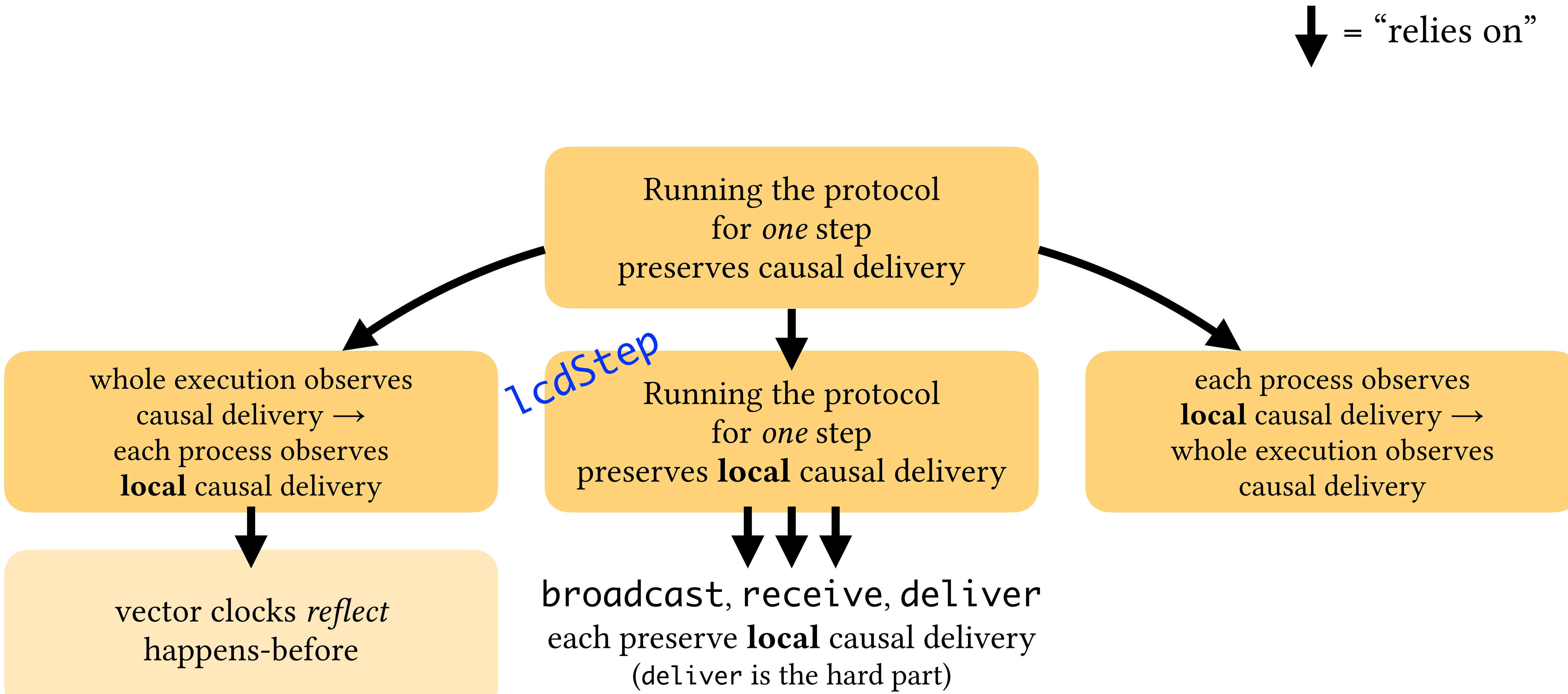

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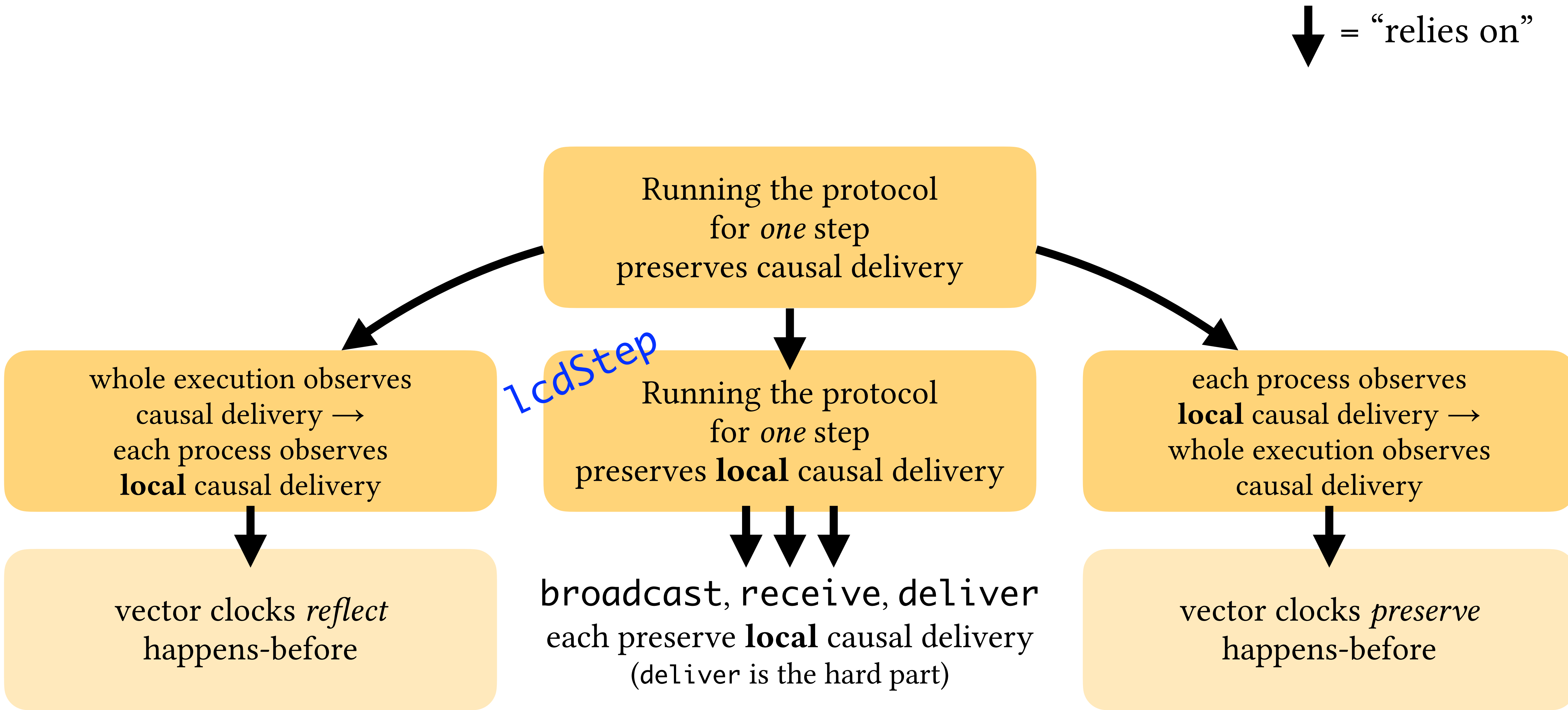

