Building Systems Resilient to Failures, Partitions and Slowdowns

PhD Thesis Defense
30.11.2022

Cristina Băsescu

EPFL

An ideal situation

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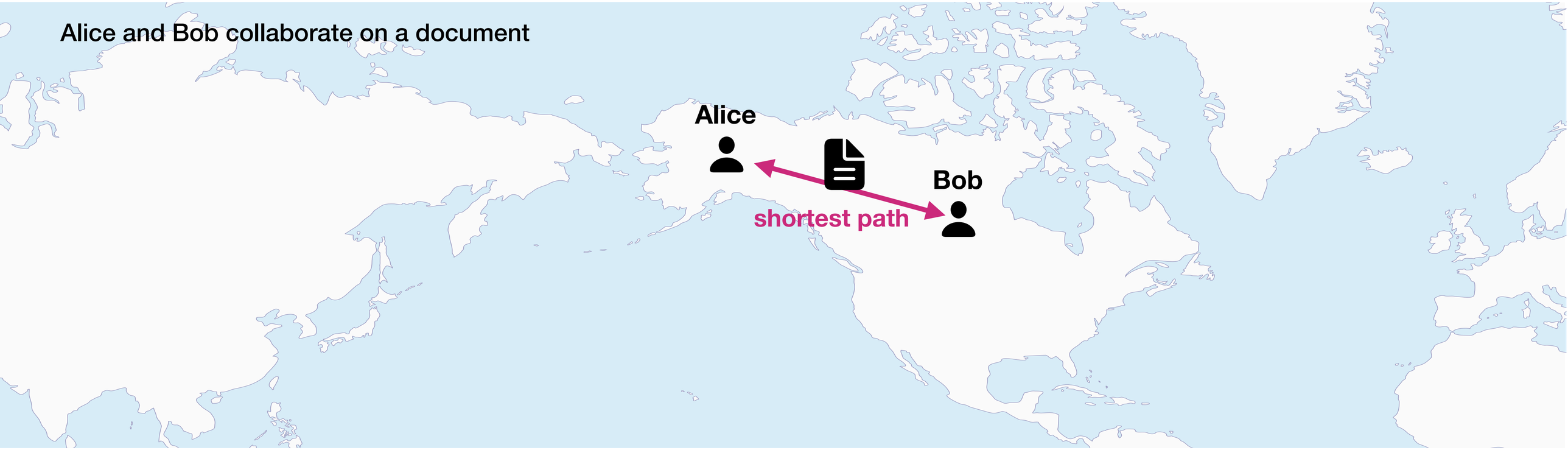

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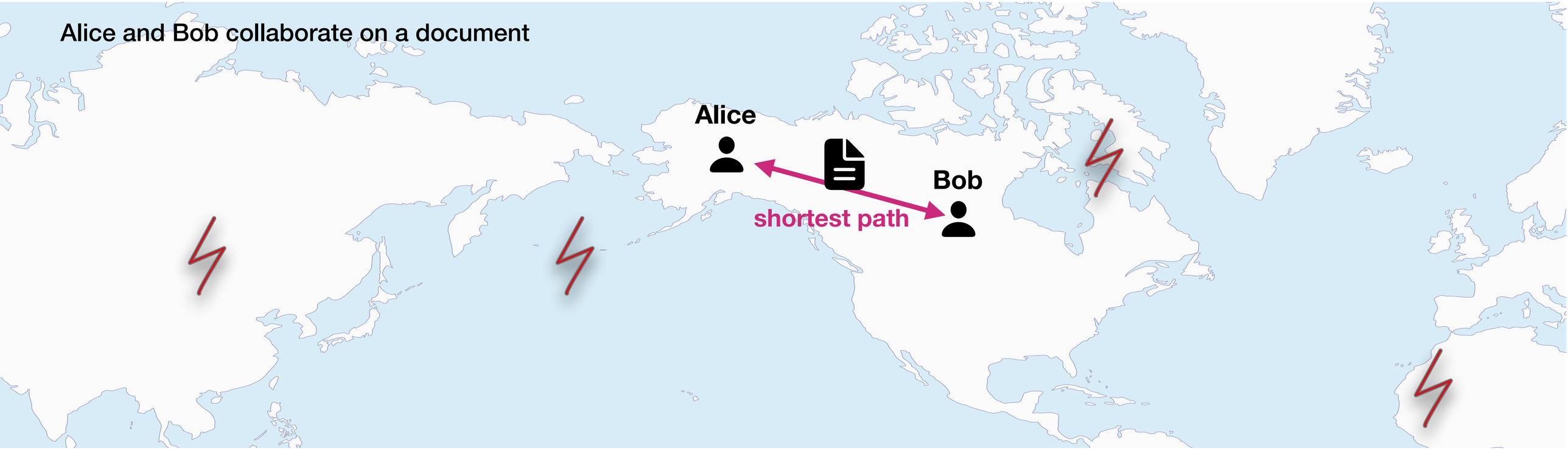

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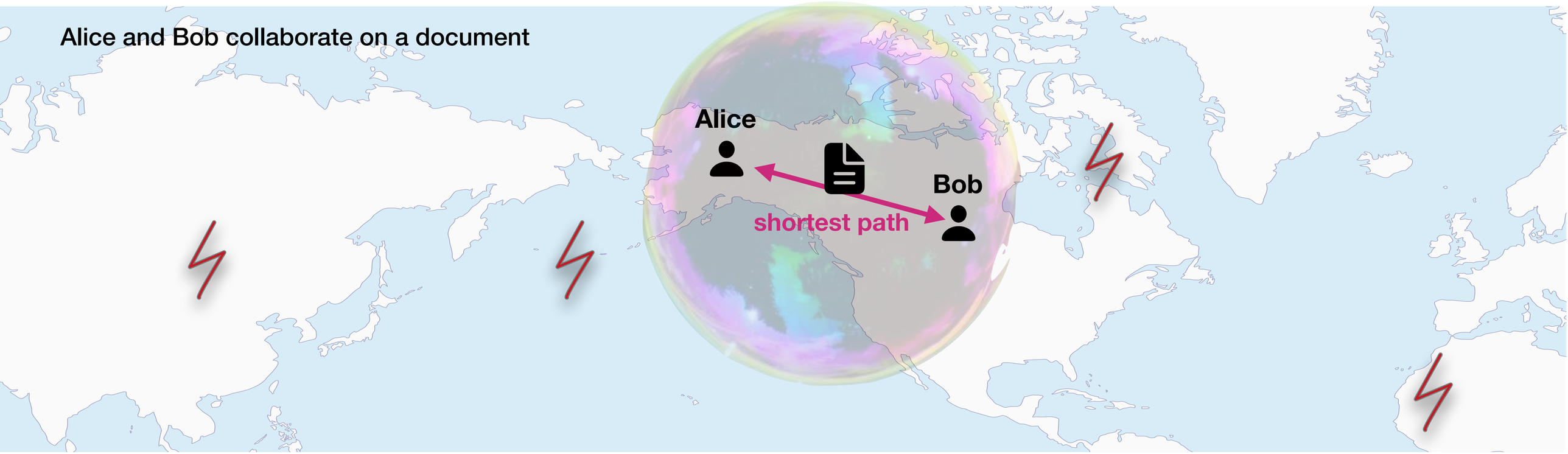

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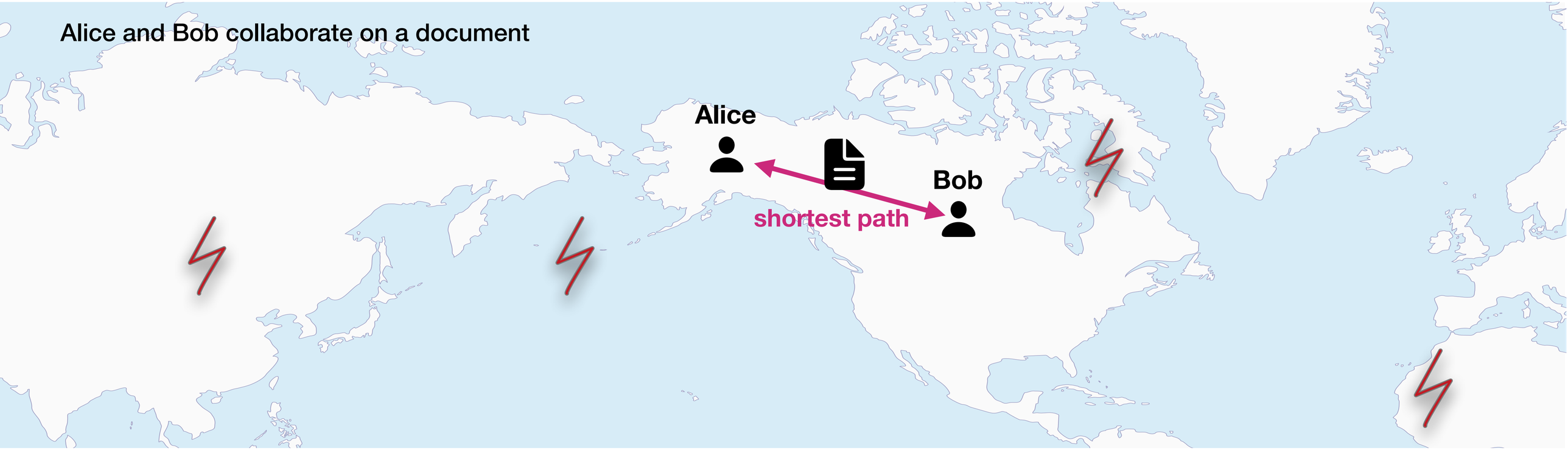

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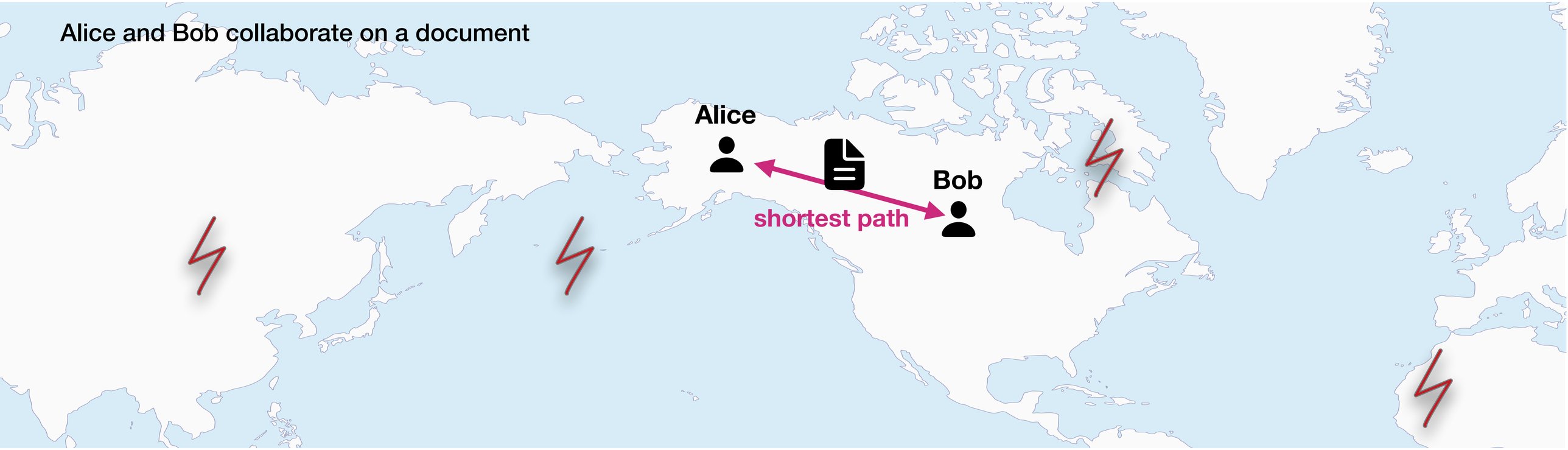

Goal: resilience

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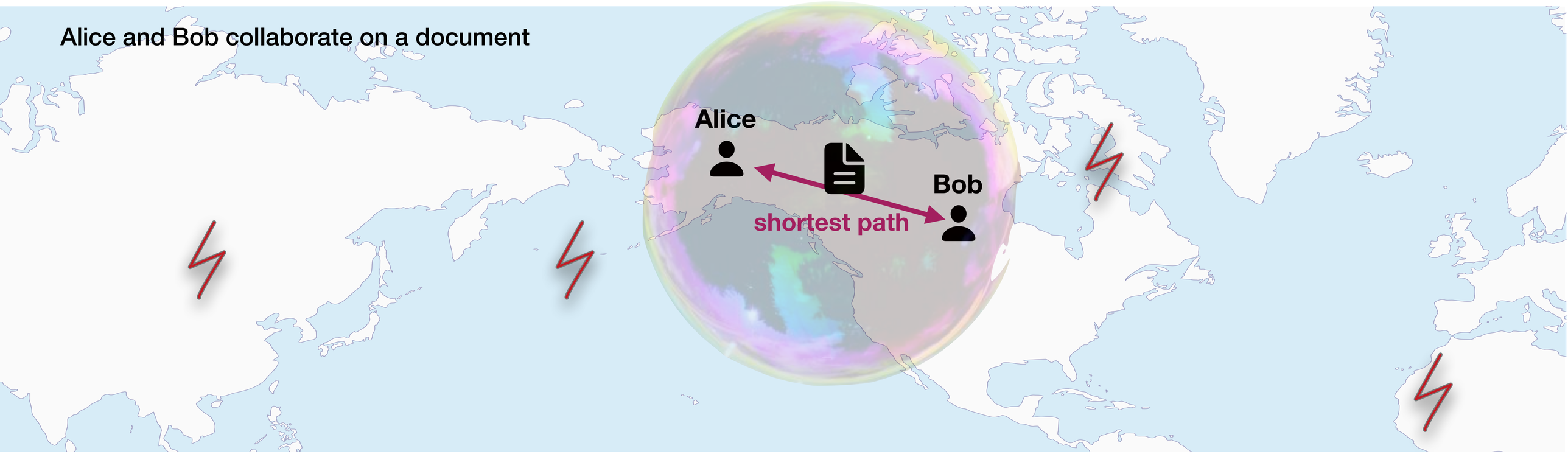
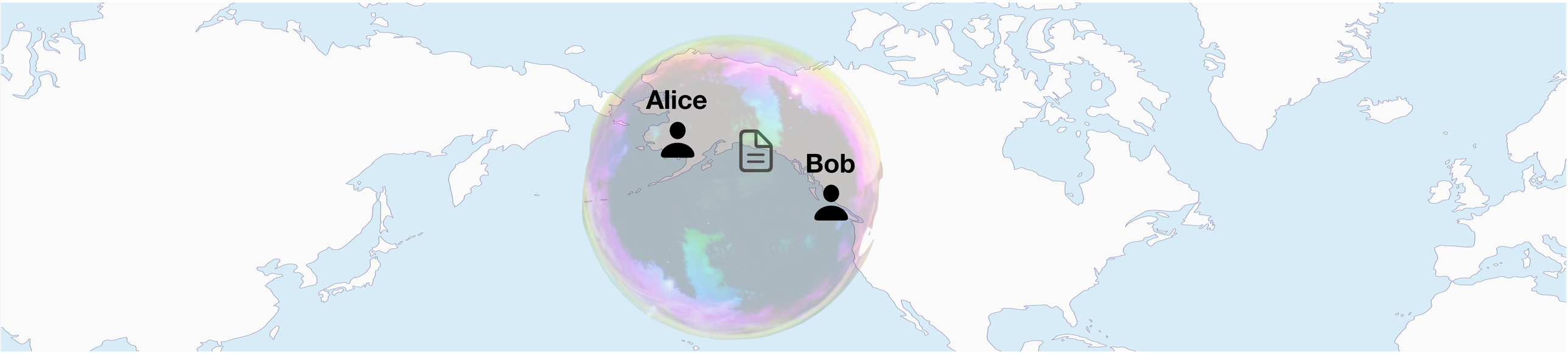


Goal: resilience

A more realistic view



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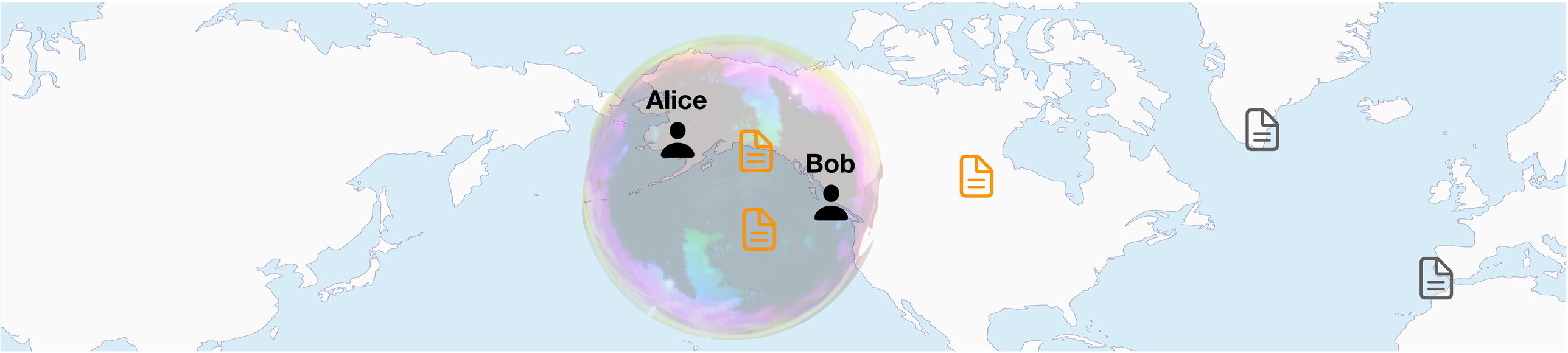
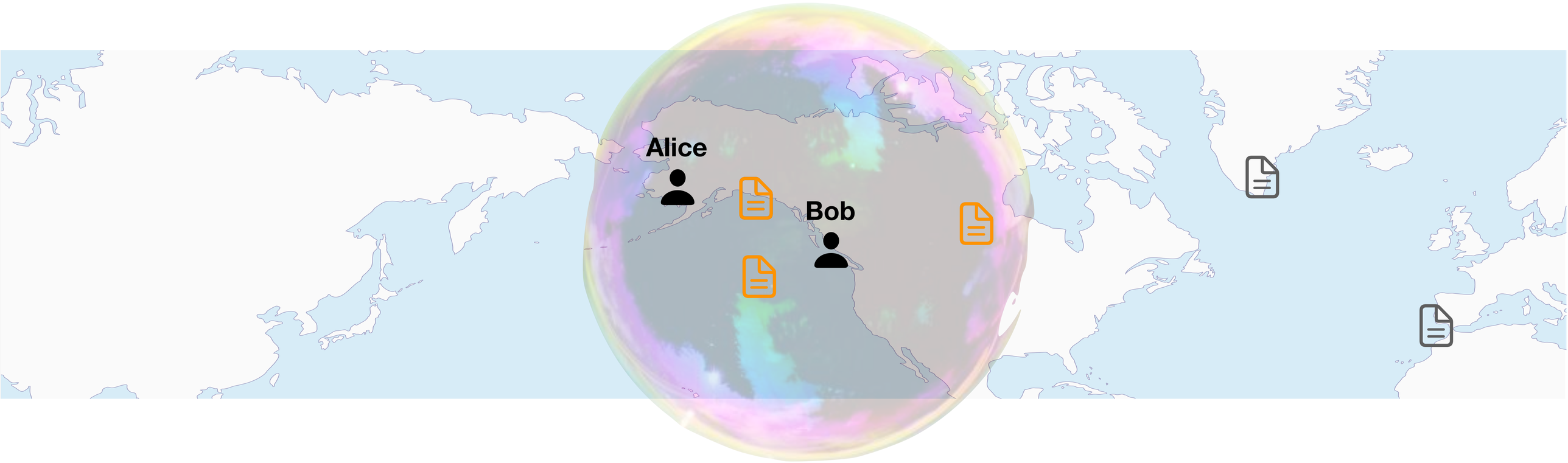


Replication masks **individual replica failures**, but adds **dependency on quorum**

A more realistic view



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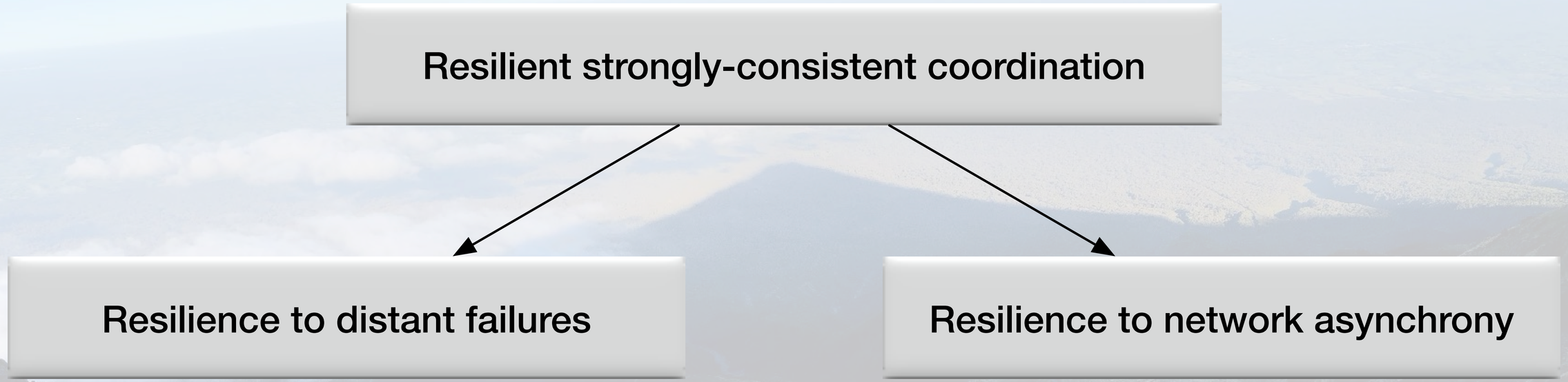
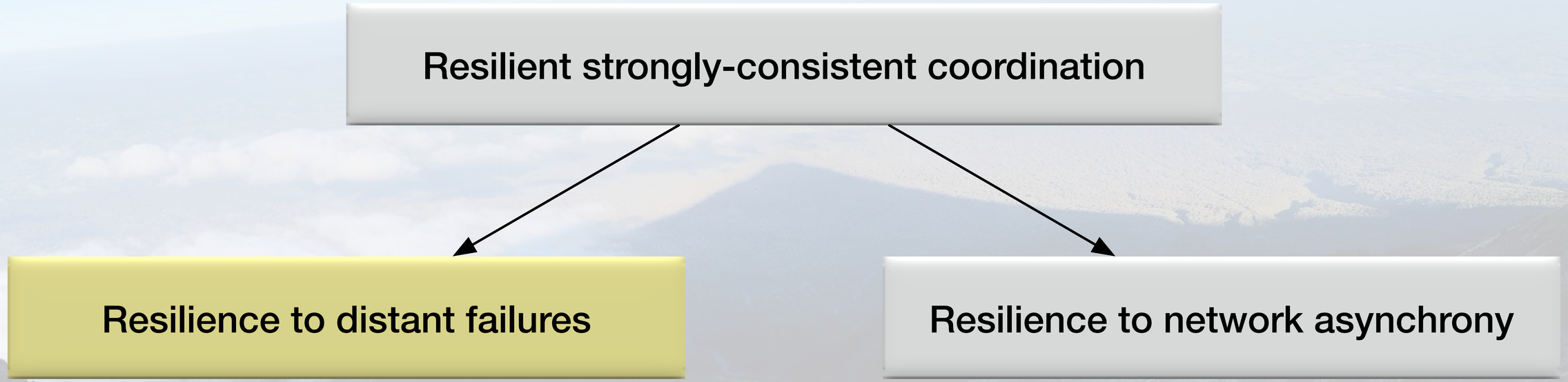

Resilient strongly-consistent coordination
Resilience to distant failures
Resilience to network asynchrony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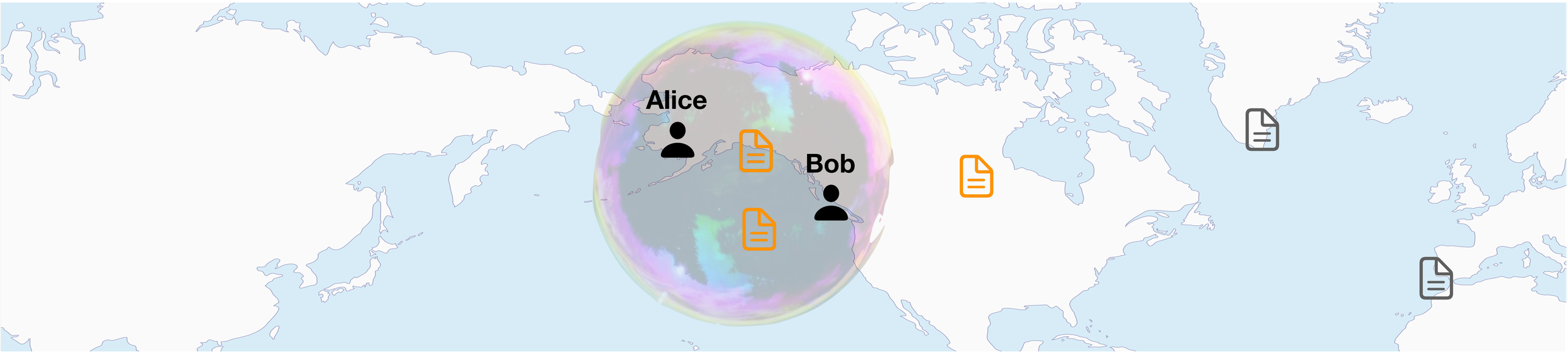
Challenge: Local resilience in a global world



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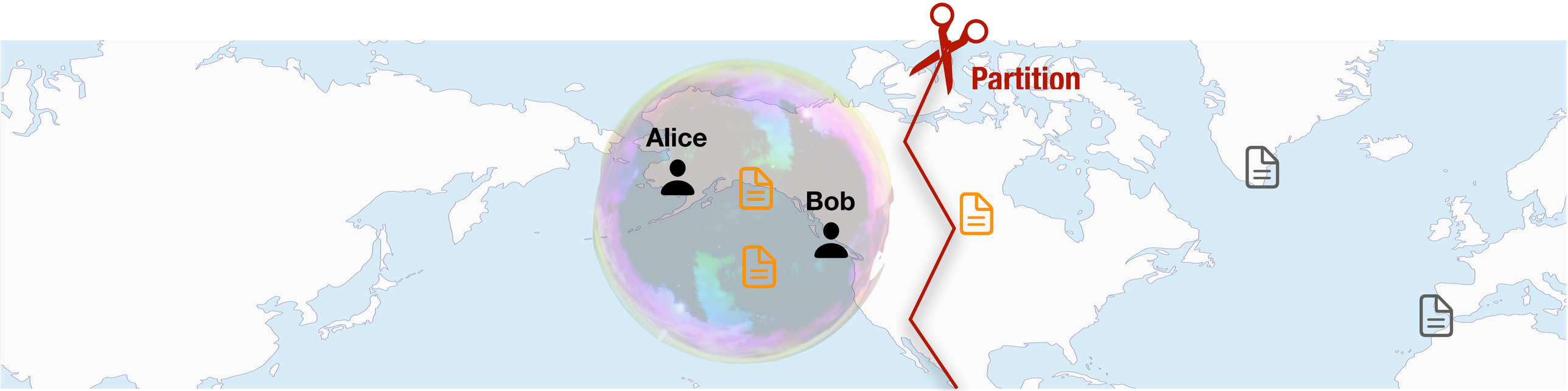

CAP theorem: **pick two** of strong consistency, availability, partition tolerance

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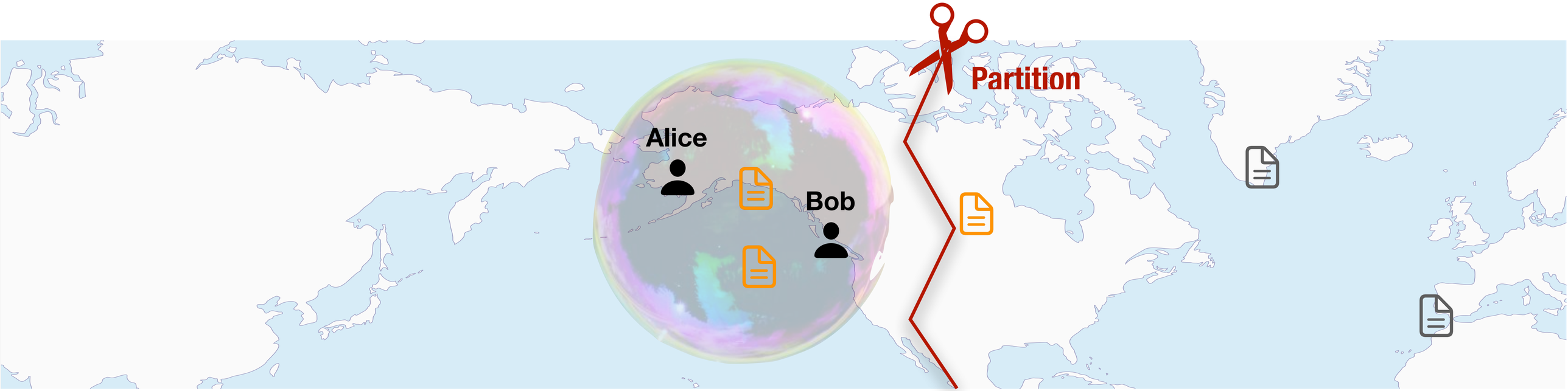

Rare events?
Naïve simplification

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Gray failures

Individual replica failure

Full partitions

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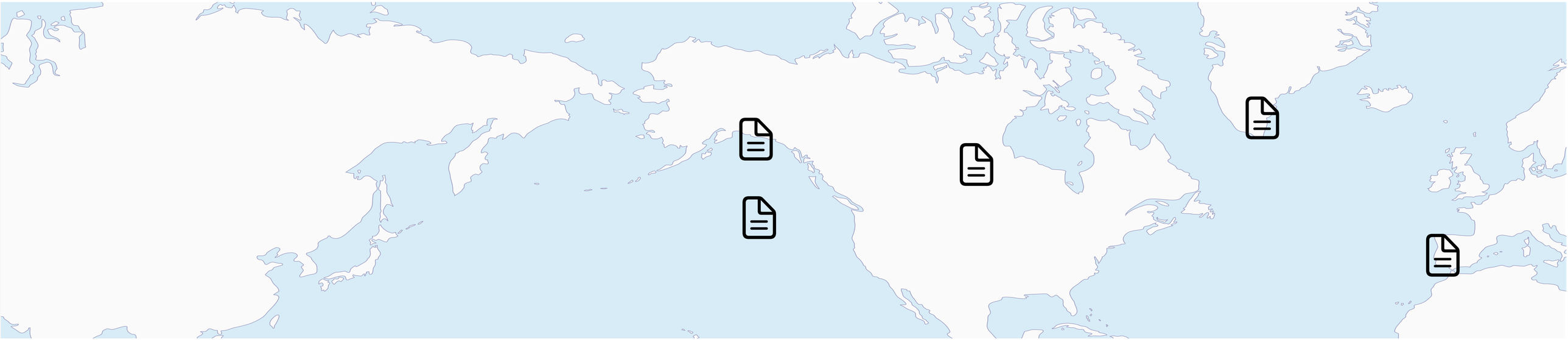

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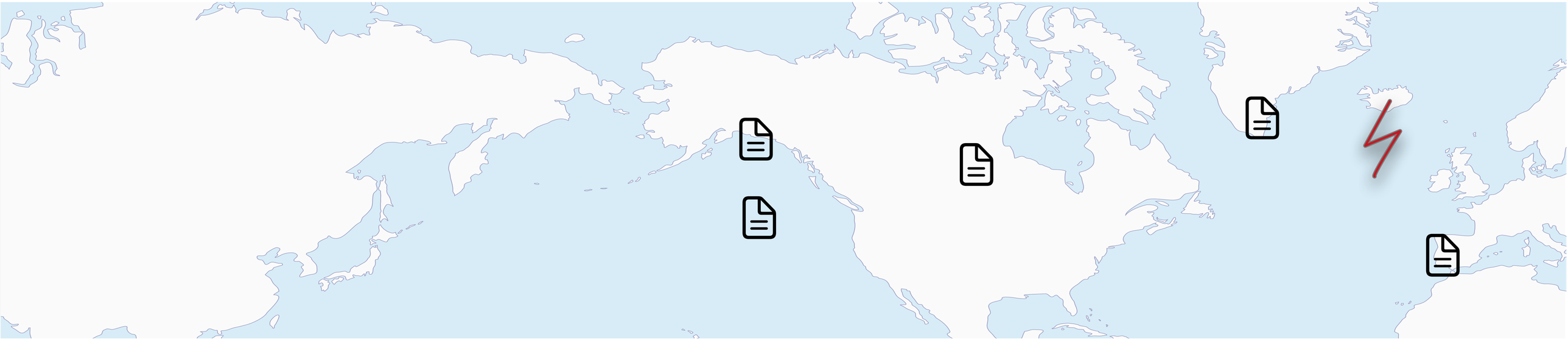

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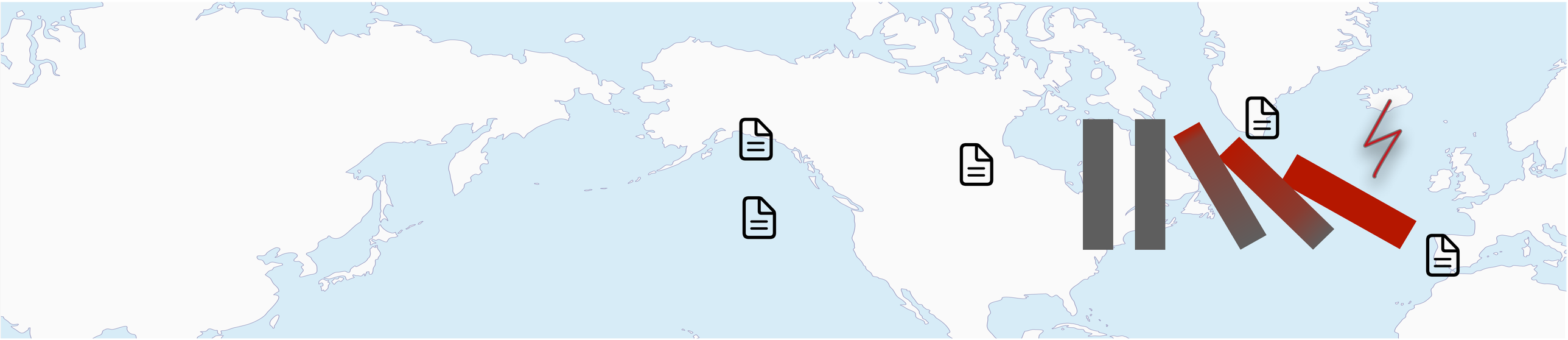

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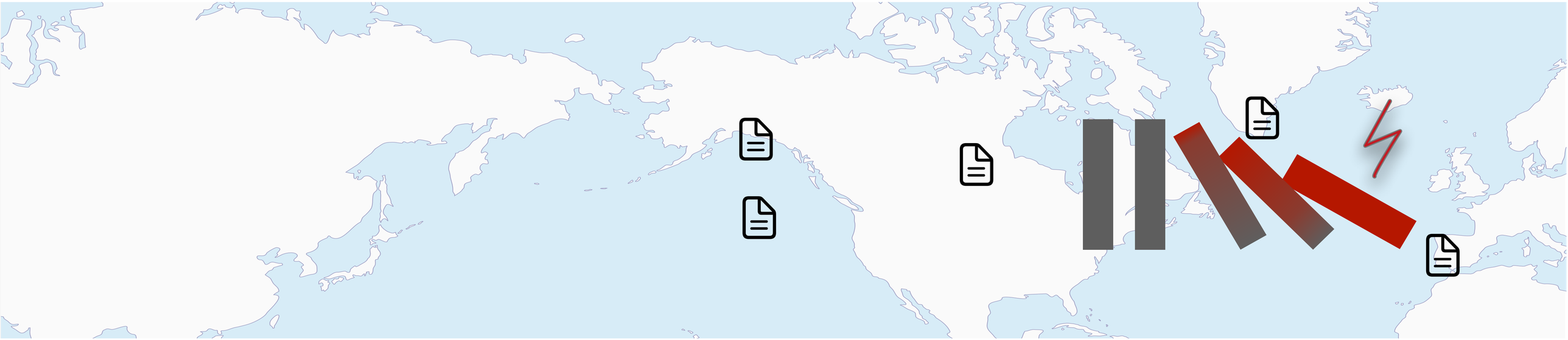

Resilience ⇔ withstanding all failure types and combinations

Why is it naïve to simplify partitions

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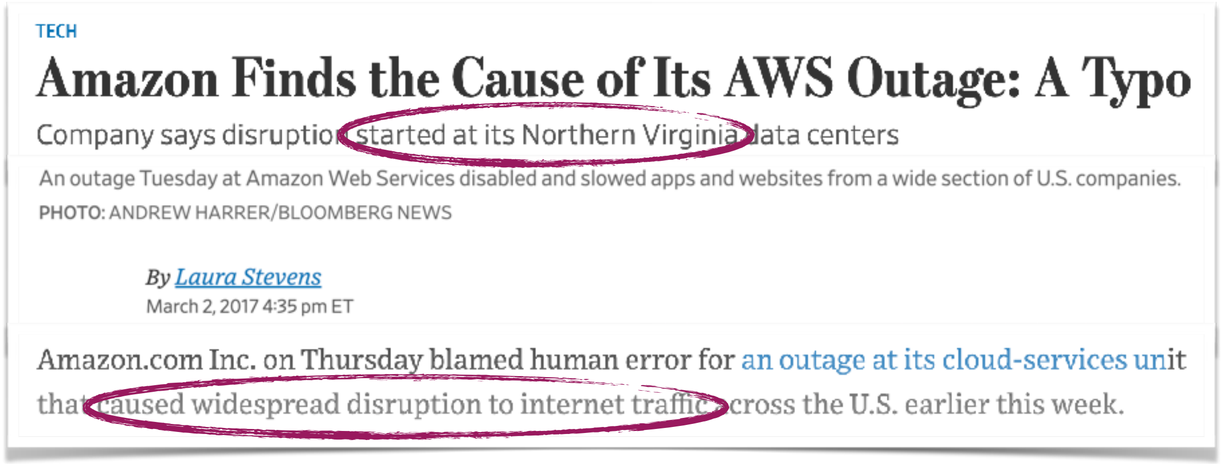

TECH

Amazon Finds the Cause of Its AWS Outage: A Typo

Company says disruption started at its Northern Virginia data centers

An outage Tuesday at Amazon Web Services disabled and slowed apps and websites from a wide section of U.S. companies.
PHOTO: ANDREW HARRER/BLOOMBERG NEWS

By Laura Stevens
March 2, 2017 4:35 pm ET

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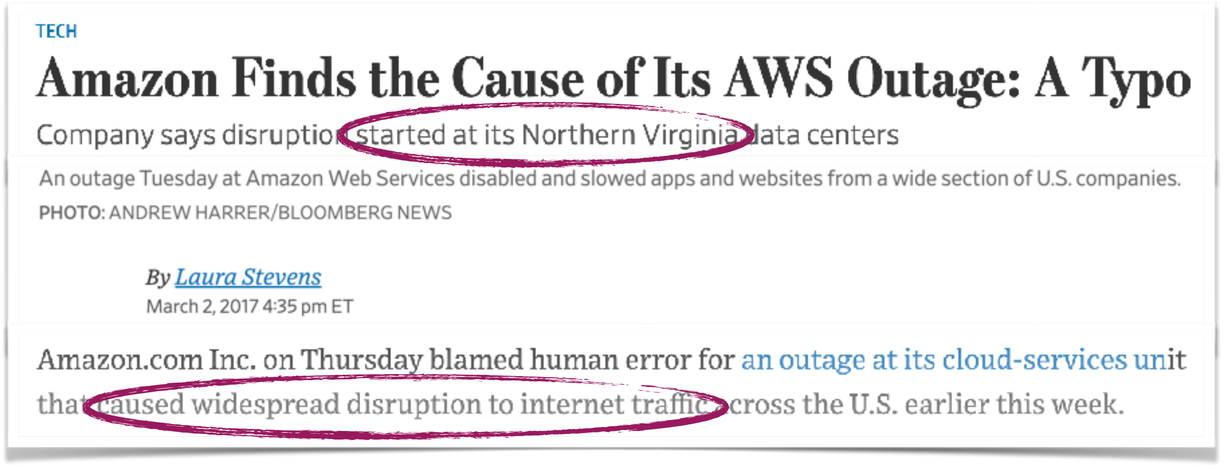

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A Byzantine failure in the real world

27/11/2020

Tom Lianza Chris Snook

An analysis of the Cloudflare API availability incident on 2020-11-02

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OSDI '18

Gray Failure: The Achilles' Heel of Cloud-Scale Systems

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HotOS '17

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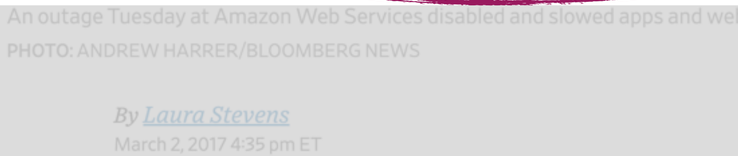

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Many real-world correlated failures in clouds

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Real-world correlated failures in blockchains

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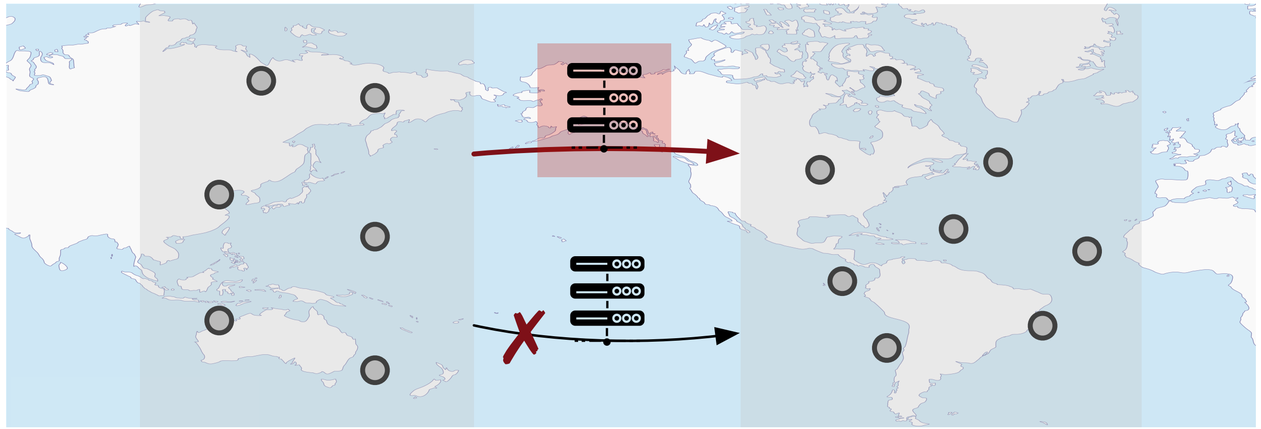

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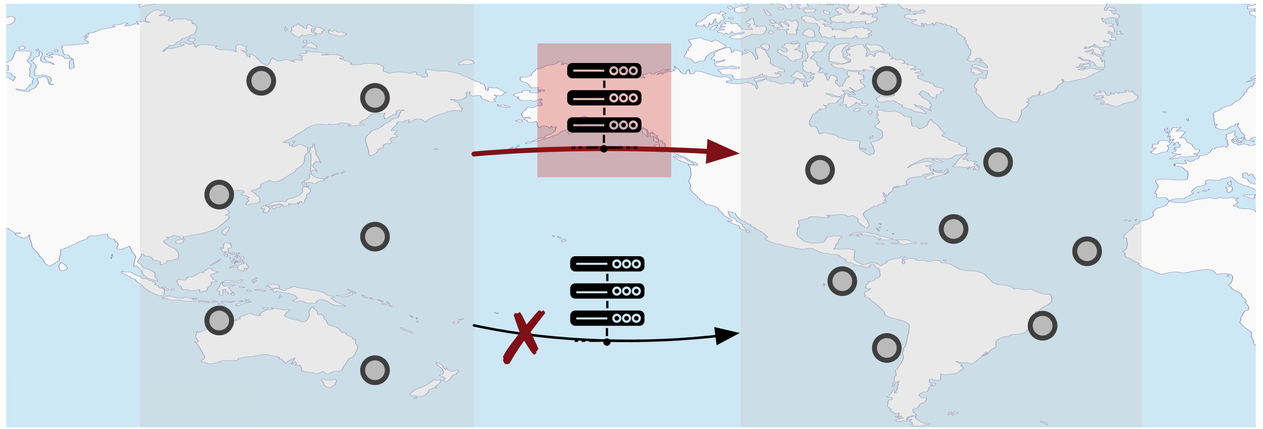

Hijacking Bitcoin: Routing Attacks on Cryptocurrencies

https://btc-hijack.ethz.ch

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Aviv Zohar
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Application-layer and network-layer defenses are critical for fortifying routing attacks.

BY YIKIN SUN, MARIA APOSTOLAKI, HENRY BIRGE-LEE, LAURENT VANBEVER, JENNIFER REXFORD, MUNG CHIANG, AND PRATEEK MITTAL

Securing Internet Applications from Routing Attacks

Routing attacks on consensus. Network-level adversaries can perform routing attacks on bitcoin to partition the set of nodes into two (or more) disjoint components.[2] Consequently, the attacks disrupt the ability of the entire network to reach consensus. The adversary must divert and cut *all* the connections connecting the various components together. To do so, the adversary can perform an interception attack by hijacking the IP prefixes of each component and selectively dropping the

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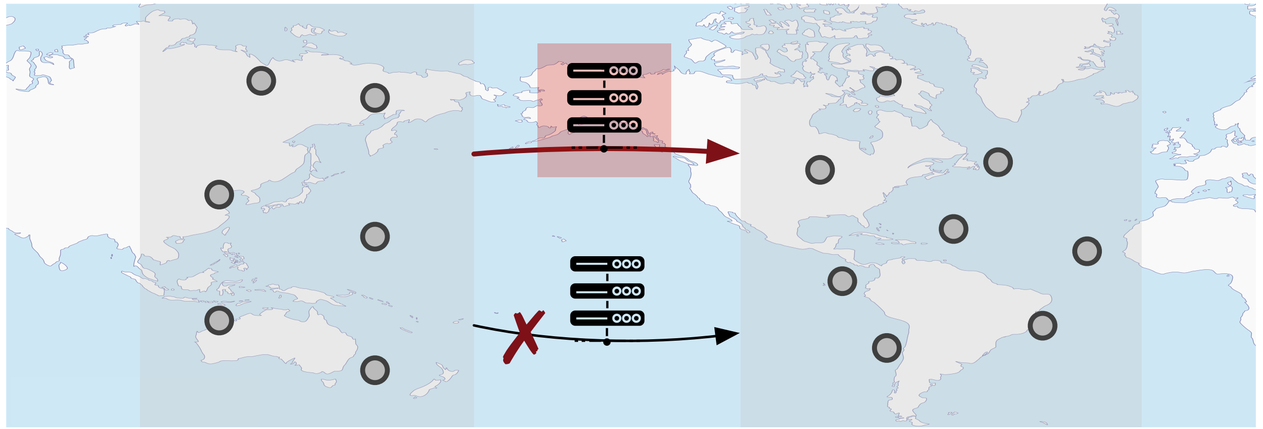

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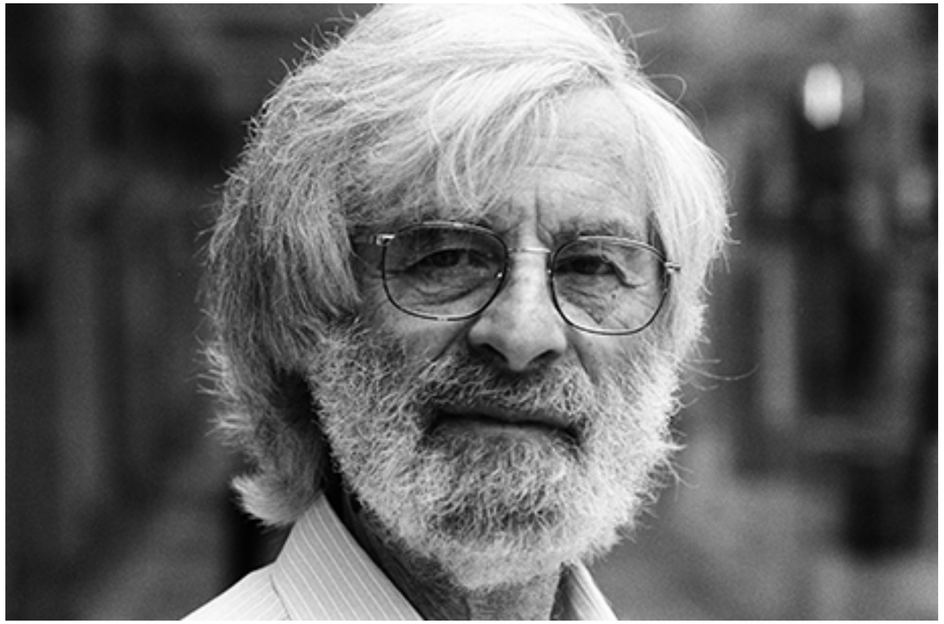
  - Censorship / validators offline ⇒ unavailability



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can render your own computer
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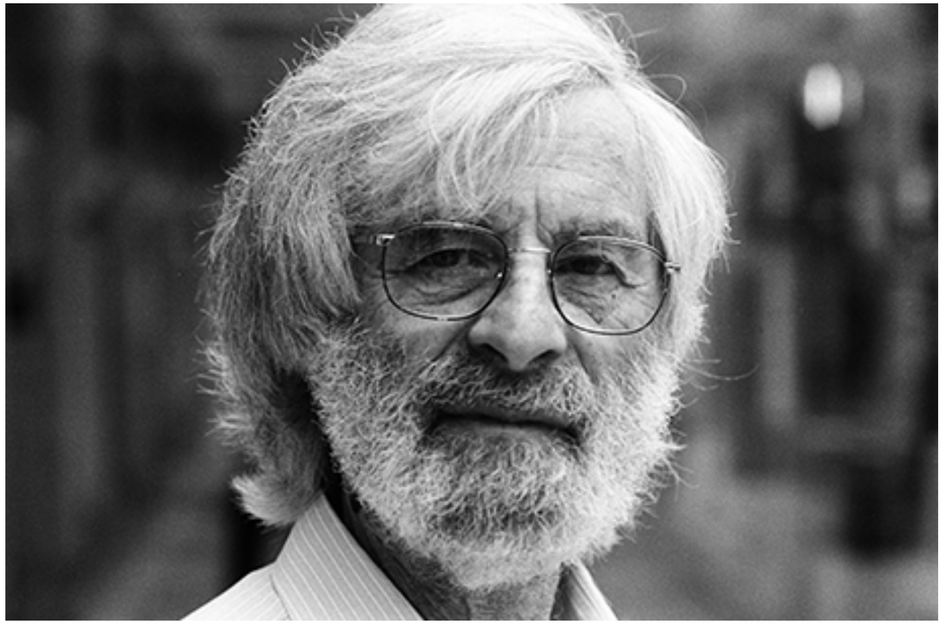

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Can we protect Alice’s access from distant failures, partitions and slowdowns?