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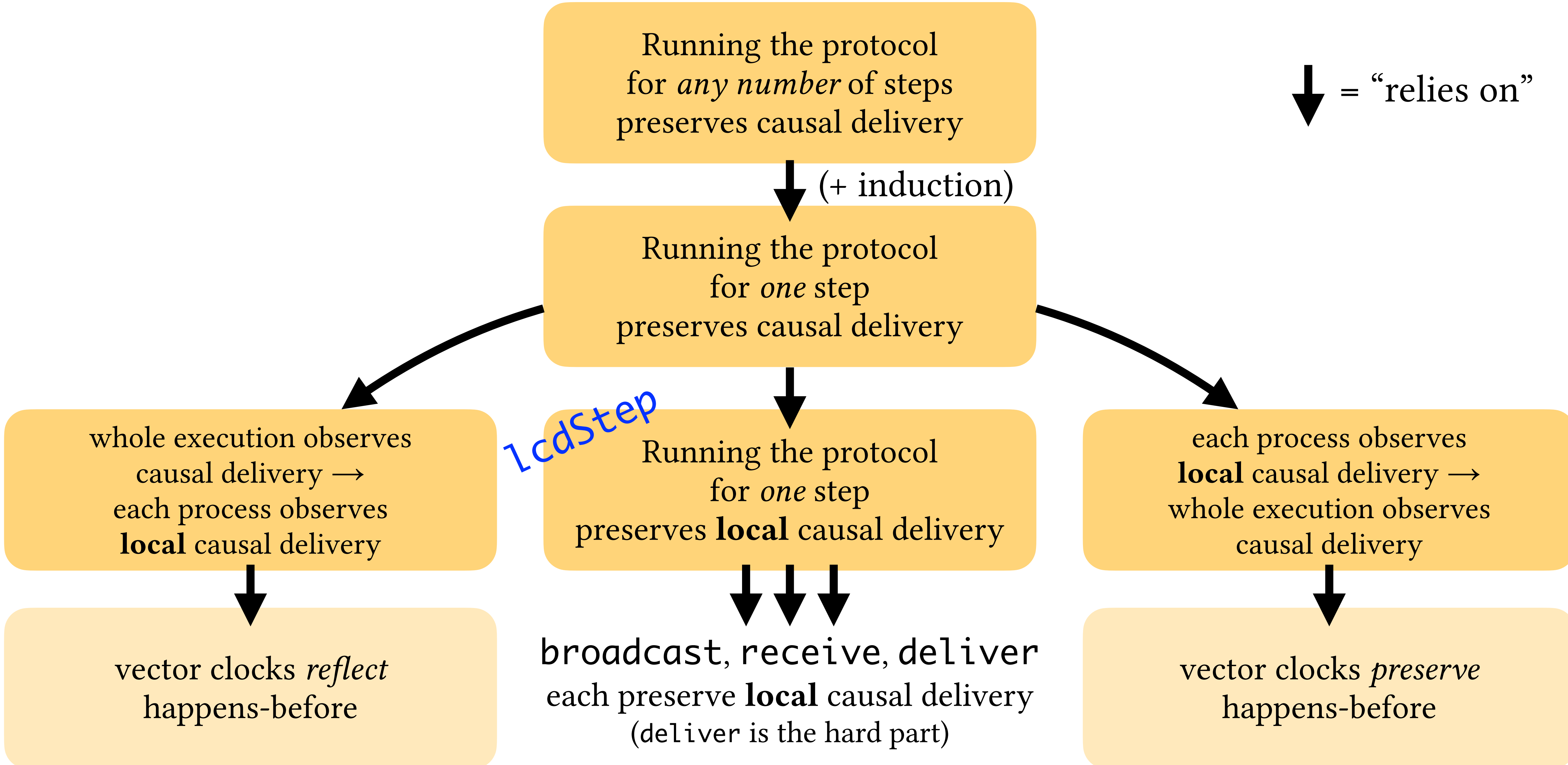

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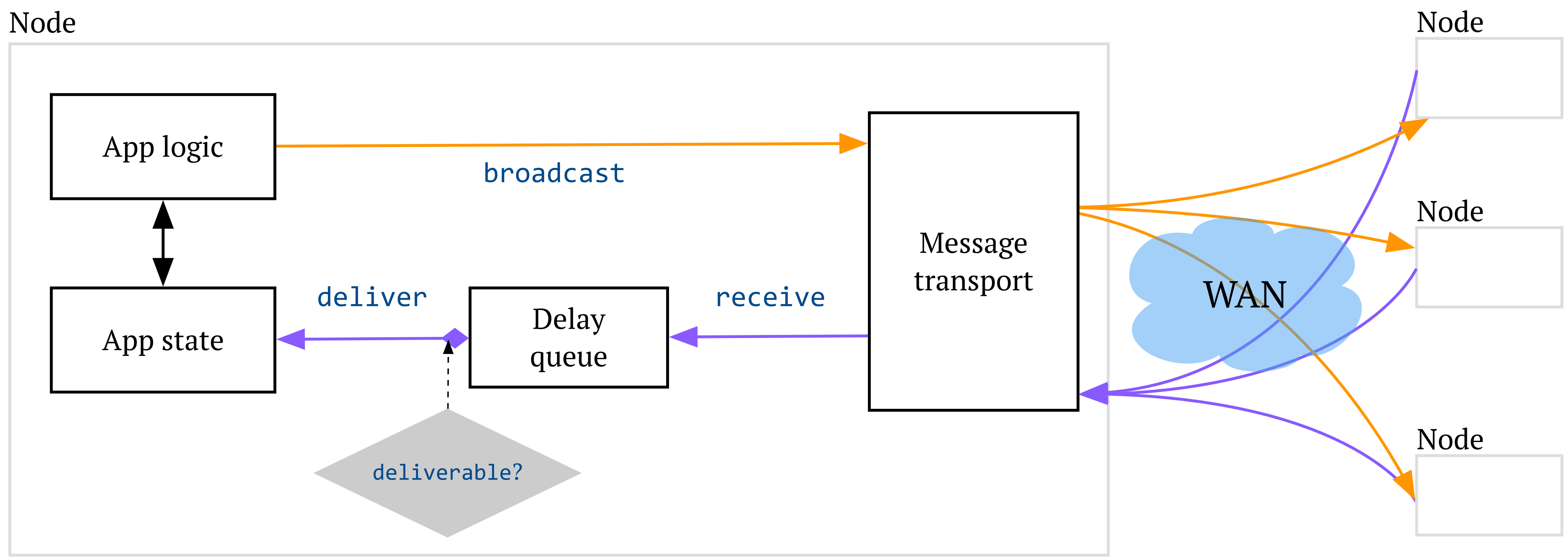
Building apps with causal broadcast