Insight 1

Alice cares that the service is
available for her access, not globally

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Alice cares that the service is
available for her access, not globally

Limit exposure:
local accesses have no global dependencies

Resilient strongly-consistent coordination

Resilience to distant failures

Resilience to network asynchrony

Limit exposure

Resilient strongly-consistent coordination

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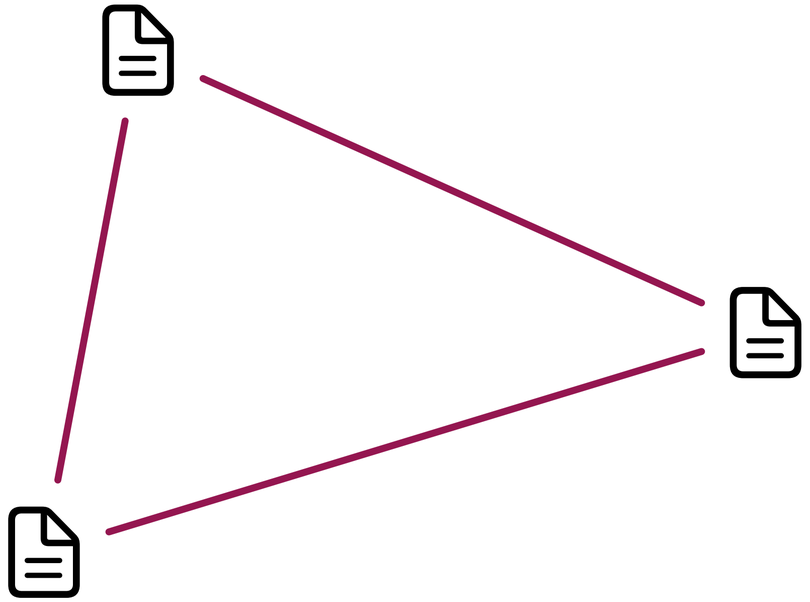
Challenge 2: Resilience despite asynchrony



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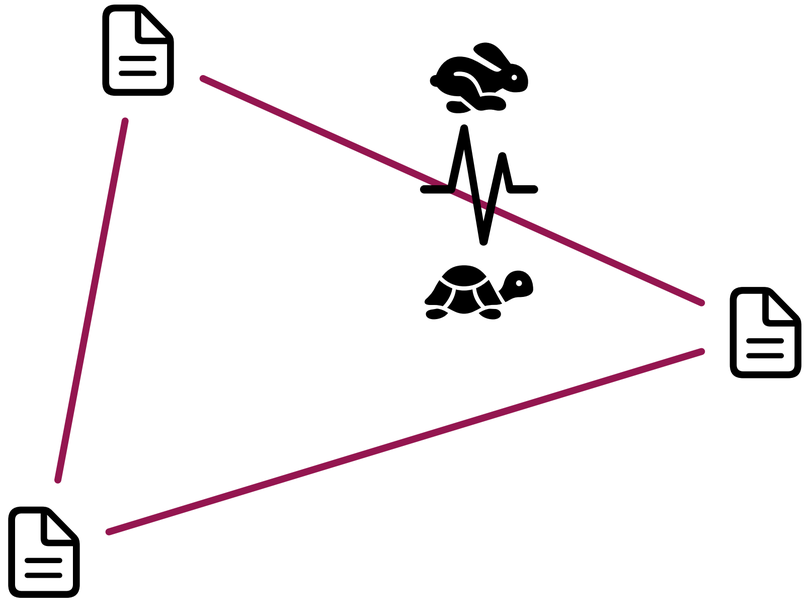

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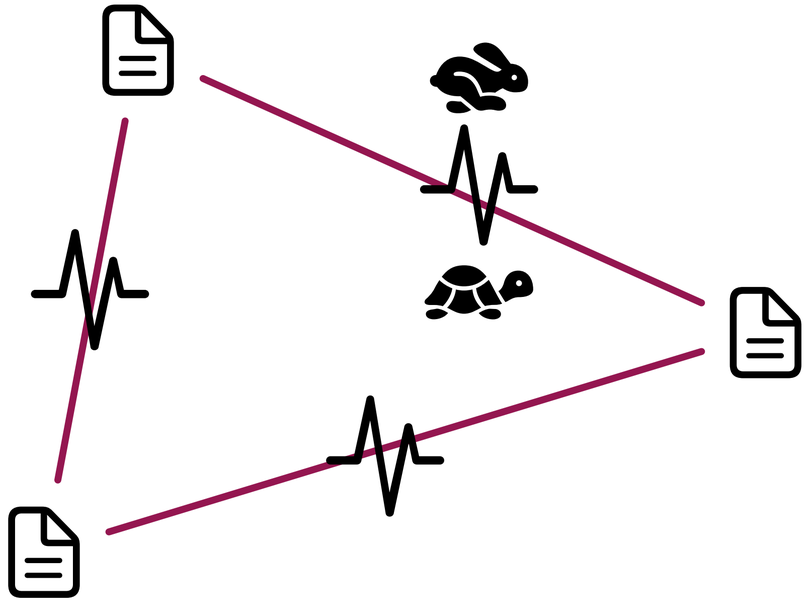

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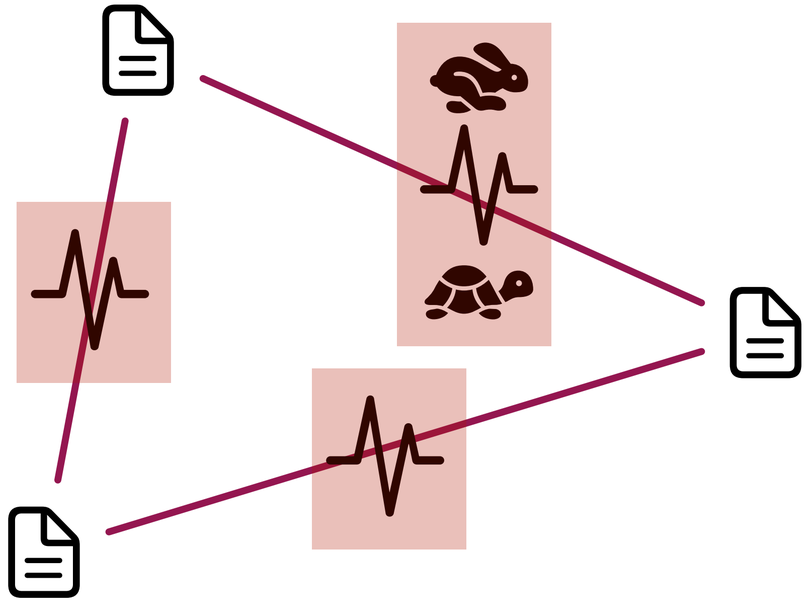

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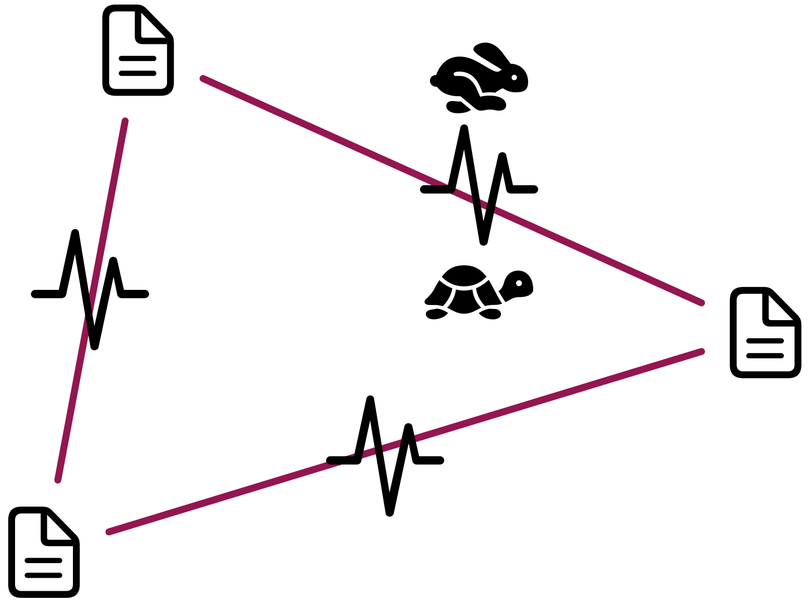

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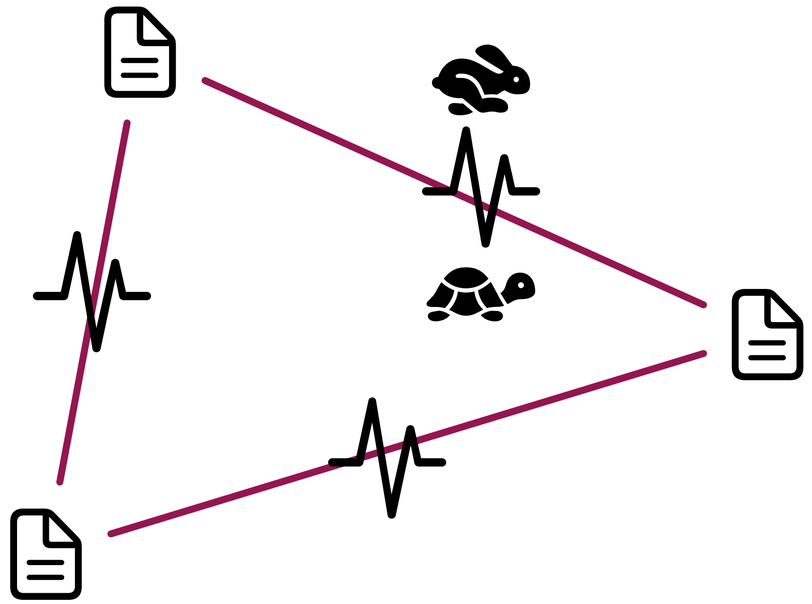

Asynchronous consensus is robust to asynchrony, but rarely deployed

Towards more practical asynchronous consensus

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Asynchronous consensus typically uses a common coin

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Why? **Asynchronous consensus requires randomness for progress (FLP*)**

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Are common coins necessary for asynchronous consensus?

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Insight 2

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Common coins not needed for asynchronous consensus (crash-fault setting)

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Though no asymptotic improvement

Open question: Byzantine setting

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First step towards more practical consensus

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Resilience to distant failures

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Limit exposure

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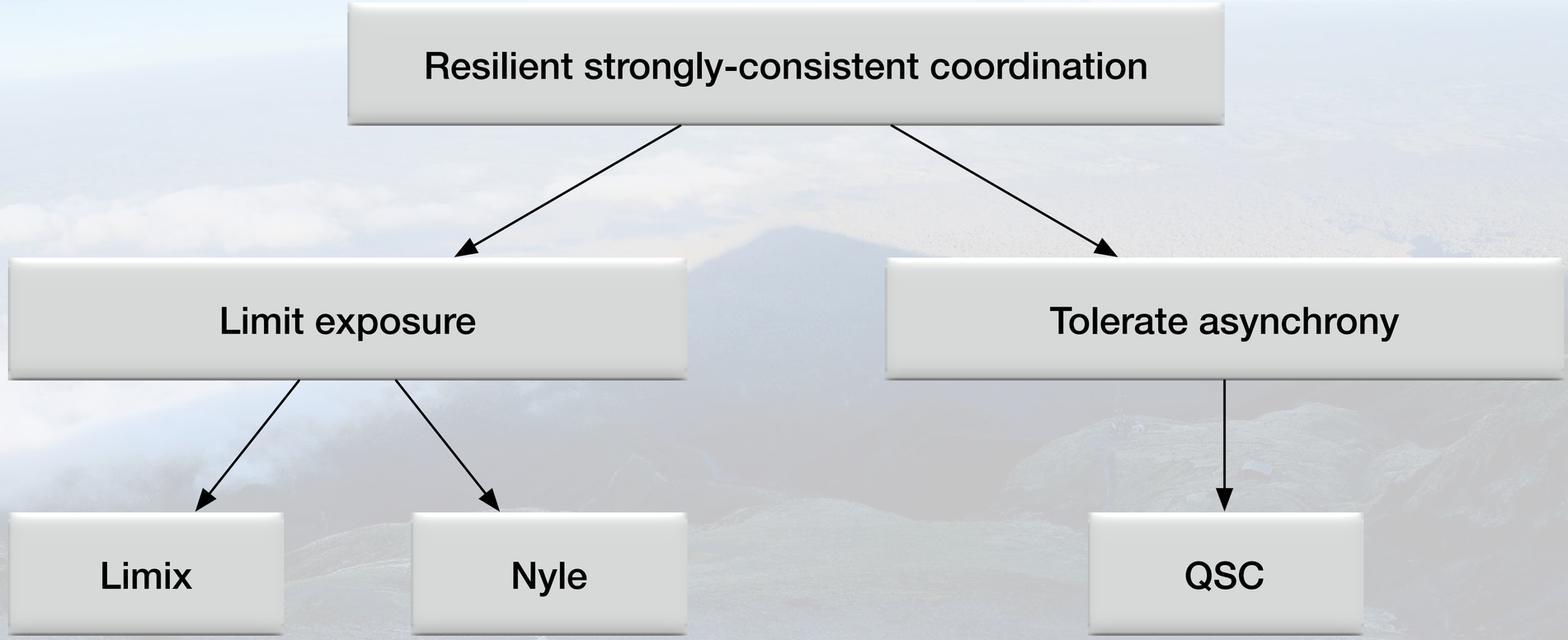
Common coin

Thesis roadmap



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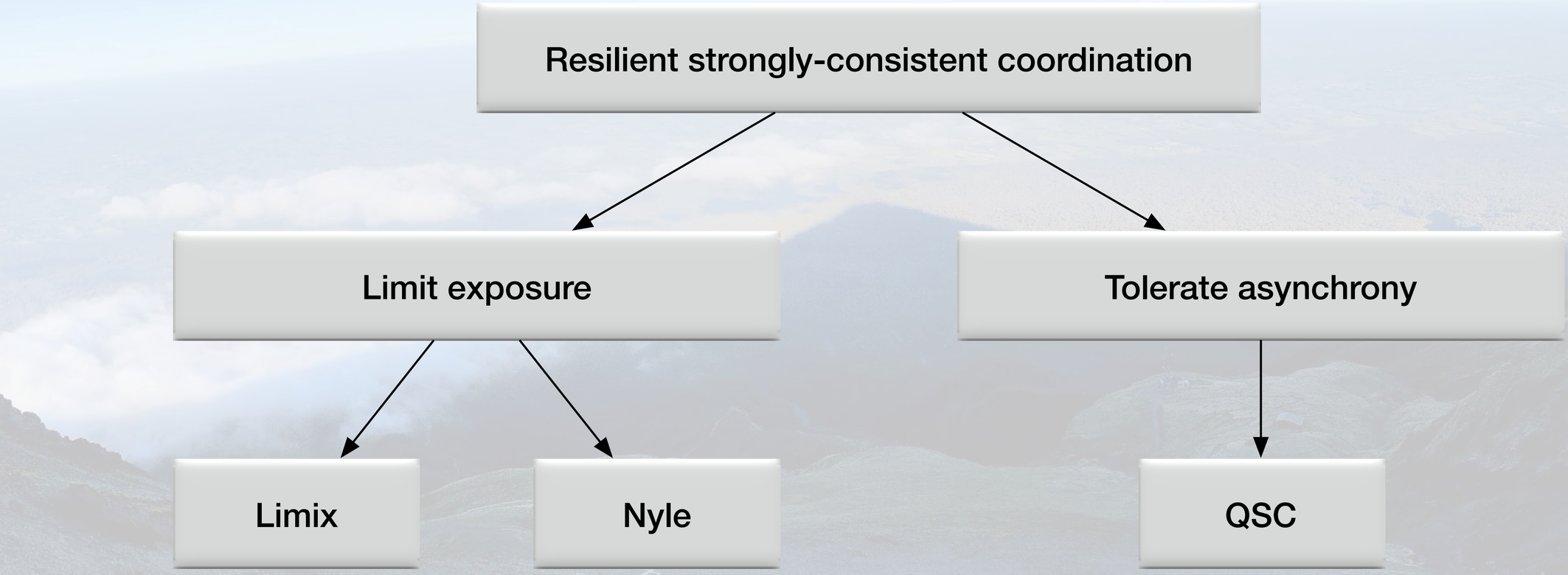
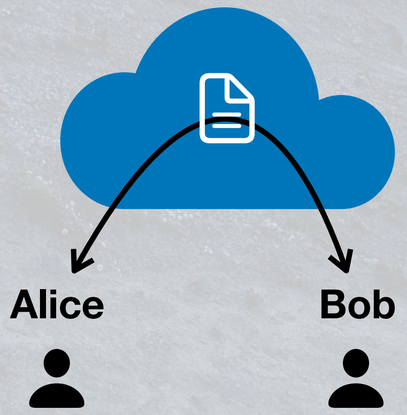




Thesis roadmap

Resilient strongly-consistent coordination

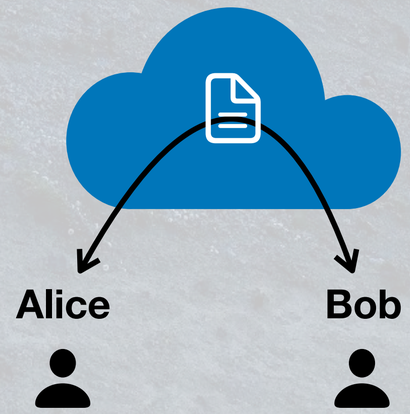
Limit exposure

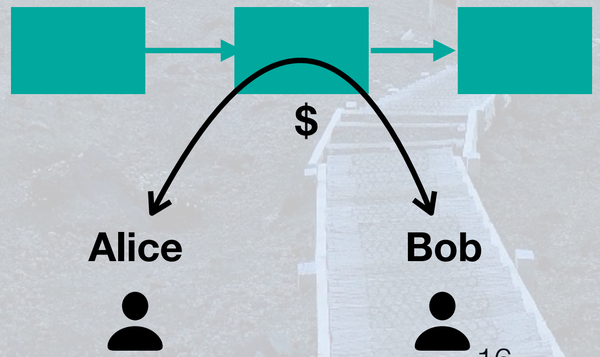
Tolerate asynchrony

Limix

Nyle

QSC





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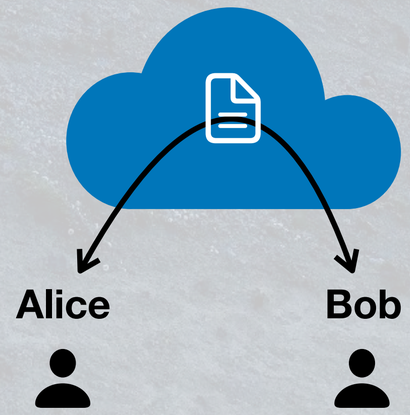

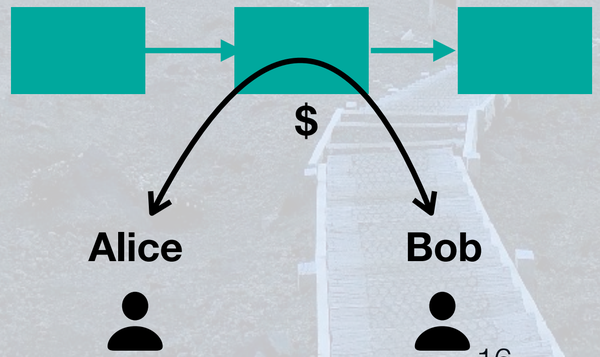

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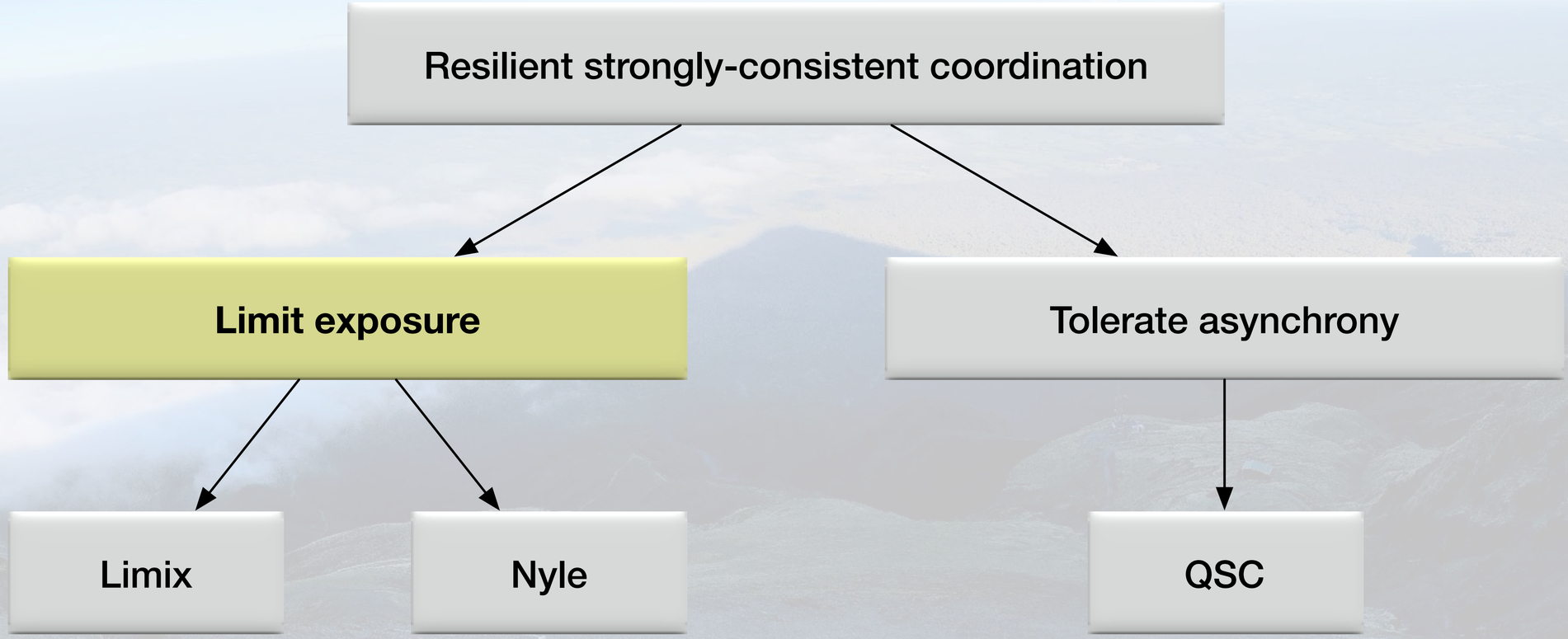
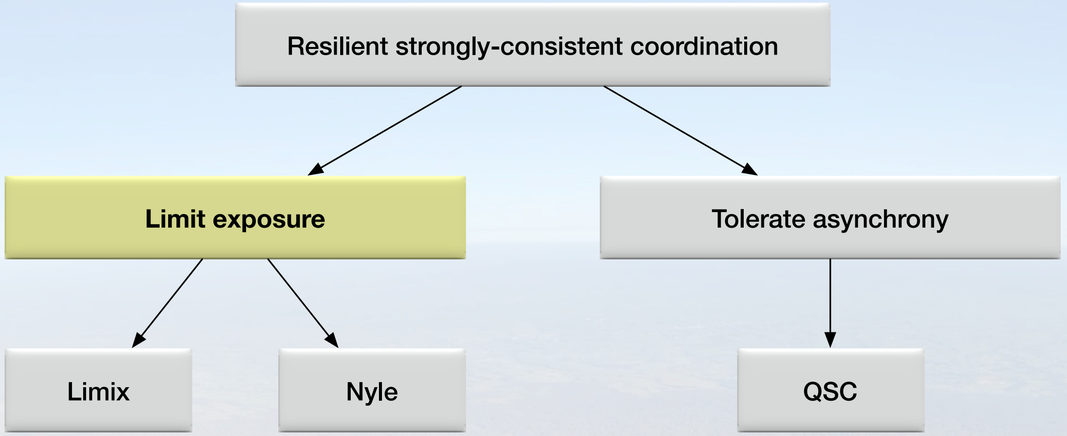
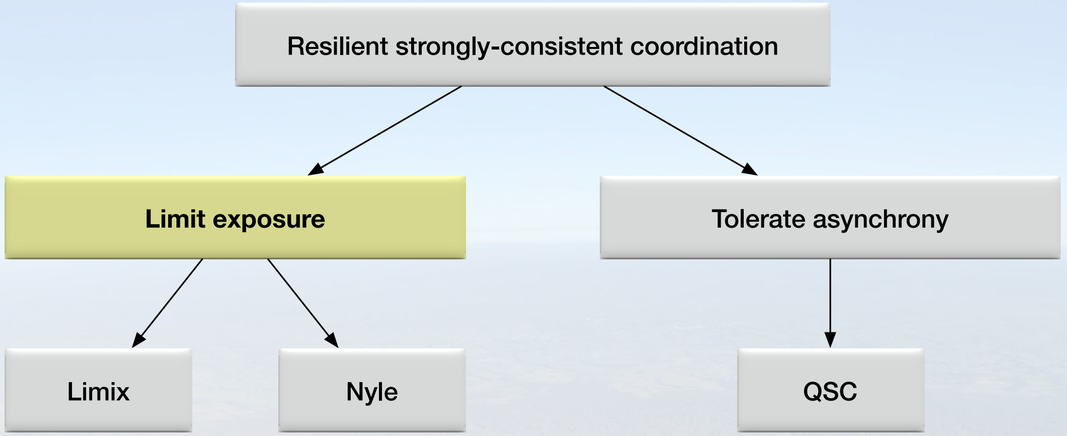


Limiting exposure roadmap



- Defining and measuring Lamport exposure
- Zoning: providing meaningful exposure guarantees
- Summary

Limiting exposure roadmap



- **Defining and measuring Lamport exposure**
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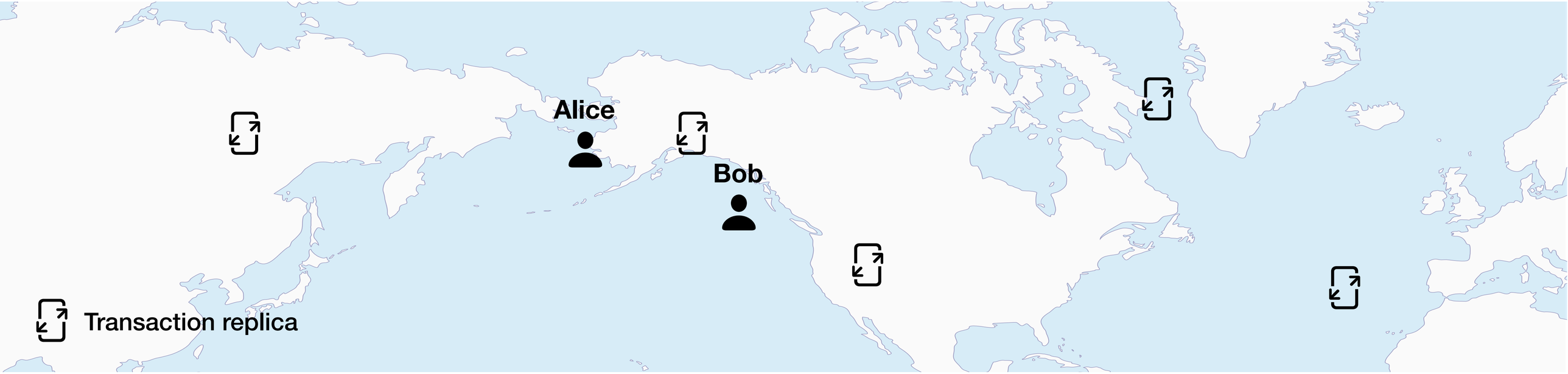
Defining Lamport exposure



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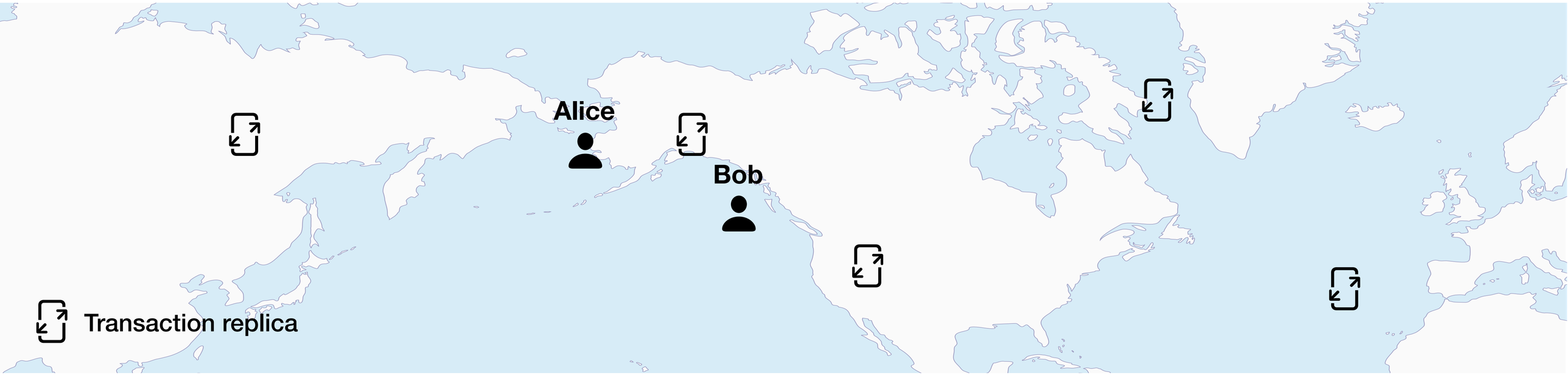
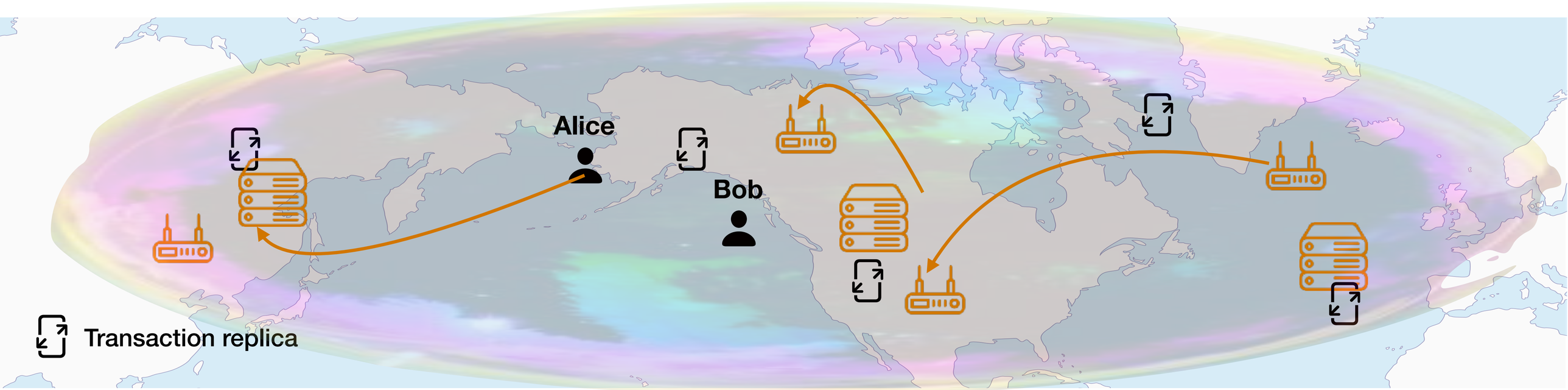


Lamport exposure for activity A of Alice
all distributed system components (servers, routers, network links, etc.)
whose failure **could** contribute to slowing or stopping activity A of a user.

Defining Lamport exposure



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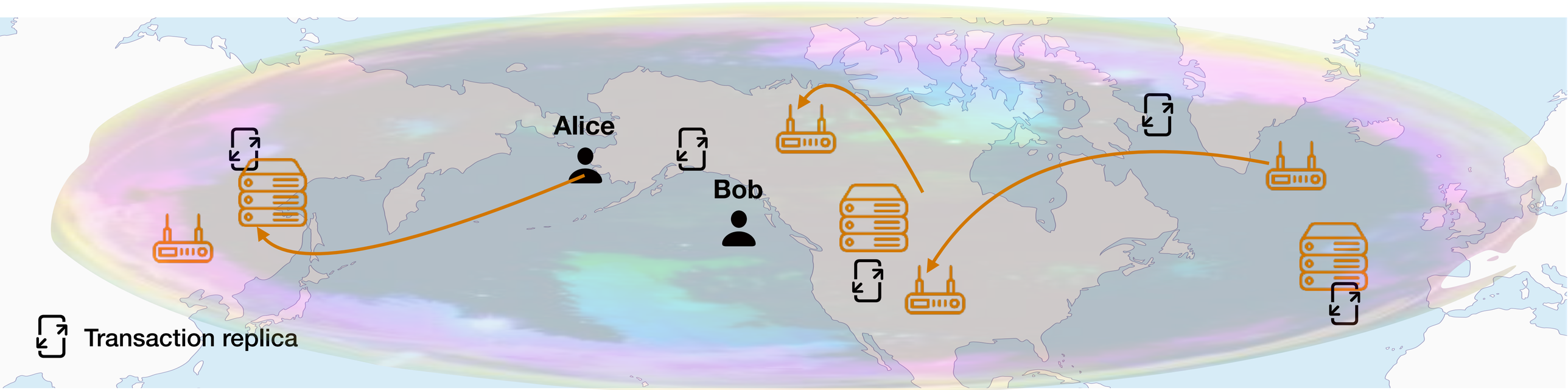

Lamport exposure for activity A of Alice
all distributed system components (servers, routers, network links, etc.)
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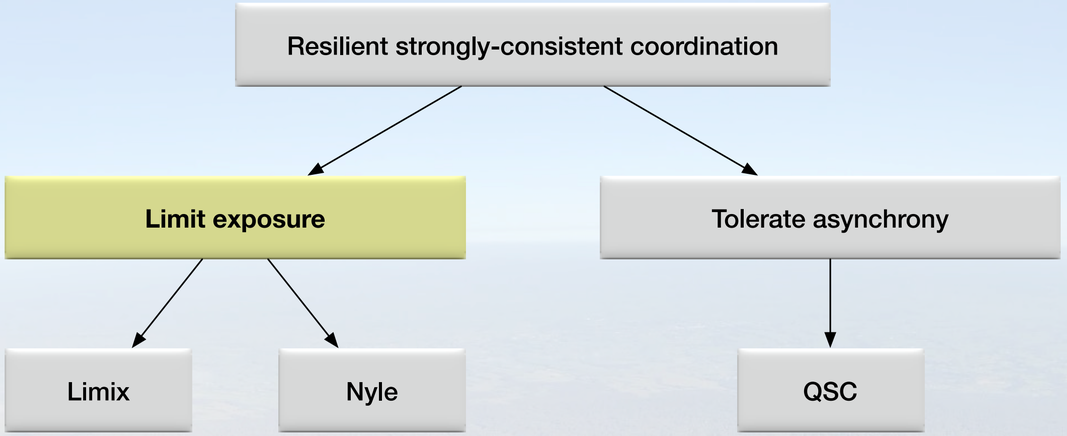
Global system: Lamport exposure is some global set the user is unaware of

Limiting exposure roadmap



- Defining and measuring Lamport exposure
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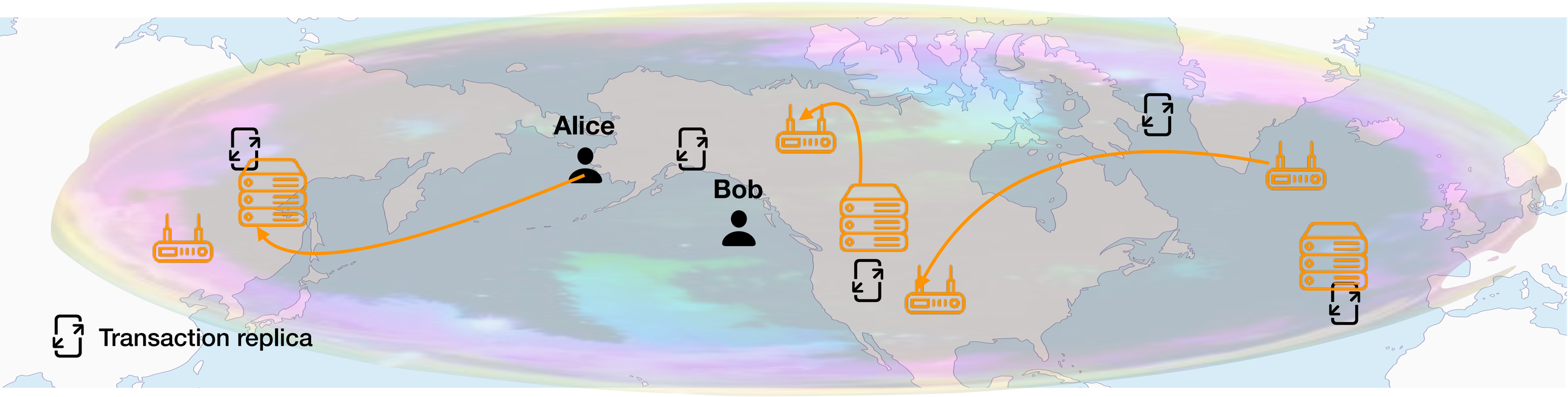
Limit exposure & preserve global manageability



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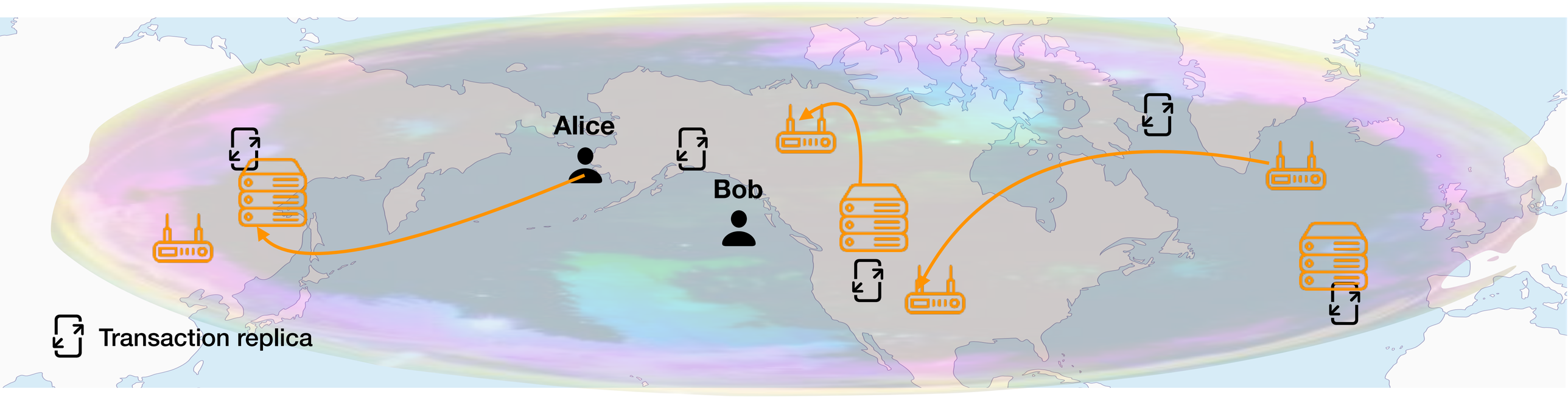

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Alice has a lower exposure as Bob gets closer

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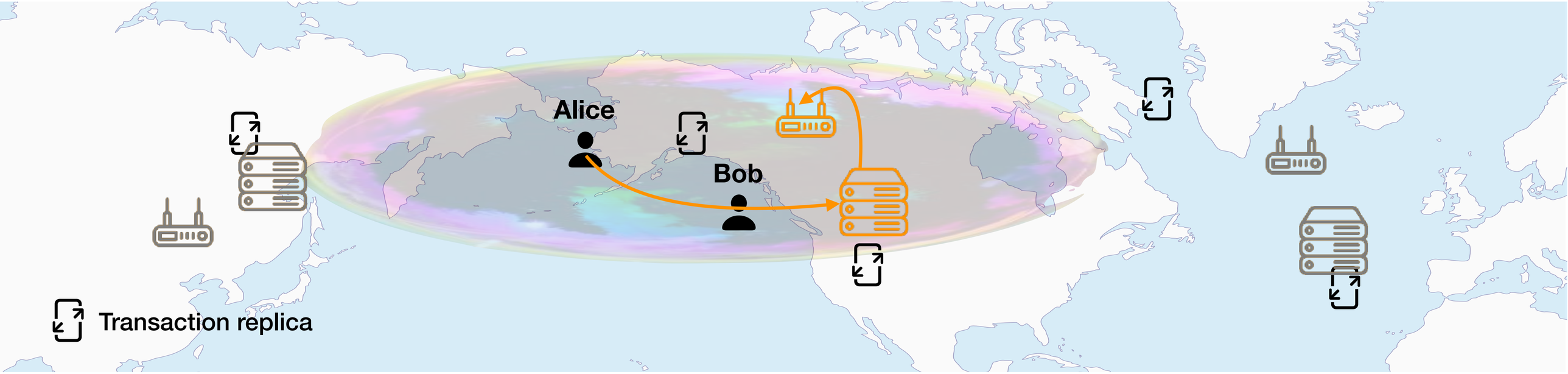

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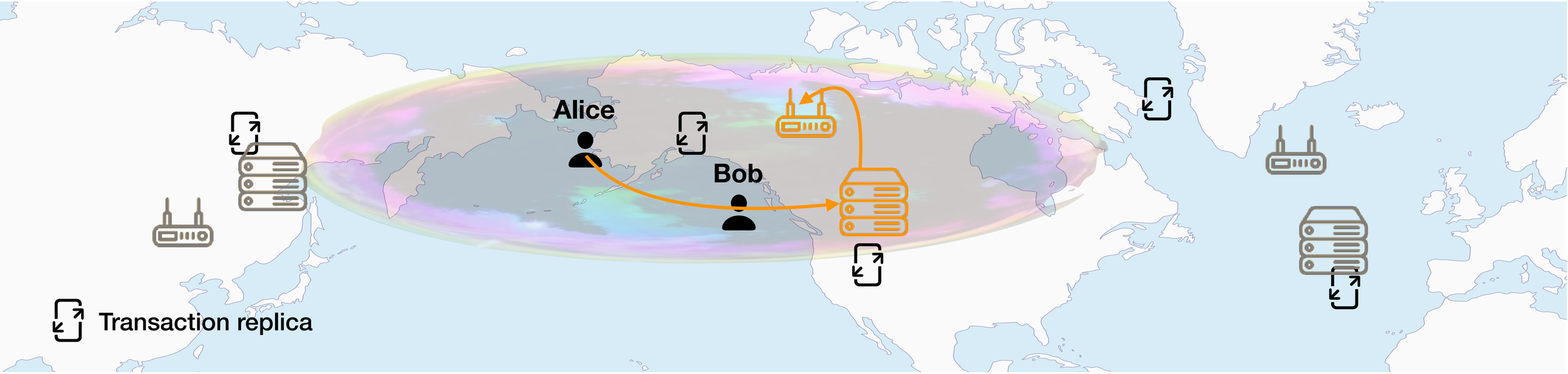

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Limiting exposure does not reduce durability

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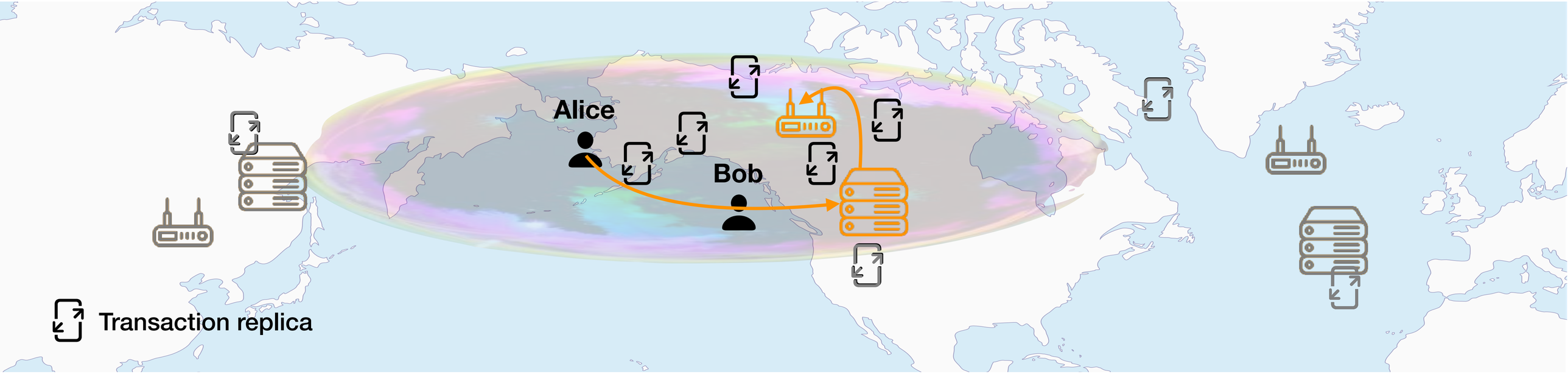

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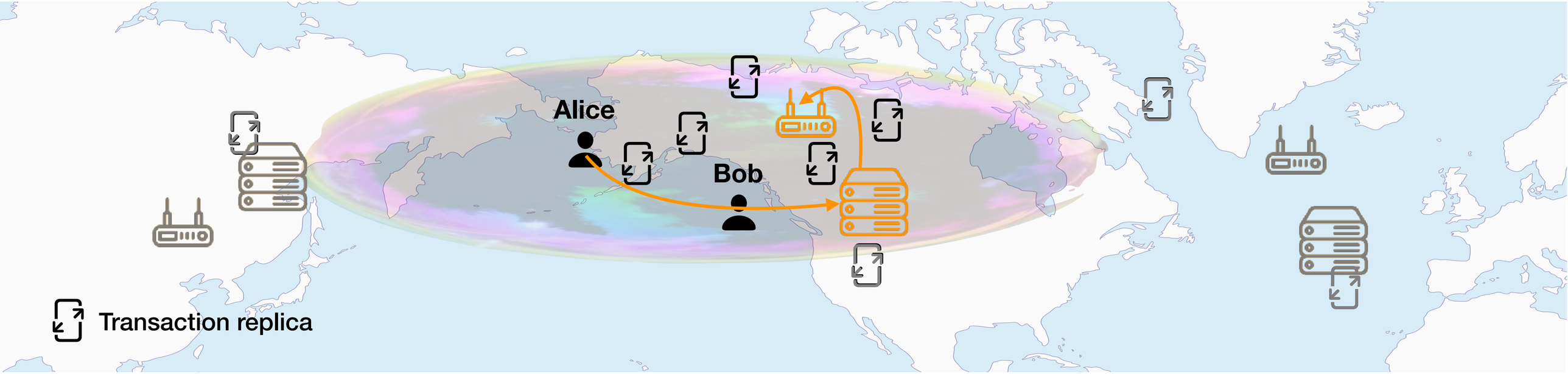

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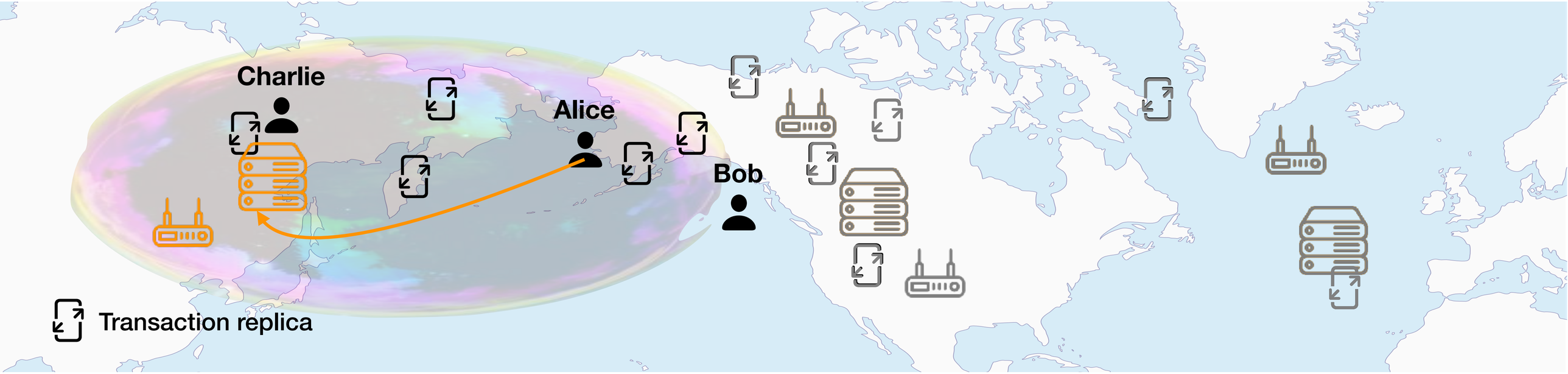

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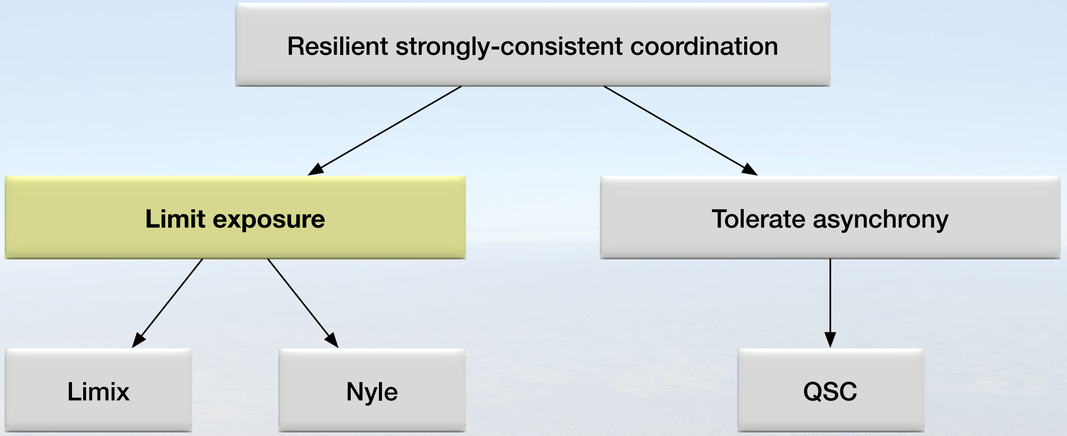
Limiting exposure roadmap



- Defining Lamport exposure
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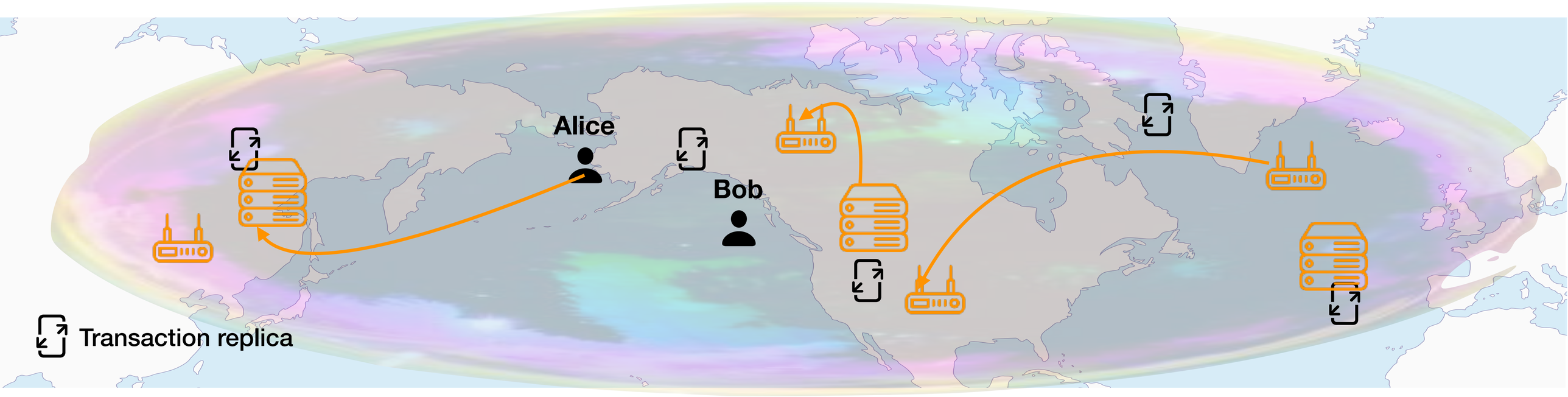
Strawman 1: localised infrastructure



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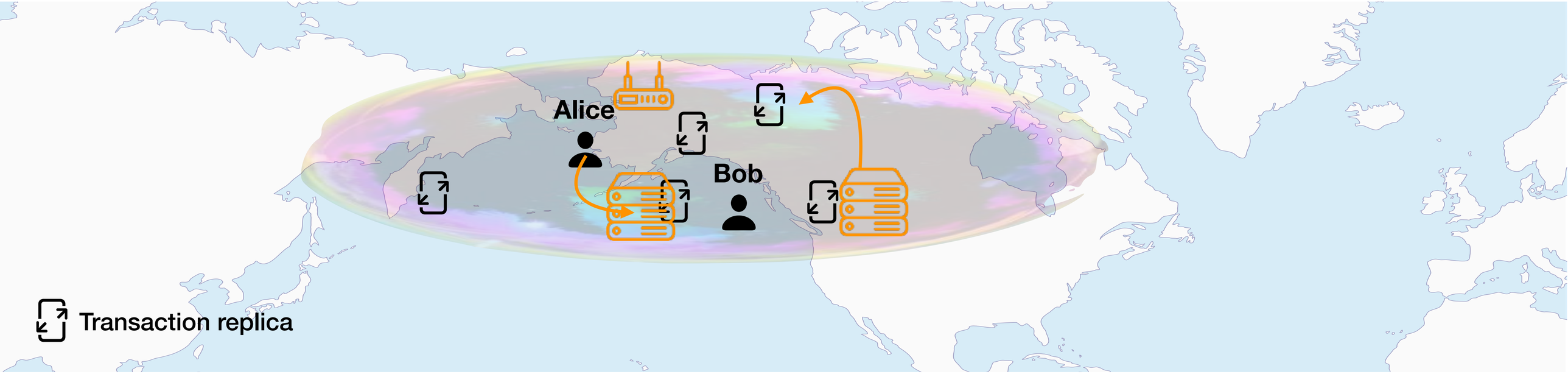

A localized deployment, e.g. local ledger, instead of globalised one

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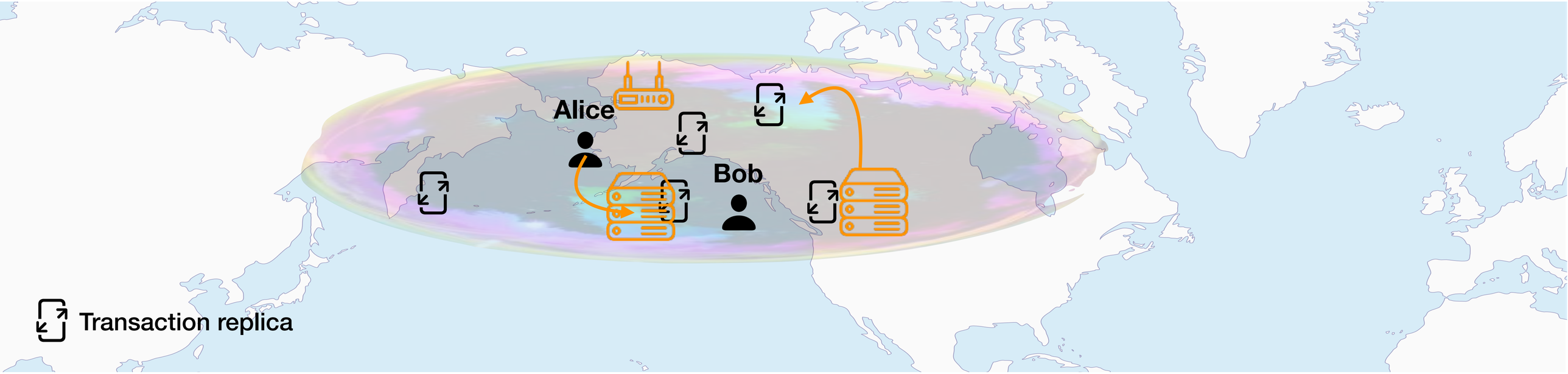