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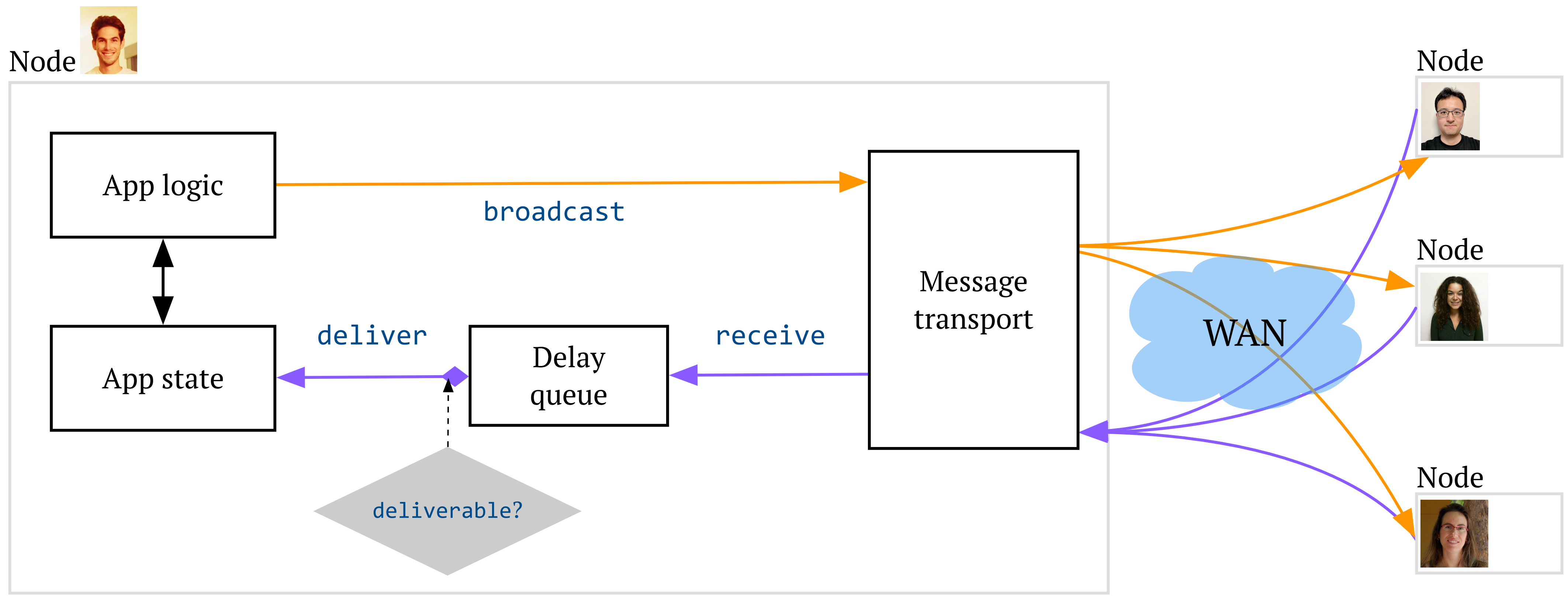

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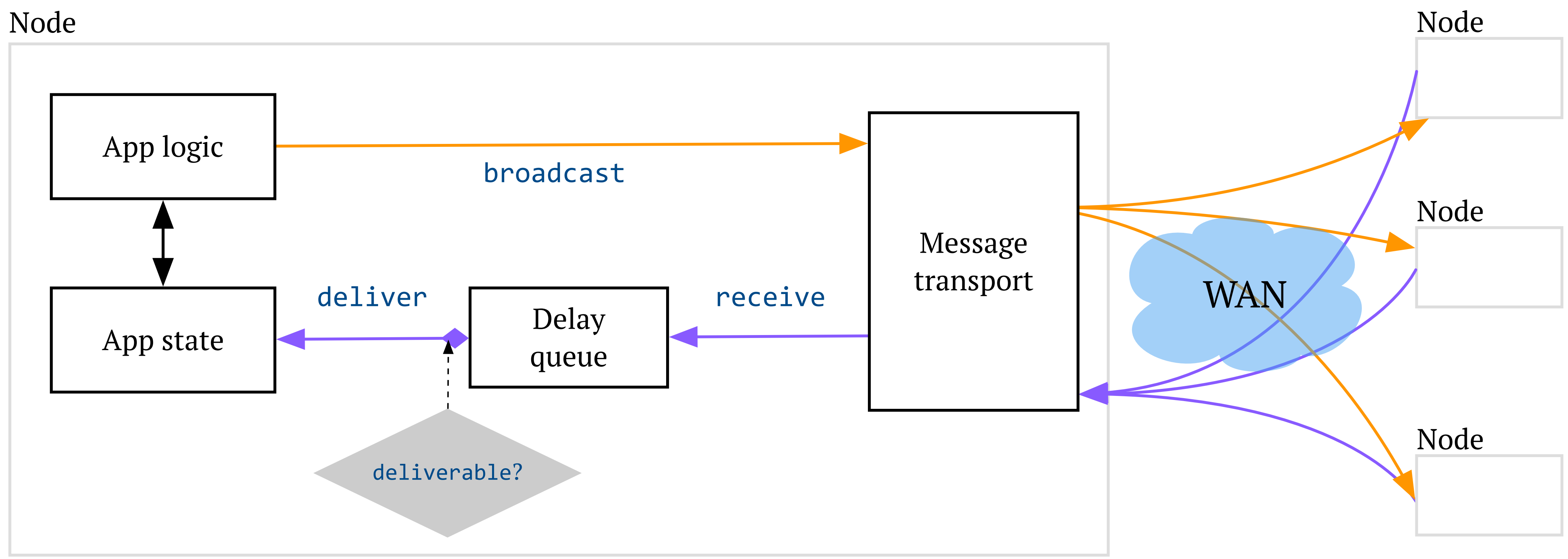