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✓ **Resilience: Lower exposure for local users**

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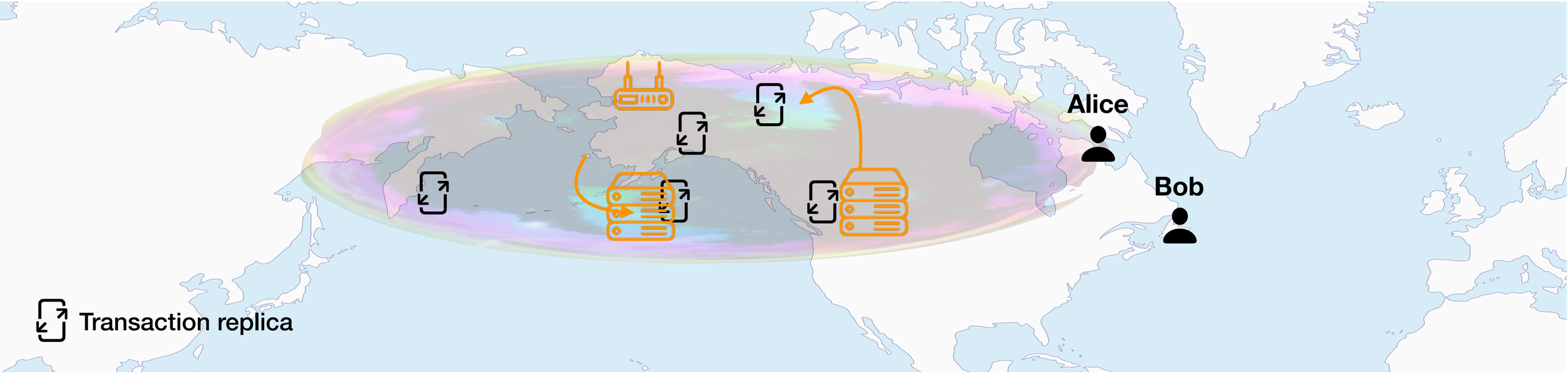

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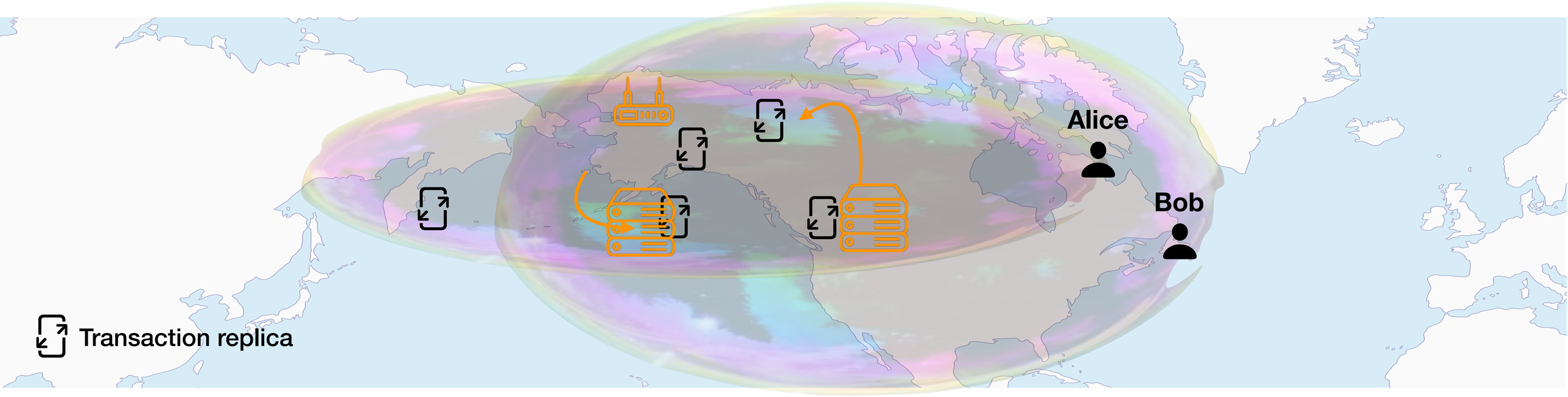

A localized deployment, e.g. local ledger, instead of globalised one

✓ **Resilience: Lower exposure for local users**

✗ **No global manageability: migrating users have remote dependencies**

Strawman 2: many zones

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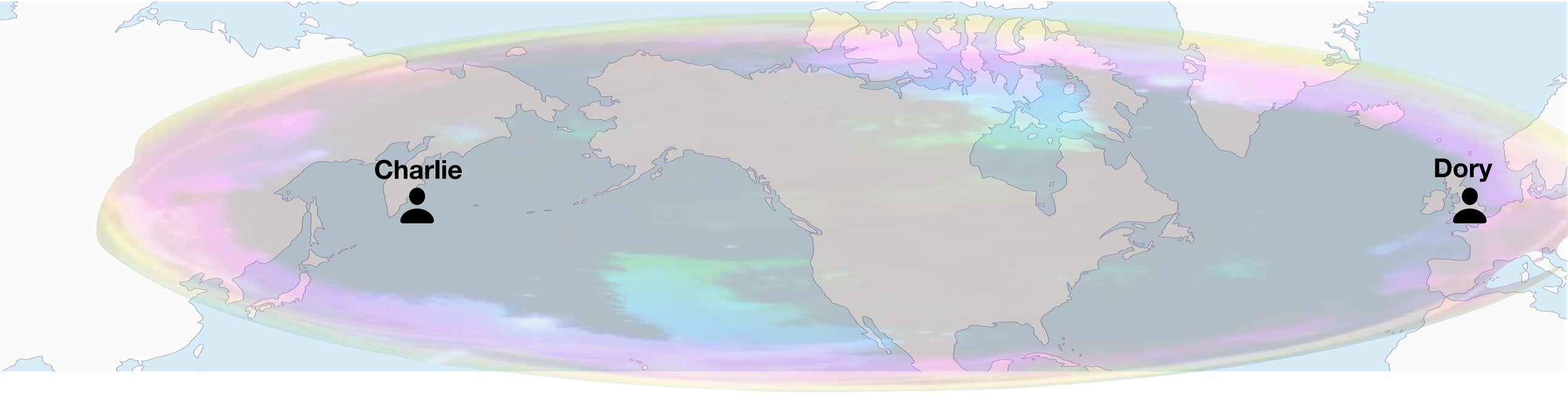

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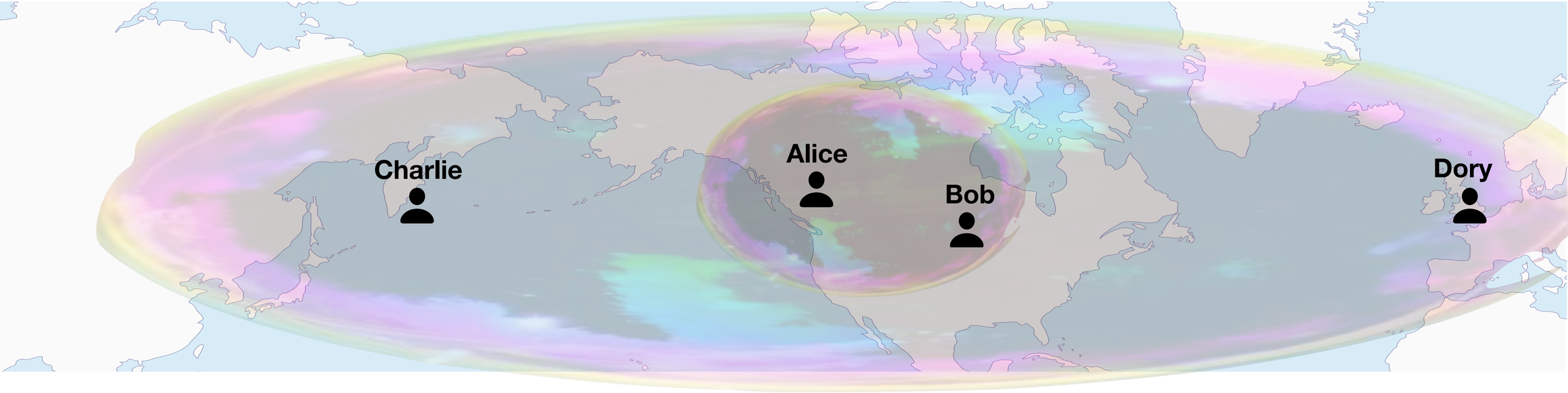

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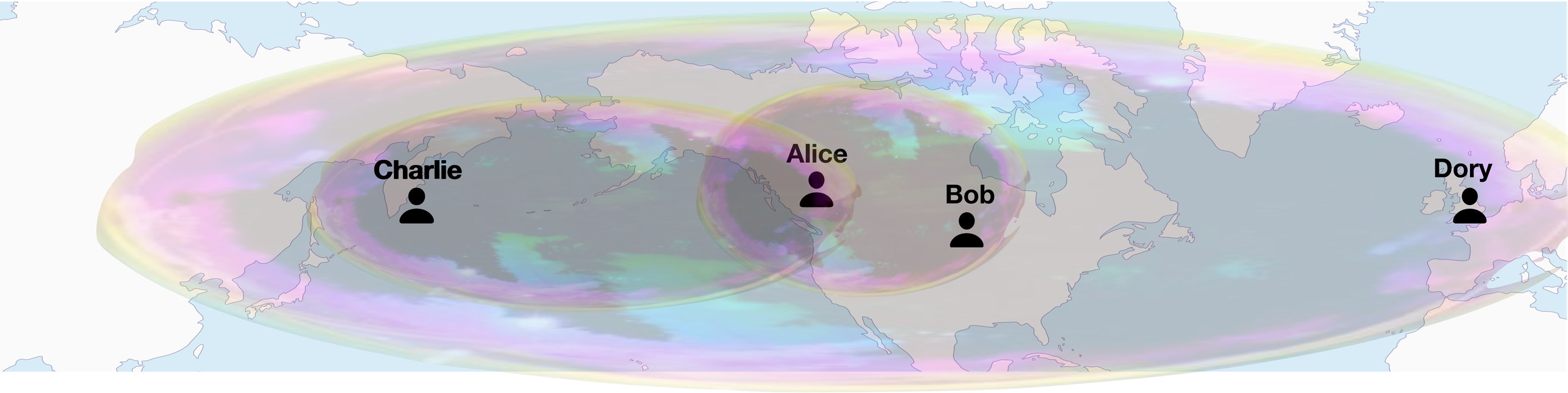

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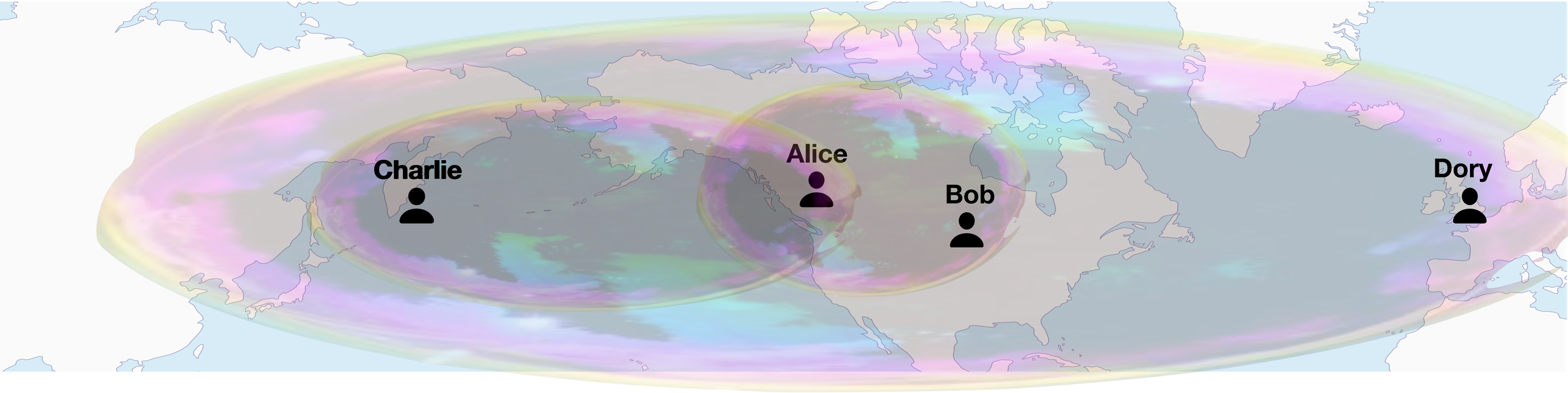
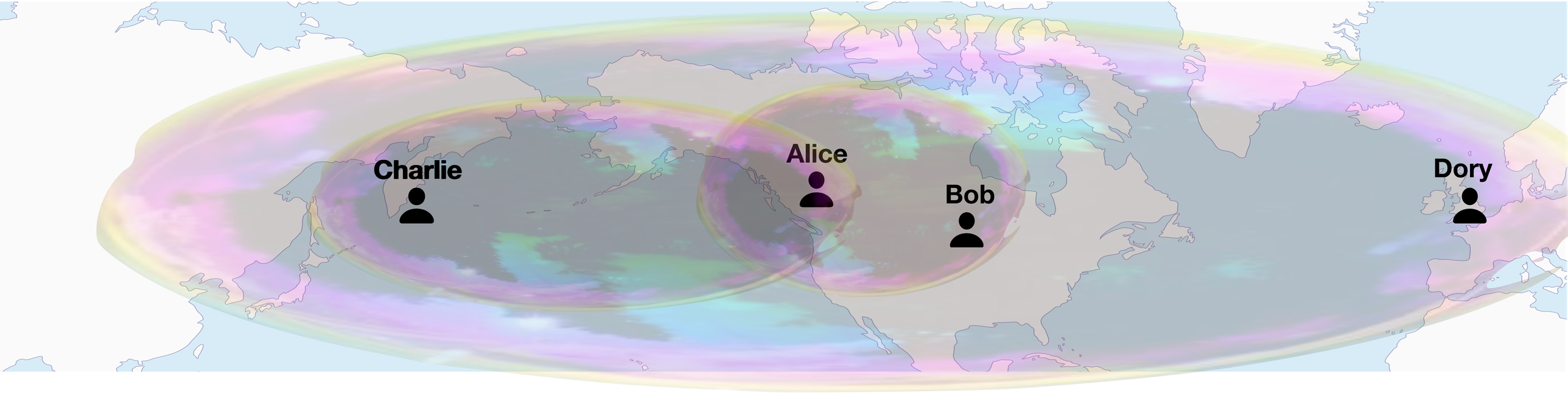


✓ **Resilience: shield users from failures outside the zone**

Strawman 2: many zones



✓ **Resilience**: shield users from failures outside the zone

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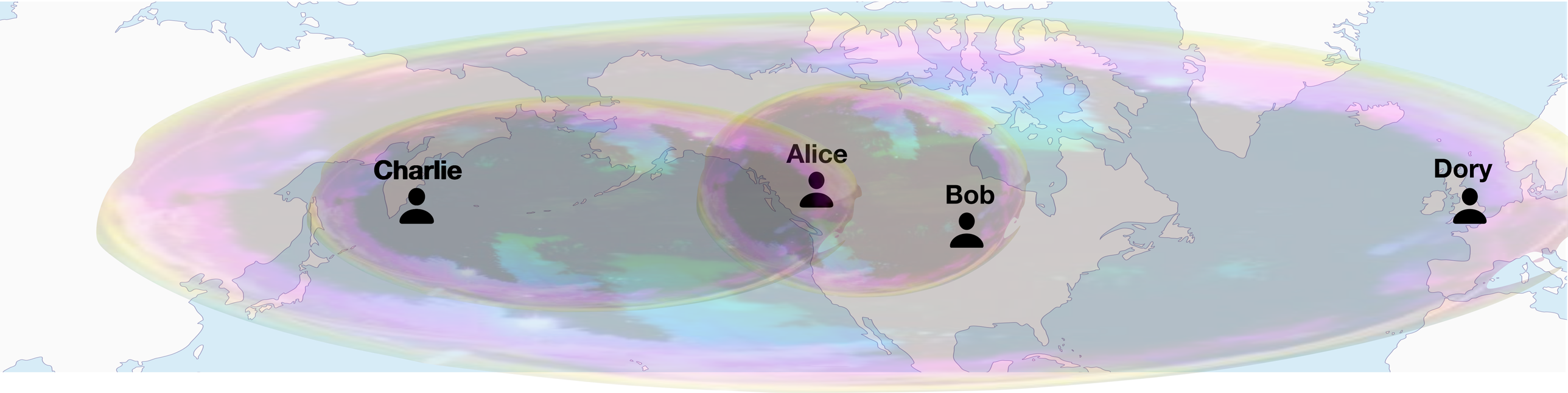


✓ **Resilience**: shield users from failures outside the zone

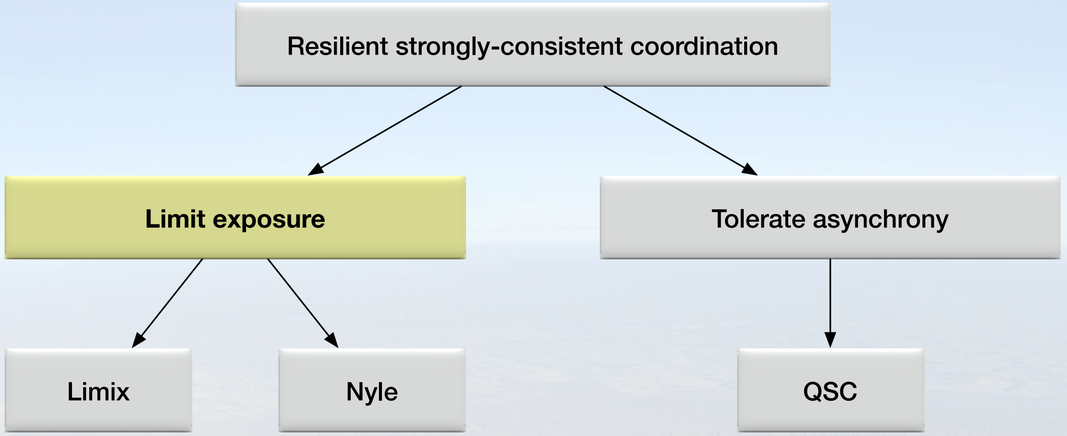
✓ **Global manageability**: dependencies follow usage pattern

✗ **Overhead**: replication inside each of the many zones

Insight

User interactions that the ledger aims to support determine the zoning policy

Limiting exposure roadmap



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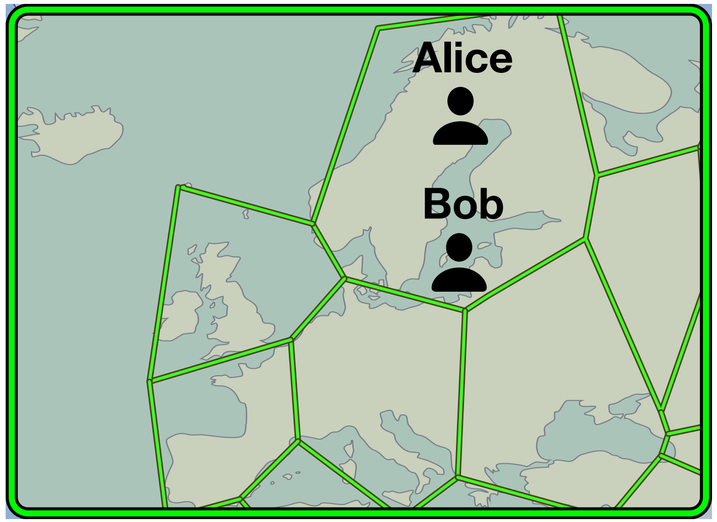
Jurisdiction-based zoning

- Administrative or legal boundaries (e.g., inside/outside the EU)
  Use case: data sovereignty, enforcing legal frameworks for transactions



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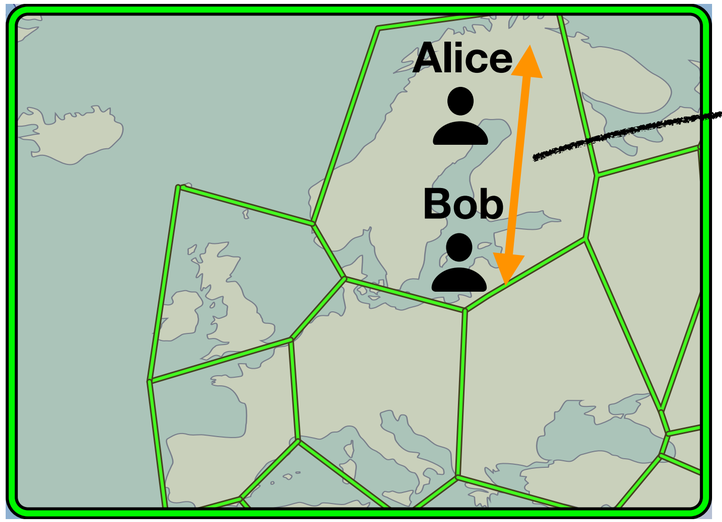

Measures **Alice's** Lamport exposure
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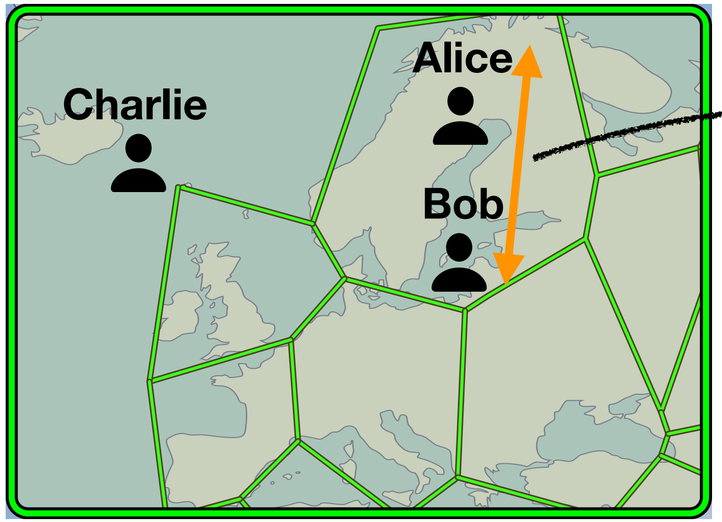

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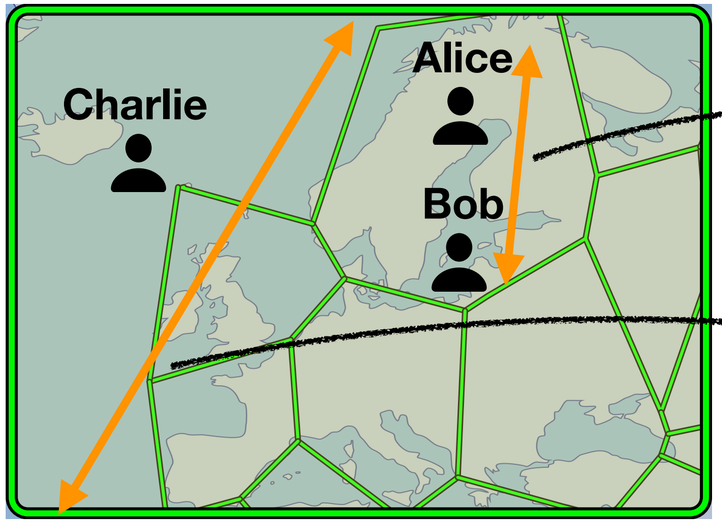

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Measures **Alice's** Lamport exposure
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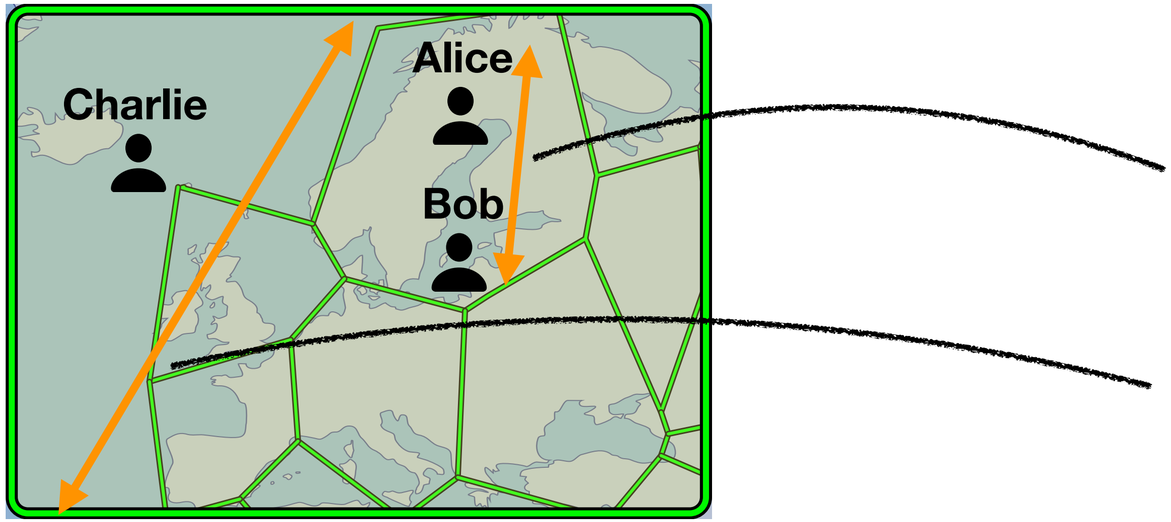
Jurisdiction-based zoning

- Administrative or legal boundaries (e.g., inside/outside the EU)
  Use case: data sovereignty, enforcing legal frameworks for transactions
- Can be used in a pay-as-you-go fashion



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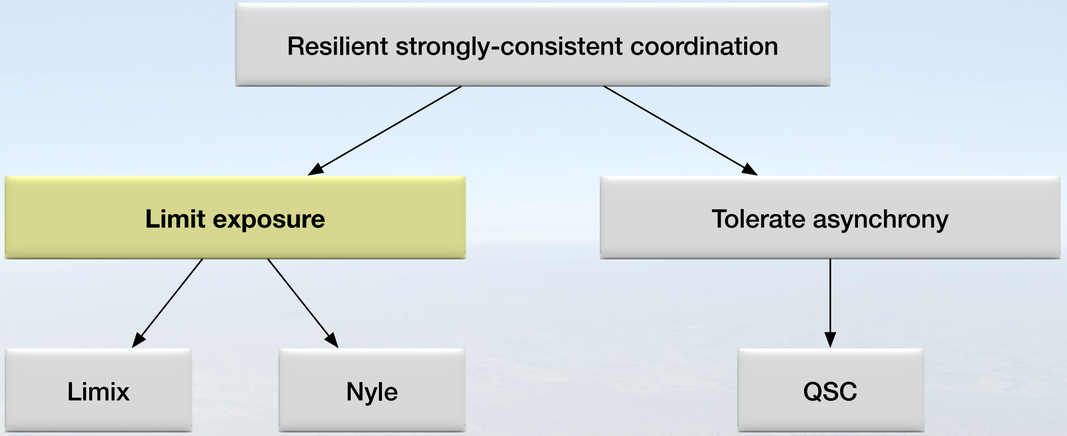
Limiting exposure roadmap



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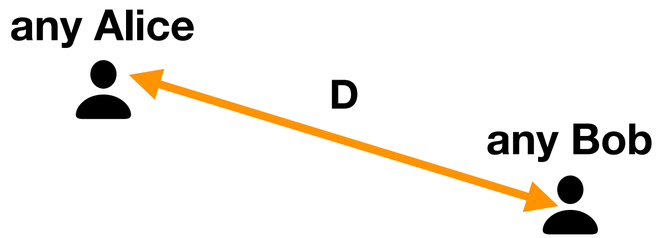
Metric-based zoning

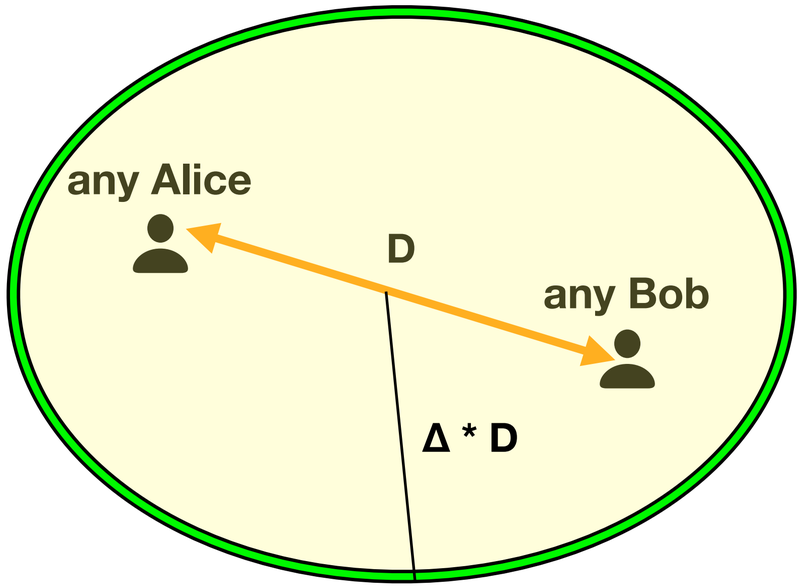
Metric-based zoning

- **Dynamic local and global interactions**



Metric-based zoning

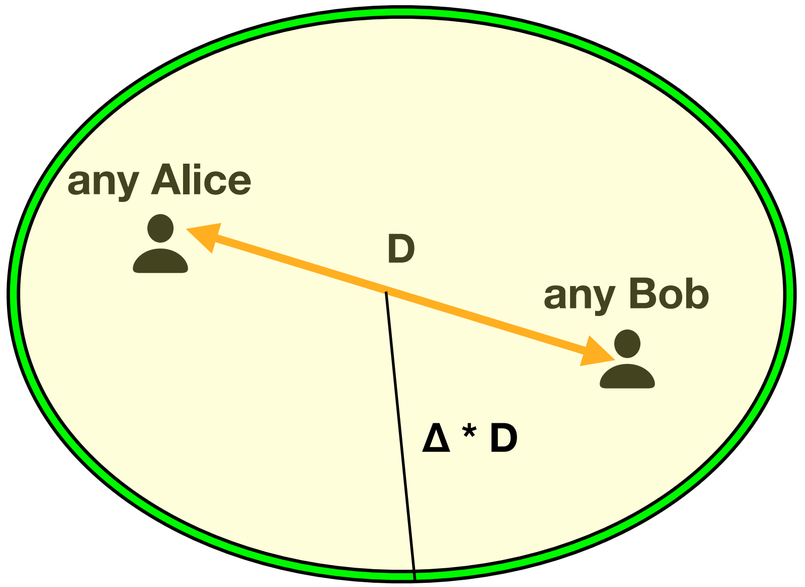
- **Dynamic local and global interactions**
  - Limit exposure to a small Δ around **any two users**



Metric-based zoning

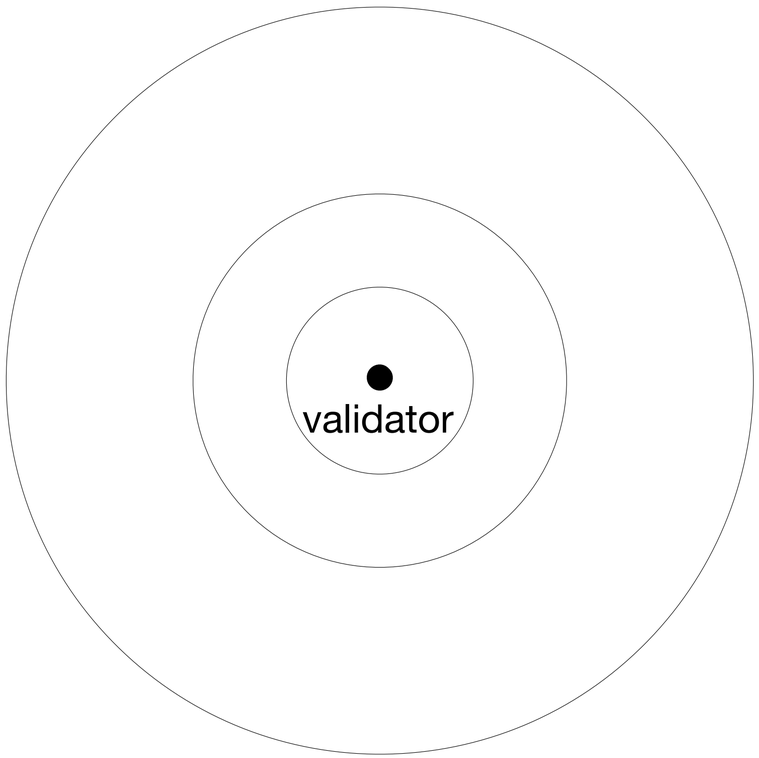
- **Dynamic local and global interactions**
  - Limit exposure to a small Δ around **any two users**

- **Metrics**
  - Round-trip time (RTT)
    Use case: low latency transactions
  - Geographic-straight line distance
    Use case: community-focused deployment
  - Network hop count
    Use case: paths with fewer hops are more resilient



Strawman

- Builds exponentially-increasing zones around each validator



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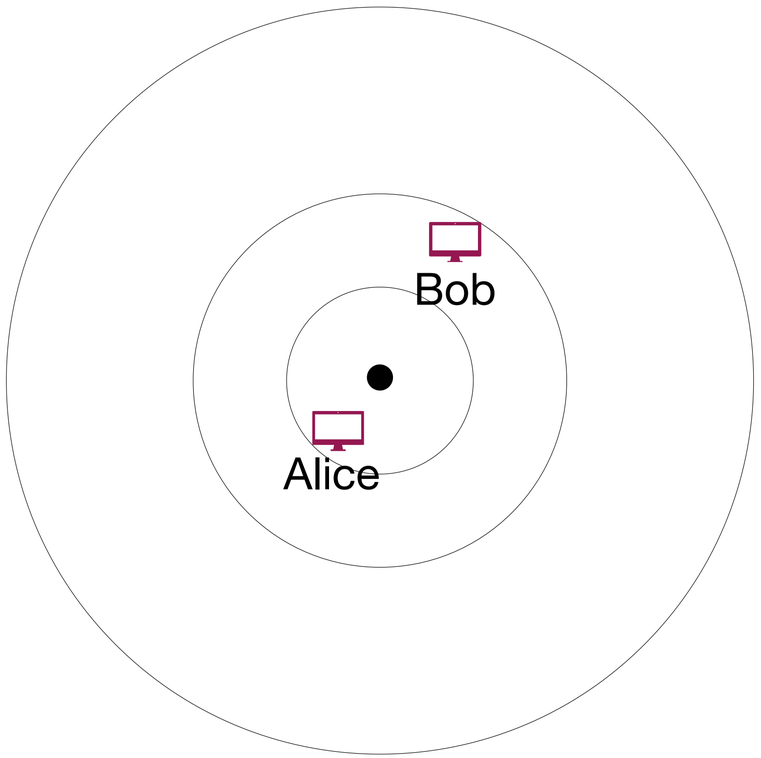

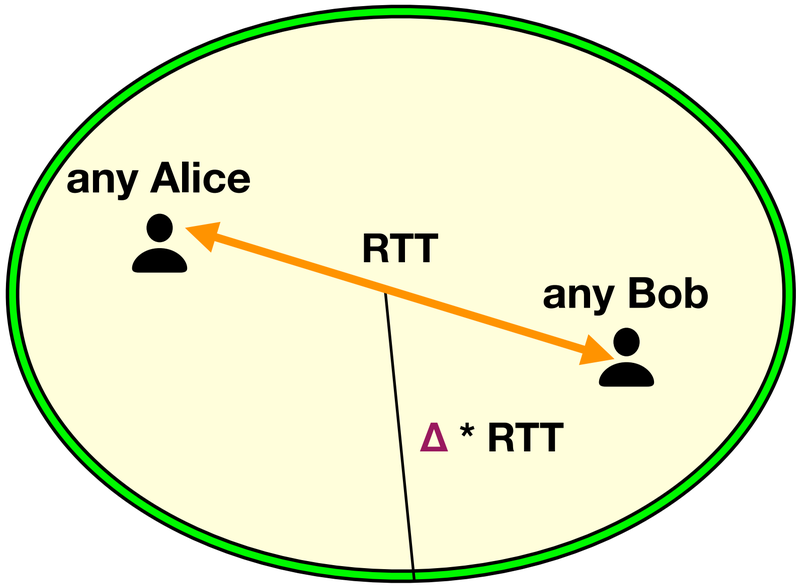

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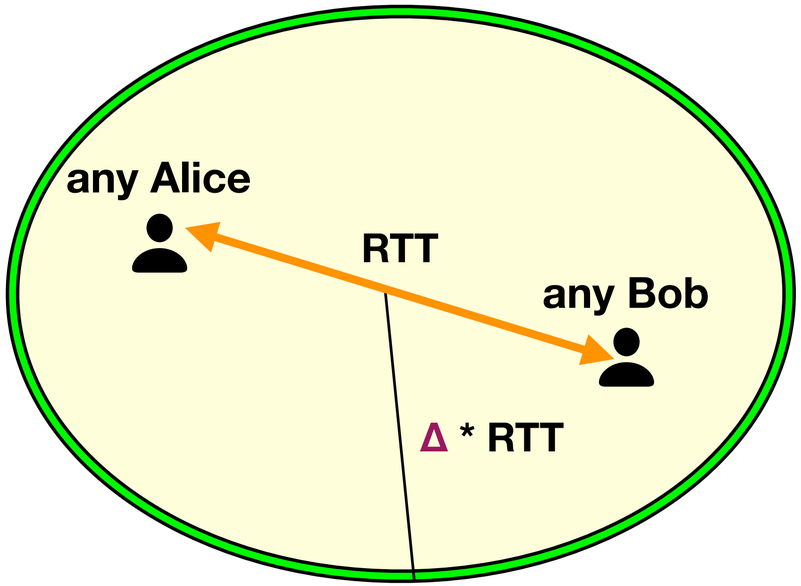

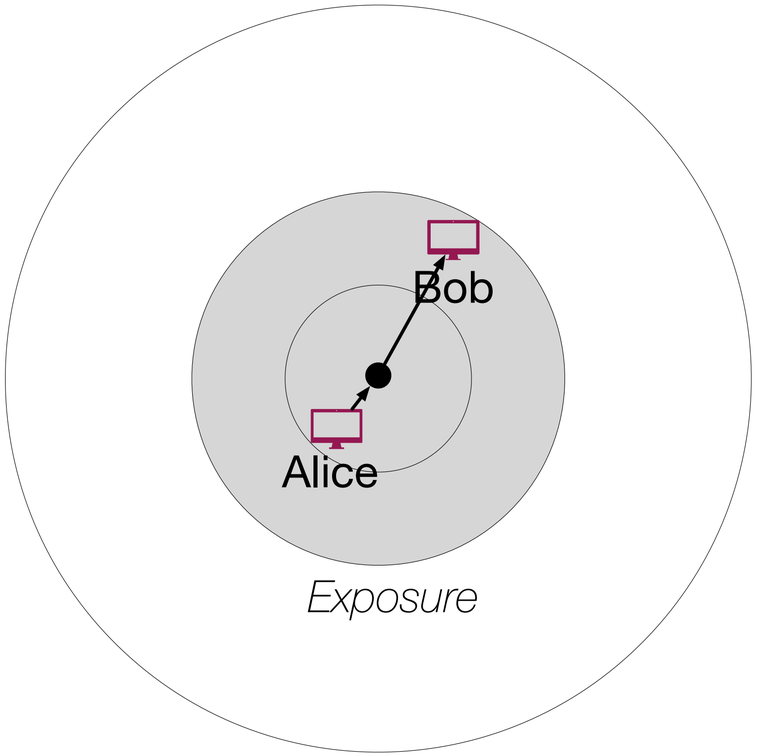

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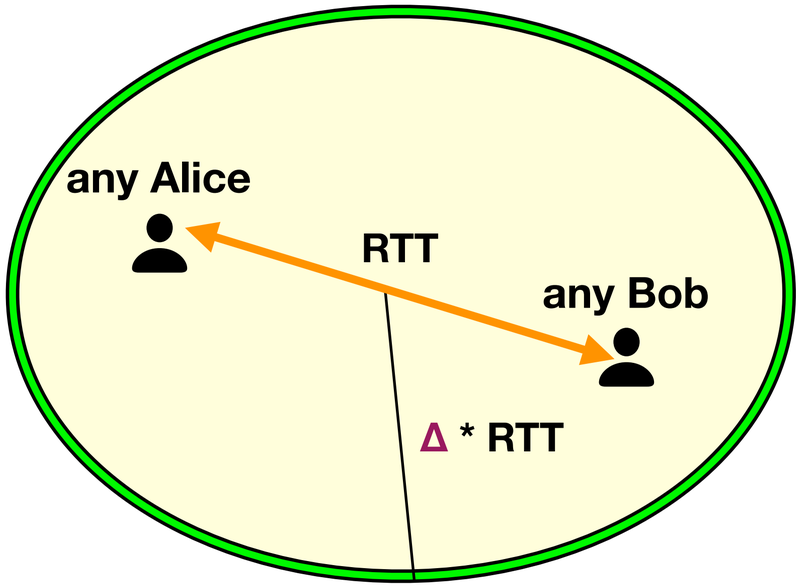

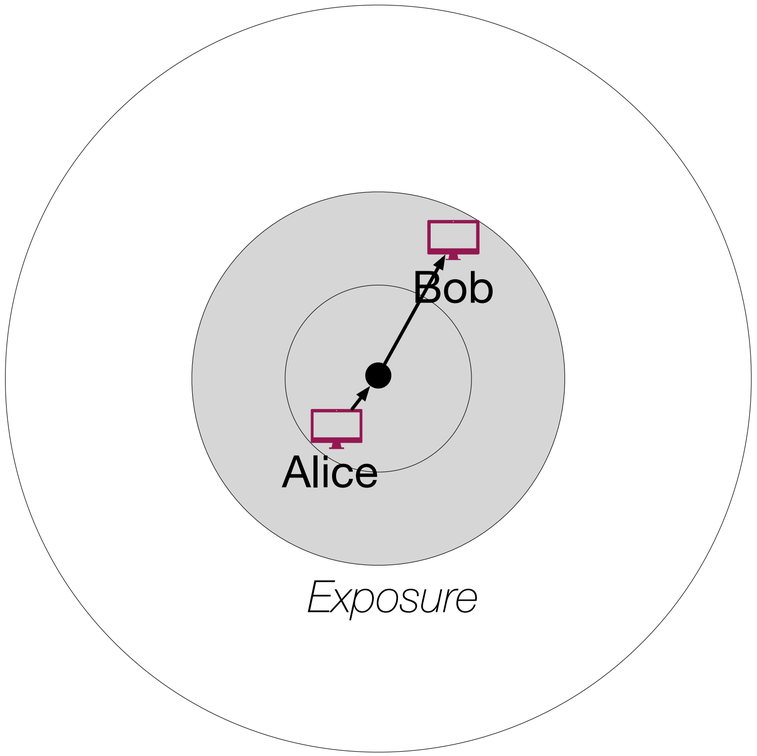

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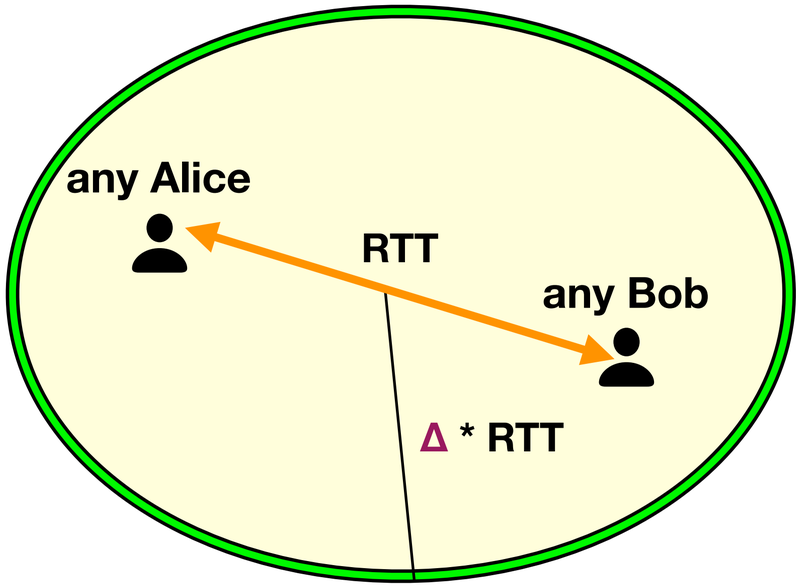

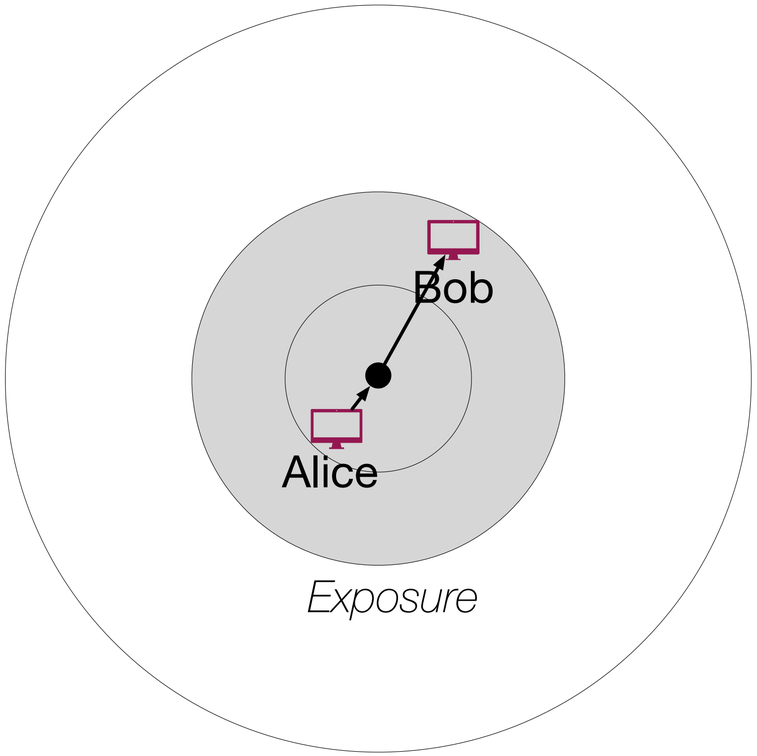

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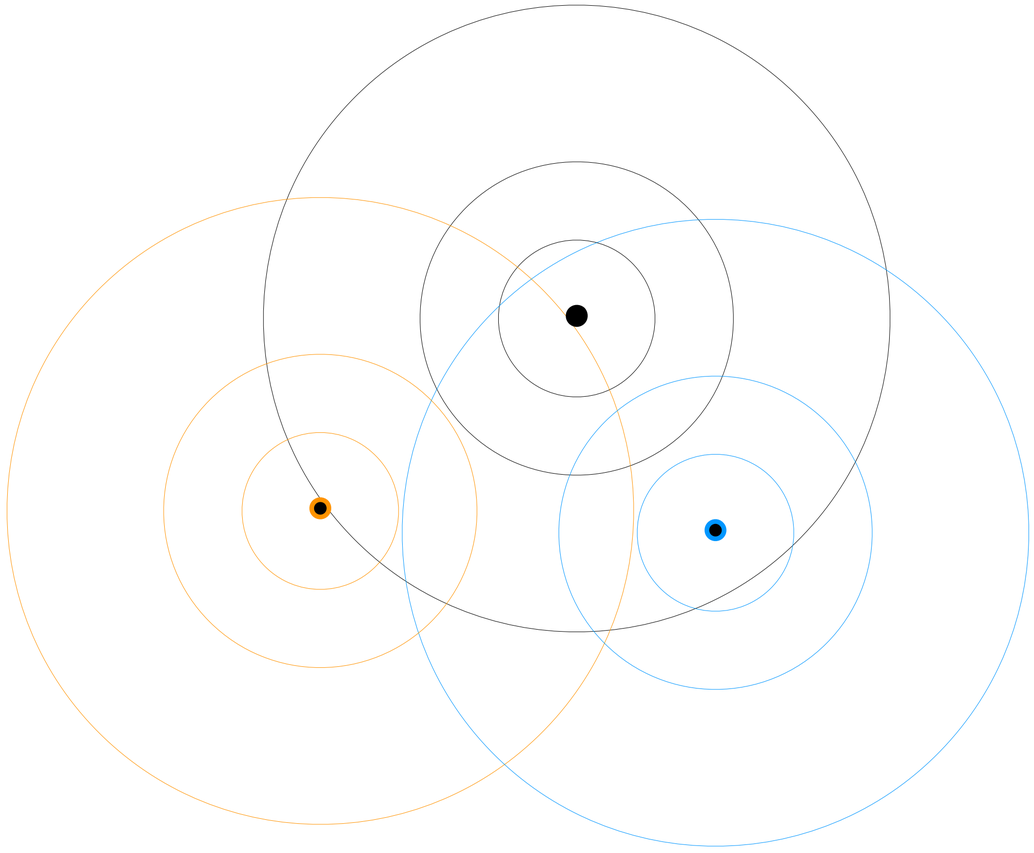

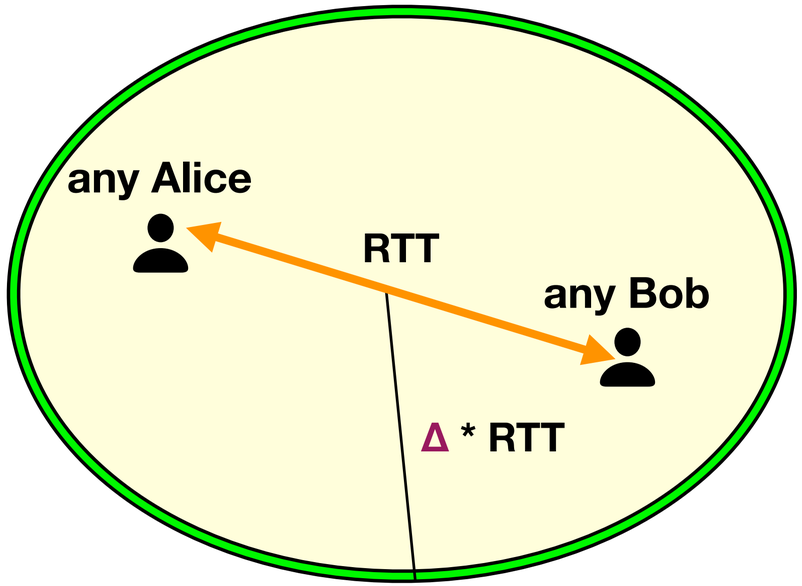

Compact metric-based zoning

- Use compact-graph approximations

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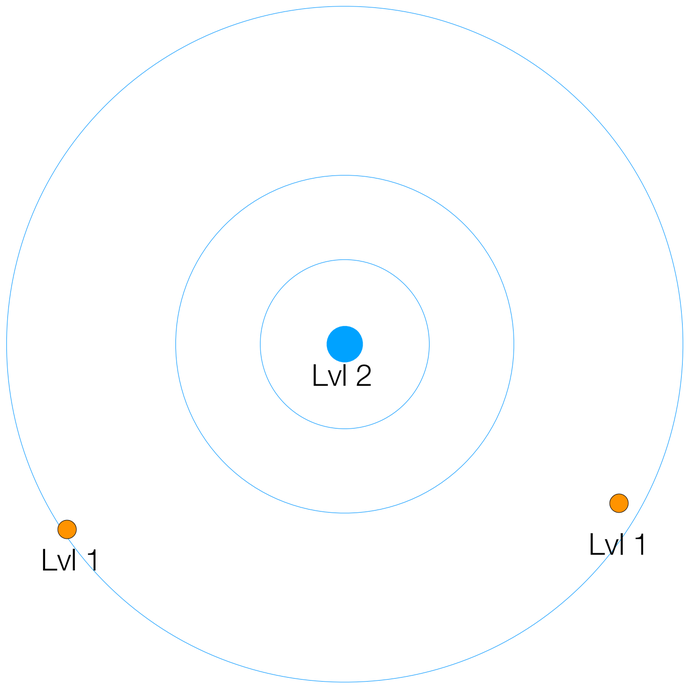

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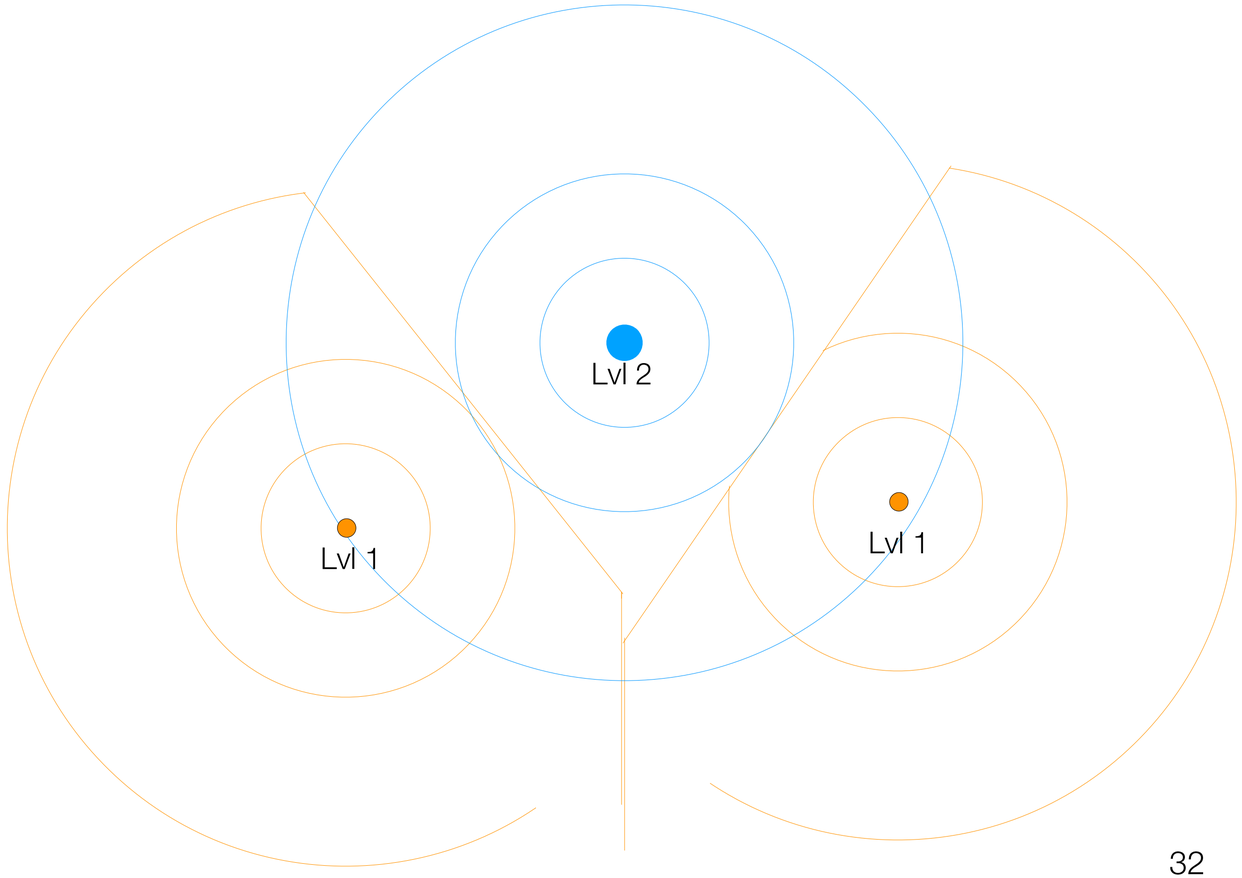

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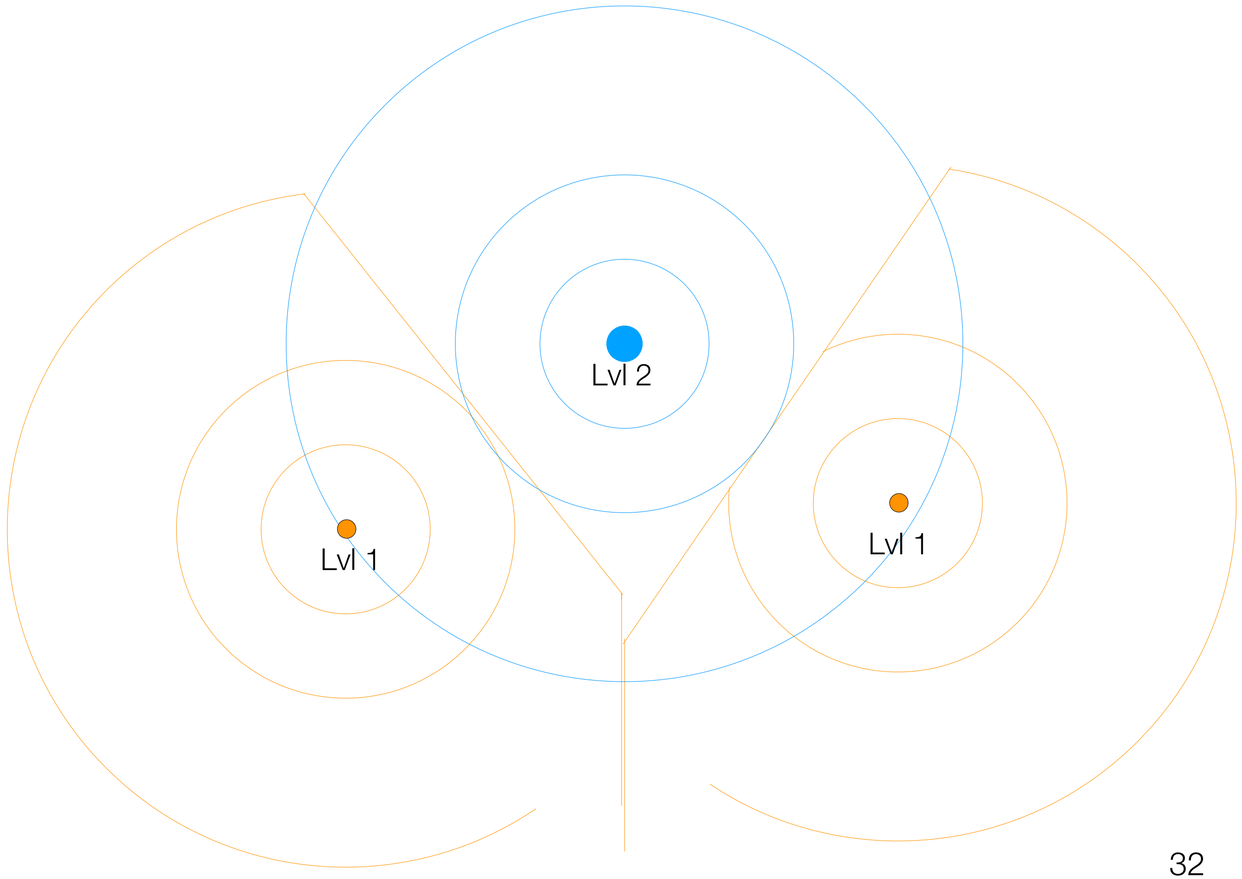

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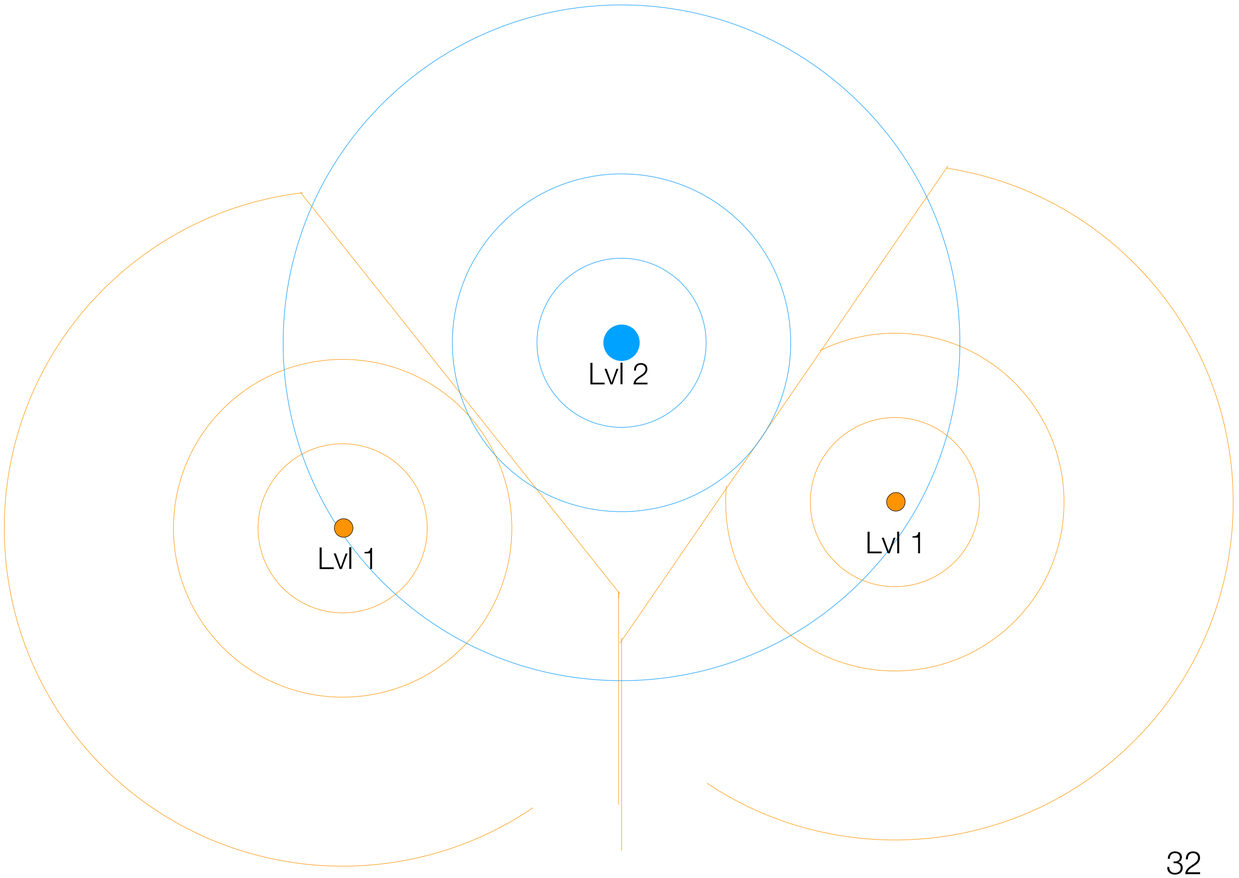

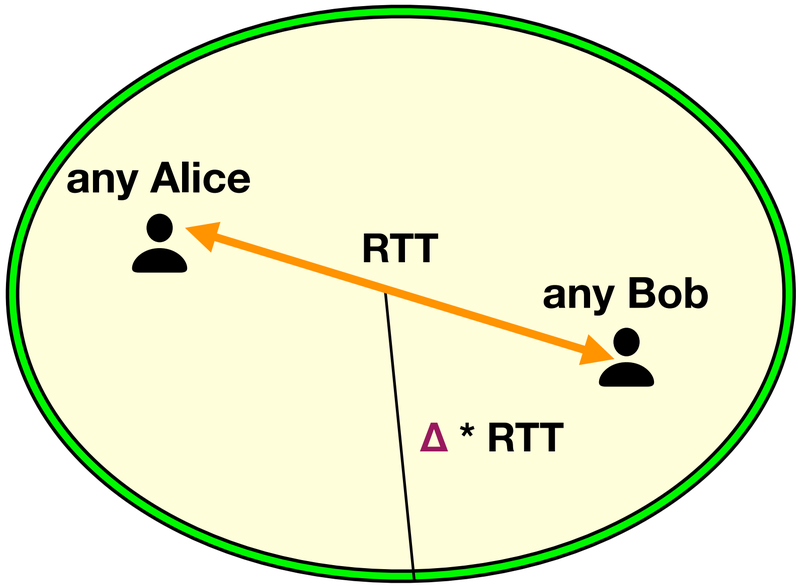

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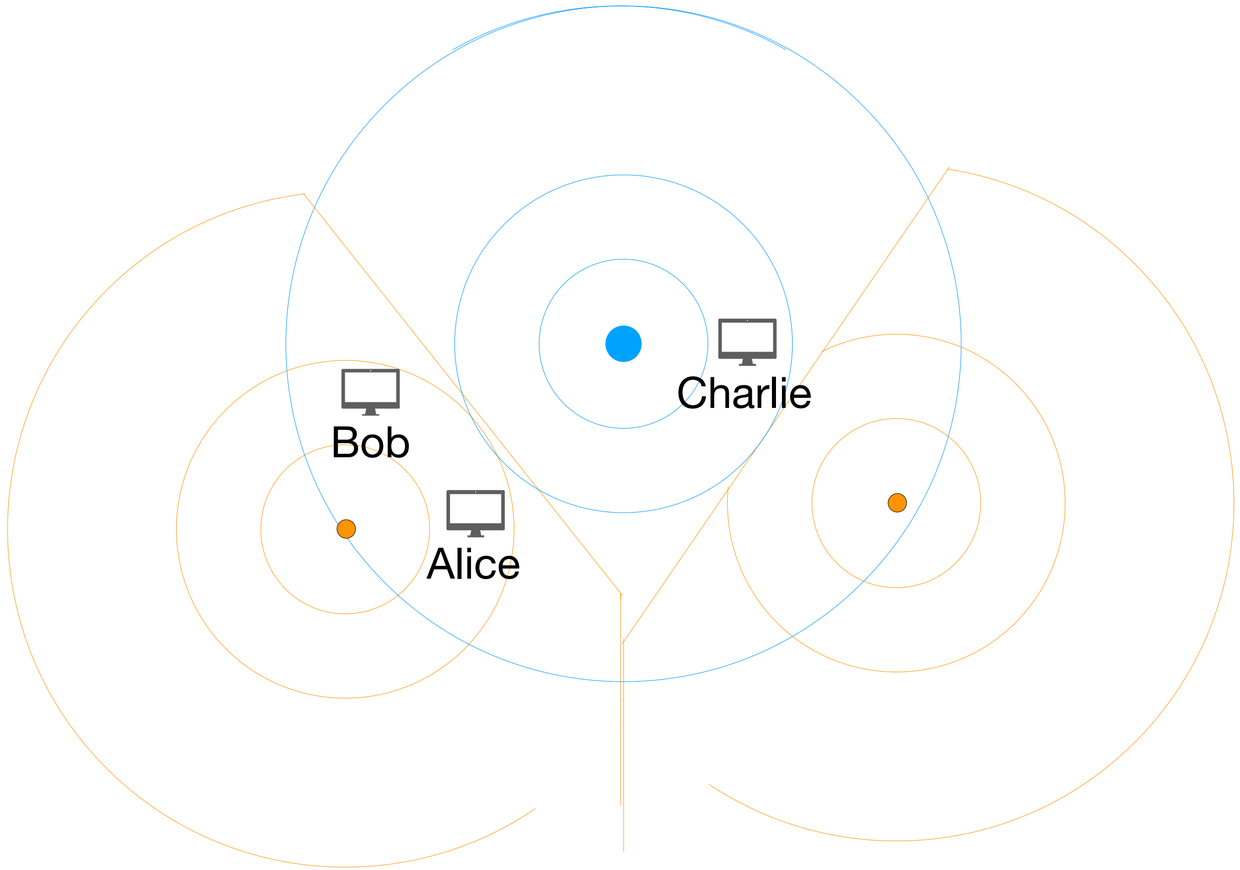

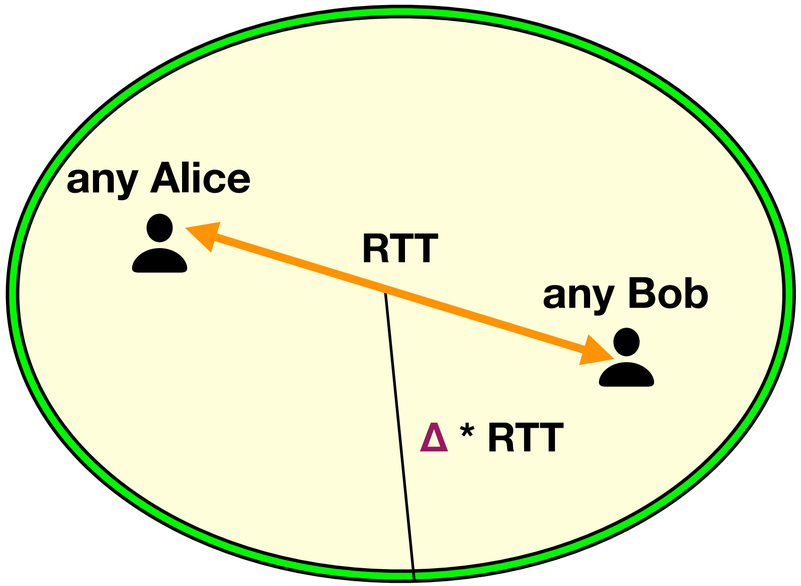

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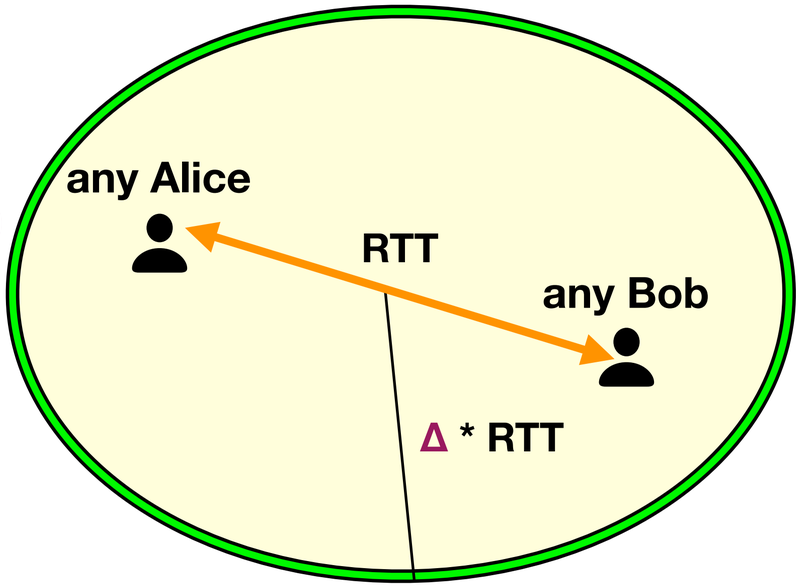
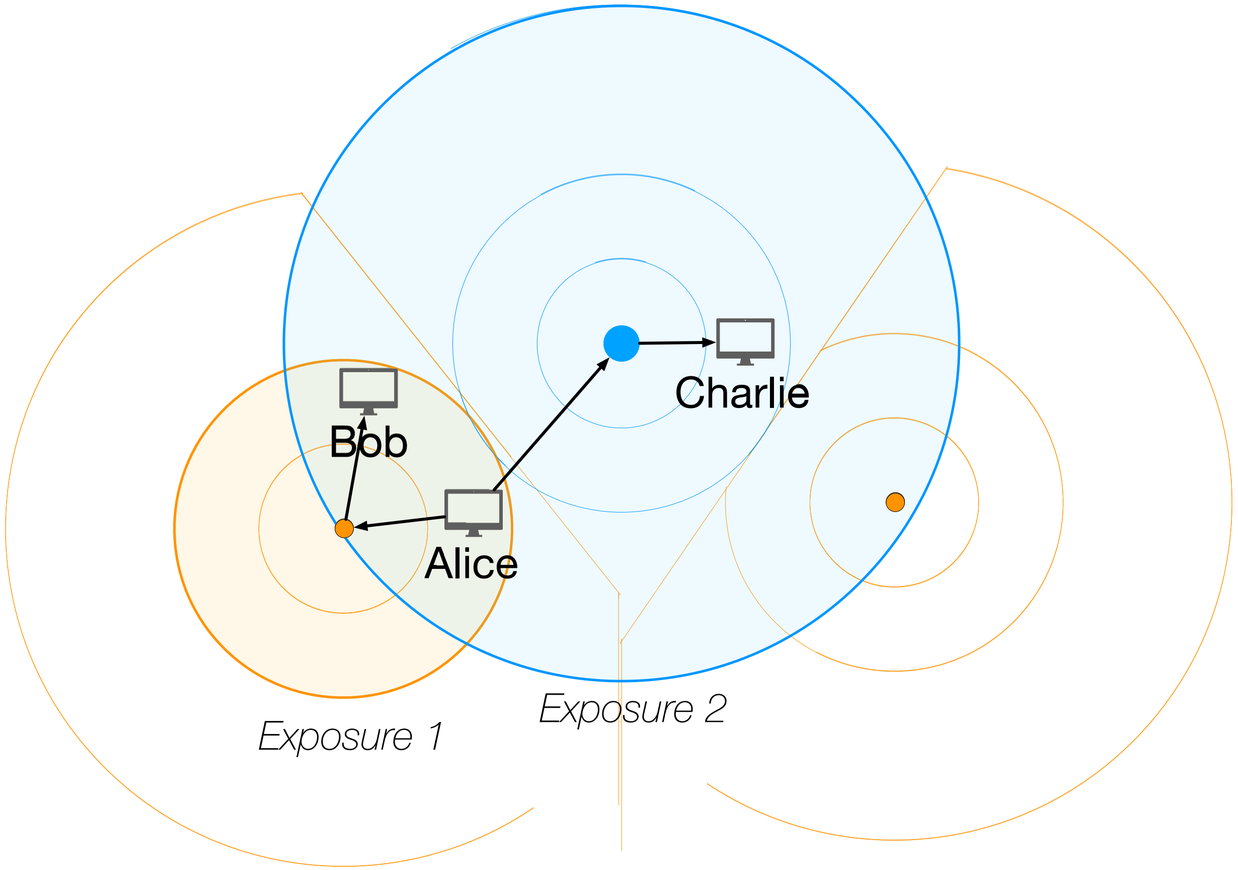
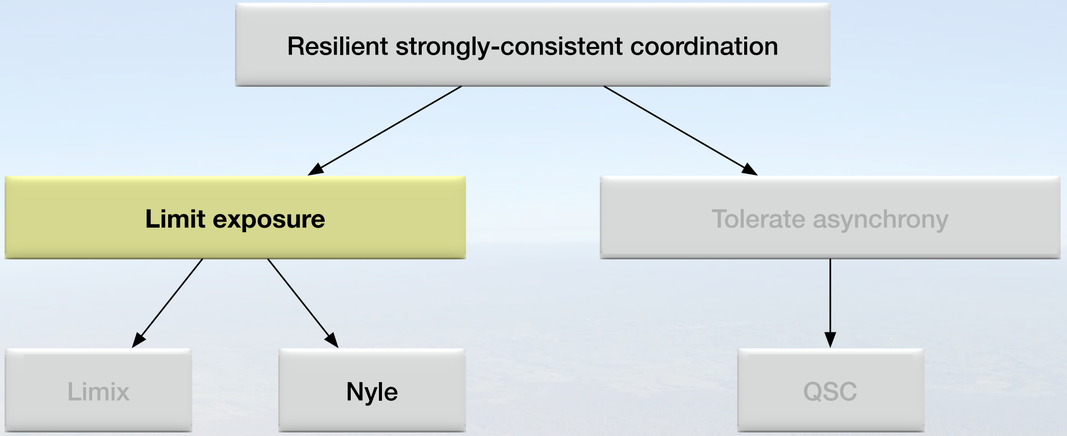




Limiting exposure roadmap

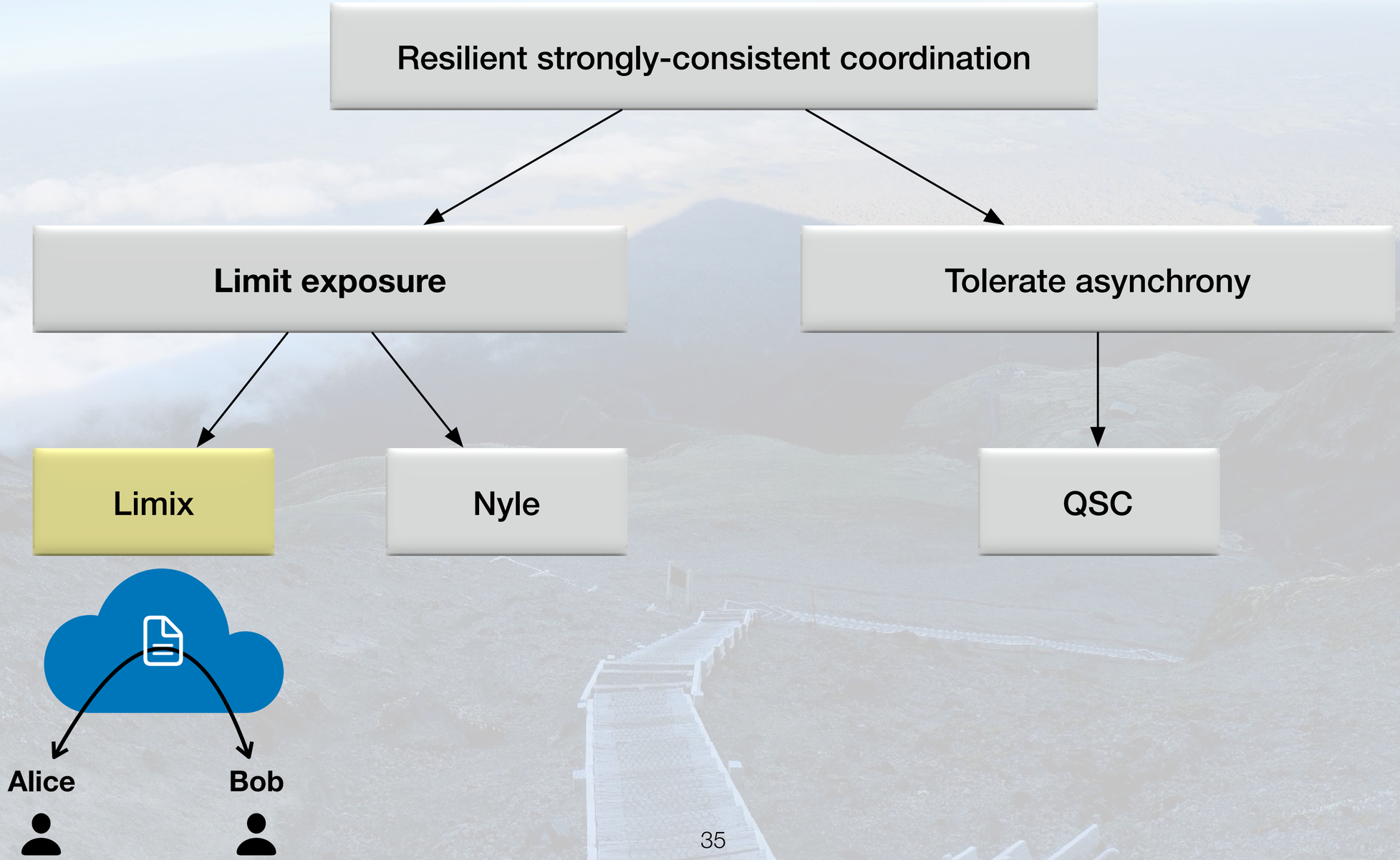


- Defining and measuring Lamport exposure
- Providing meaningful exposure guarantees
- **Summary**

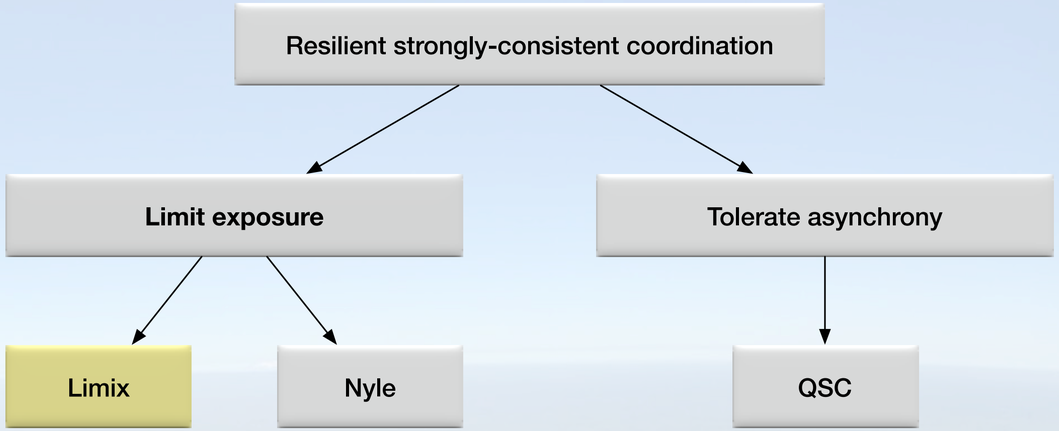
Limiting exposure summary

- **Practical metrics for assessing Lamport exposure**
- **Zoning for building globalised systems with localized resilience guarantees**

Thesis roadmap



Limix roadmap



- **The problem: exposure of metadata**
- Design of exposure-limiting metadata service
- Strongly-consistent item lookup
- Architecture
- Evaluation
- Summary

Problem: “another layer of indirection”

Control plane (metadata)

Data plane

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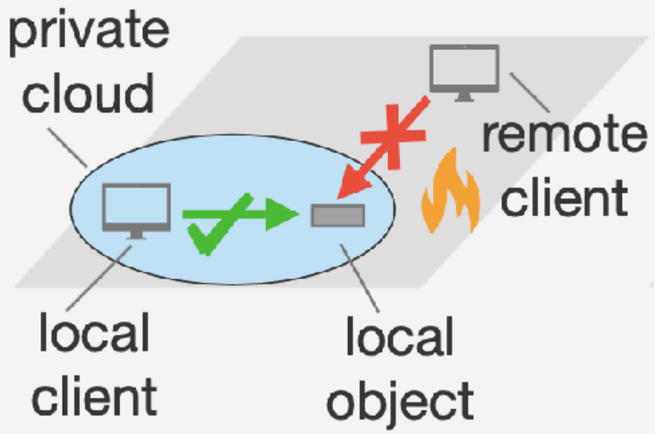


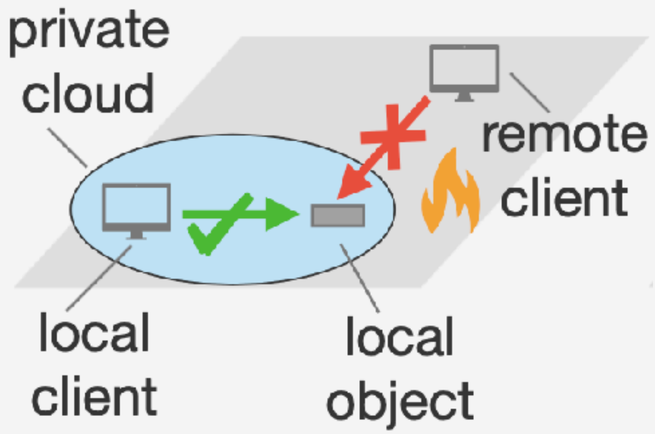
(a) local access to local infrastructure

Embed locally-scoped location in object

Problem: “another layer of indirection”

Control plane (metadata)

Data plane



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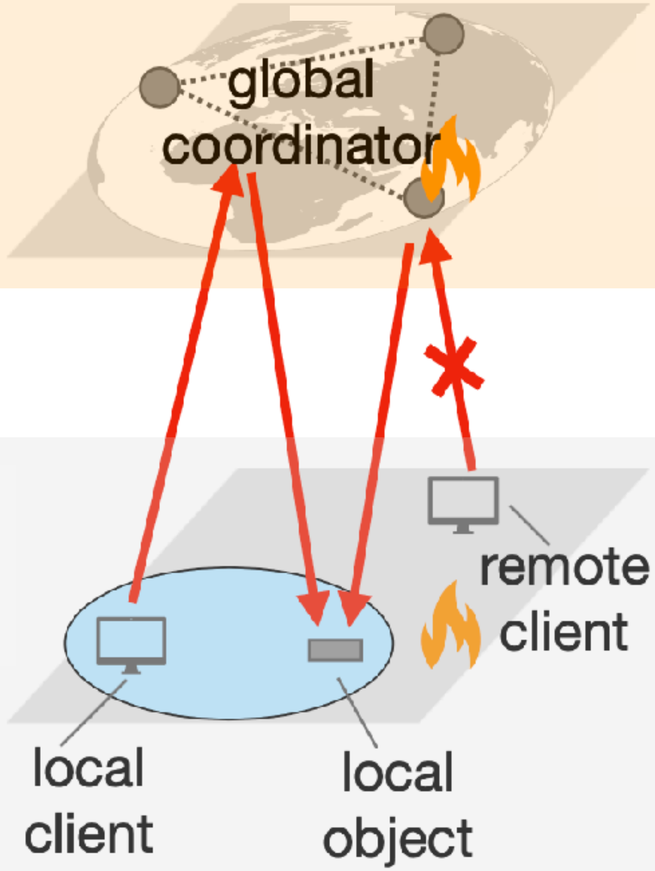


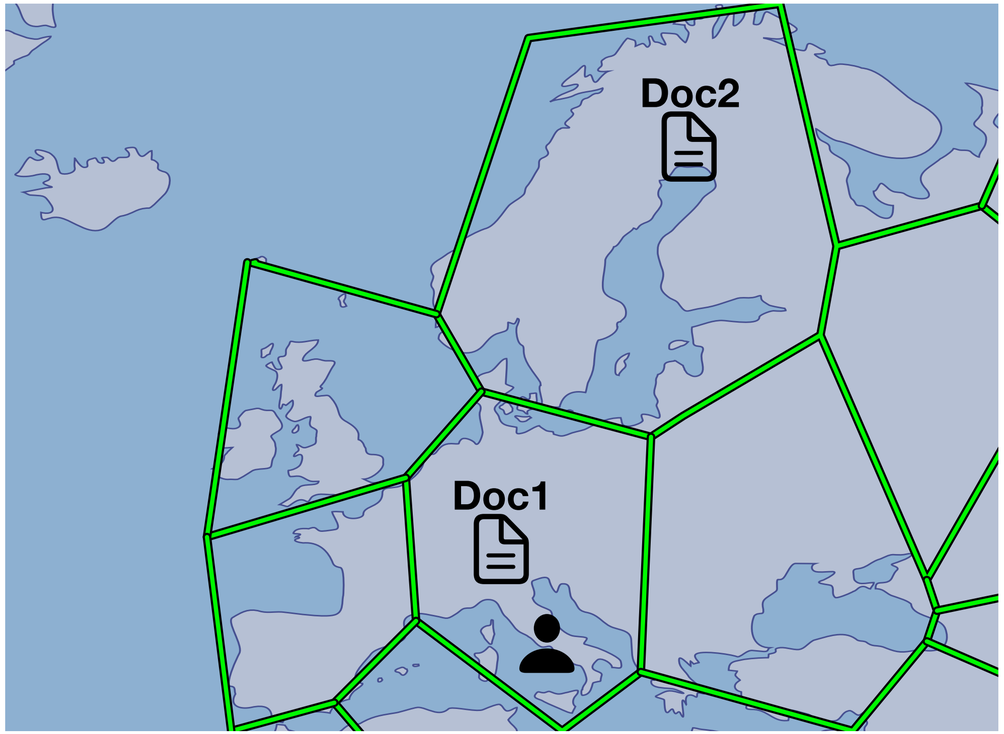
(b) access via global coordination

Embed locally-scoped location in object

Add a level of indirection

Geo-replication is not enough

Two documents in a geo-replicated system
(replicas not depicted)



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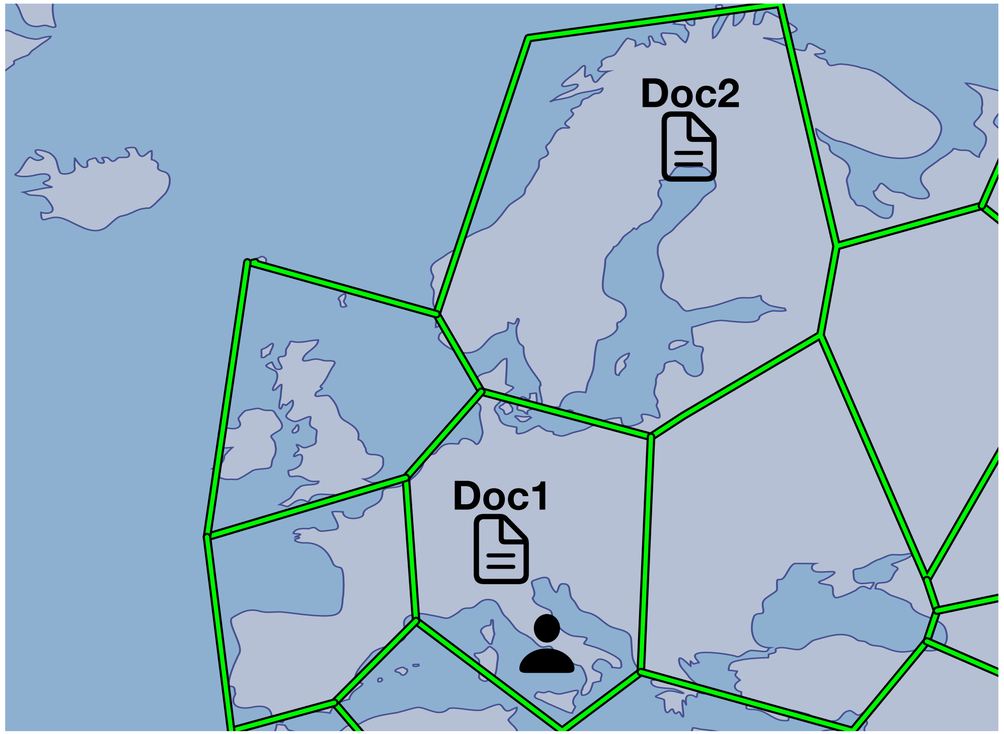

Challenge 1:
Maintain Lamport exposure while performing file lookup

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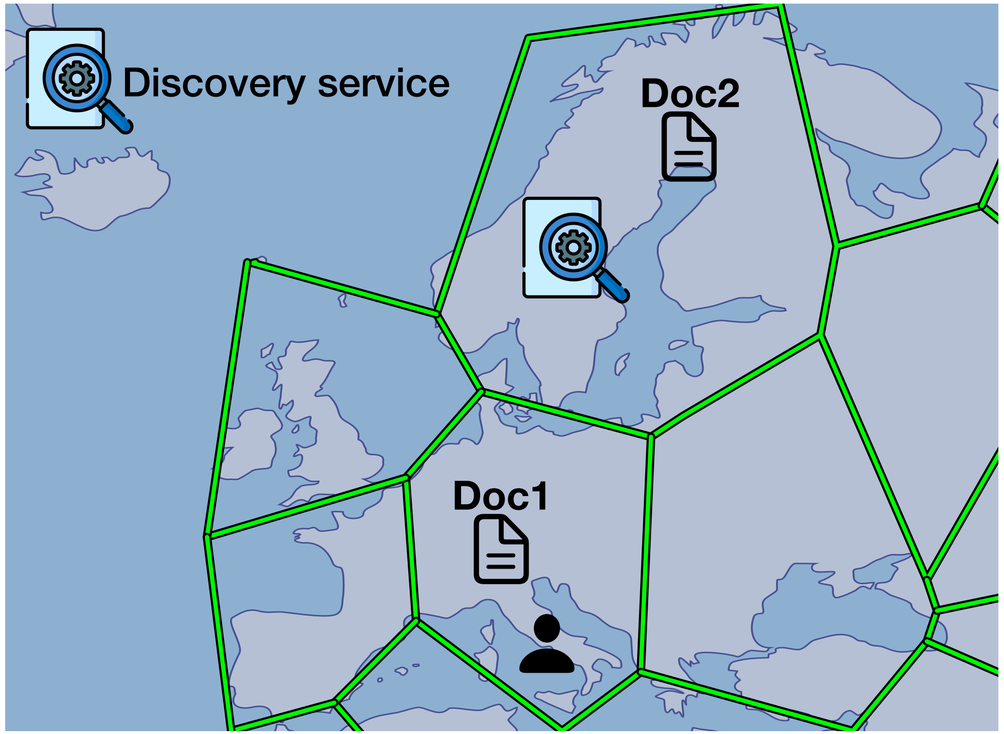

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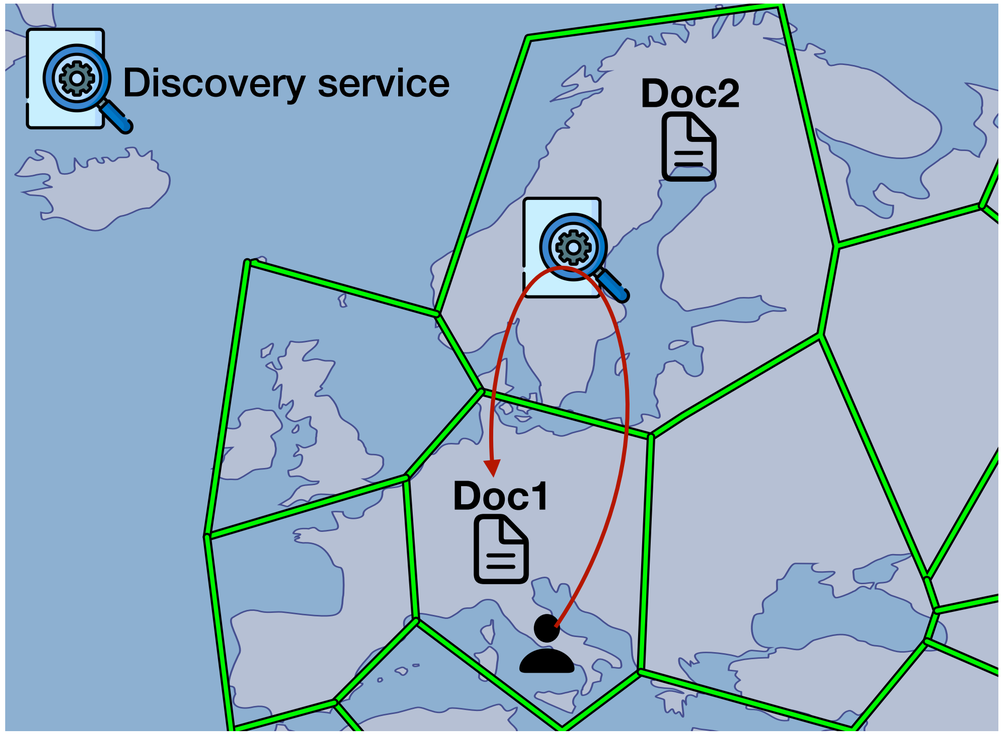

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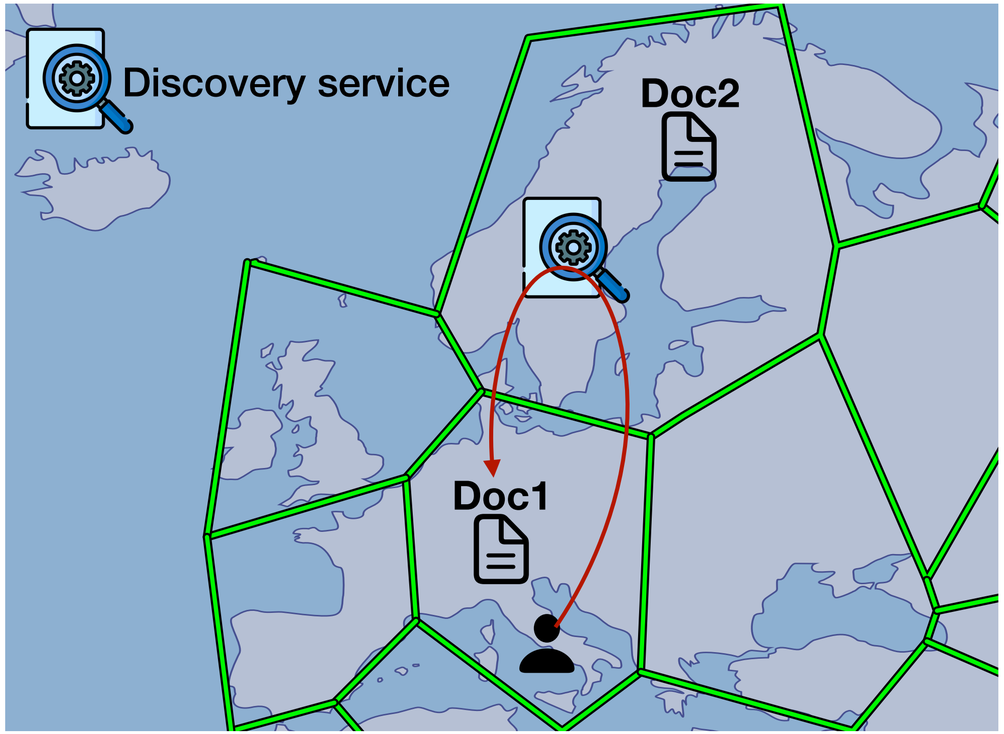


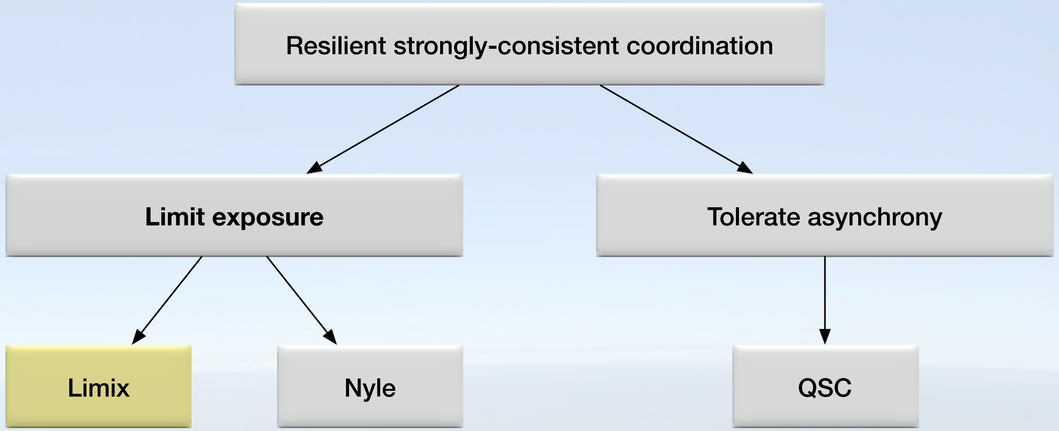
X Challenge 1:
Maintain Lamport exposure while performing file lookup

Limix focuses on the metadata problem:

How to find a localized strongly-consistent item when the location metadata is normally globalized?

Limix roadmap

- The problem: metadata exposure
- **Design of exposure-limiting metadata service**
  - Limiting exposure of data lookup
  - Scalable metadata service
  - Fine-grained exposure
- Strongly-consistent item lookup
- Architecture
- Evaluation
- Summary



Strawman 1: limits exposure but does not scale

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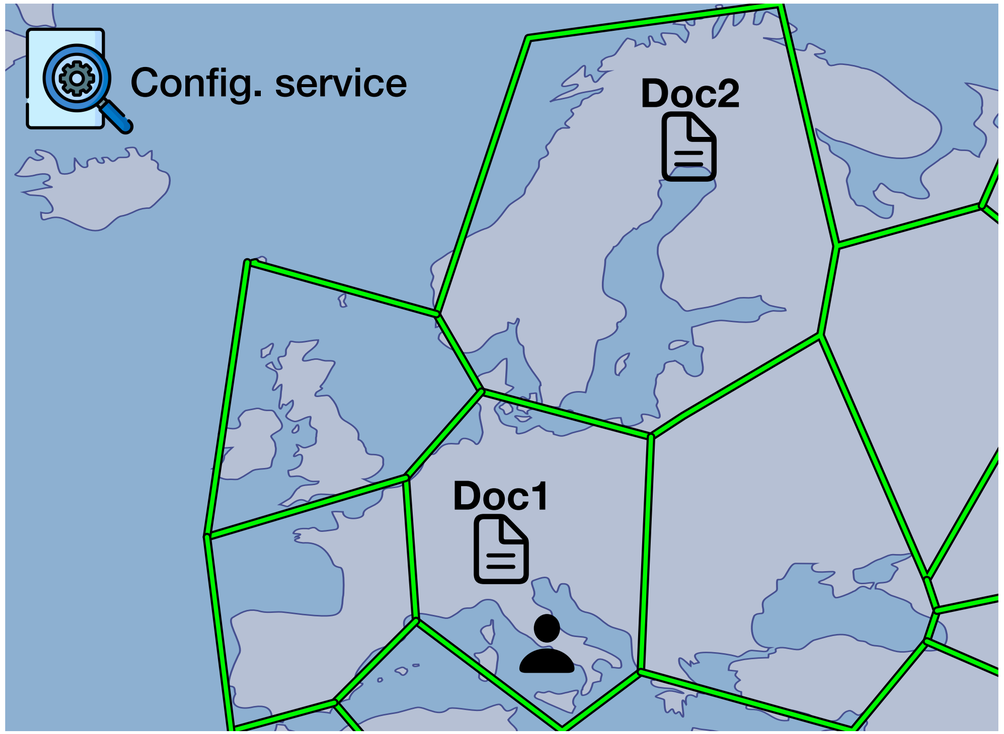

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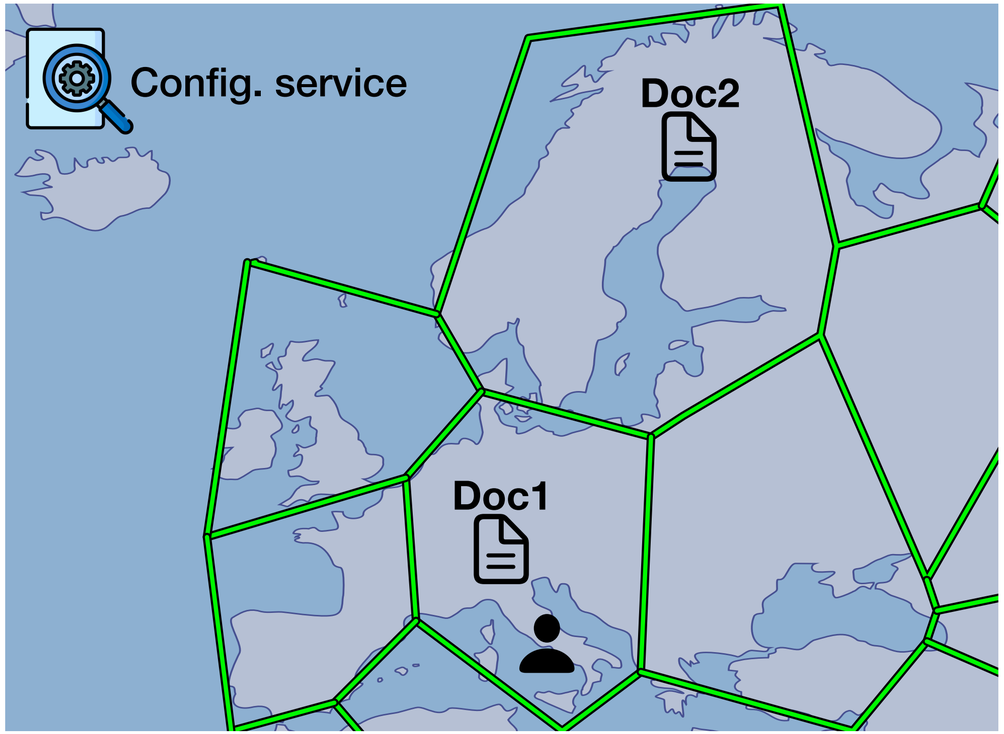

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Solution:
Replicate the discovery service

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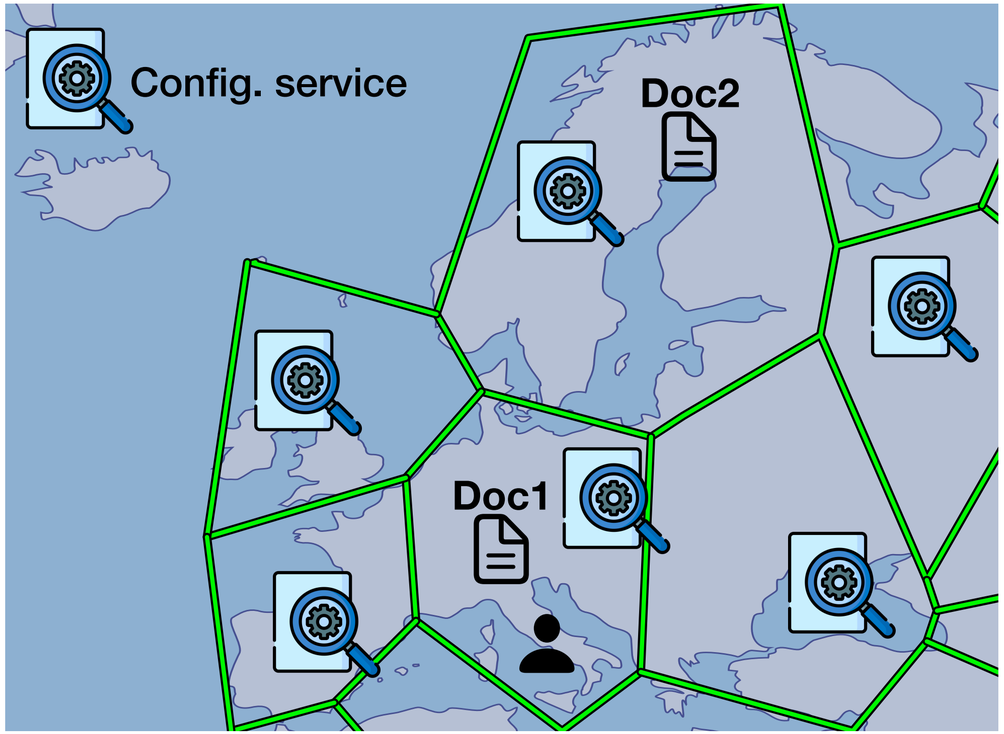