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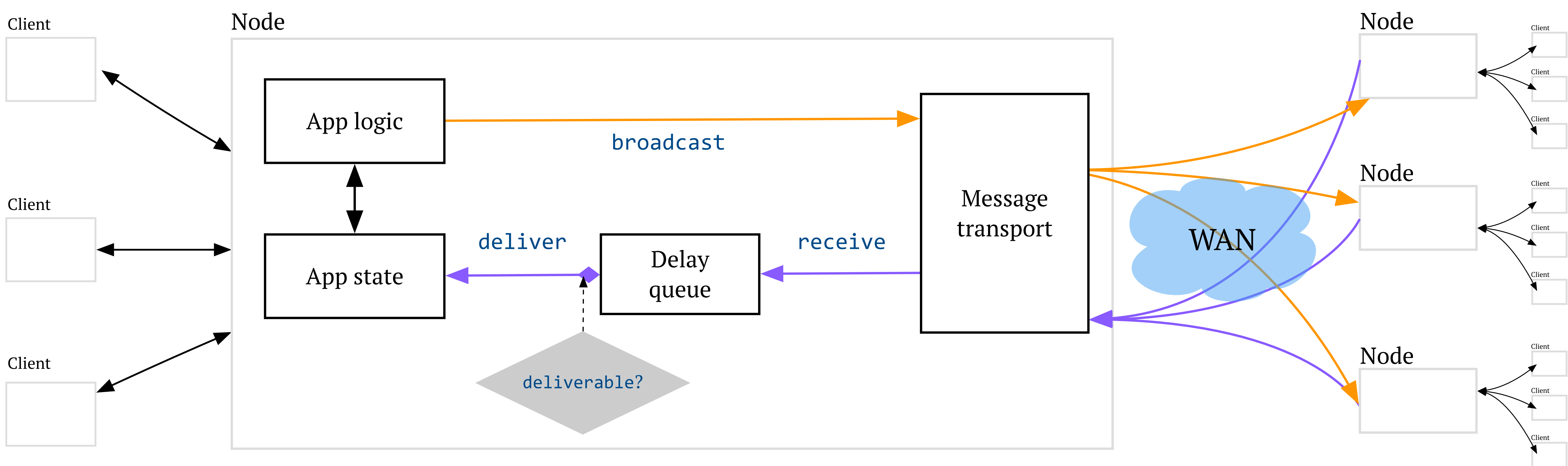
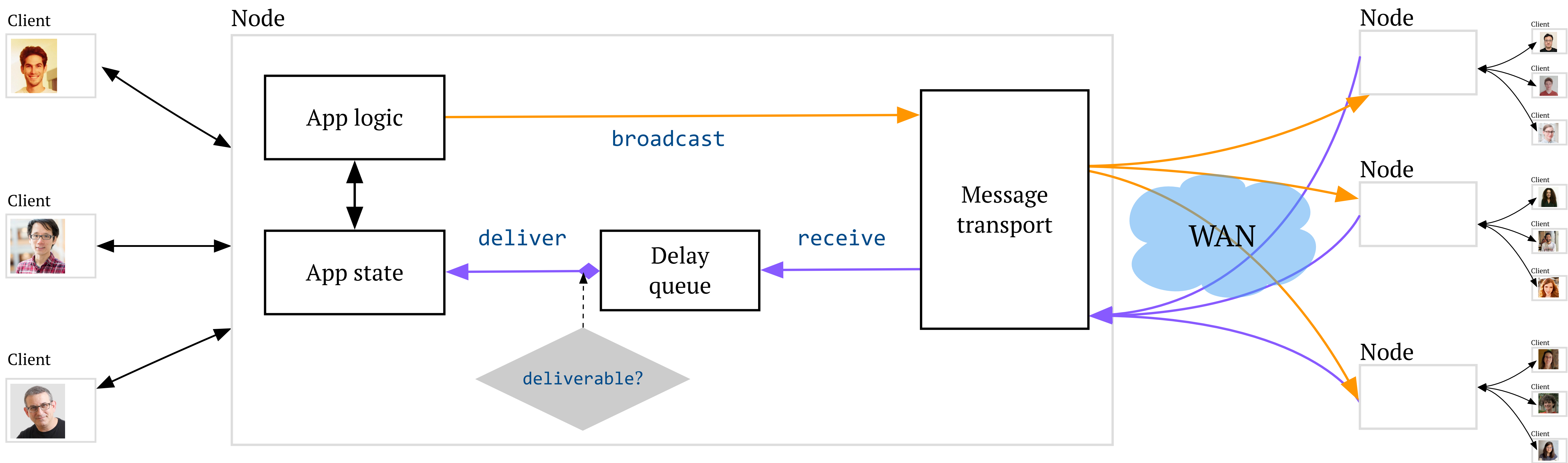
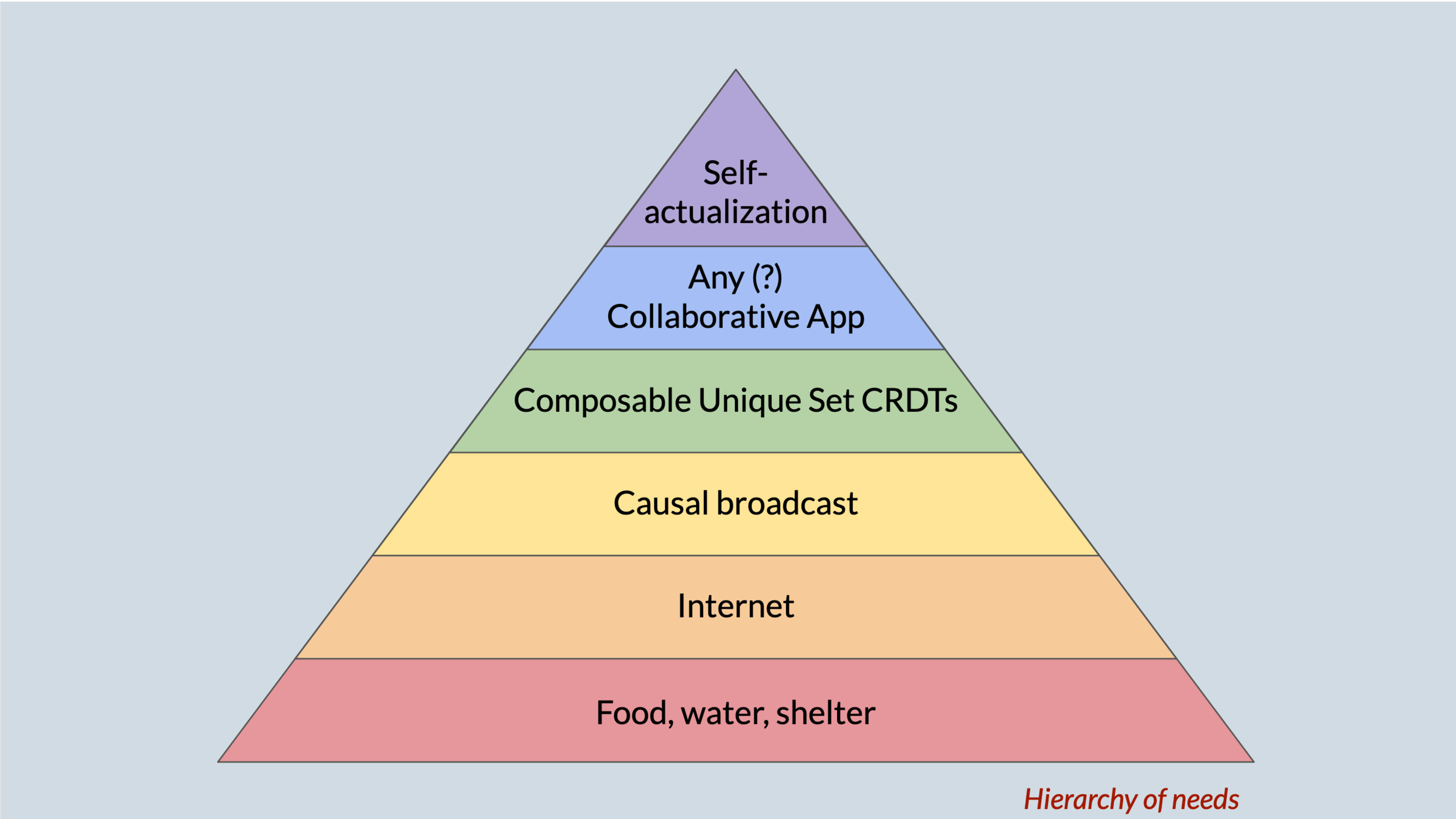


Building apps with causal broadcast



Building apps with causal broadcast



Credit: Matthew Weidner

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

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[HATRA 2021]

Toward Hole-Driven Development in Liquid Haskell

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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 with the compiler. While GHC Haskell already has its own Agda-inspired support for typed holes, we posit

Thank you!

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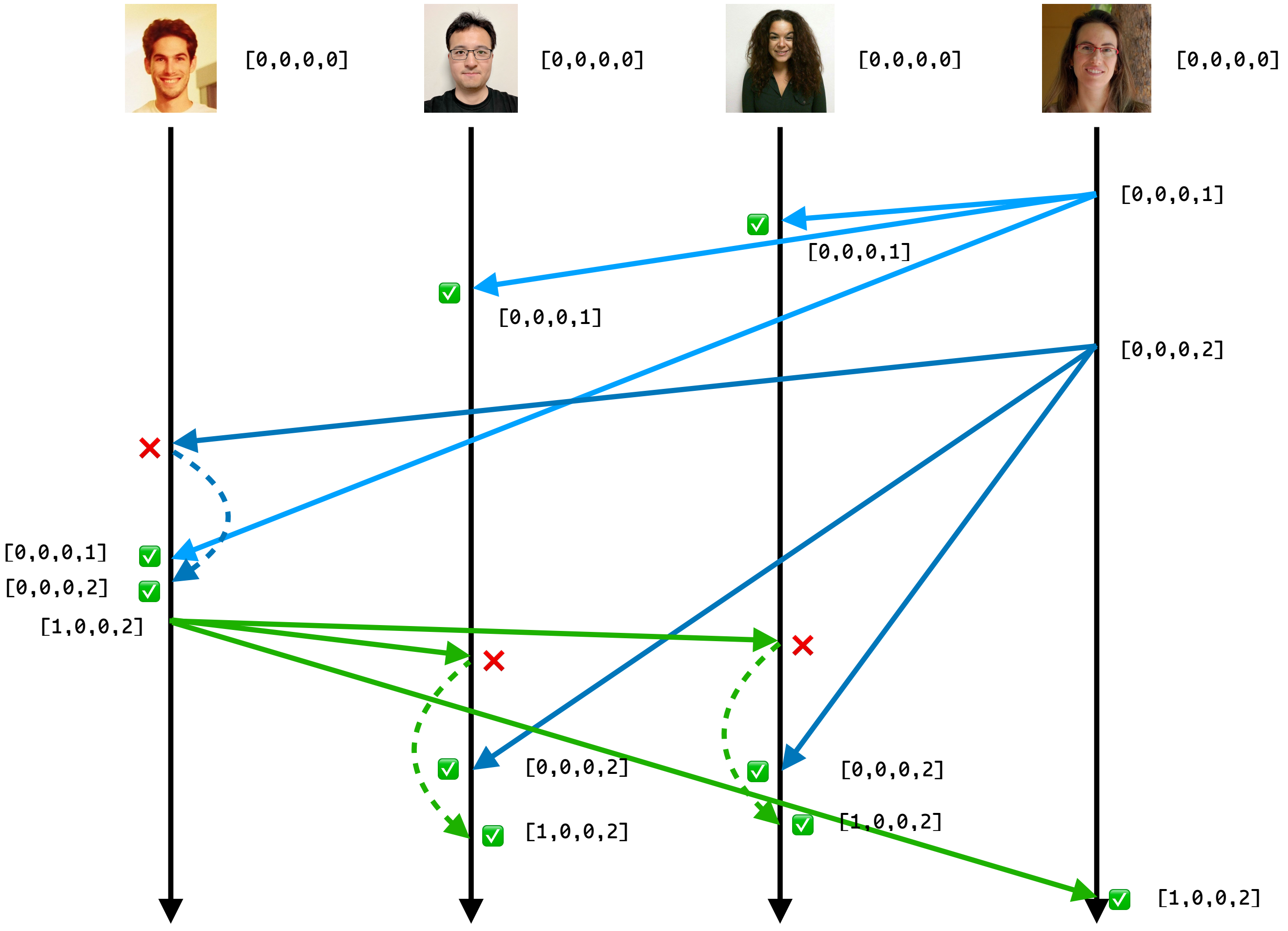

github.com/lsd-ucsc/cbcast-lh

Thank you!