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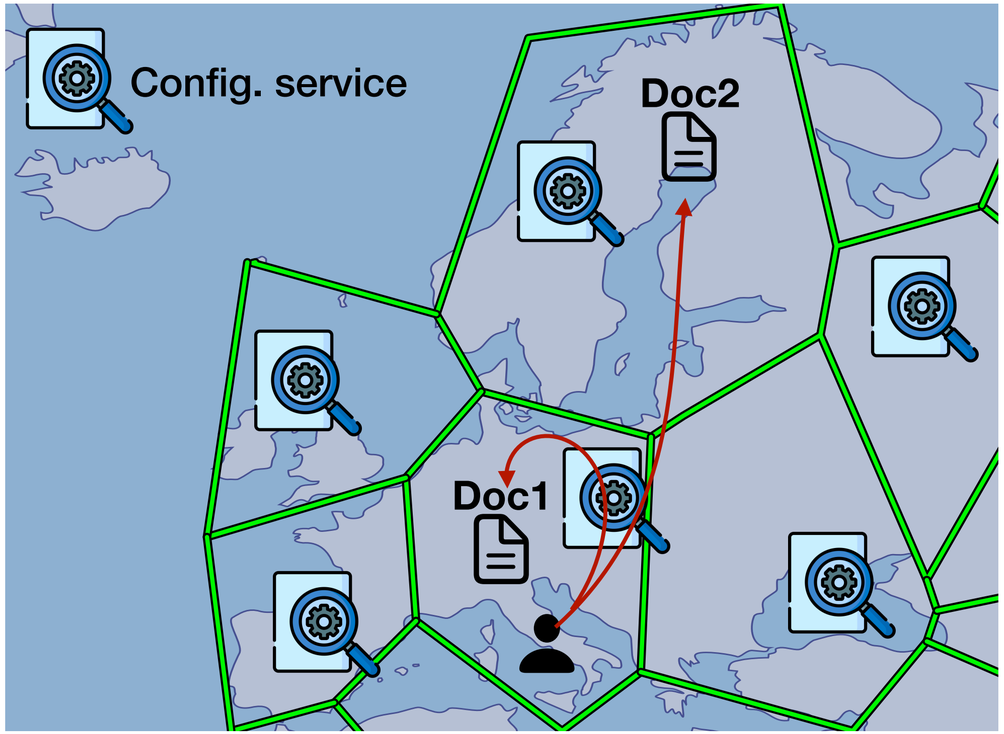

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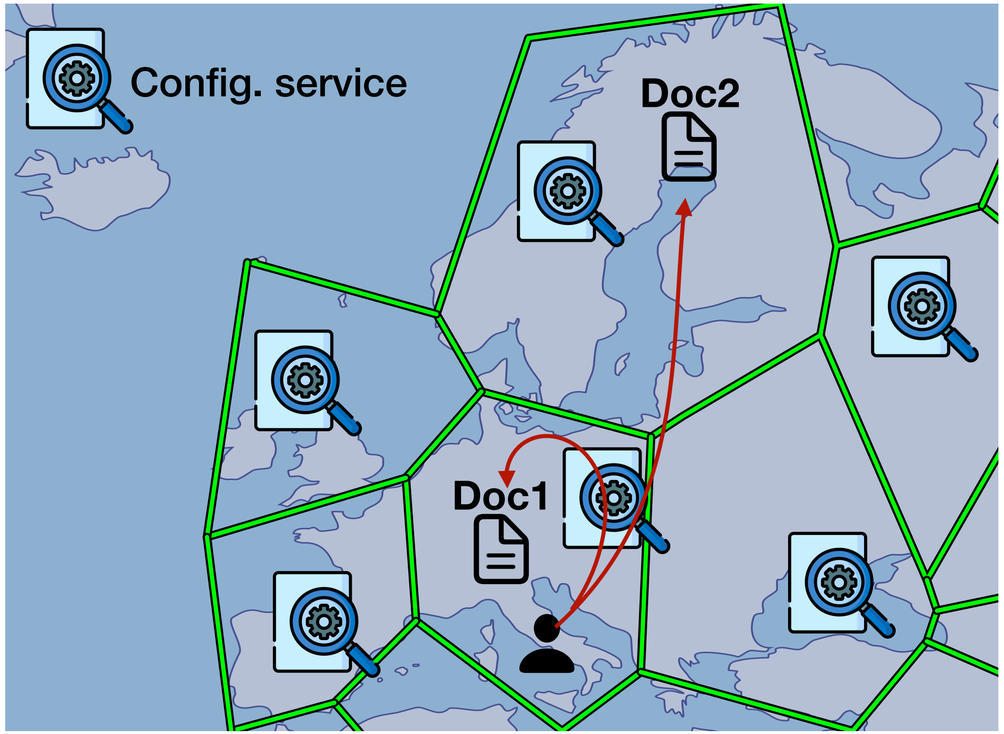

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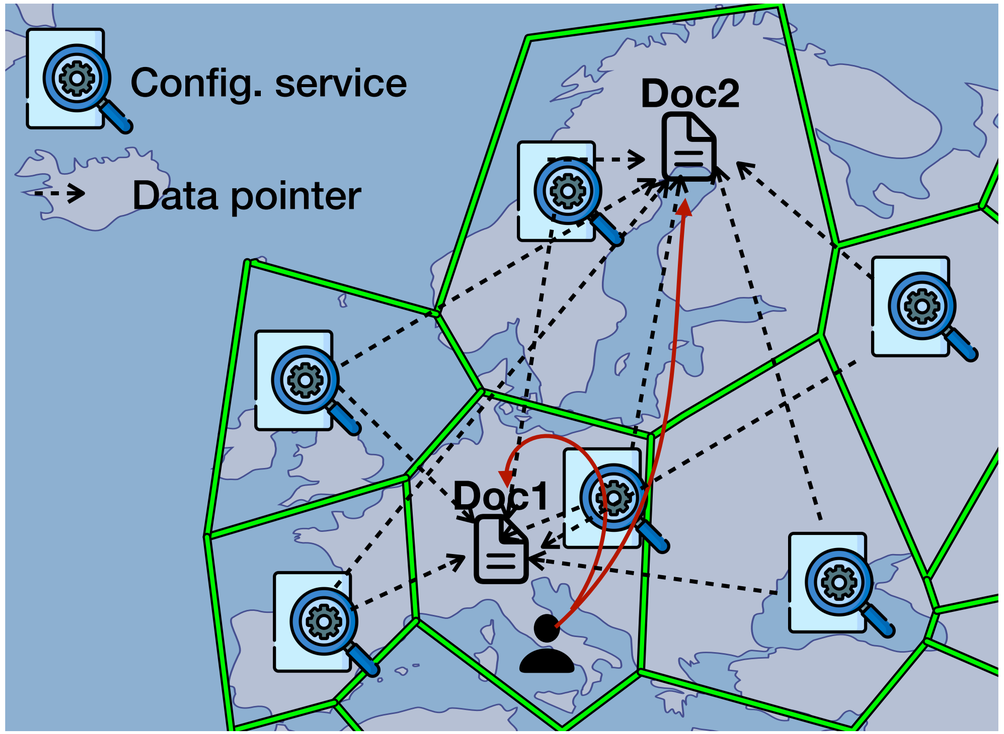

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Maintain Lamport exposure while performing file lookup

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Replicate the discovery service
Per-zone discovery service, each service points to all data

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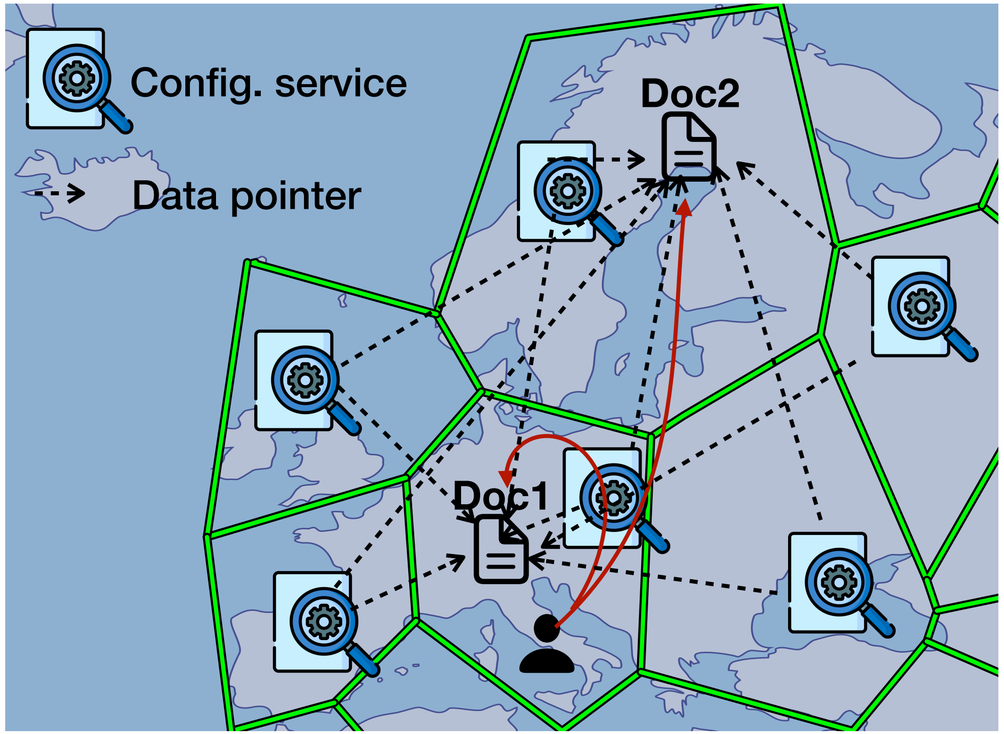

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X **Challenge 2:**
Scalable discovery service enforcing Lamport exposure

Strawman 2: scales but provides coarse-grained exposure

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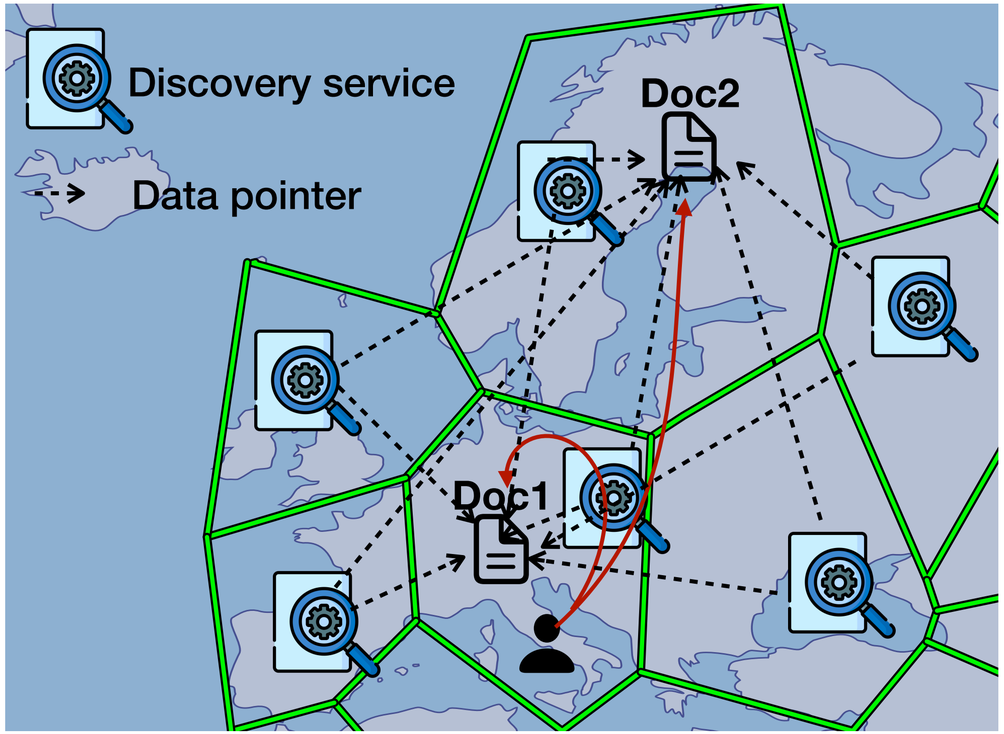

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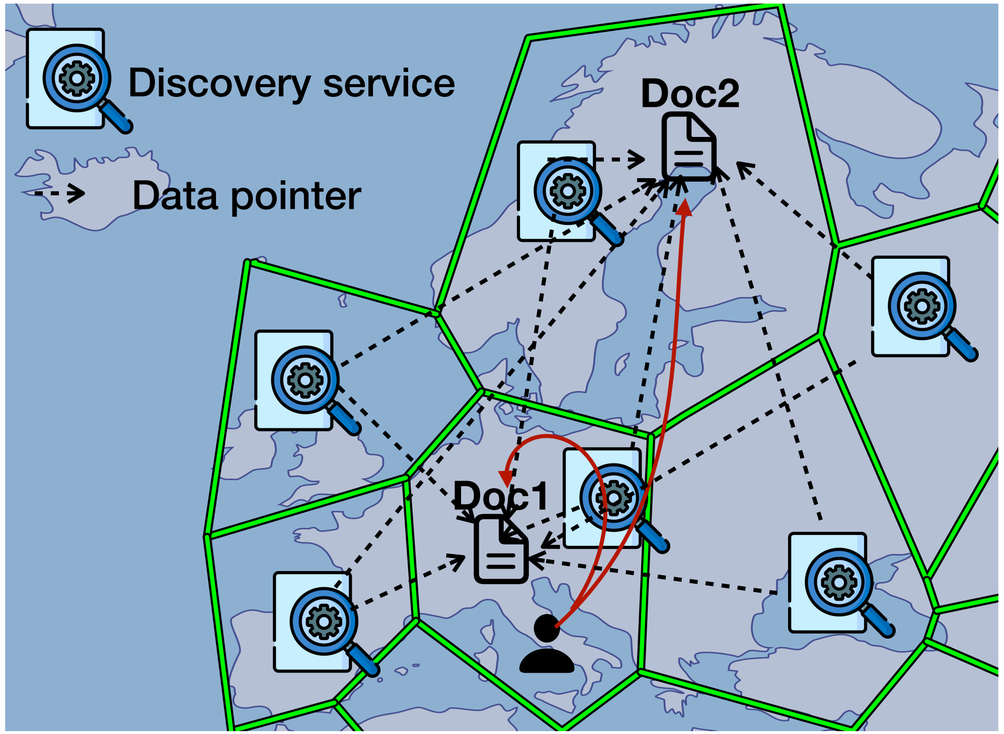

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Challenge 2:
Scalable discovery service enforcing Lamport exposure

Solution:
Add a global zone
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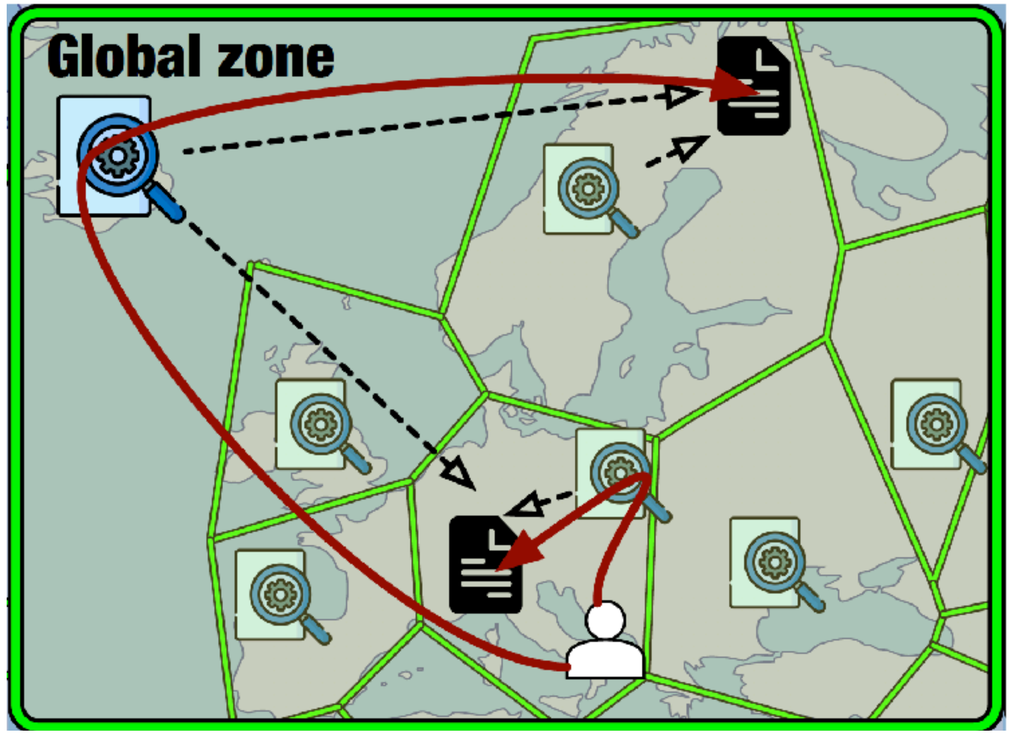

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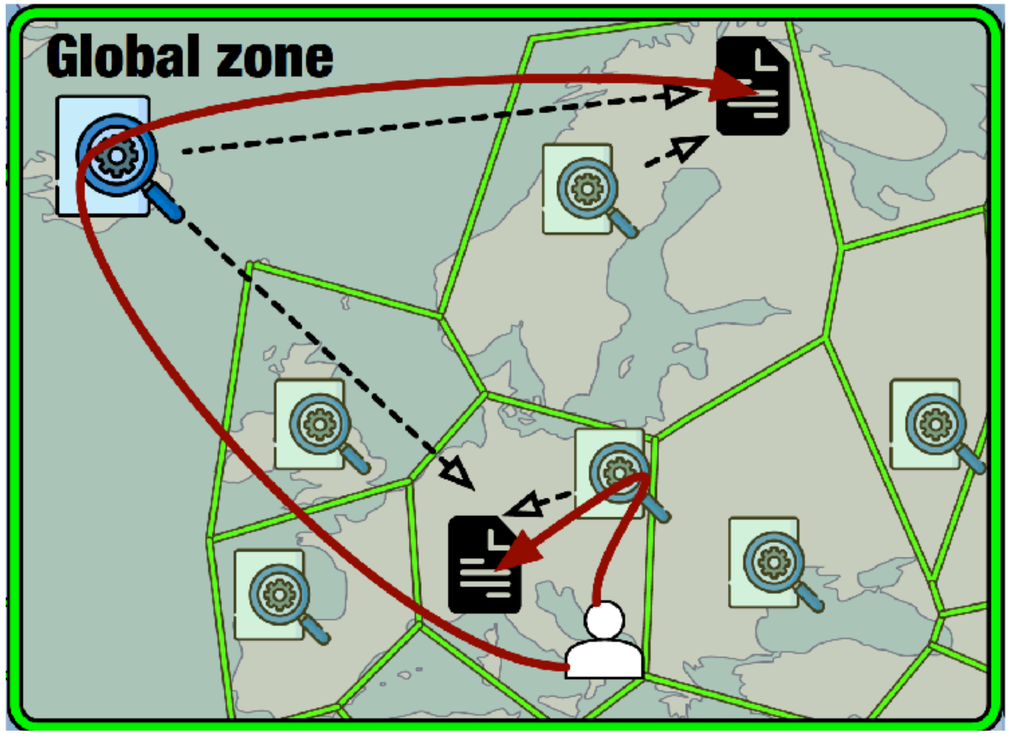

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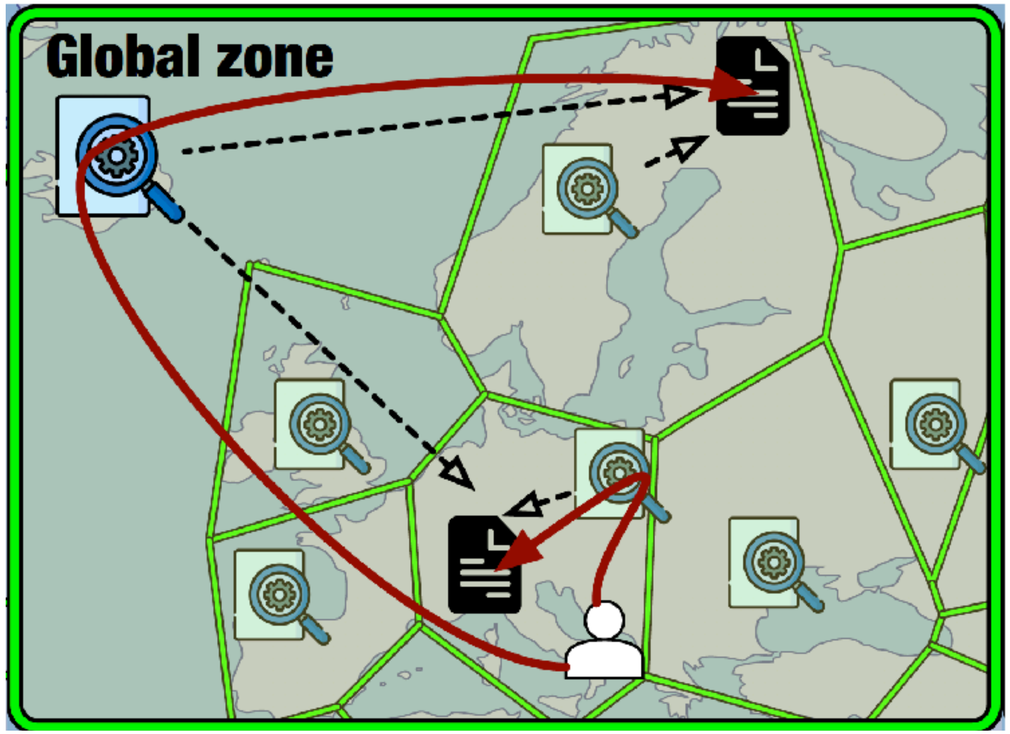

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X **Challenge 3**
Fine-grained overlapping Lamport exposure

Limix: our proposal for limiting Lamport exposure

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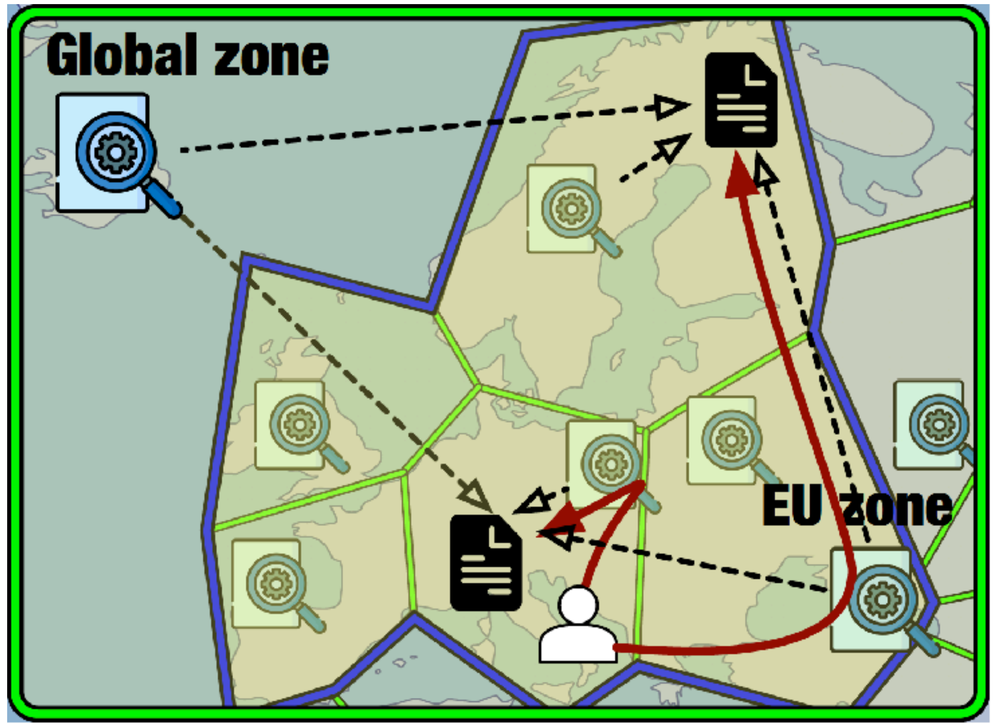

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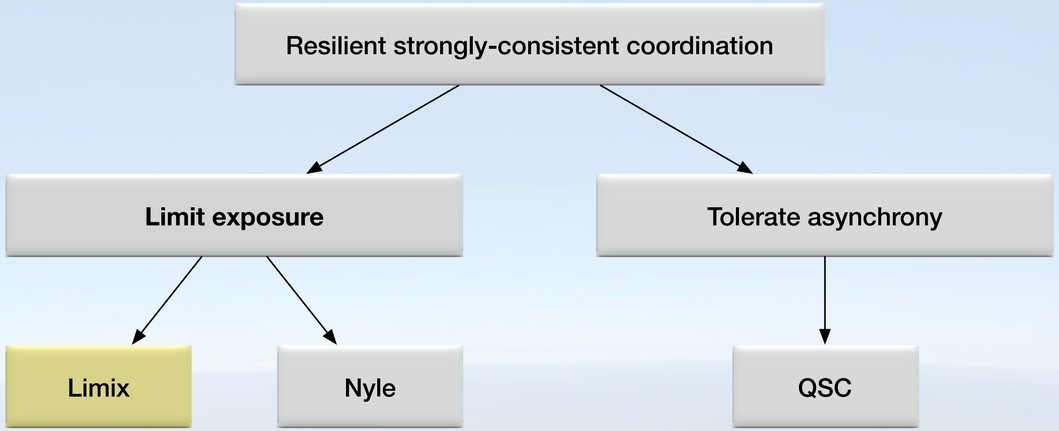
Limix roadmap



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- **Strongly-consistent item lookup**
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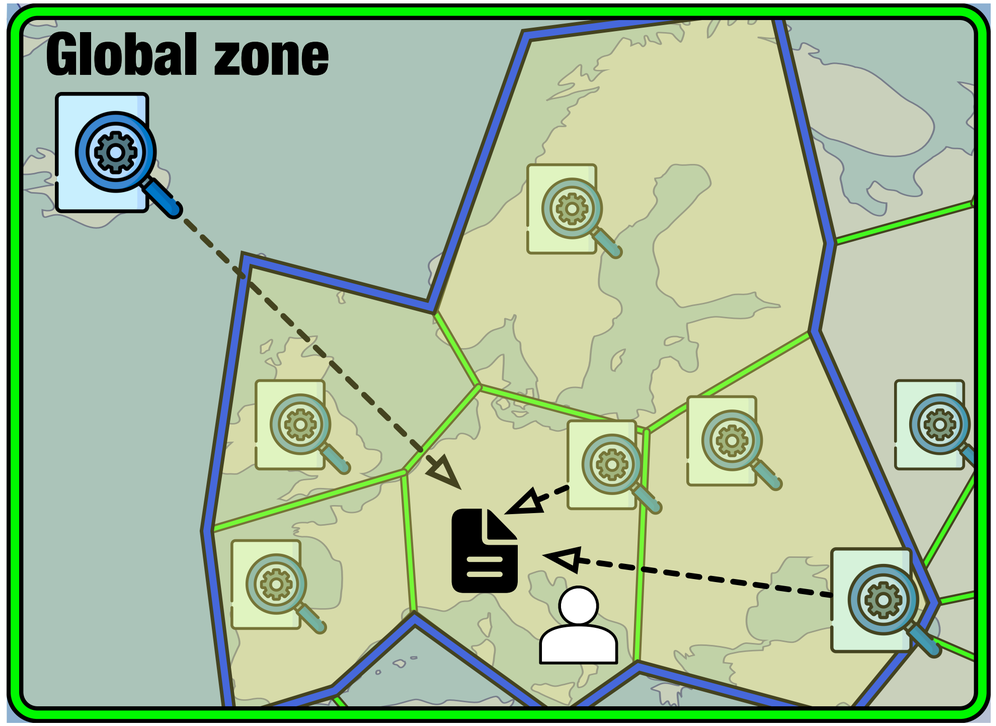
- Summary

Locating latest data version during migration



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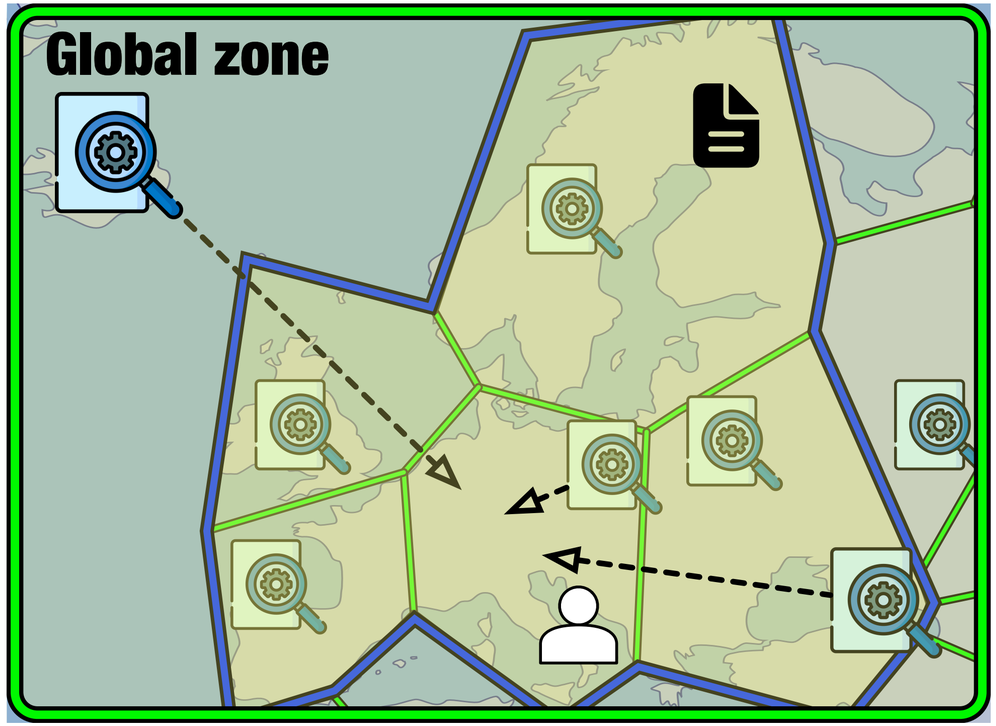

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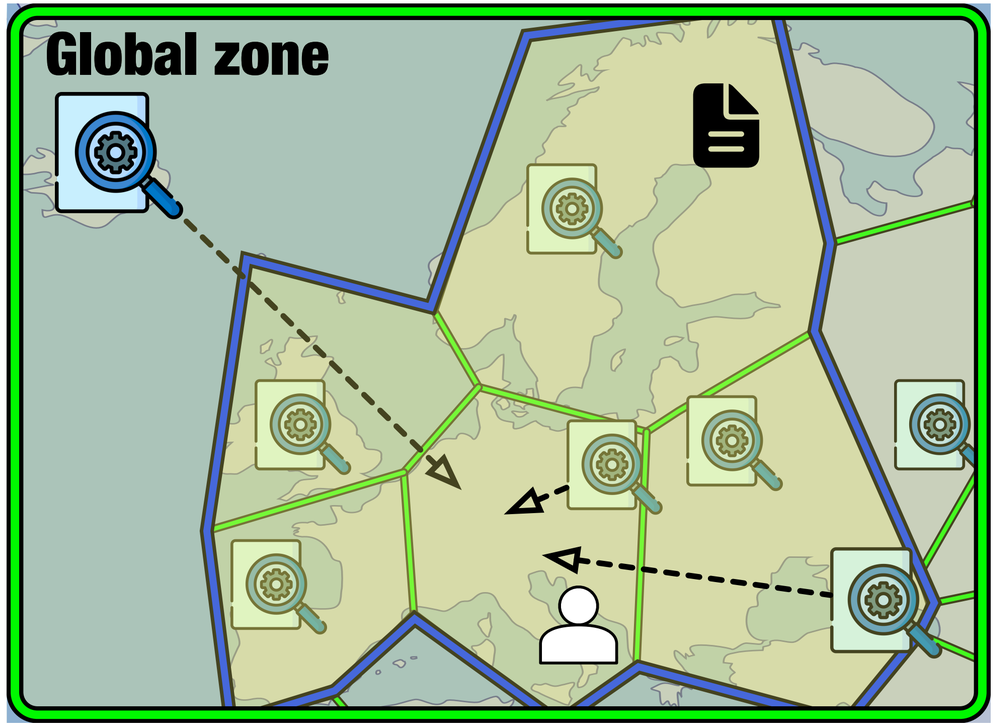

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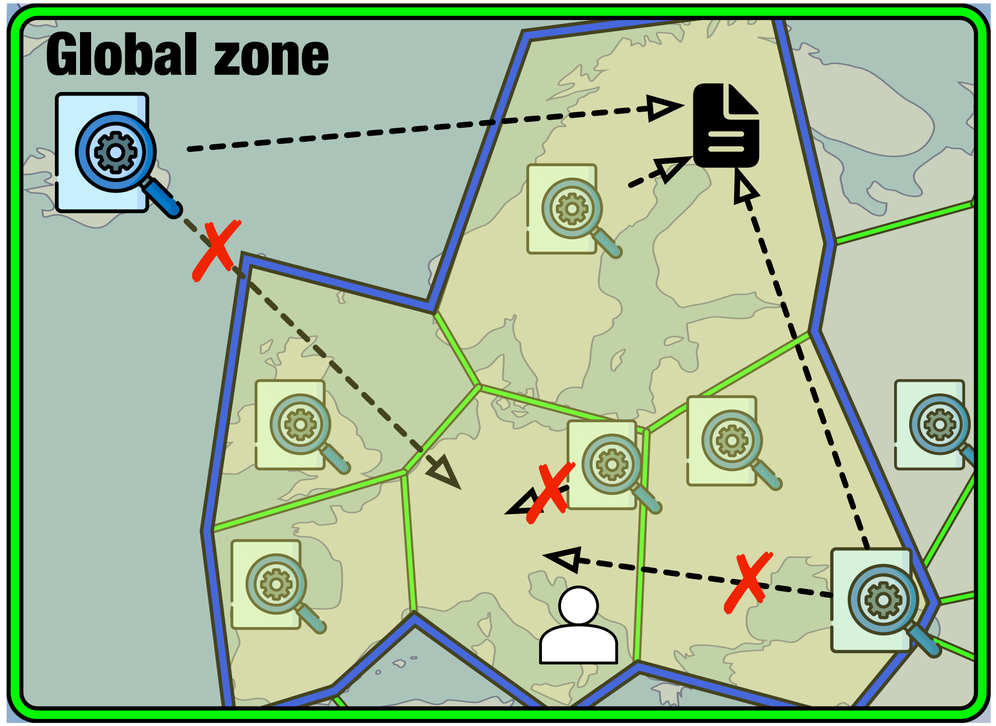

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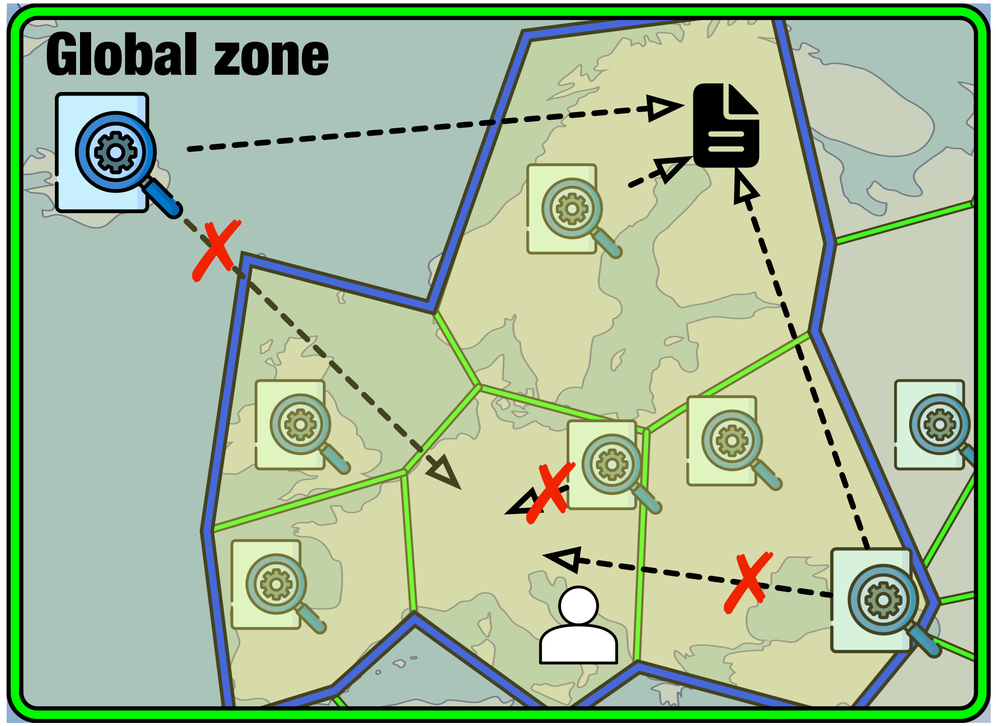

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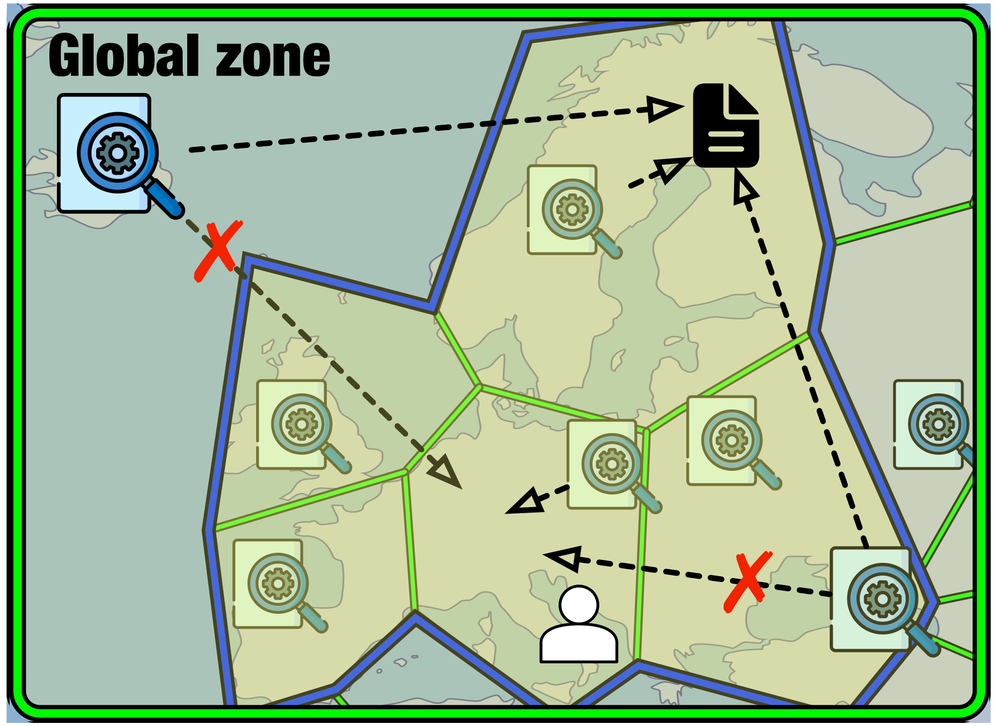

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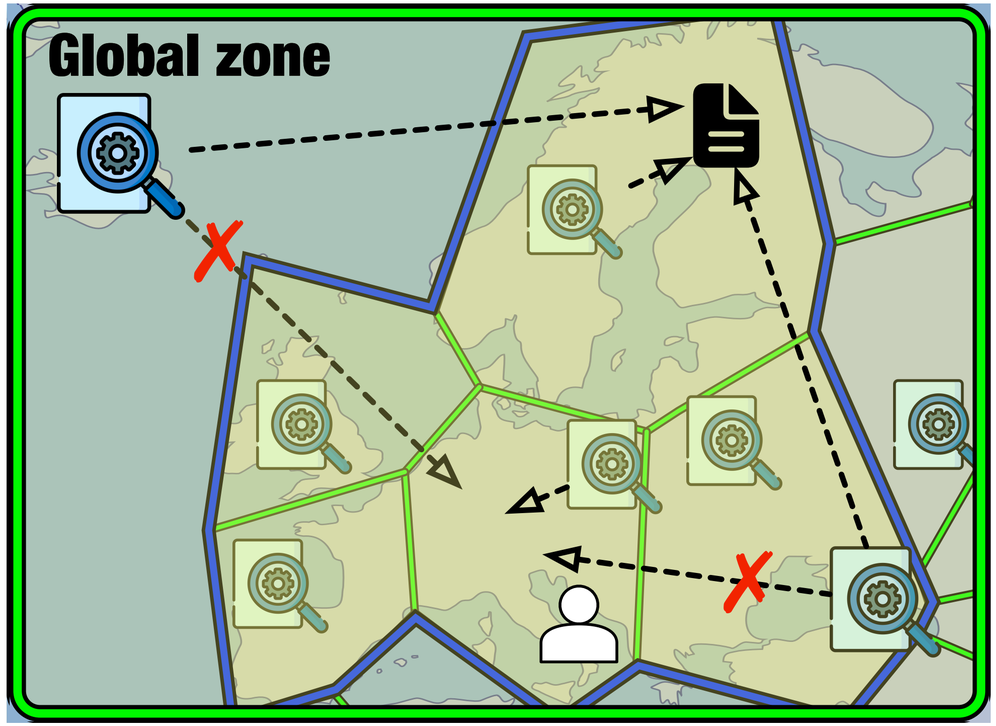

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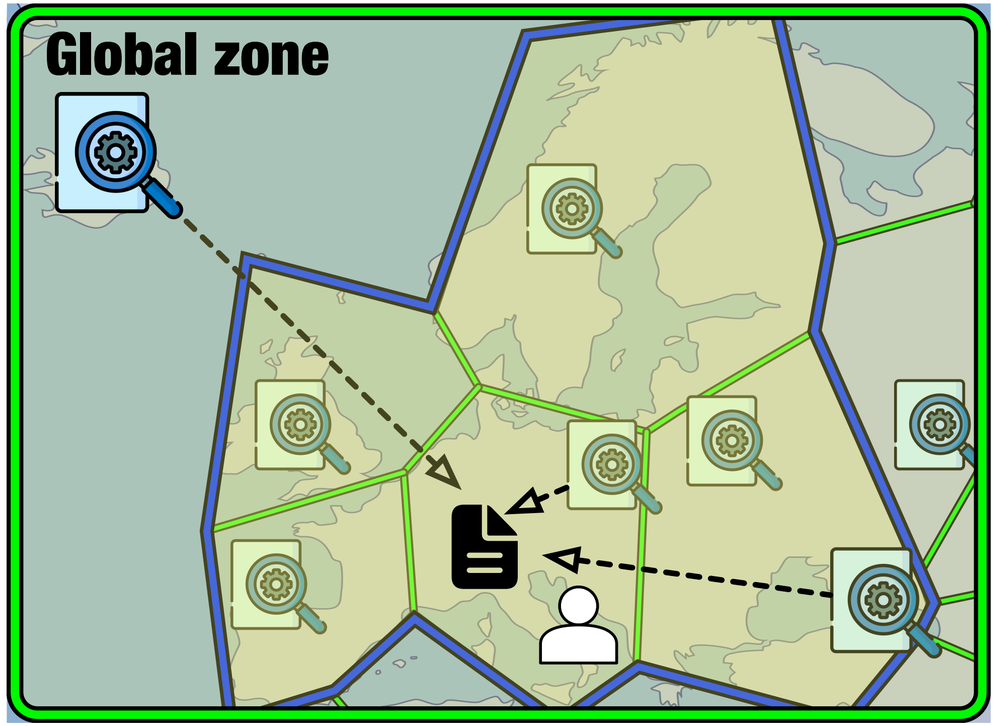

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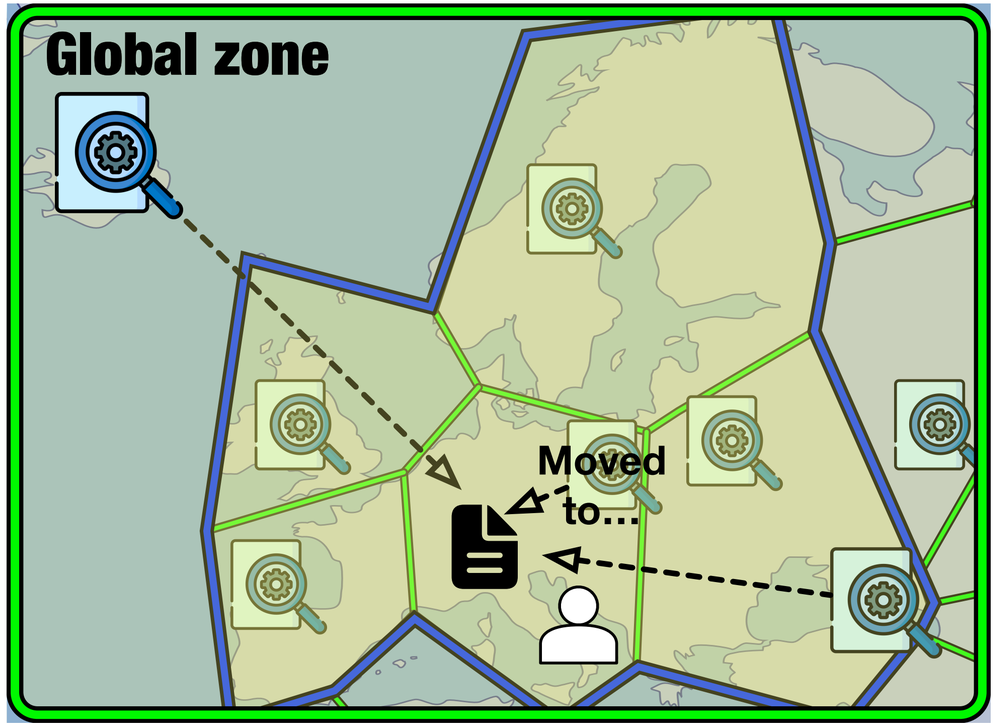

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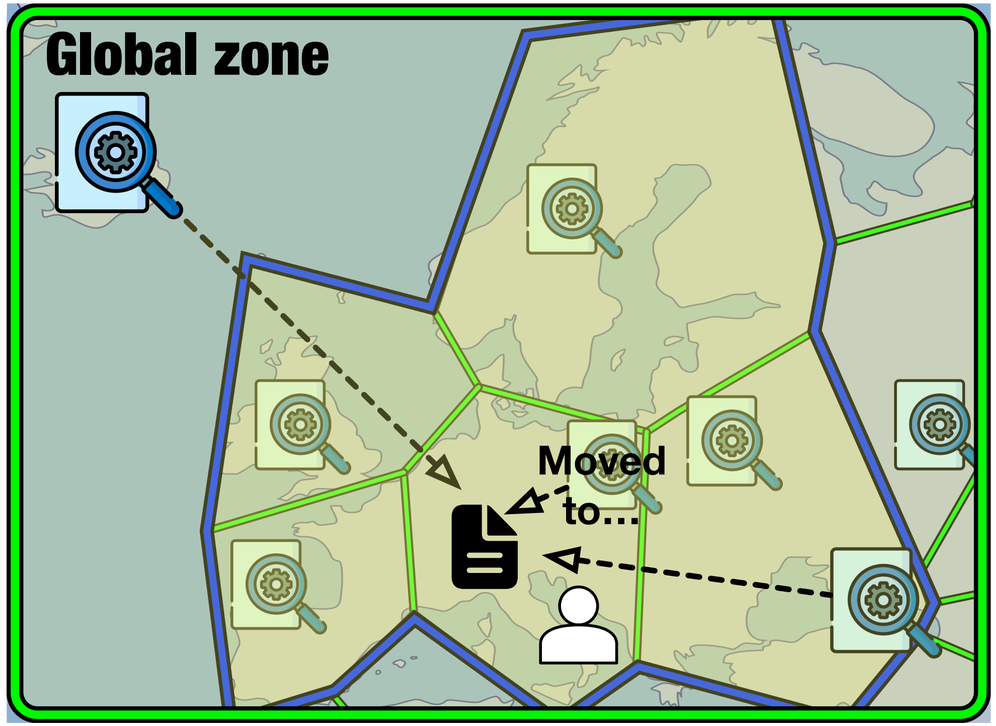

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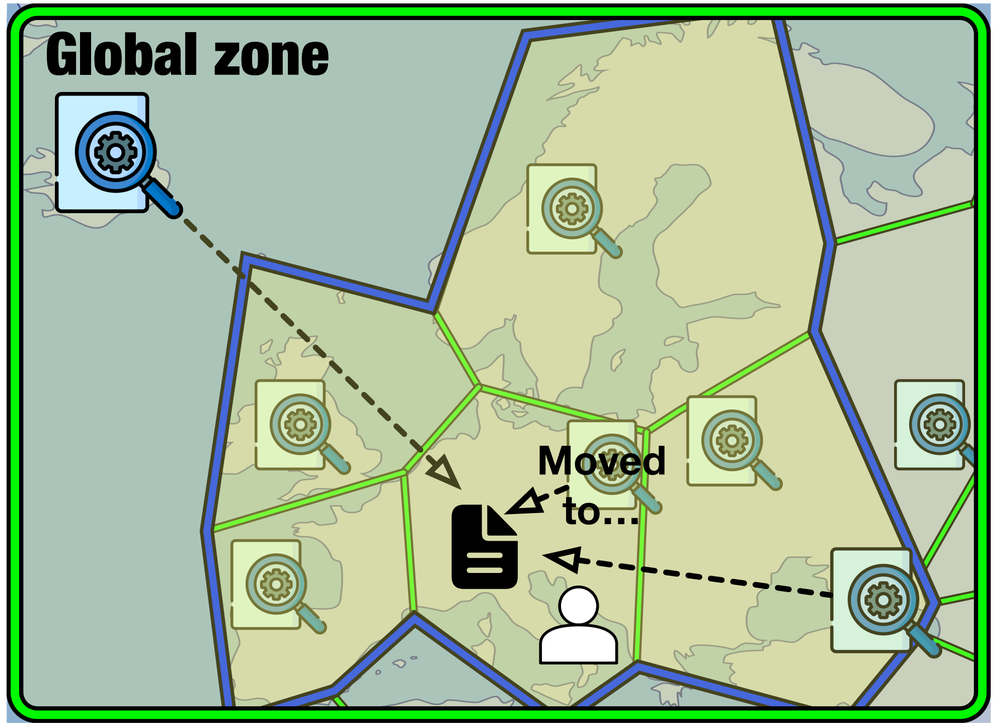

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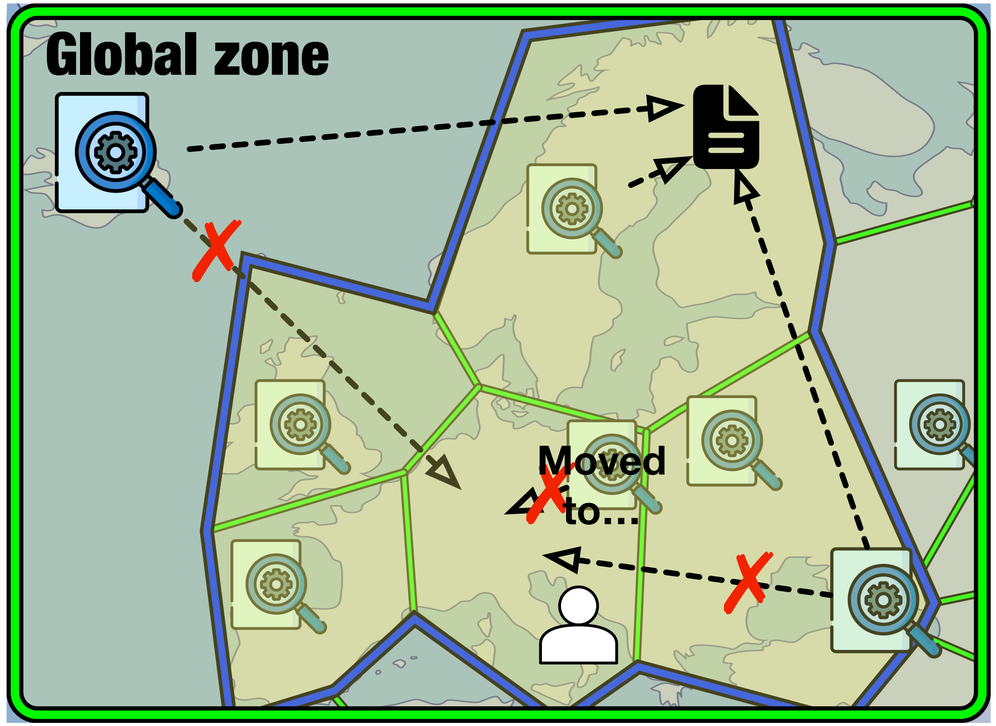

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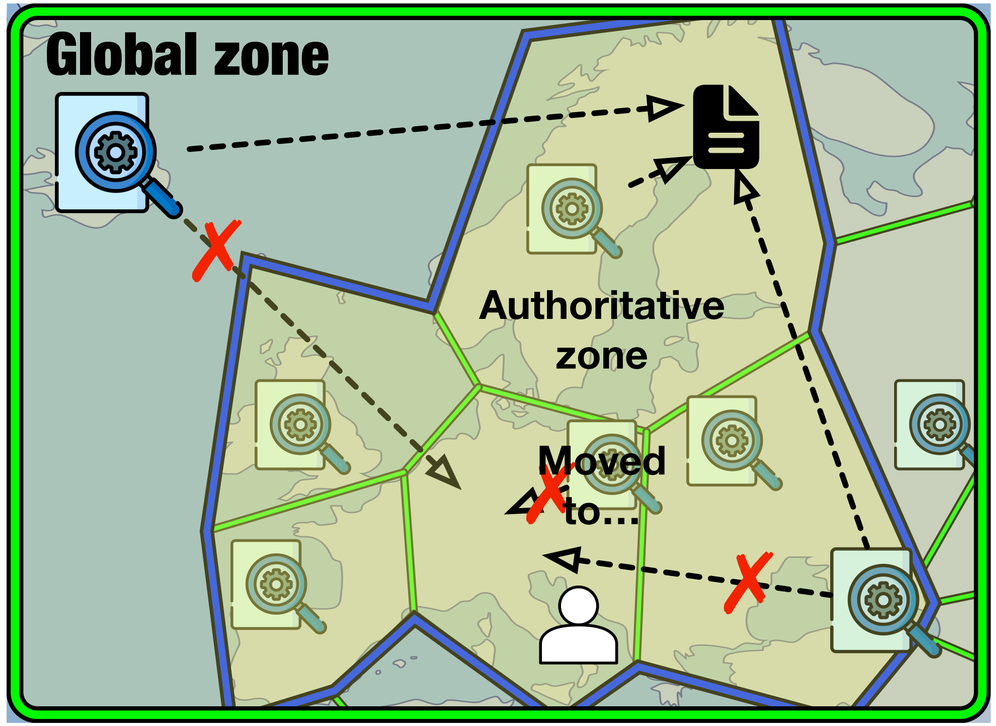

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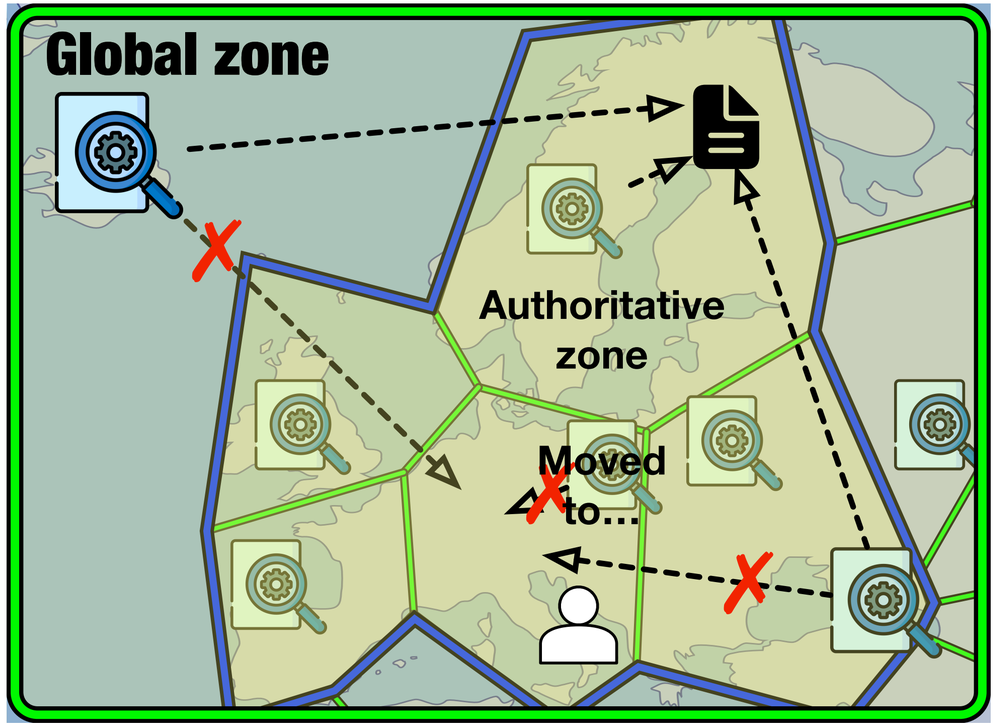

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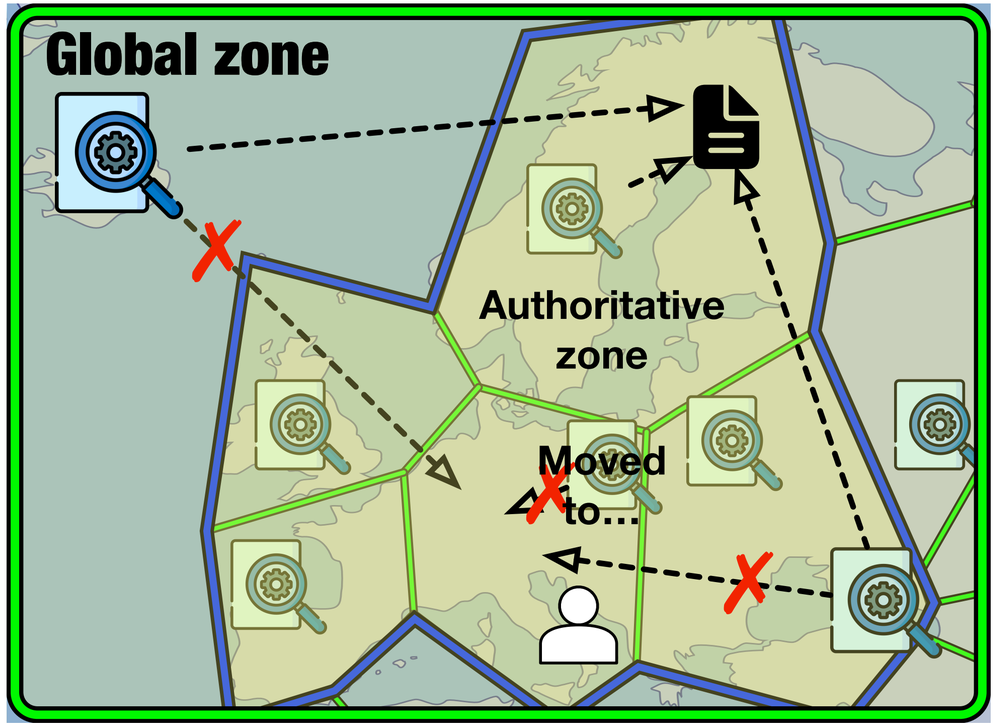

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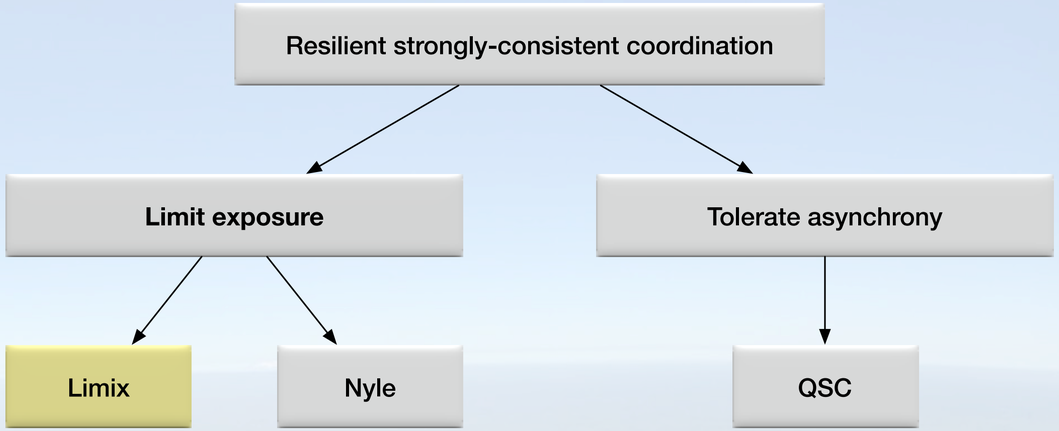
Solutions:
Pointer updates take place outside the critical path
Pointer versioning

Limix roadmap



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- Object administratively localized in a single region
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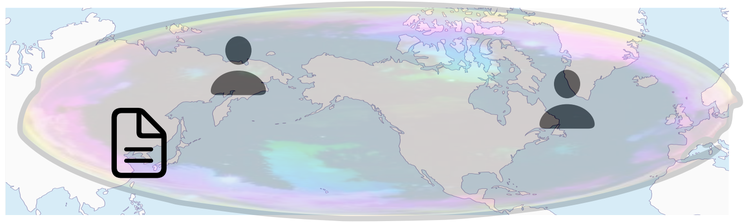
Private cloud

Geo replication



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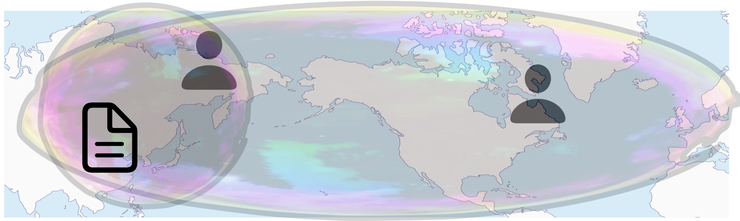

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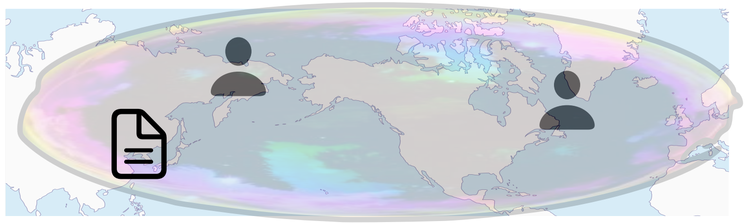

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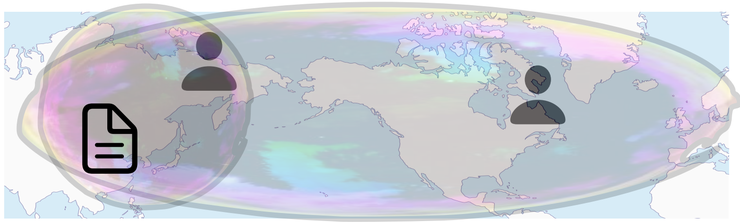

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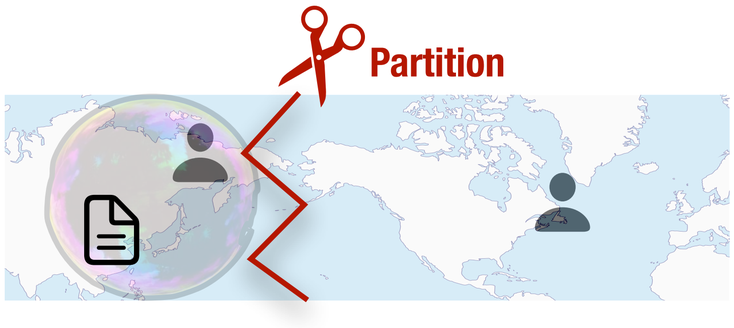

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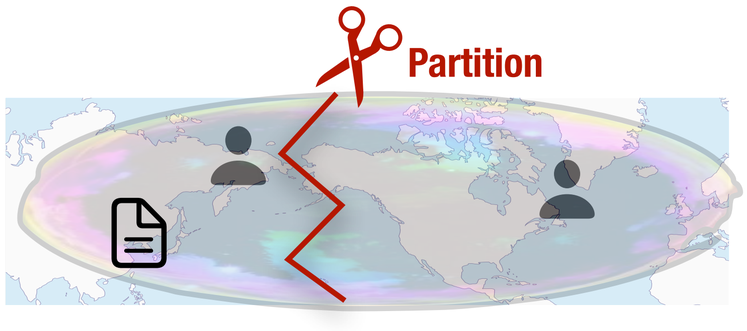

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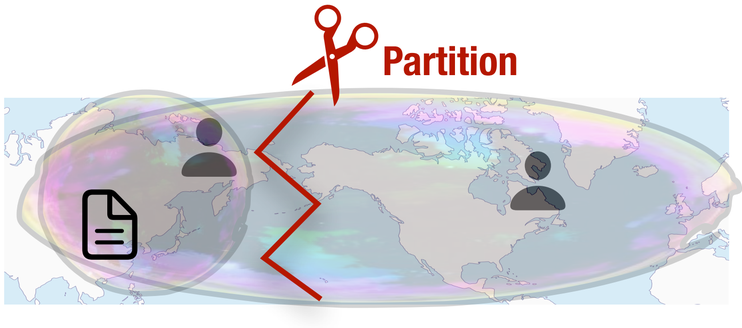

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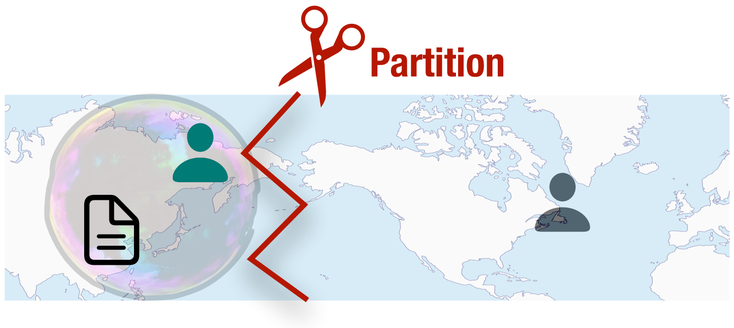

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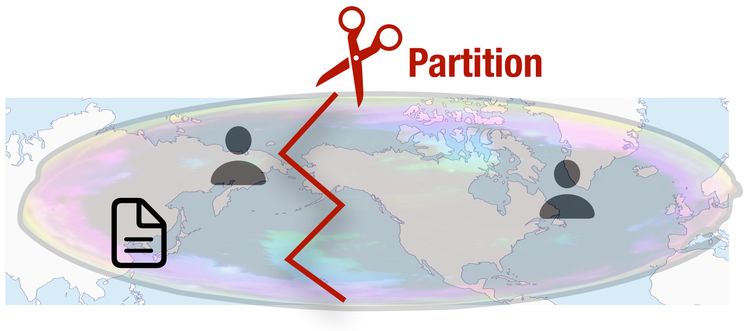

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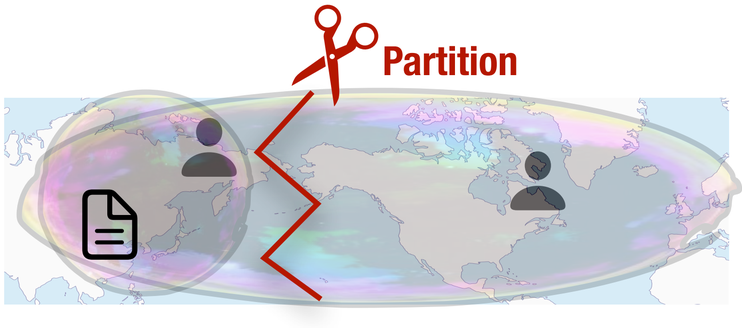

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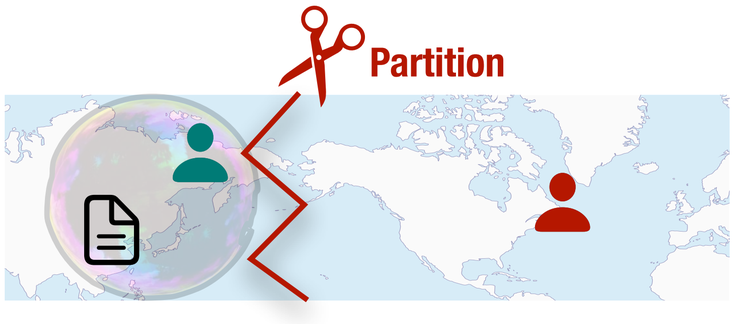

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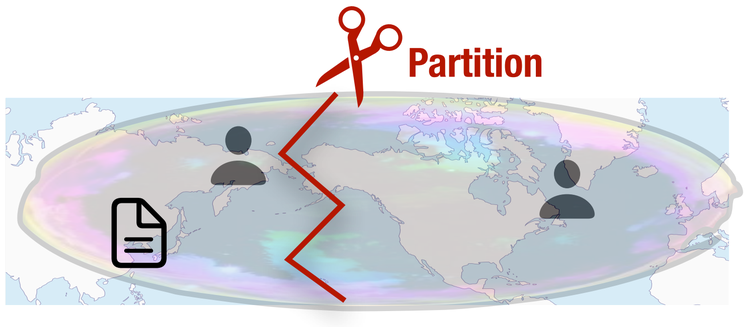

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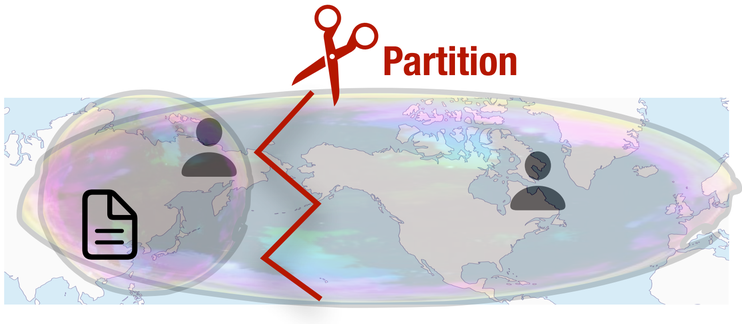

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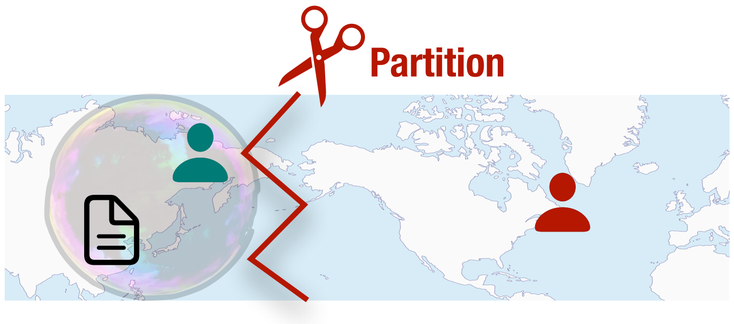

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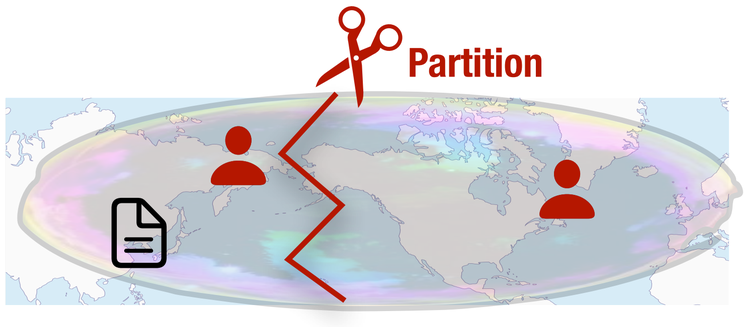

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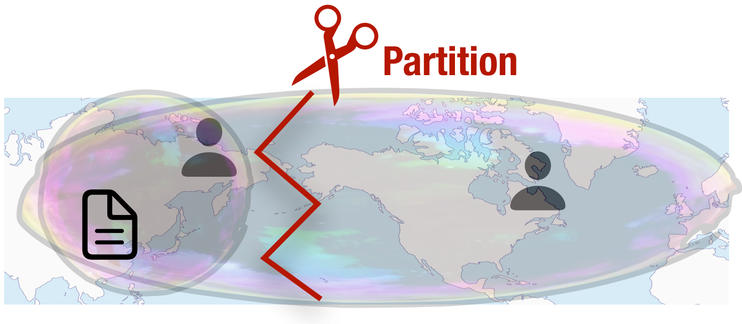

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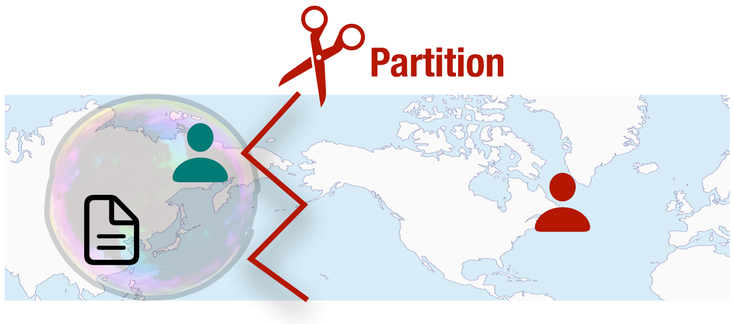

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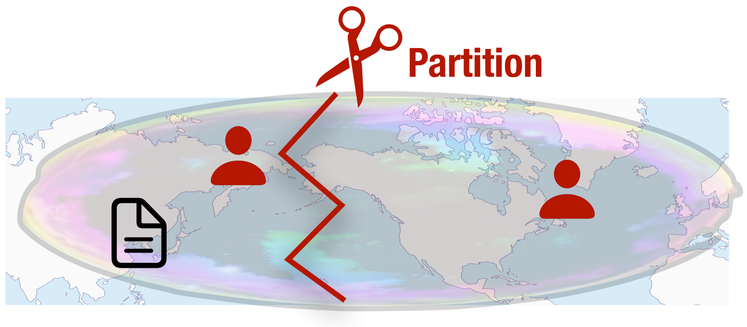

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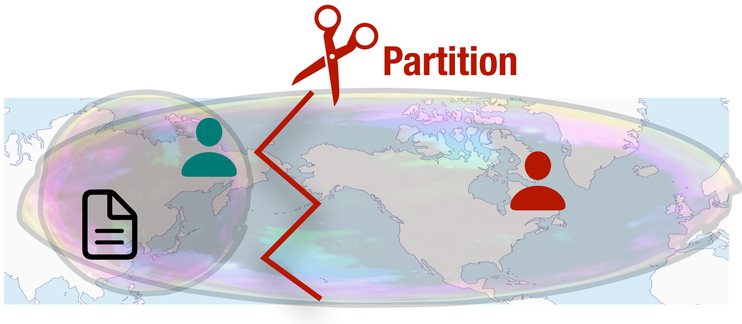

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- **Cost per extra region deployed**
- Synthetic workload of 2000 ops (Limix: 1000 x 2 zones)

Private cloud

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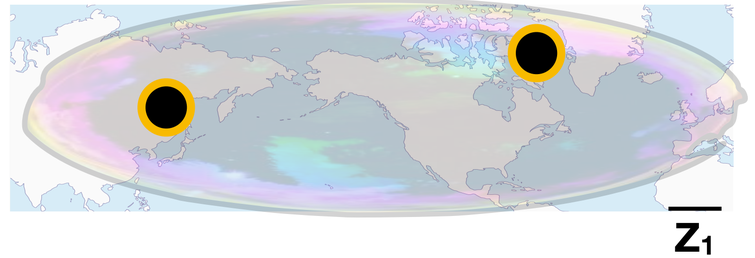

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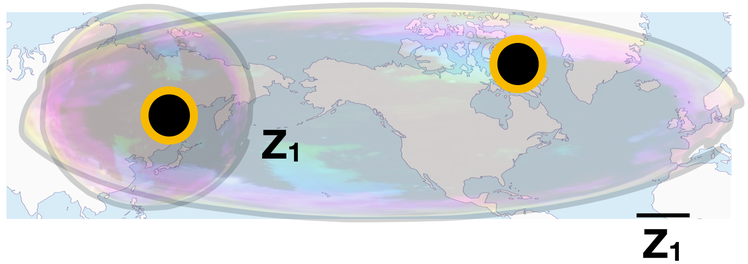

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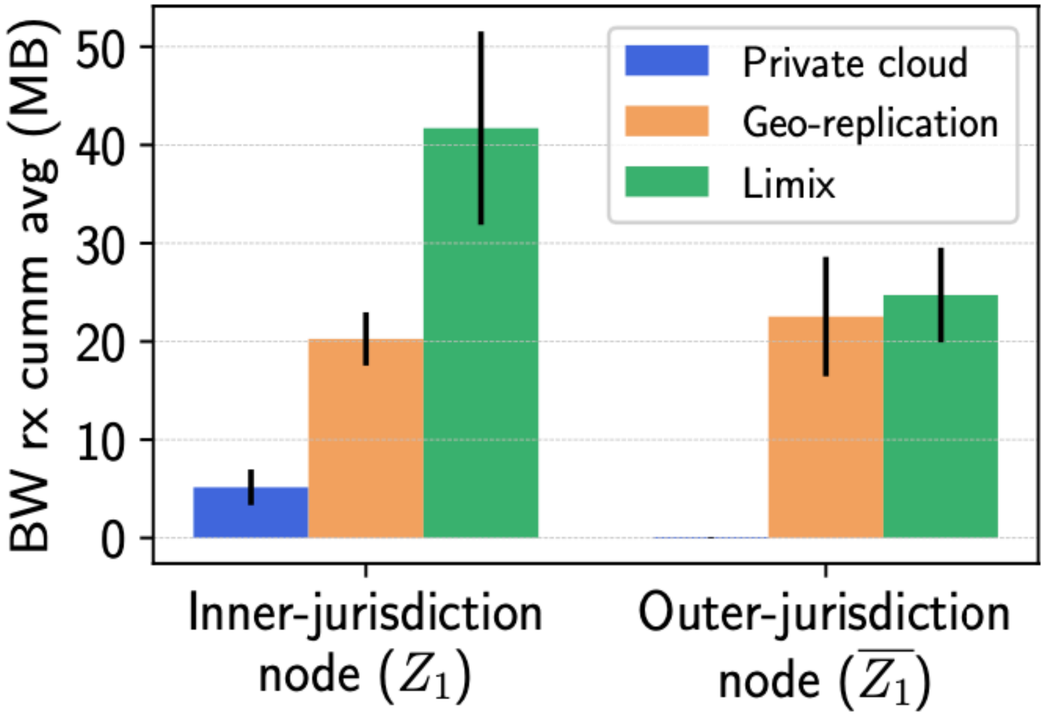

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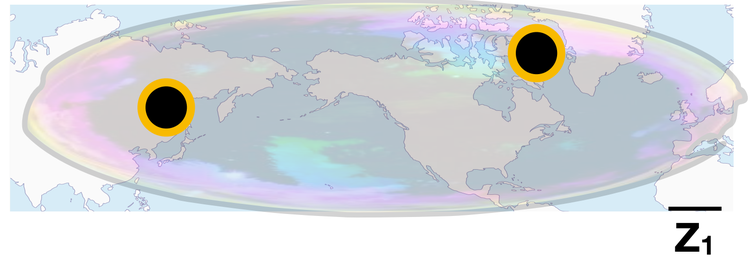

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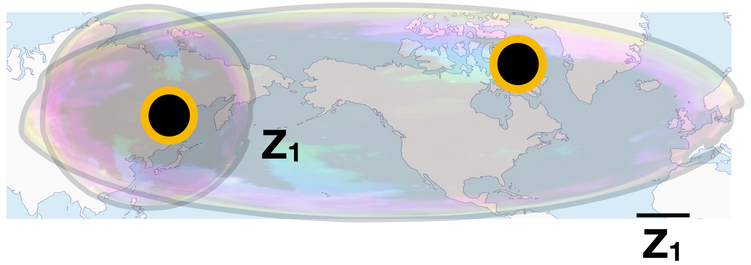

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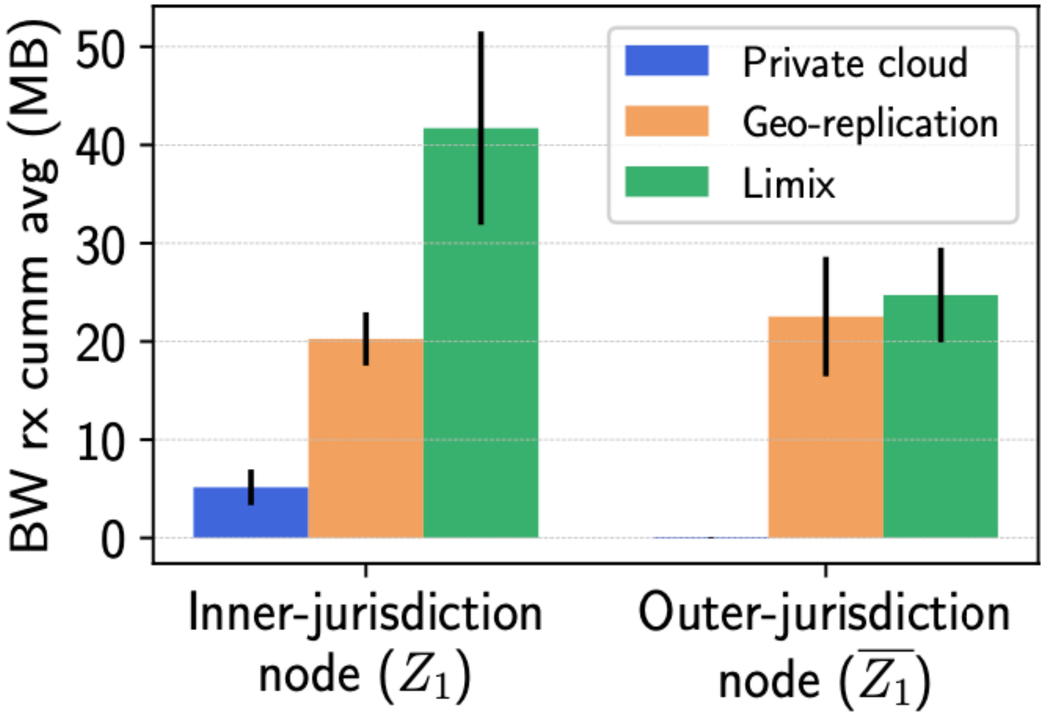

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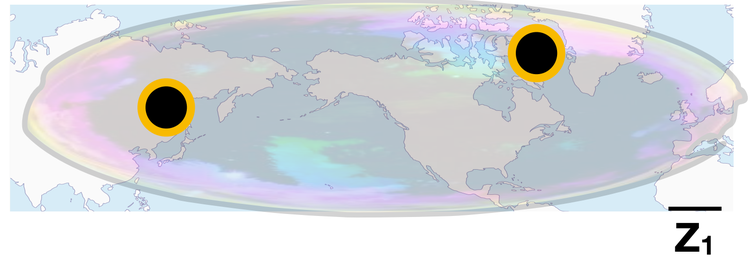

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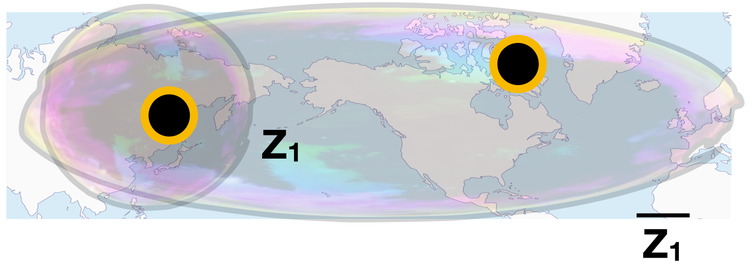
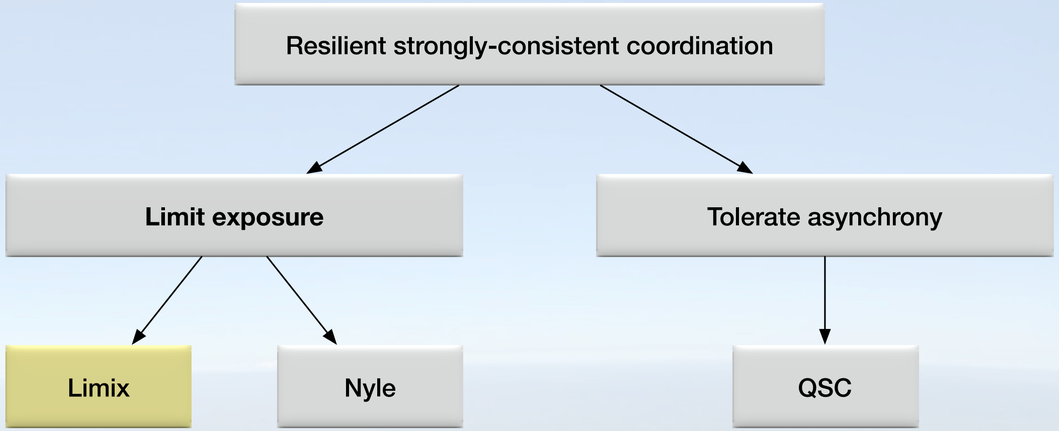


Suitable for a “pay-as-you-go” model

Limix roadmap



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- **Do far away failures affect accesses?**

- **20 AWS sites**: N America, Europe and Asia-Pacific; RTTs [0.43, 250.31] ms

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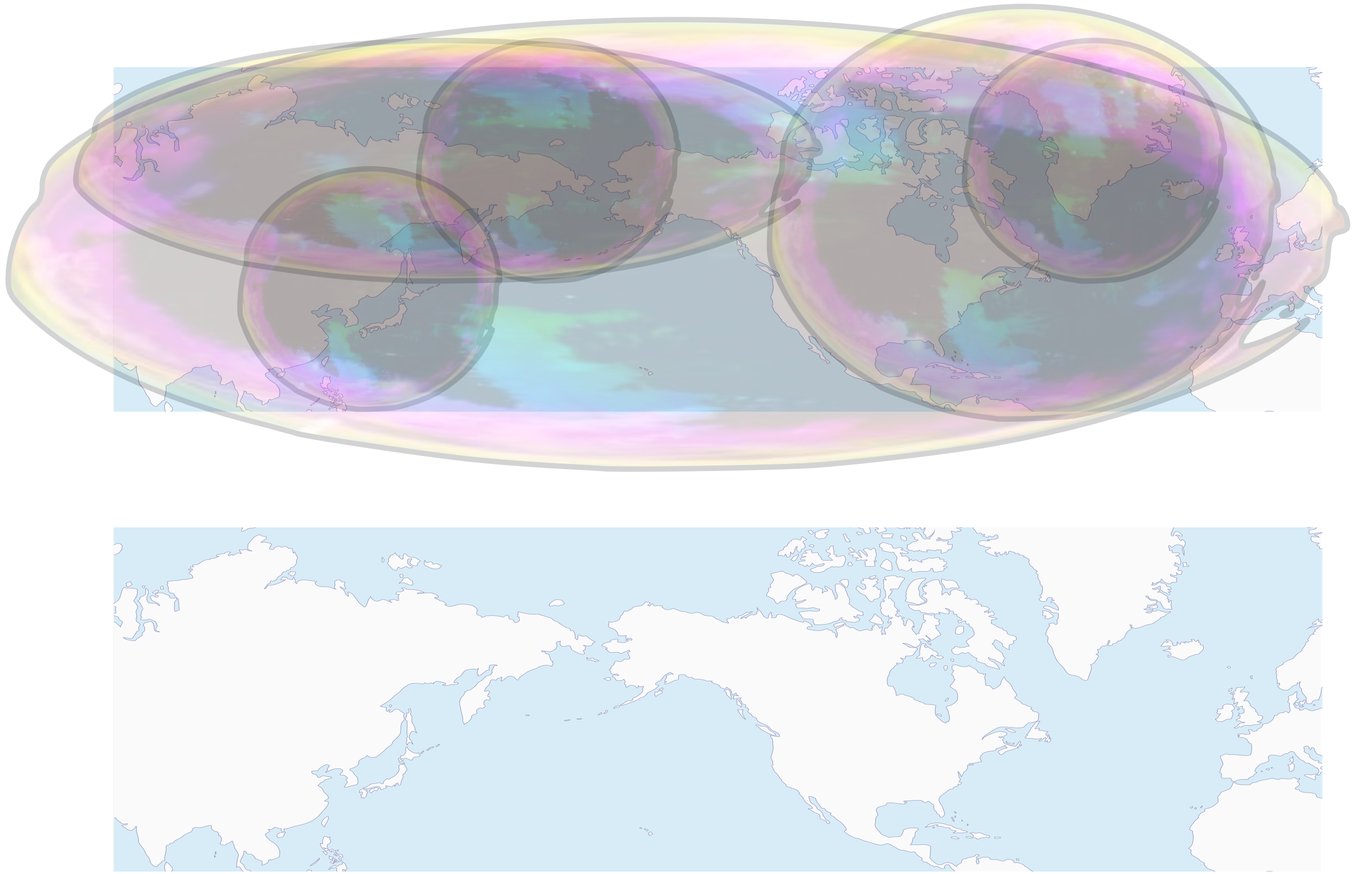

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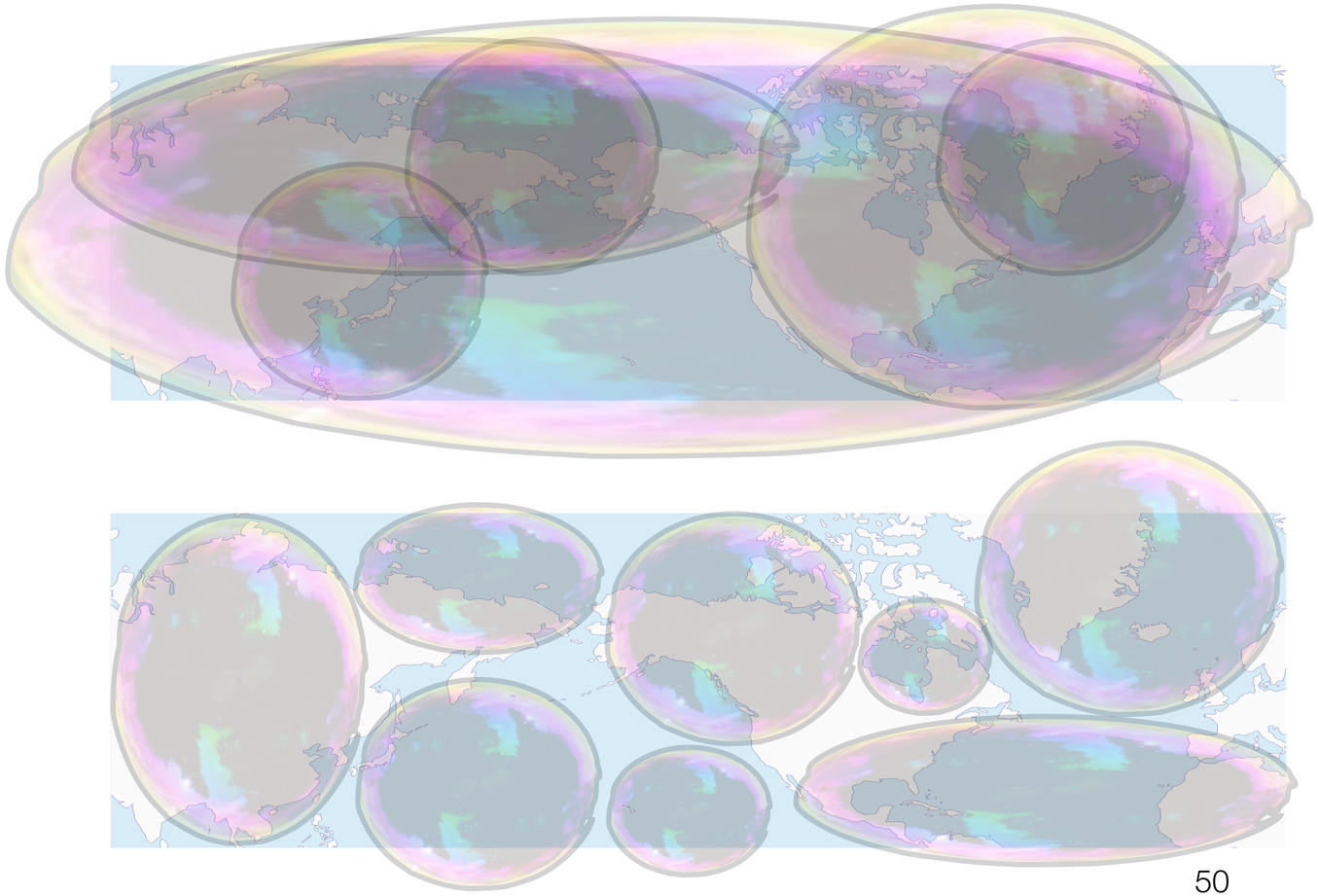

- **Limix RTT-based autozoning**
- **Physalia***
  - Cells of max 50ms RTT diameter

*Marc Brooker, Tao Chen, and Fan Ping. Millions of tiny databases. In *Conference on Networked Systems Design and Implementation (NSDI)*, 2020.

Limix vs Physalia setup

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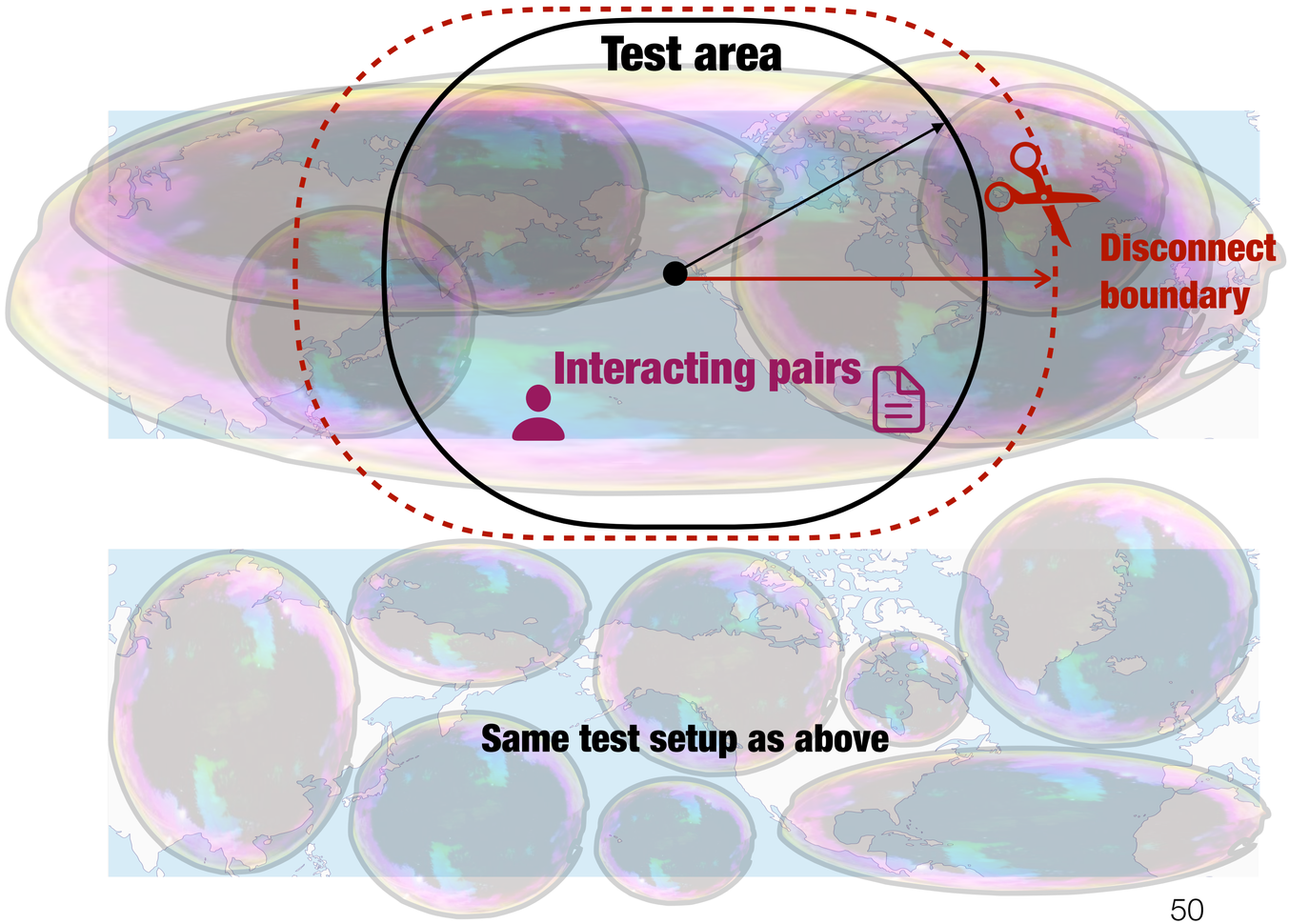

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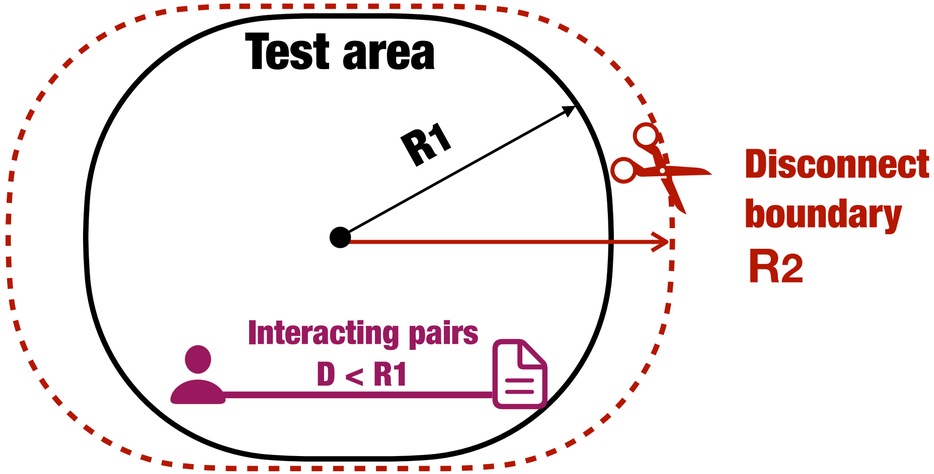

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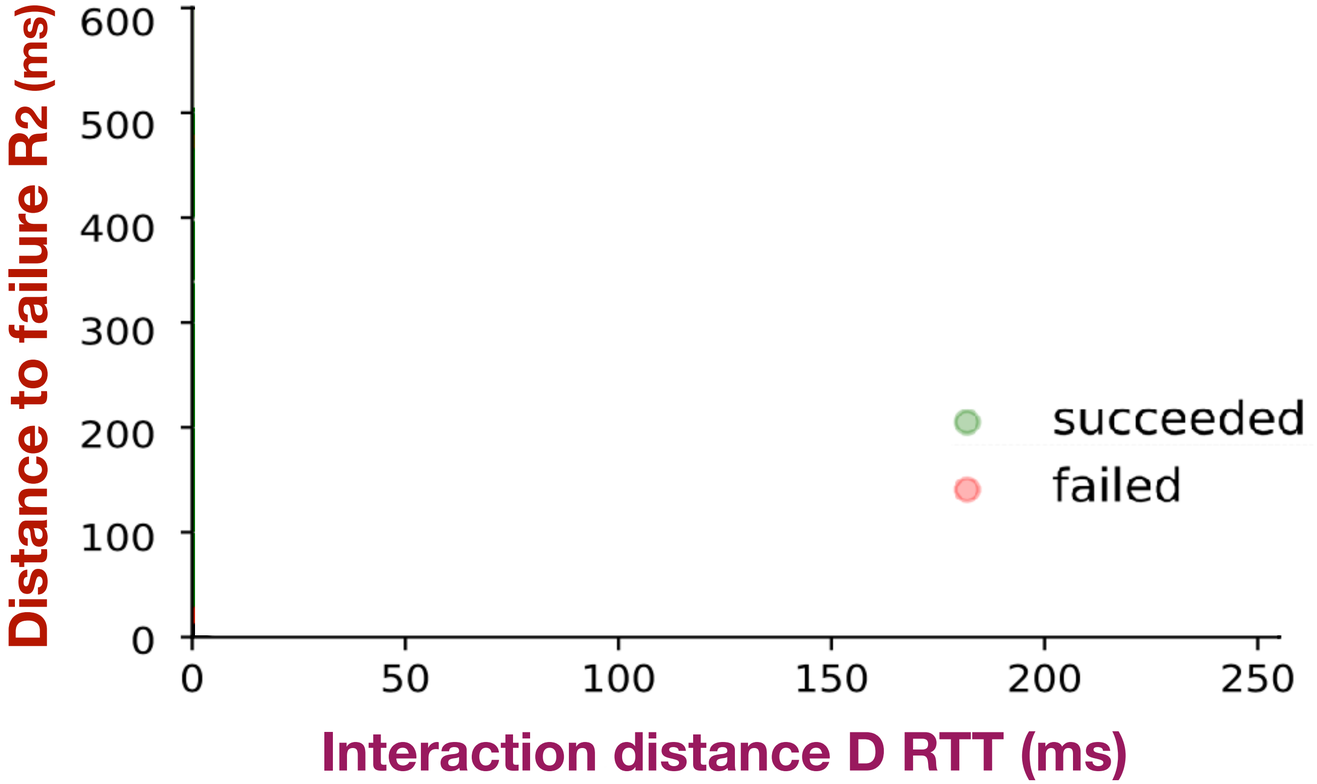

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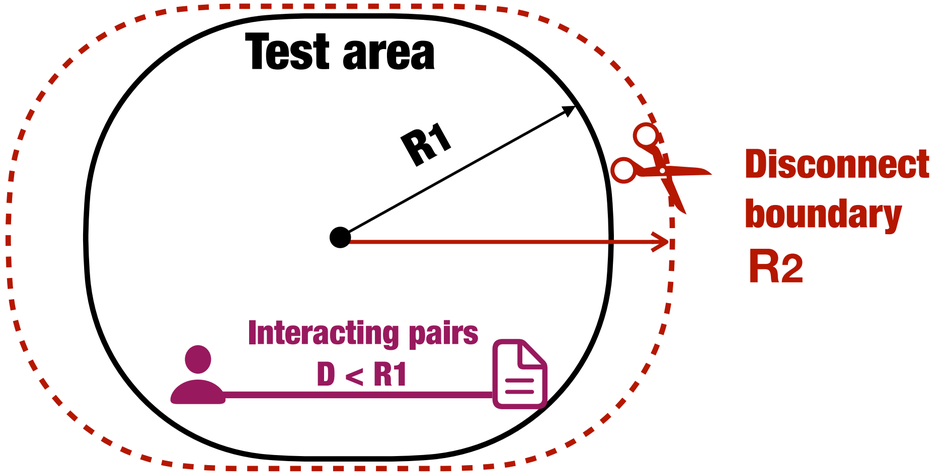

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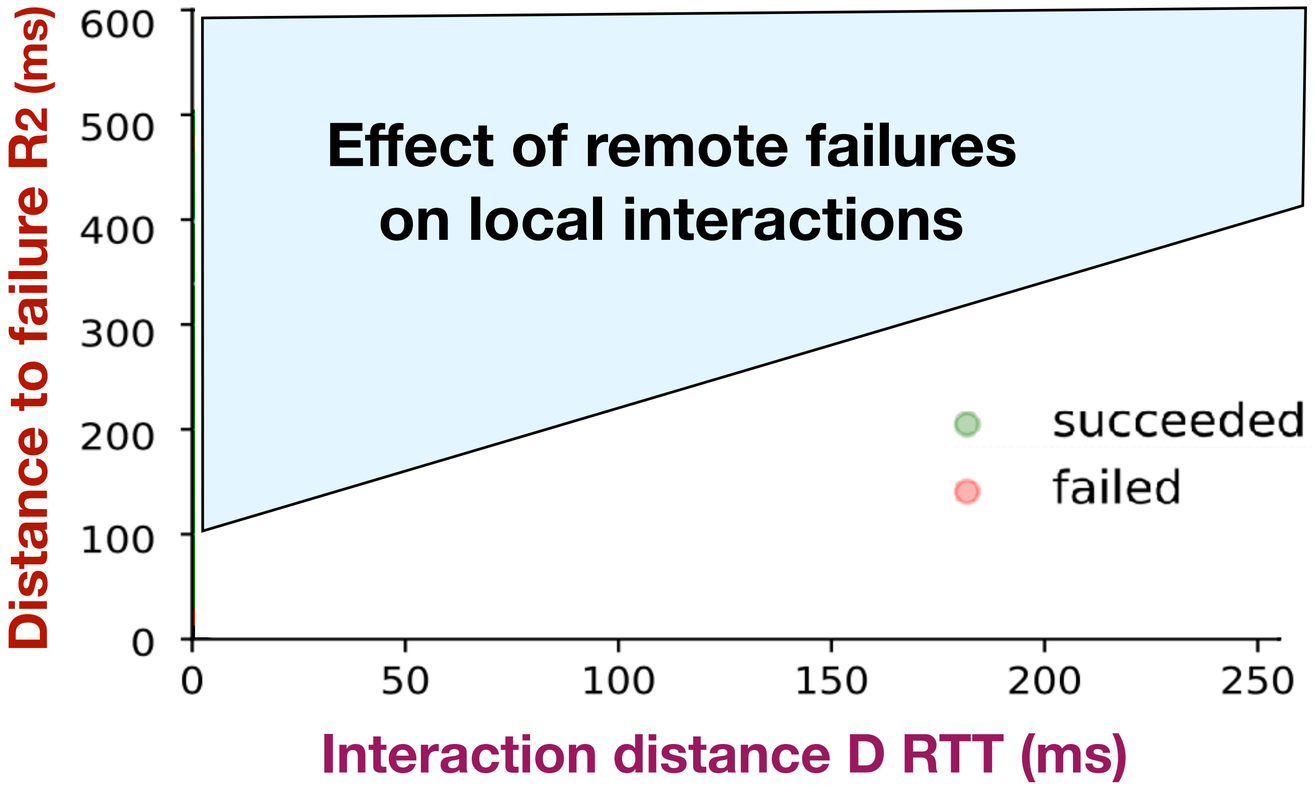