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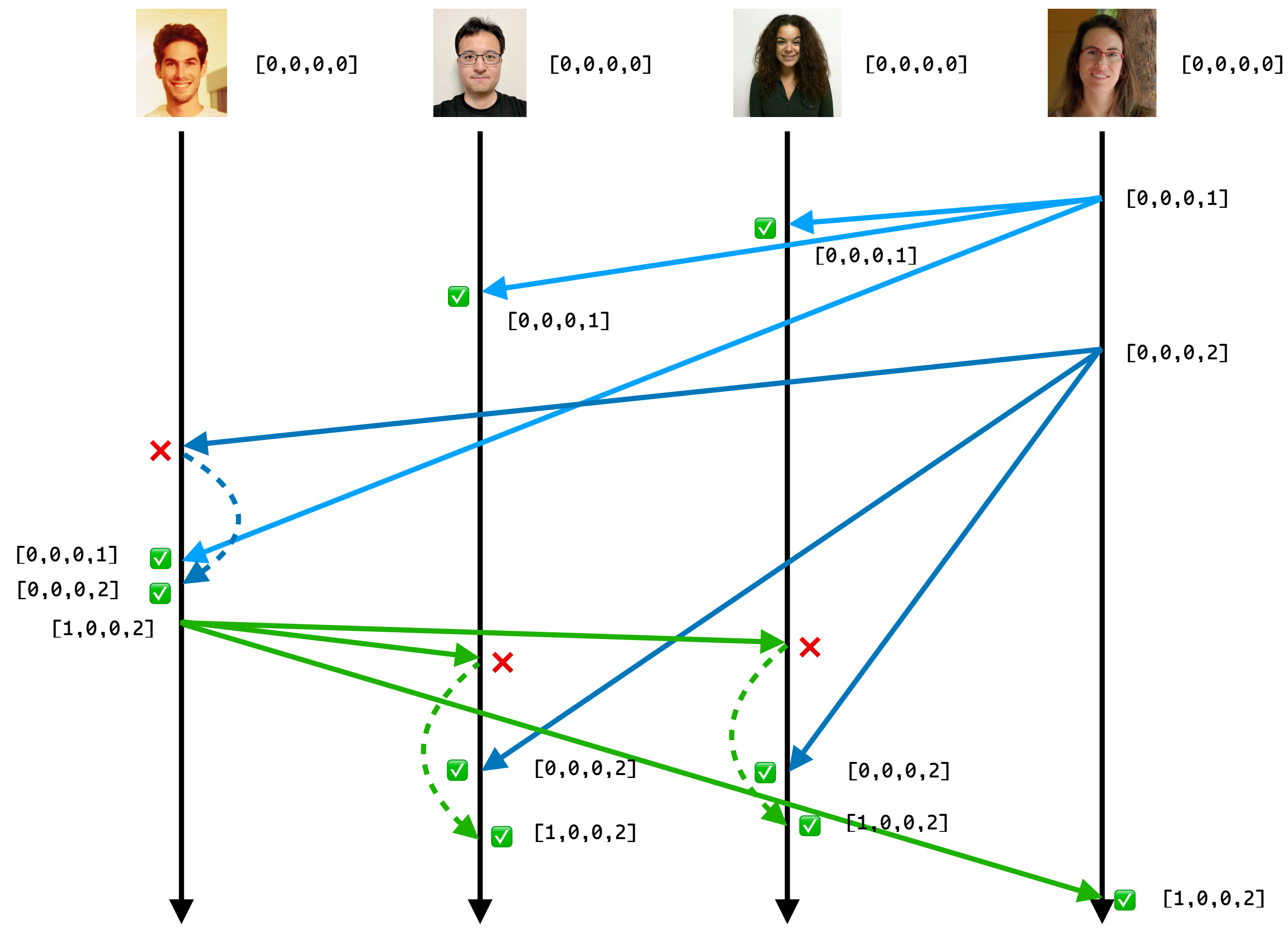

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