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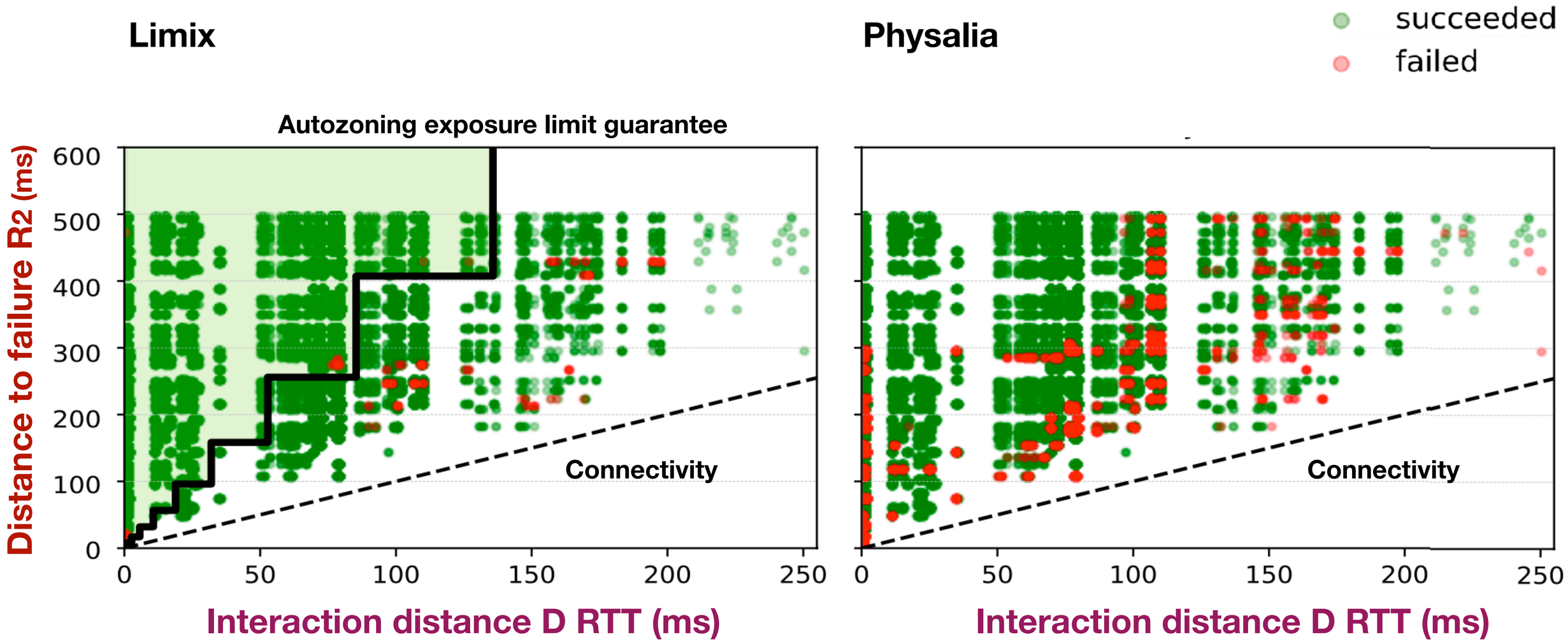
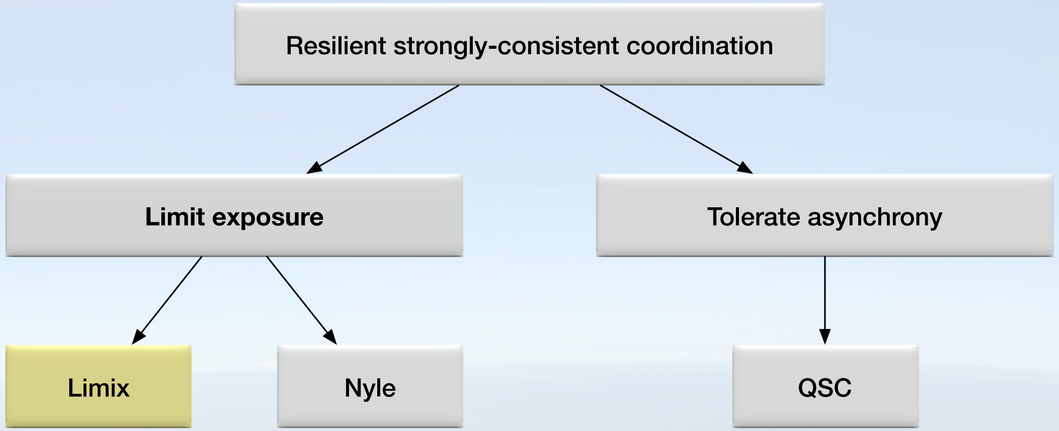


Limix roadmap

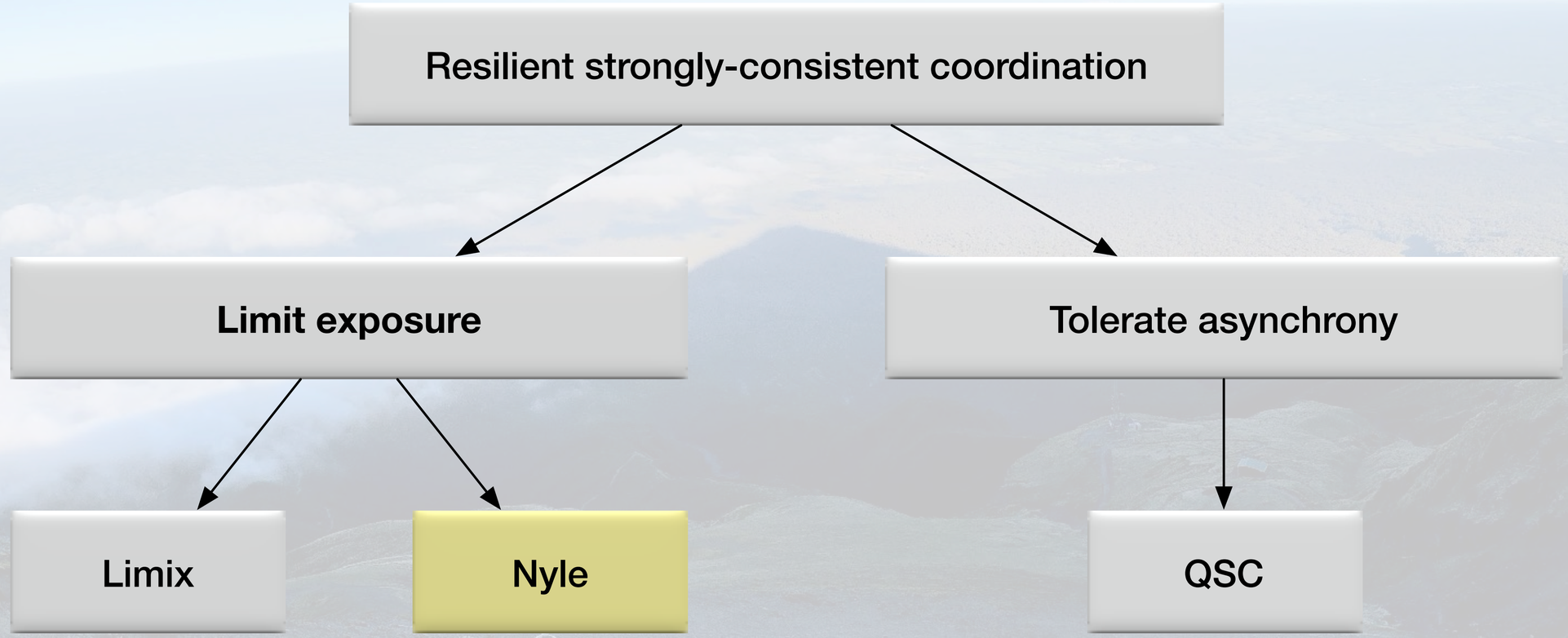


- The problem: exposure of data lookup
- Design of exposure-limiting metadata service
- Strongly-consistent item lookup
- Architecture
- Evaluation
- **Summary**

Limix summary

- **Global metadata service that protects local accesses from distant failures**
  - Suitable for strongly consistent data planes
- **Pay-as-you-go administrative zone deployment**
- **RTT-based autozoning outperforms related work**

Thesis roadmap



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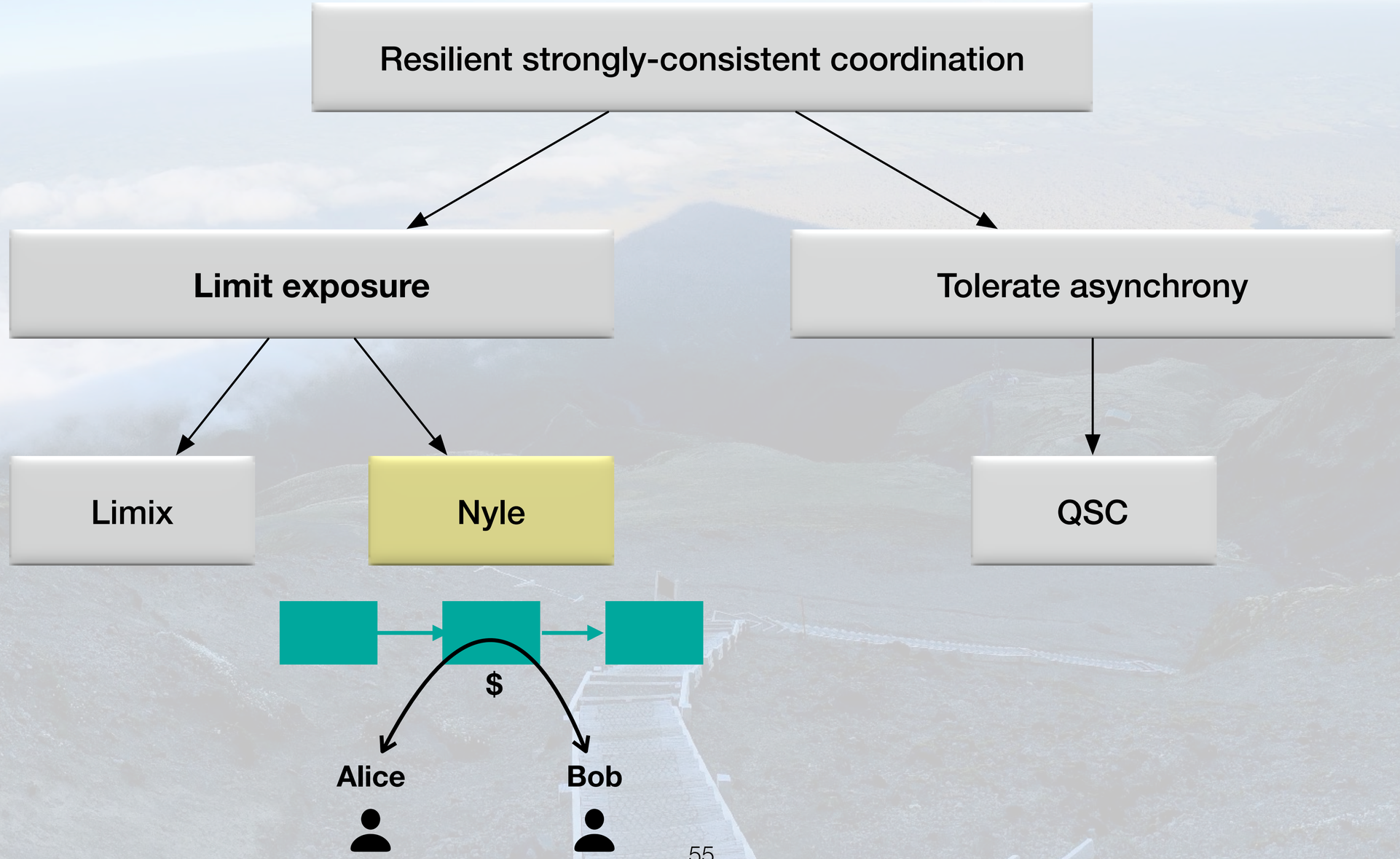
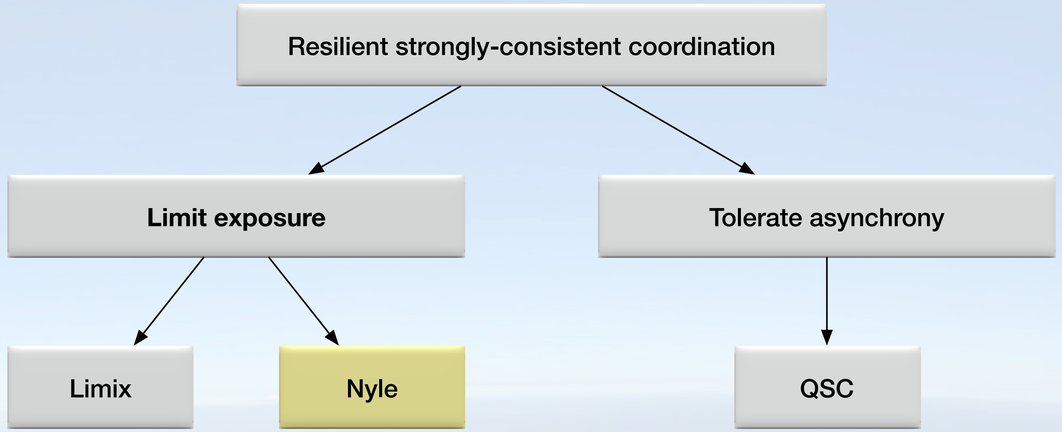


Nyle roadmap



- The problem: exposure-limiting distributed ledger
- Secure zoning with Byzantine validators
- A trust-but-verify design for transaction validation
- Multi-input multi-output transactions
- Clearance zone change and censorship attacks
- Simulation
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Nyle roadmap

- **The problem: exposure-limiting distributed ledger**
  - Motivation
  - Setup and goals
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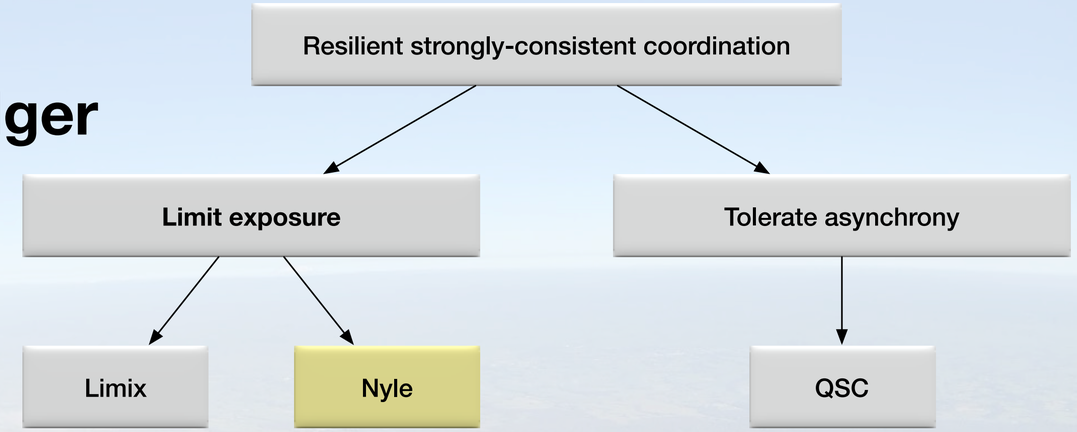
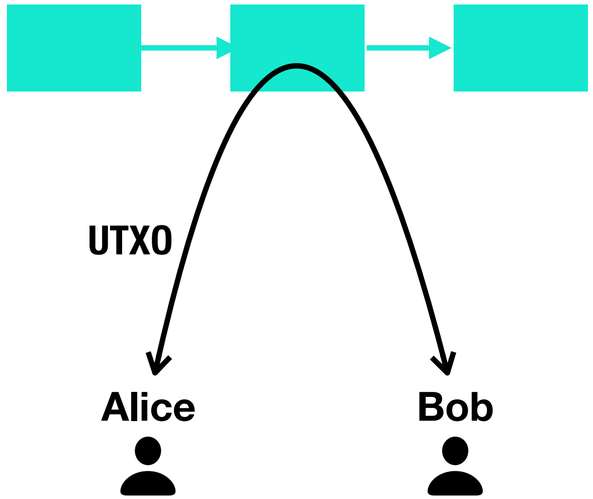
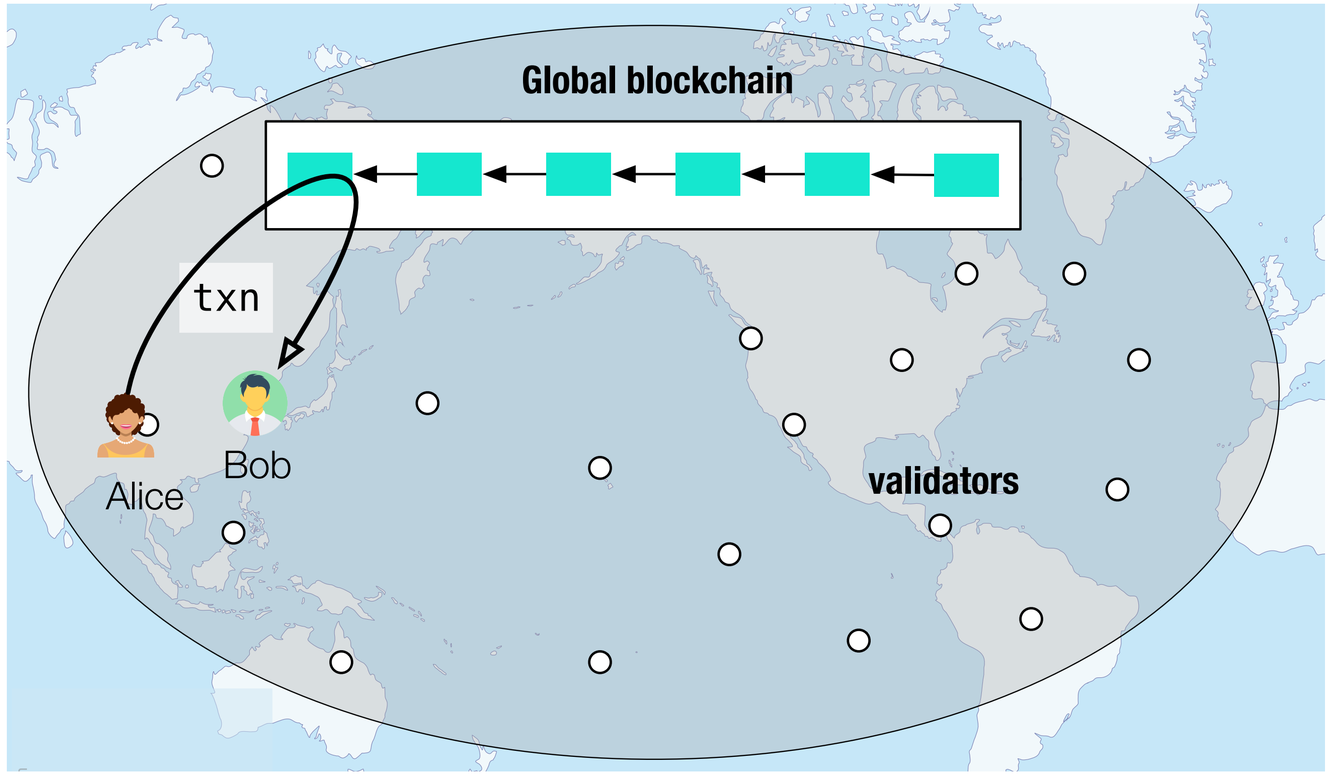


Distributed ledger





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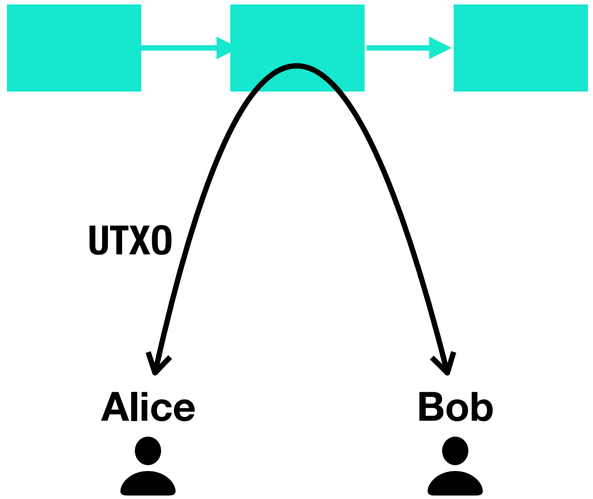
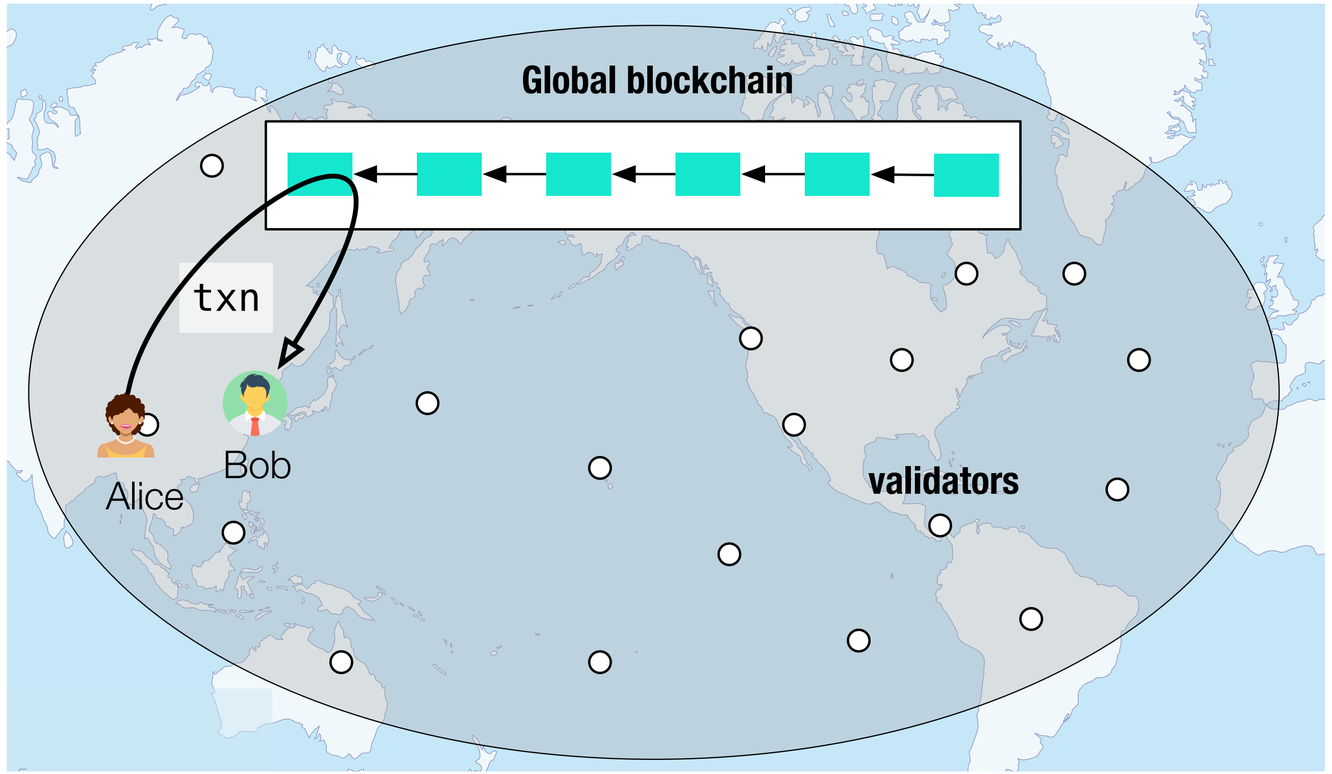
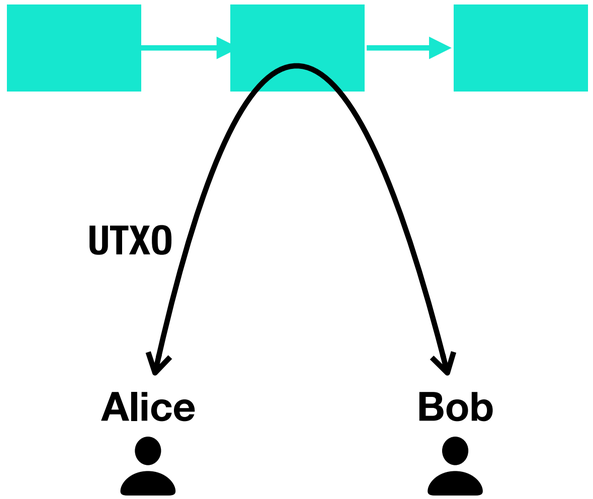
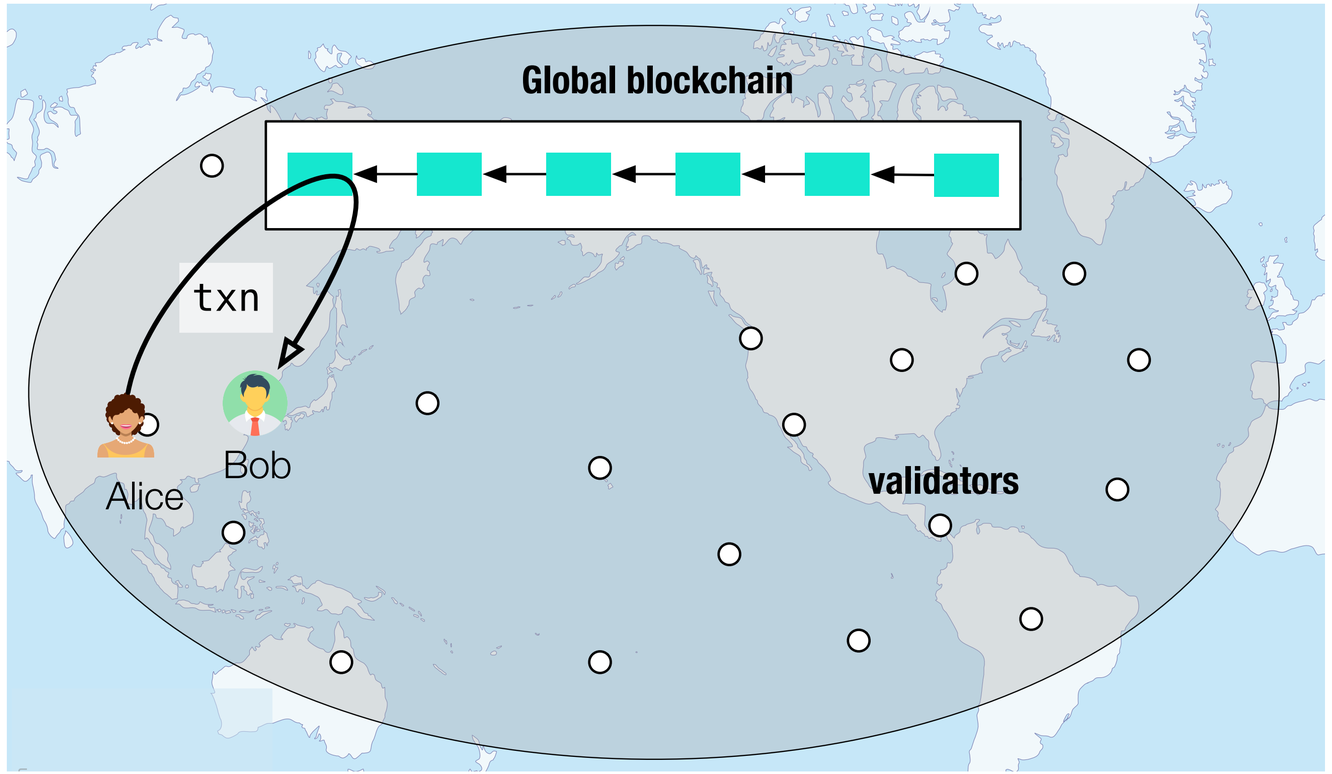




- **Many payments are localized**

Distributed ledger





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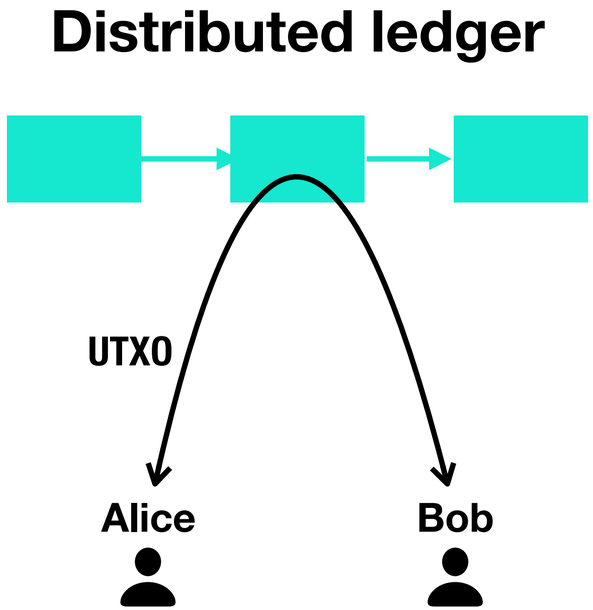

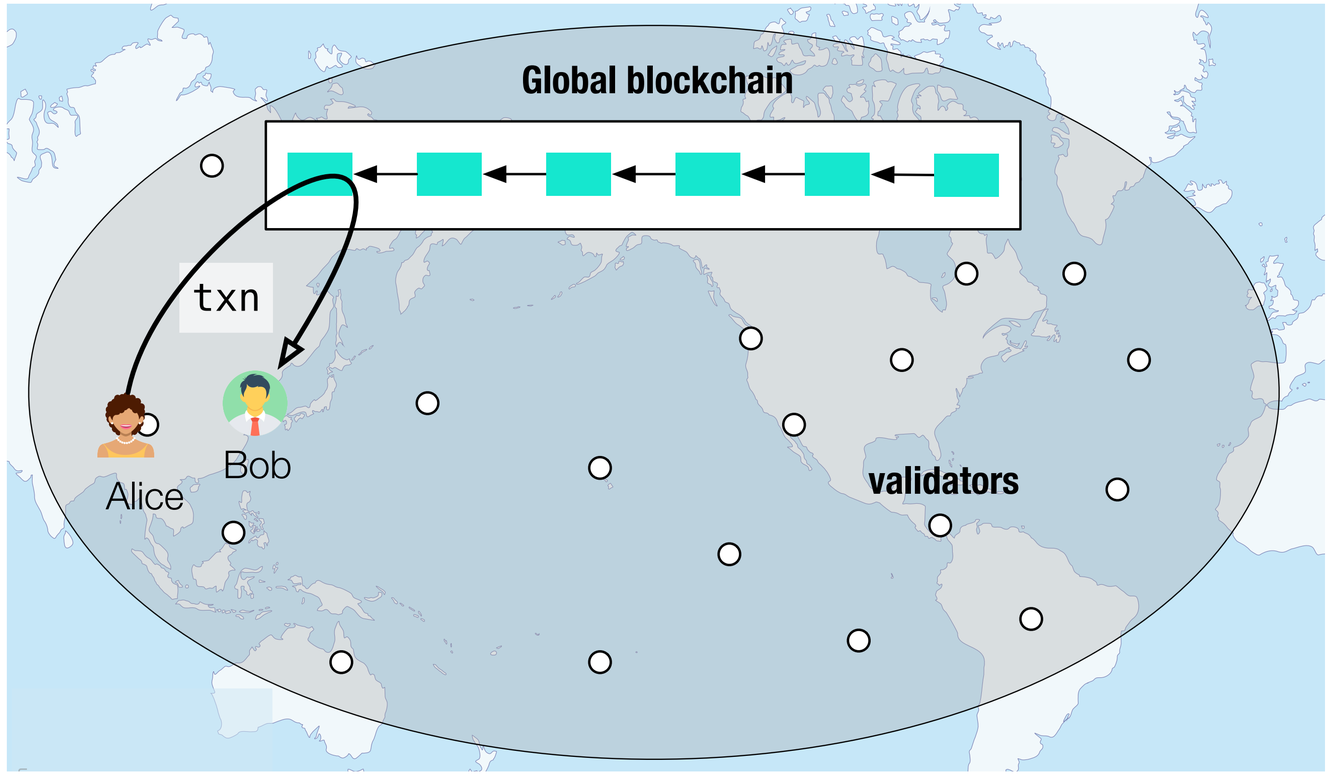

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Setup and goals

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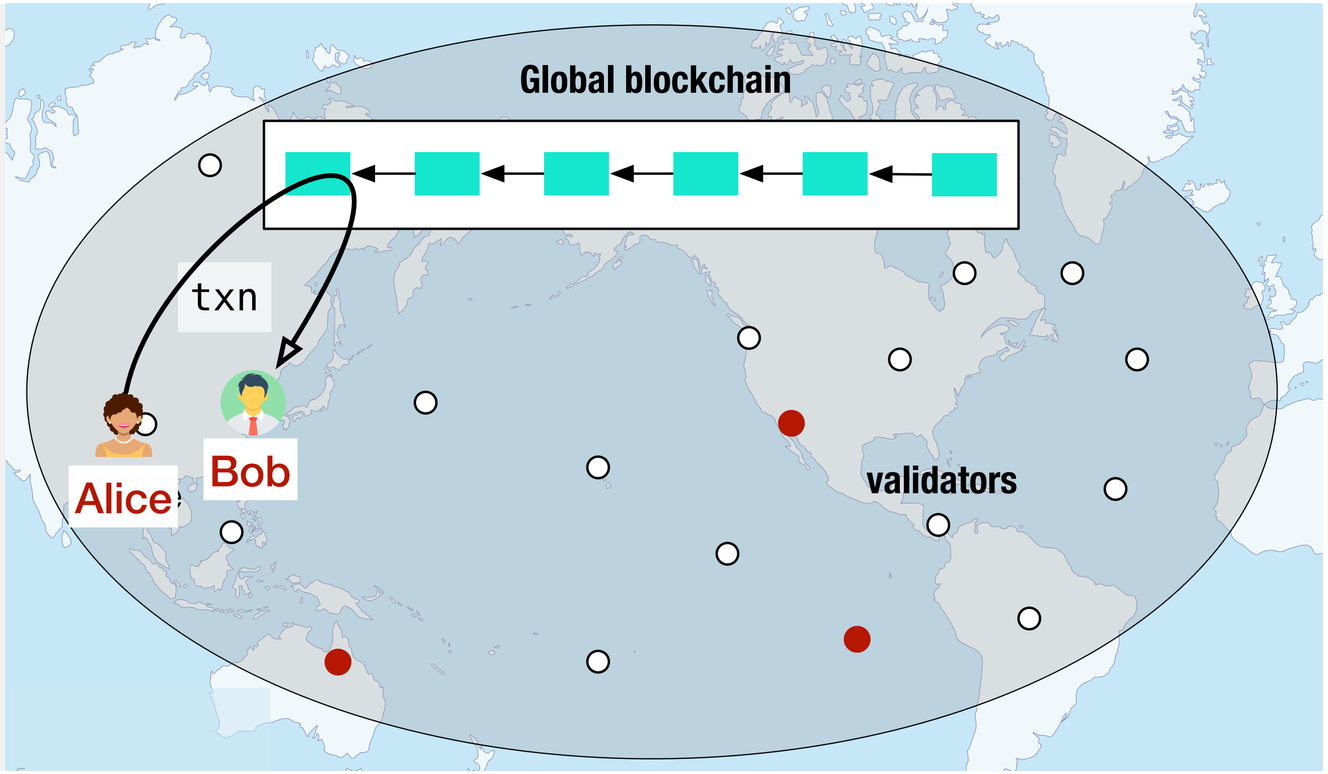

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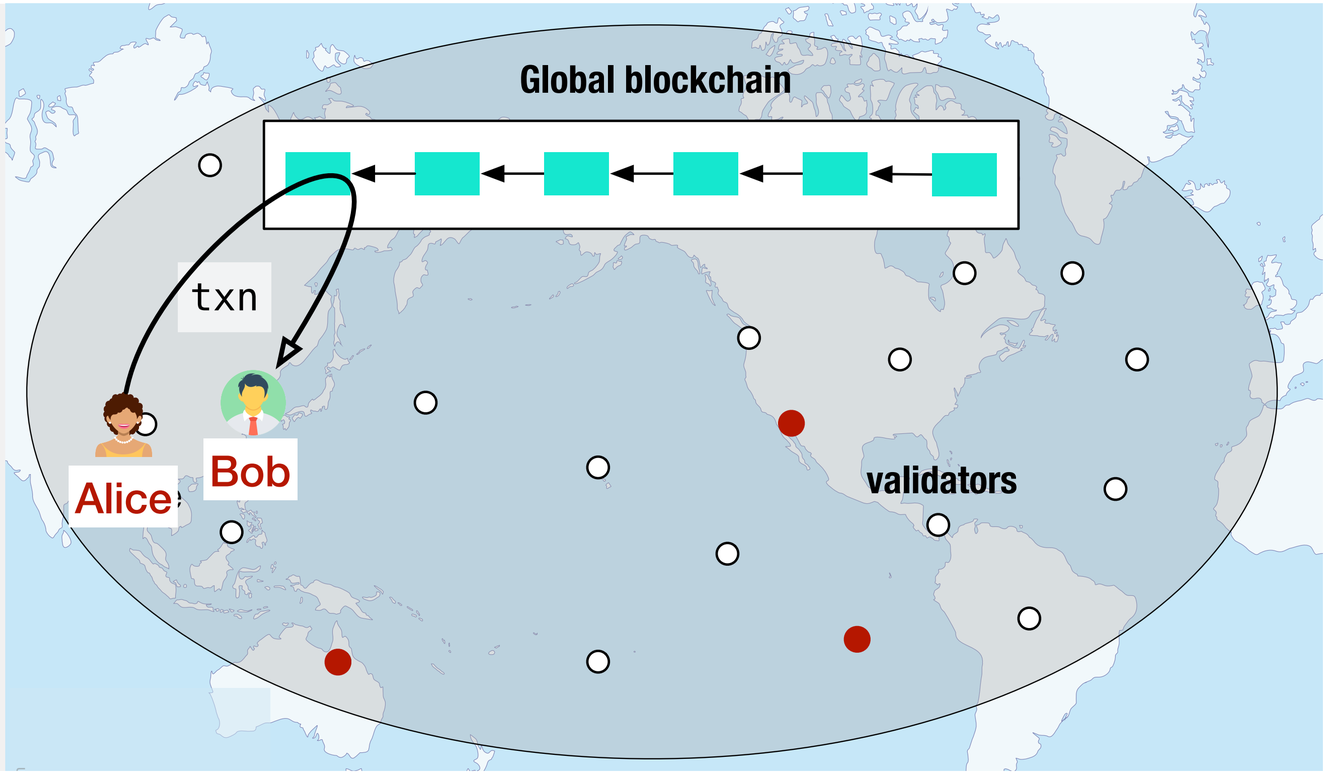

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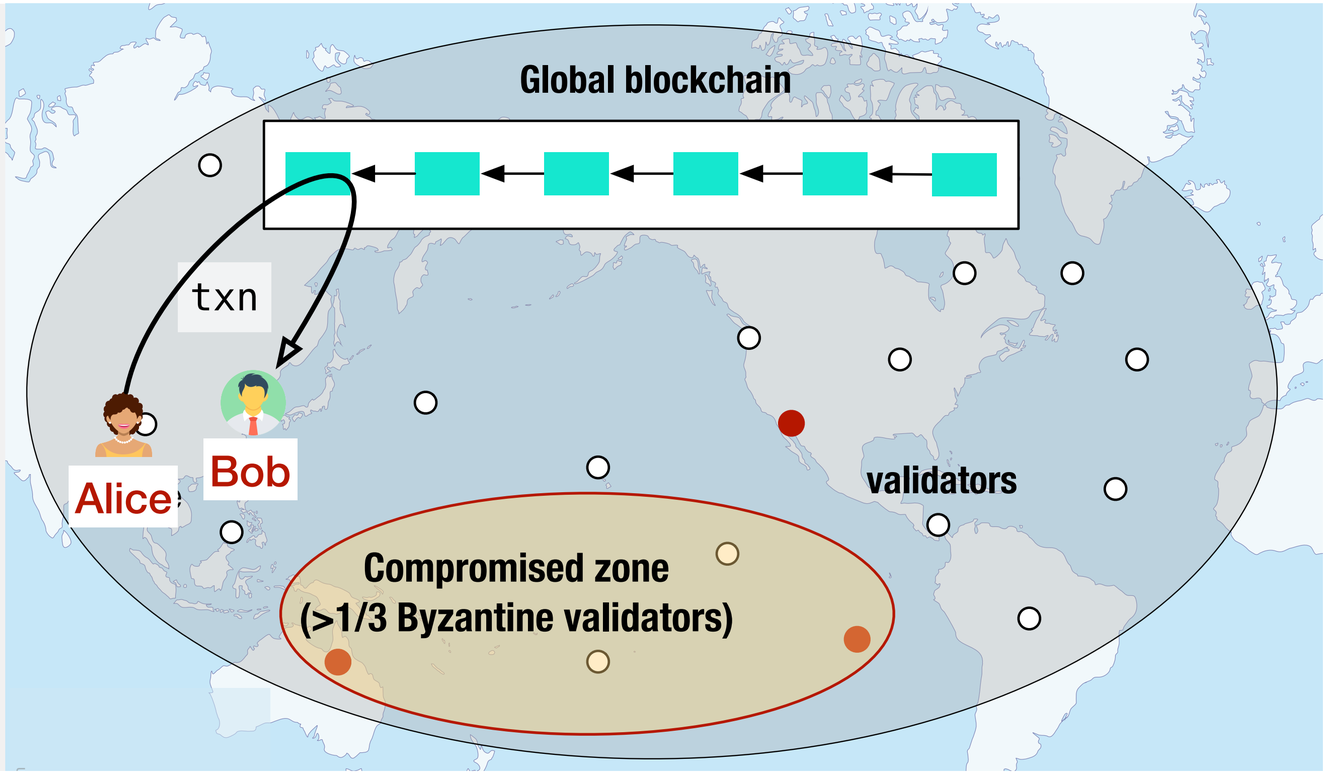

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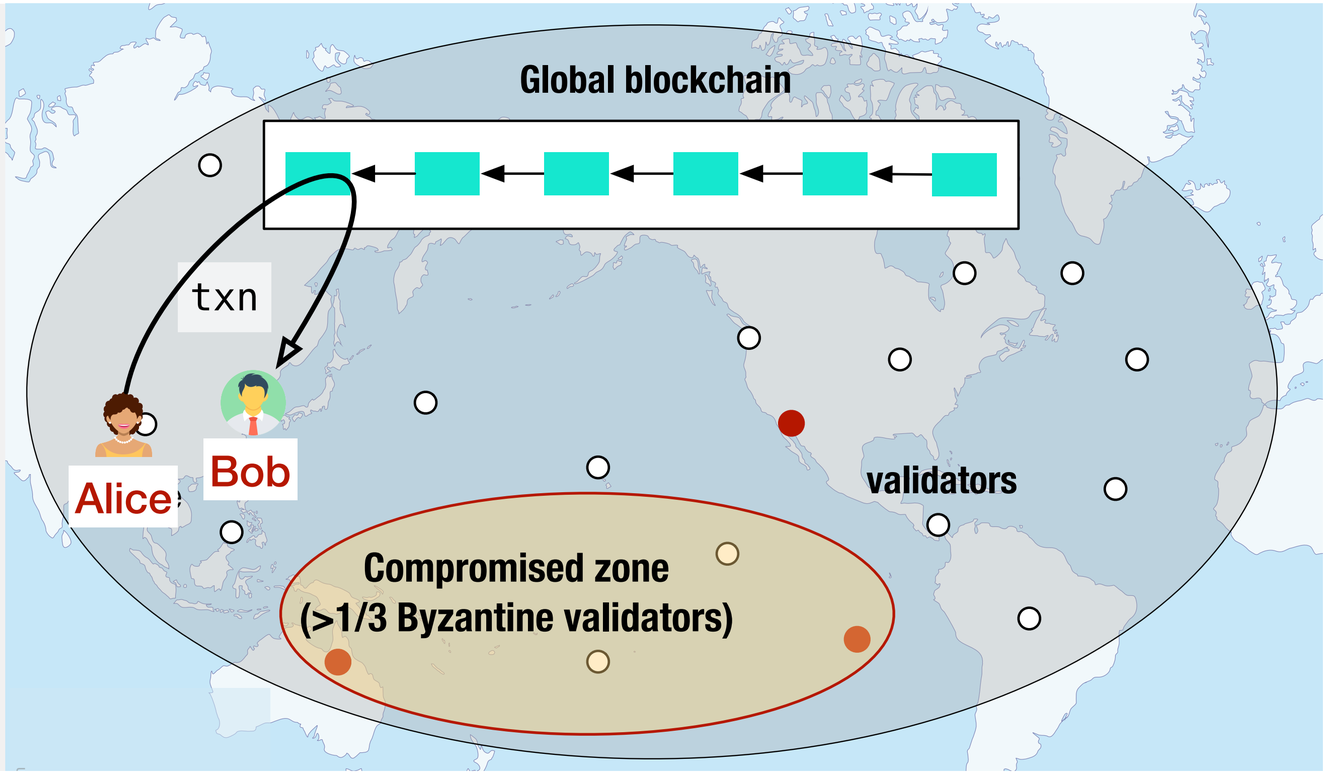
Client attacks	Validator attacks
Double spend	Approve double spend
Zone overload	Censor clients
	Craft its location



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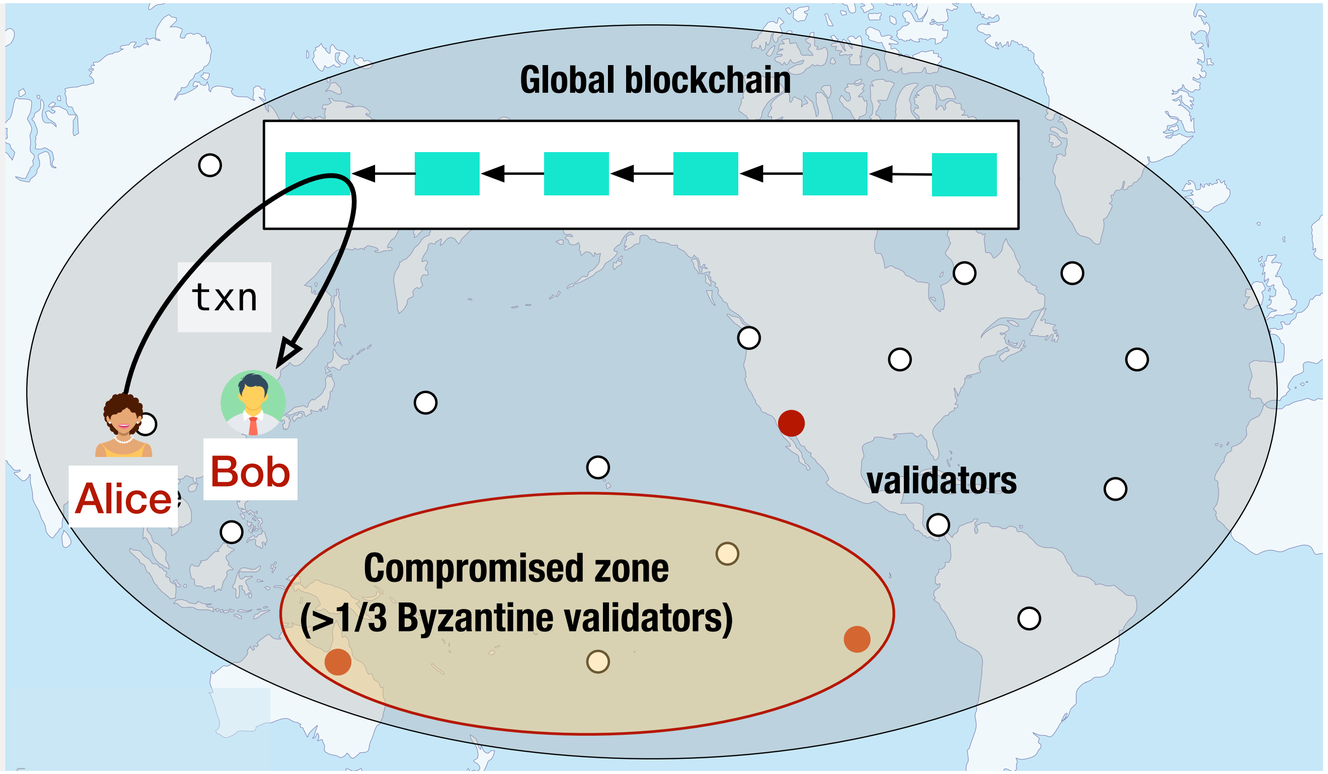

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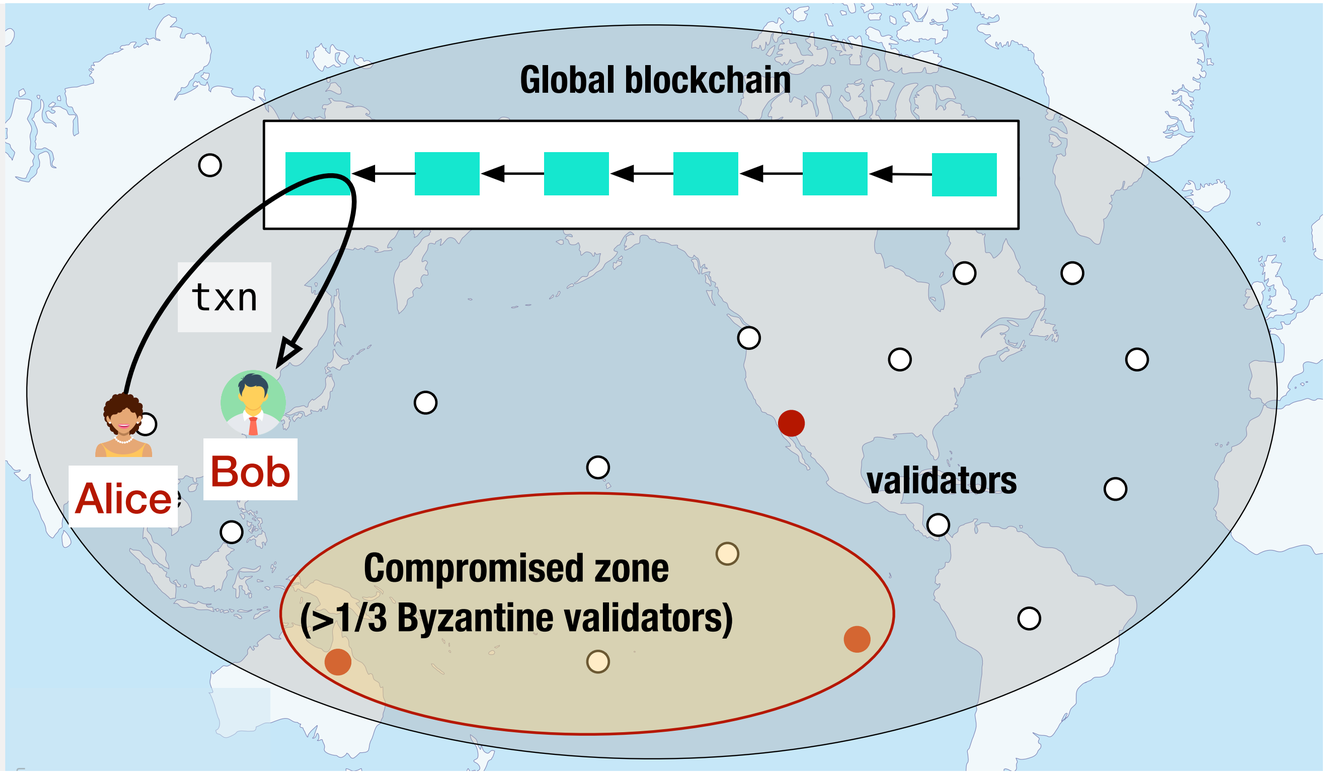

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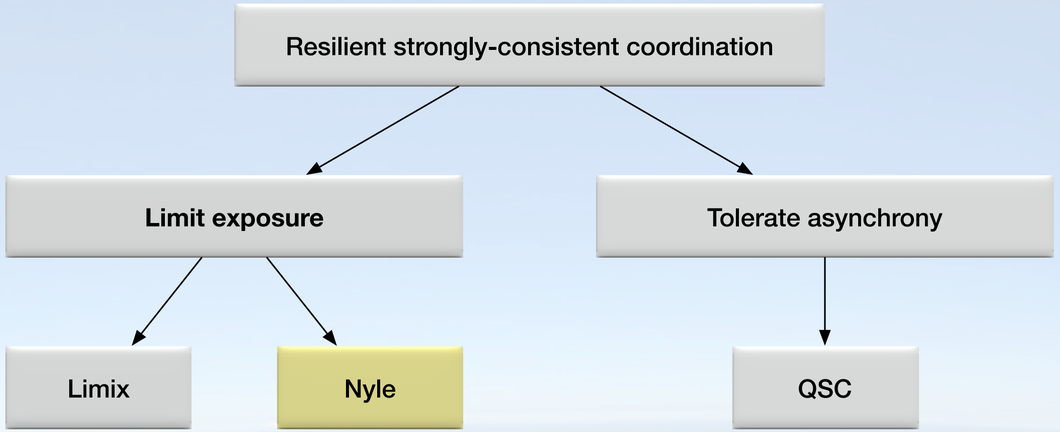

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- **A trust-but-verify design for transaction validation**
  - Exposing double-spending
  - Preventing zone overload
  - Joint sender-receiver control over exposure
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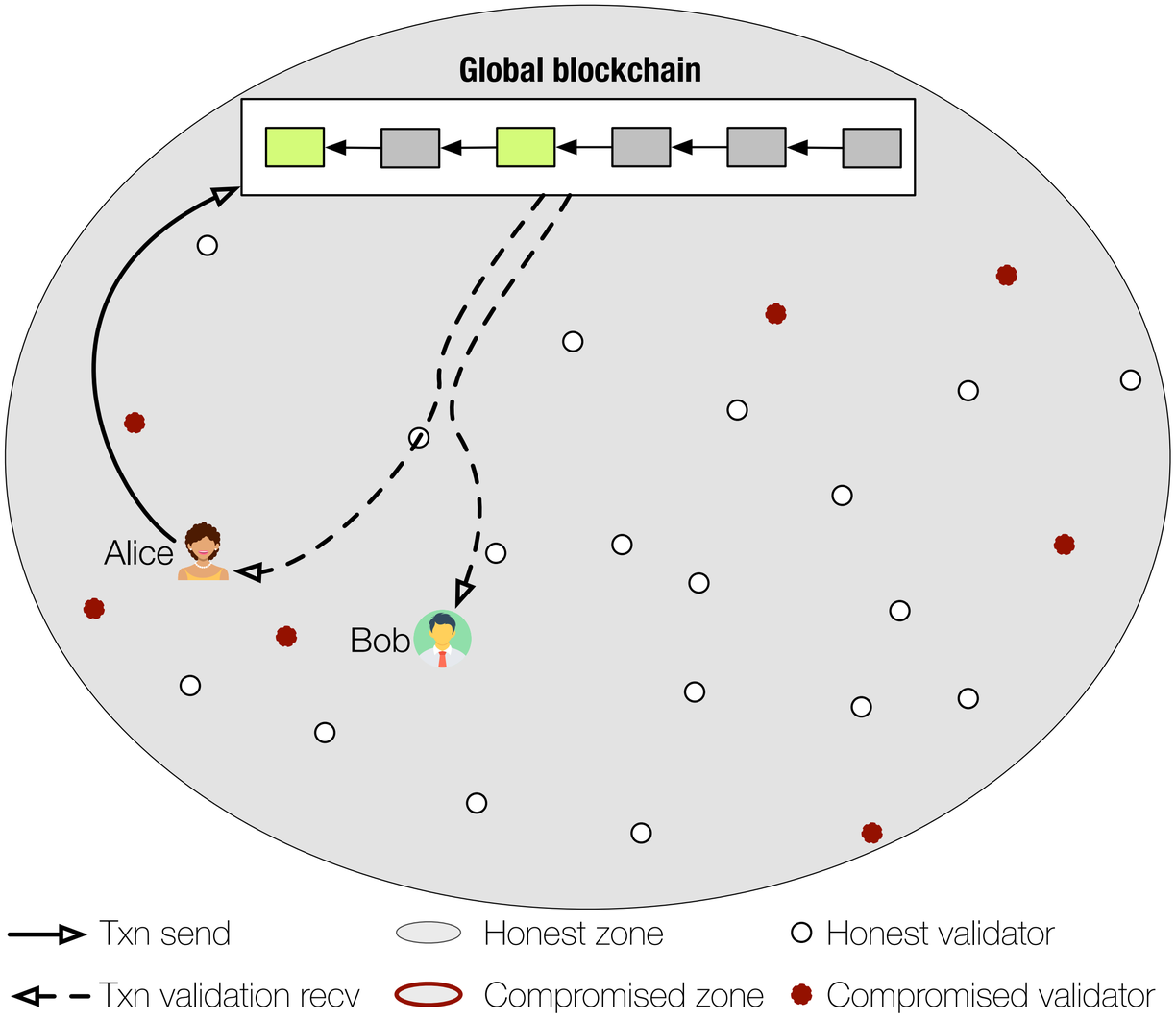
Trust-but-verify design



Global blockchain

Prevents double spending

No local availability

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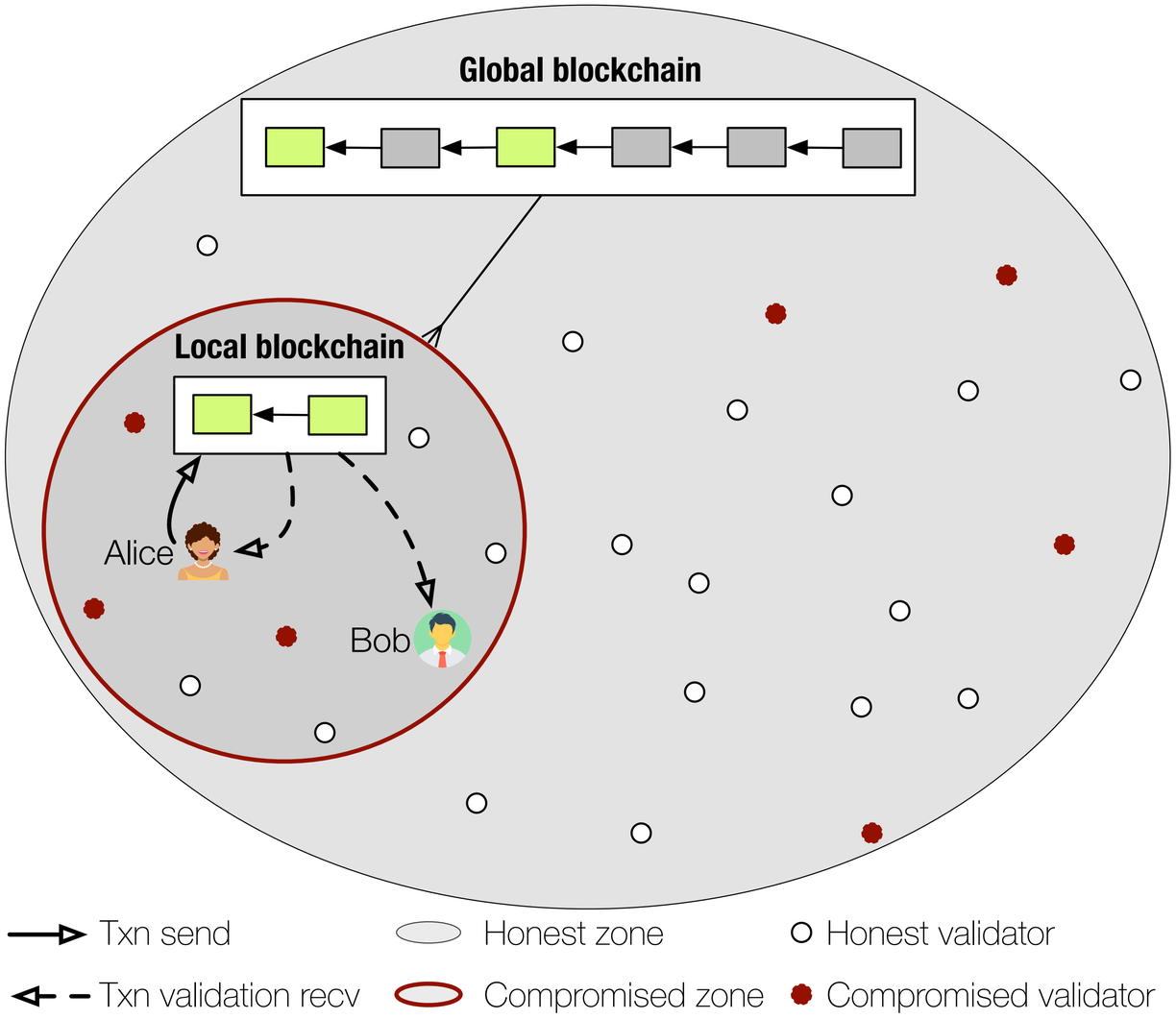

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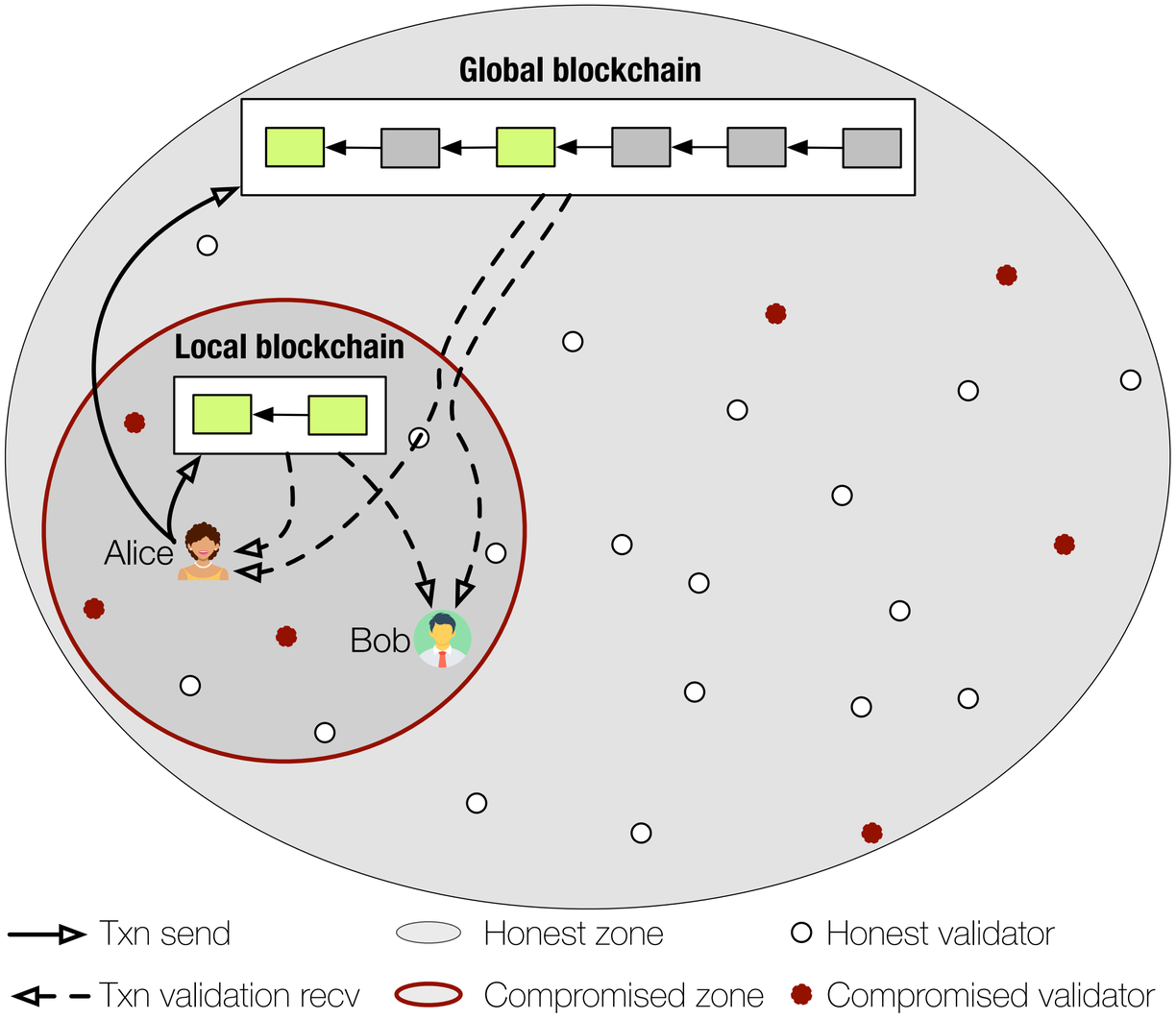

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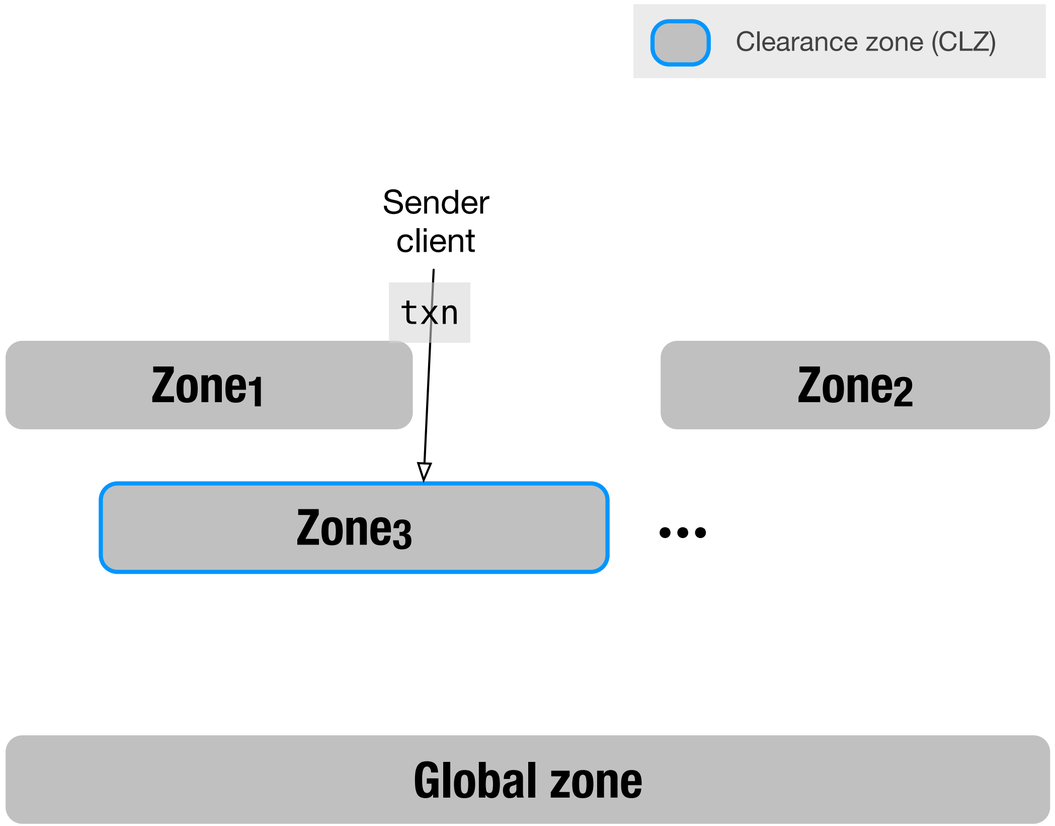
Retroactively detect local double spending

User's choice

Transaction validation

Challenge 1: Sender S double spends via more zones

Transaction validation



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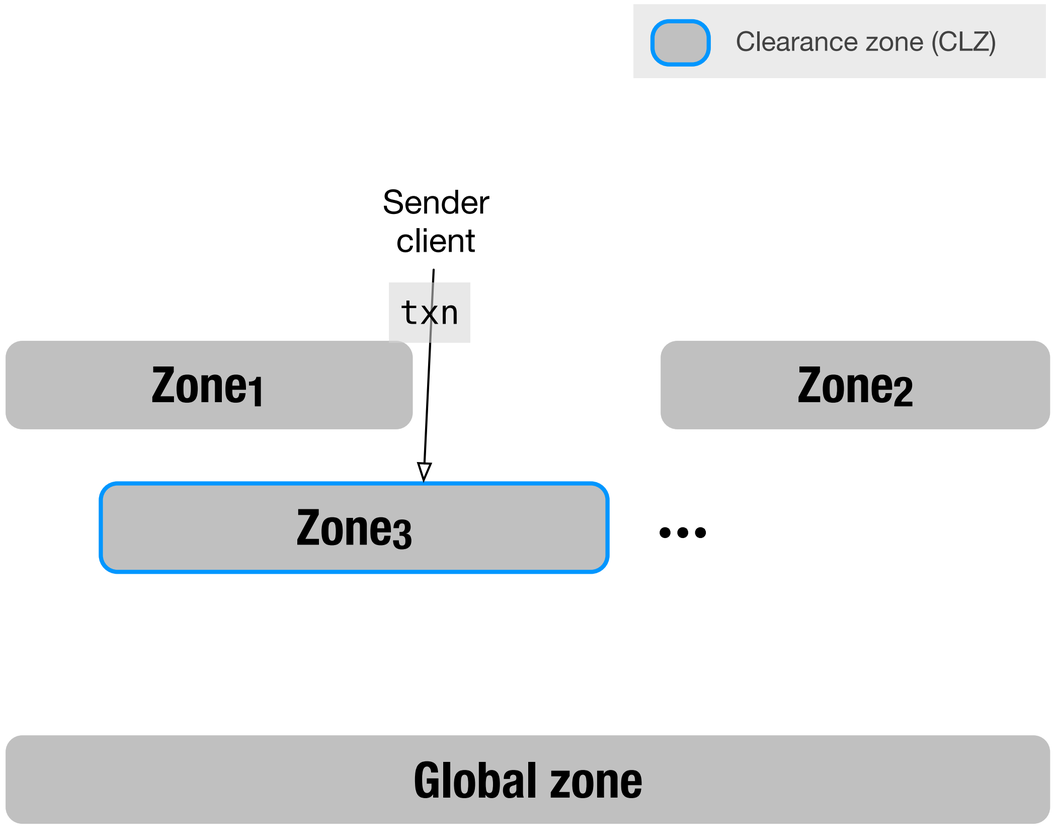

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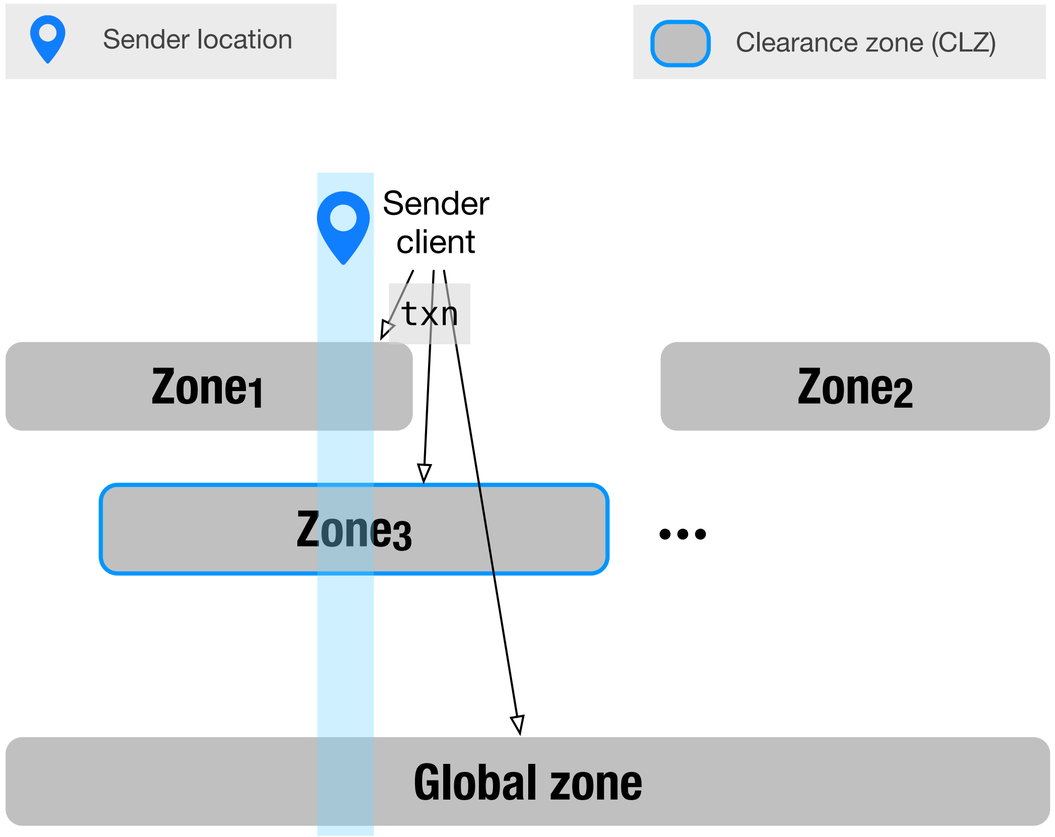

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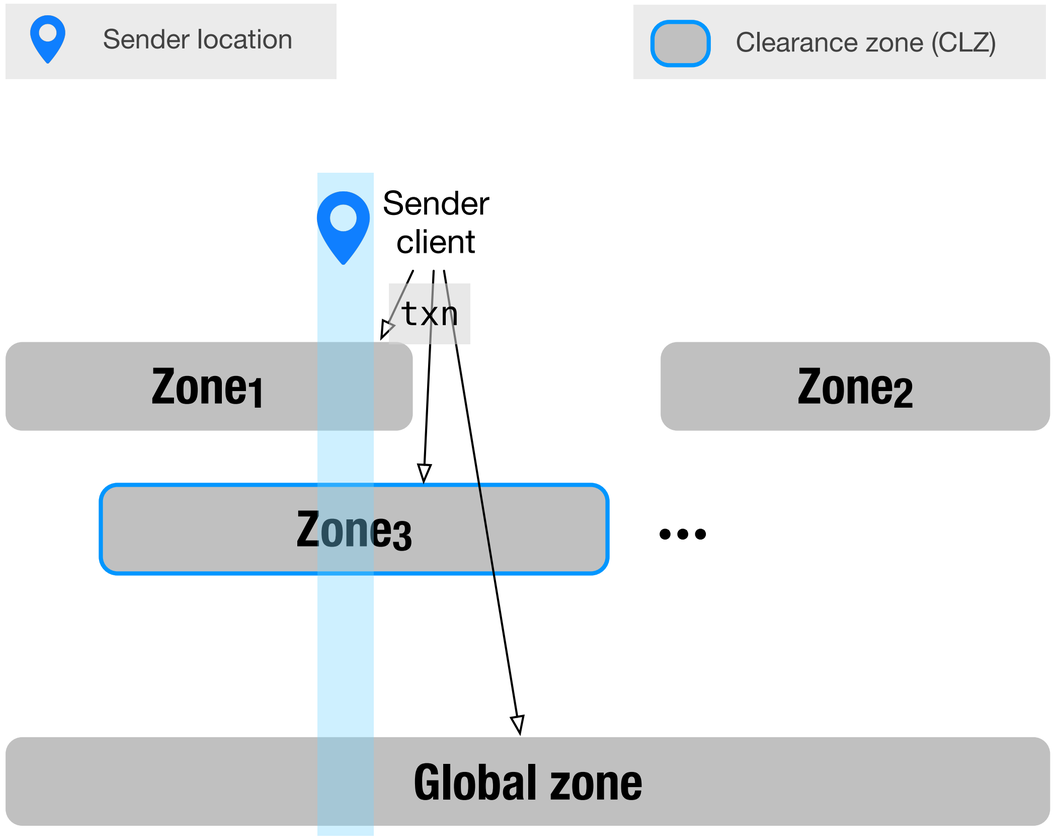

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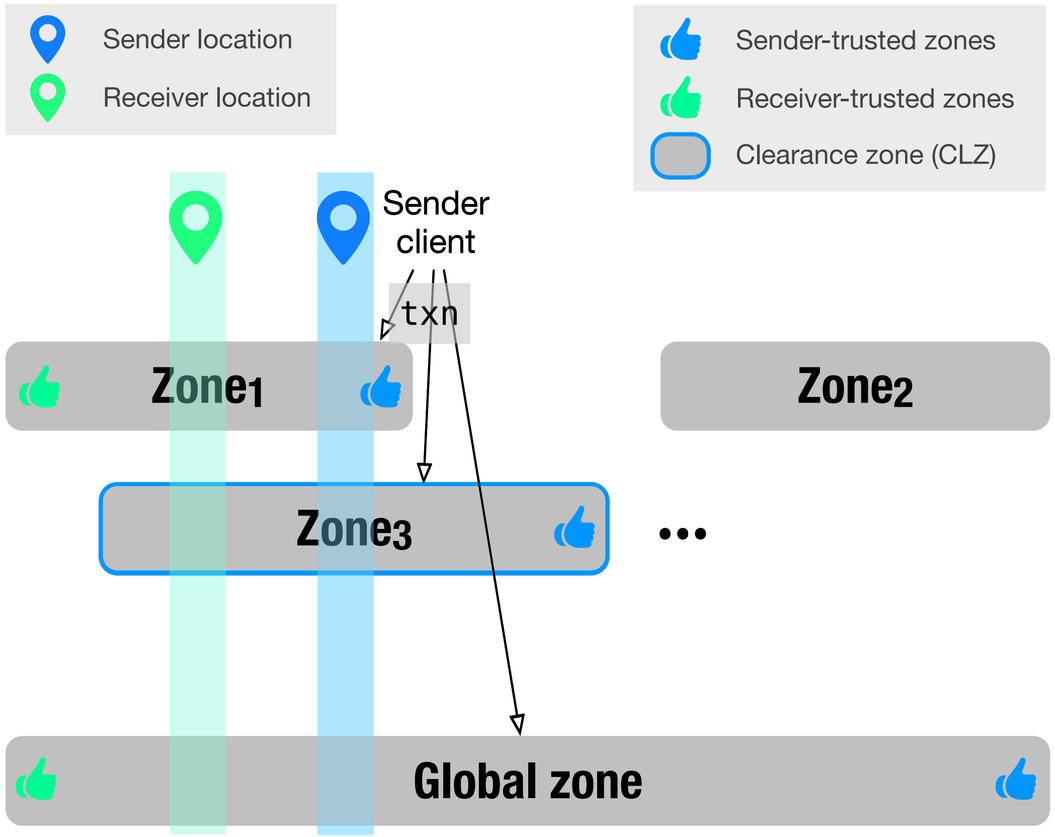

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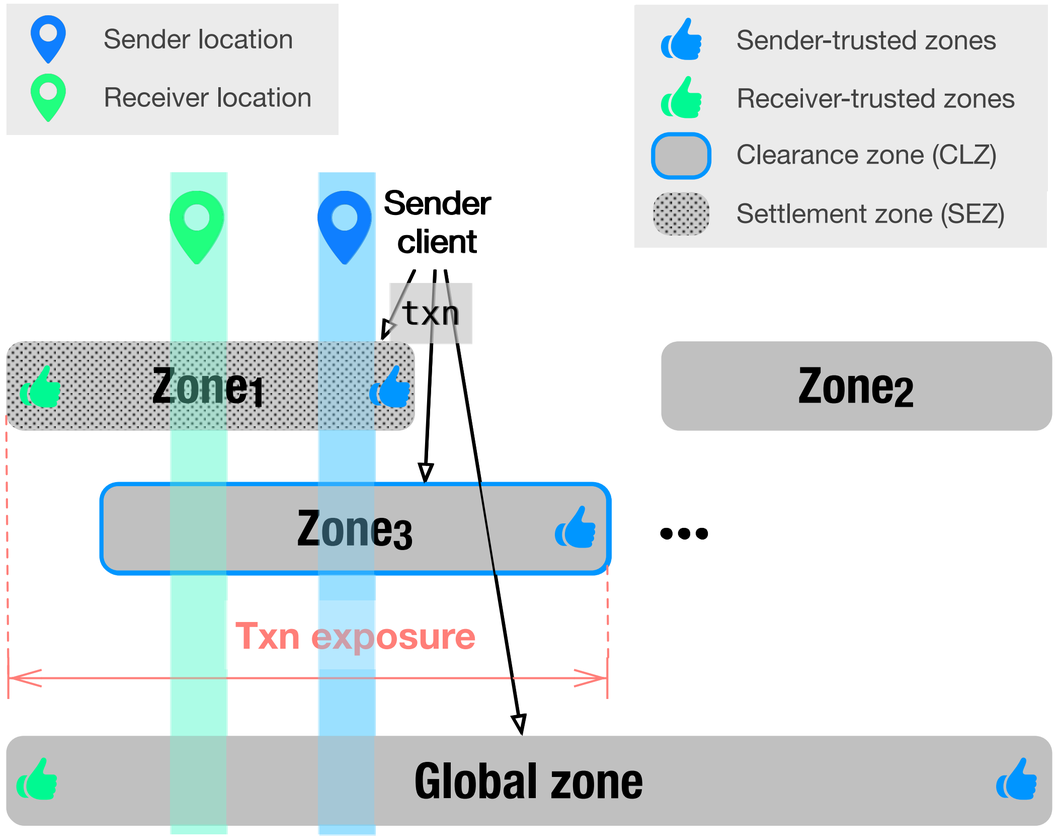

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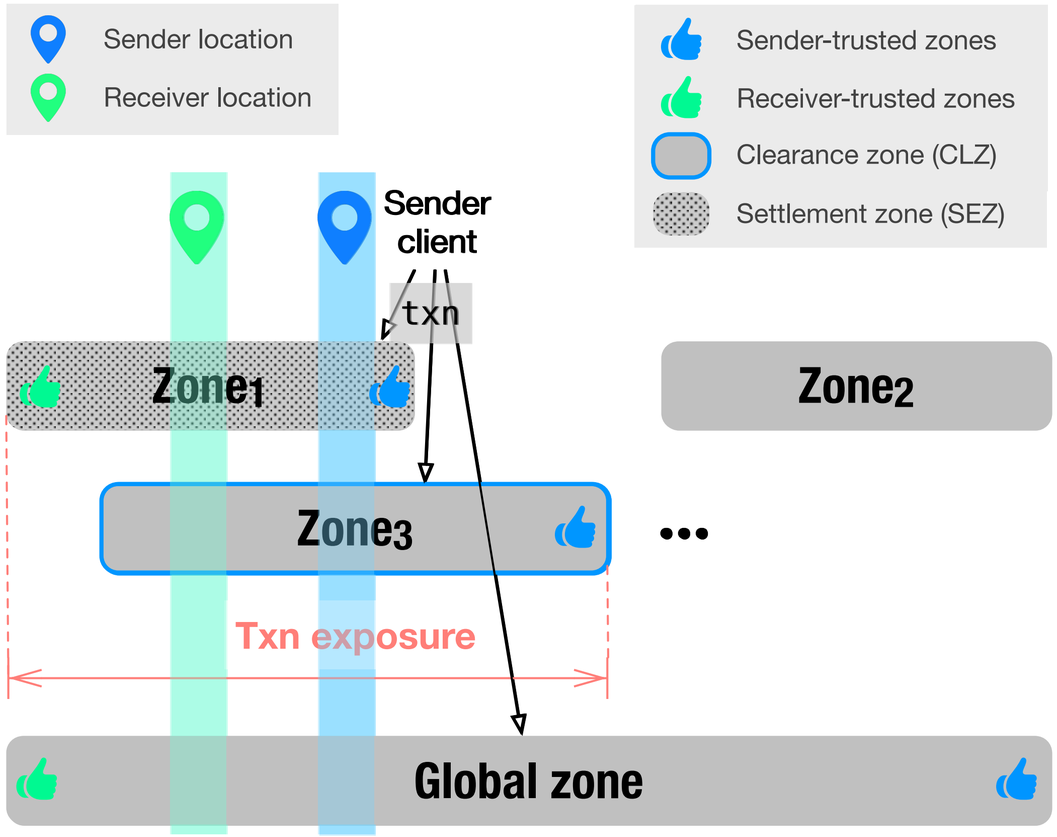

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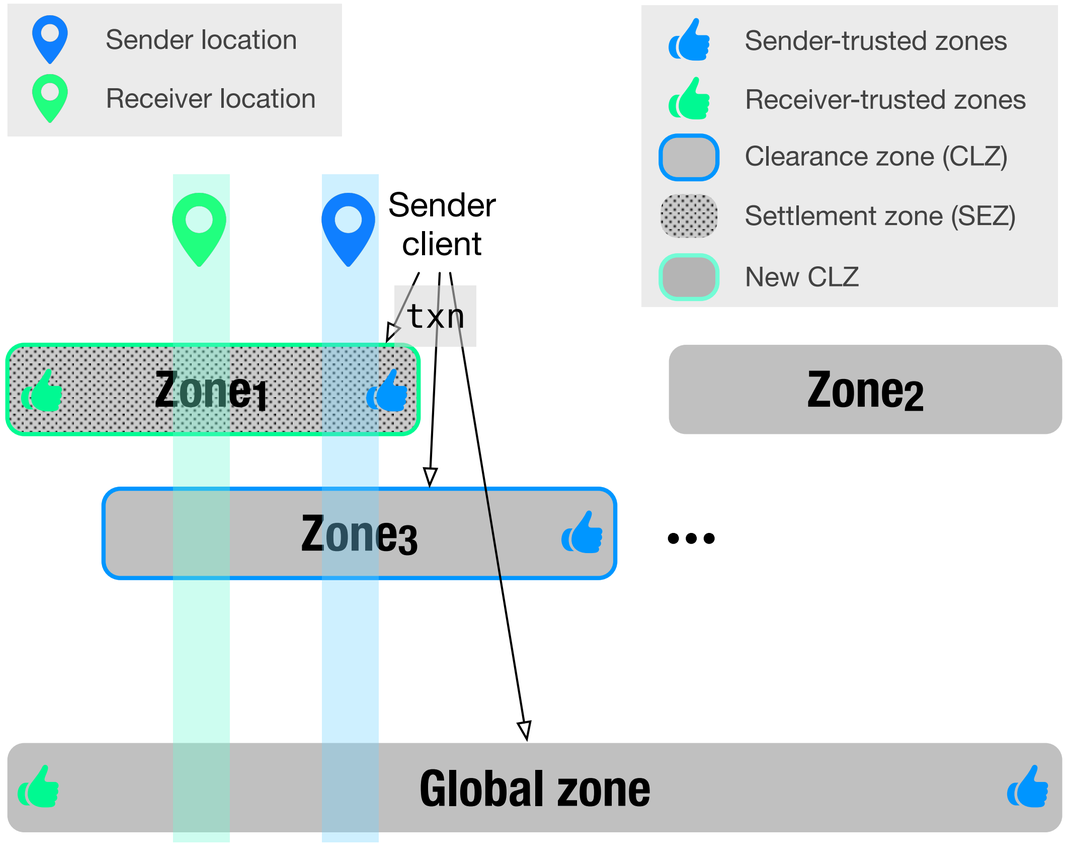

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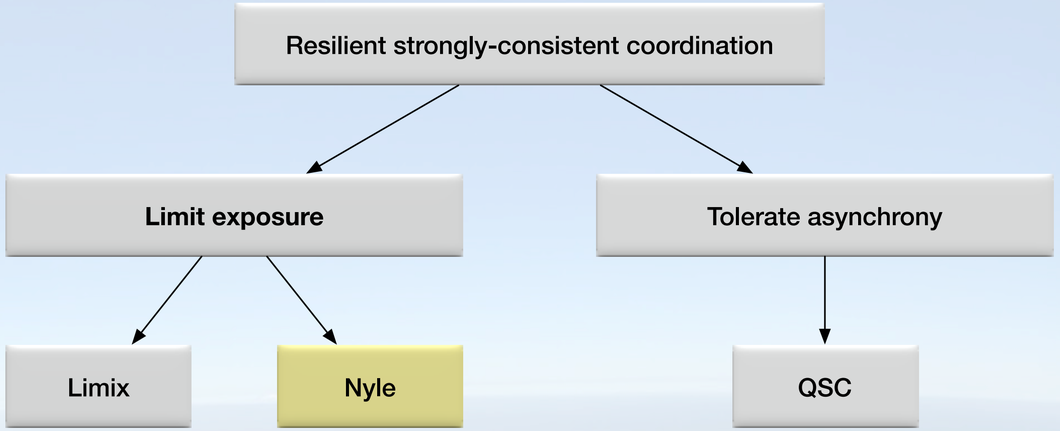
Solution: CLZ is smallest R trusted zone that validates txn

Nyle roadmap



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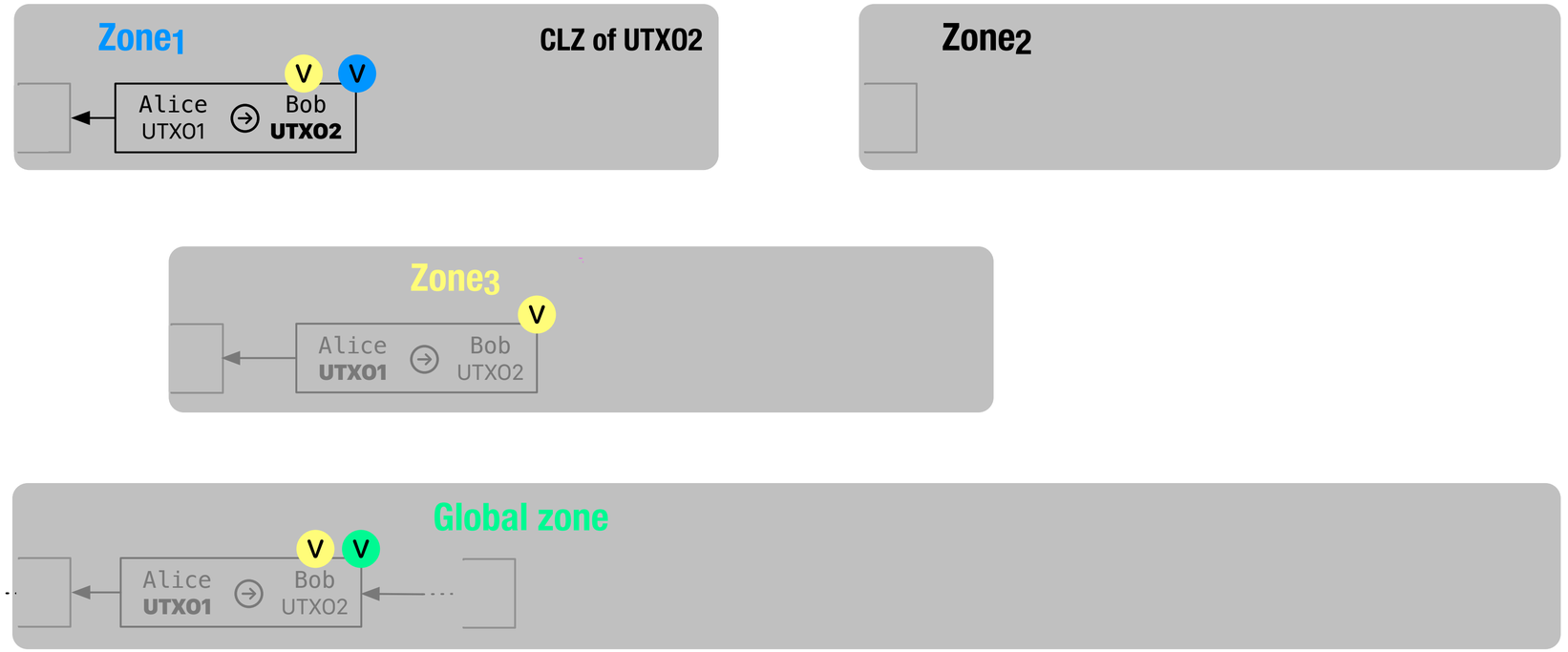
Changing the CLZ



V V V Transaction validation by a zone. The color identifies the zone.

Pending transaction validation by a zone. The color identifies the zone.

Zone transfer txn

Token transfer txn

Use cases

User changes location

User does not trust zone anymore, e.g., after proven misbehavior

User transfers funds to a single zone for a multi-input txn

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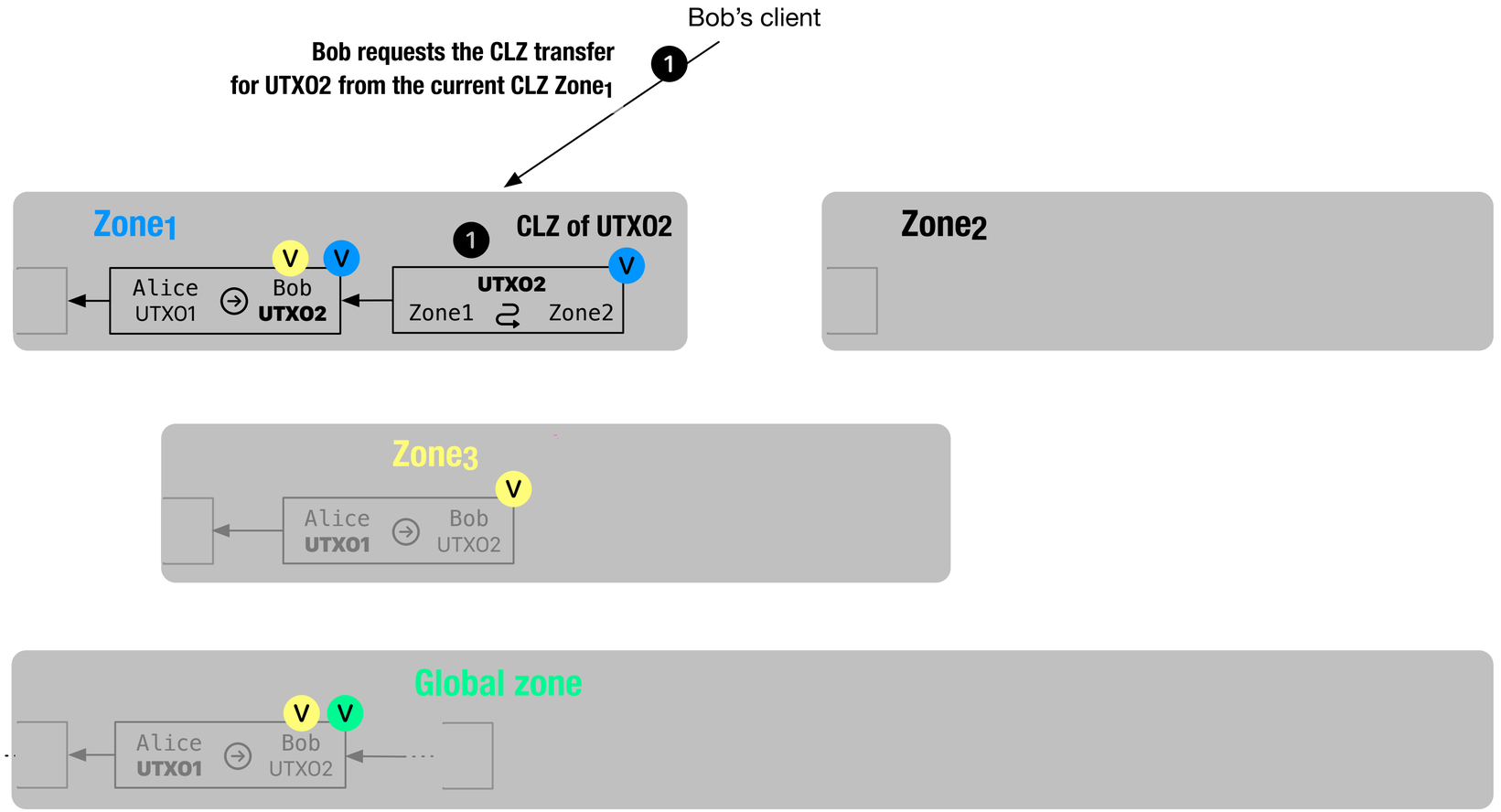

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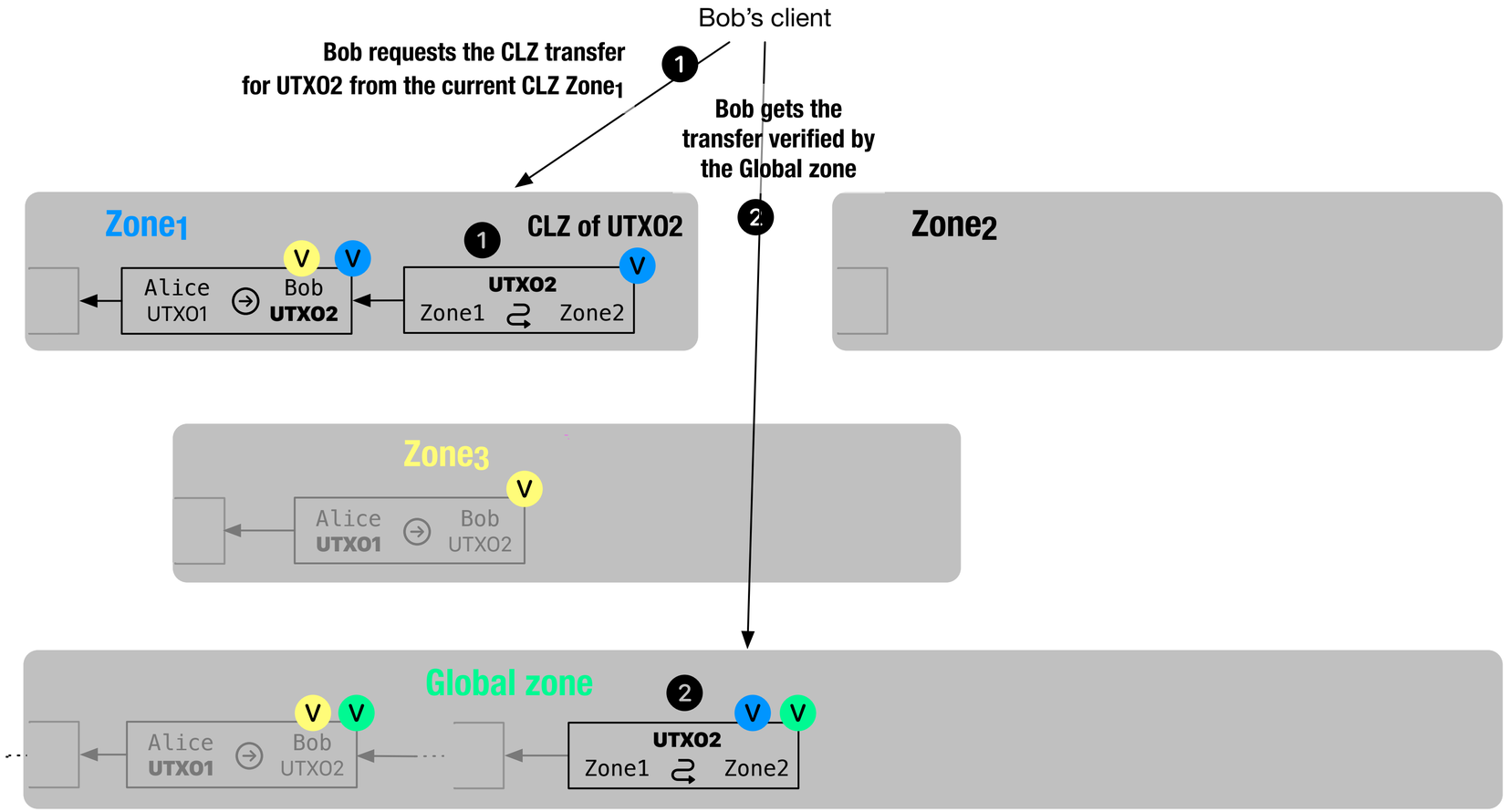

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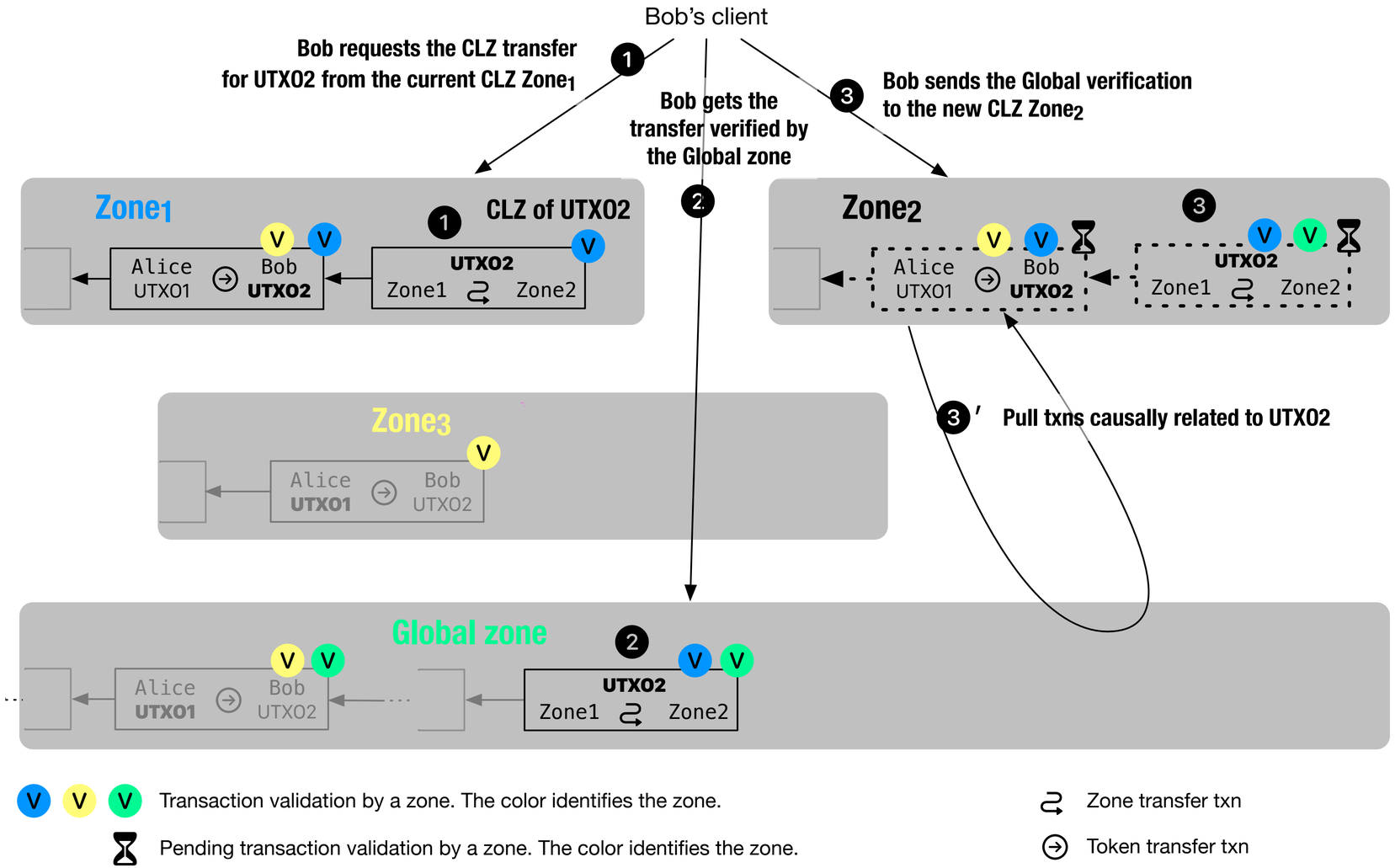

Use cases

User changes location

User does not trust zone anymore, e.g., after proven misbehavior

User transfers funds to a single zone for a multi-input txn

Defending against CLZ censorship

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- **CLZ censors the UTXO owner**

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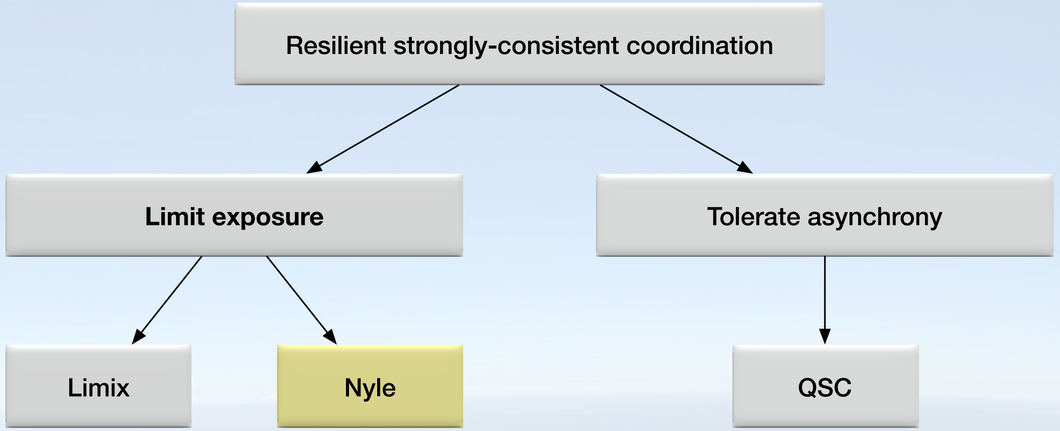
Nyle roadmap



- The problem: exposure-limiting distributed ledger
- Secure zoning with Byzantine validators
- A trust-but-verify design for transaction validation
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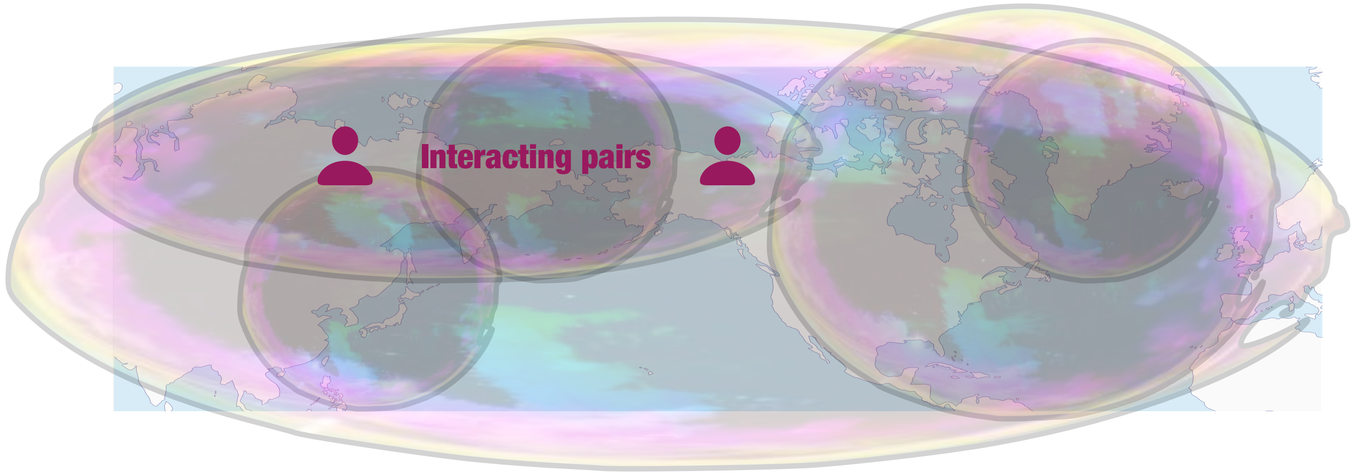
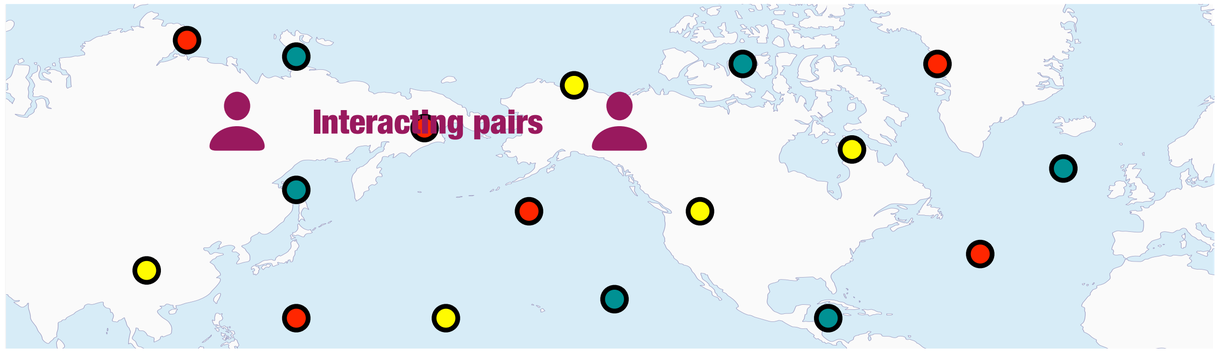
- Clearance zone change and censorship attacks
- **Simulation**
- Summary

Simulation setup

- **Do far away failures affect transactions?**

- 400 nodes, max RTT 1 second





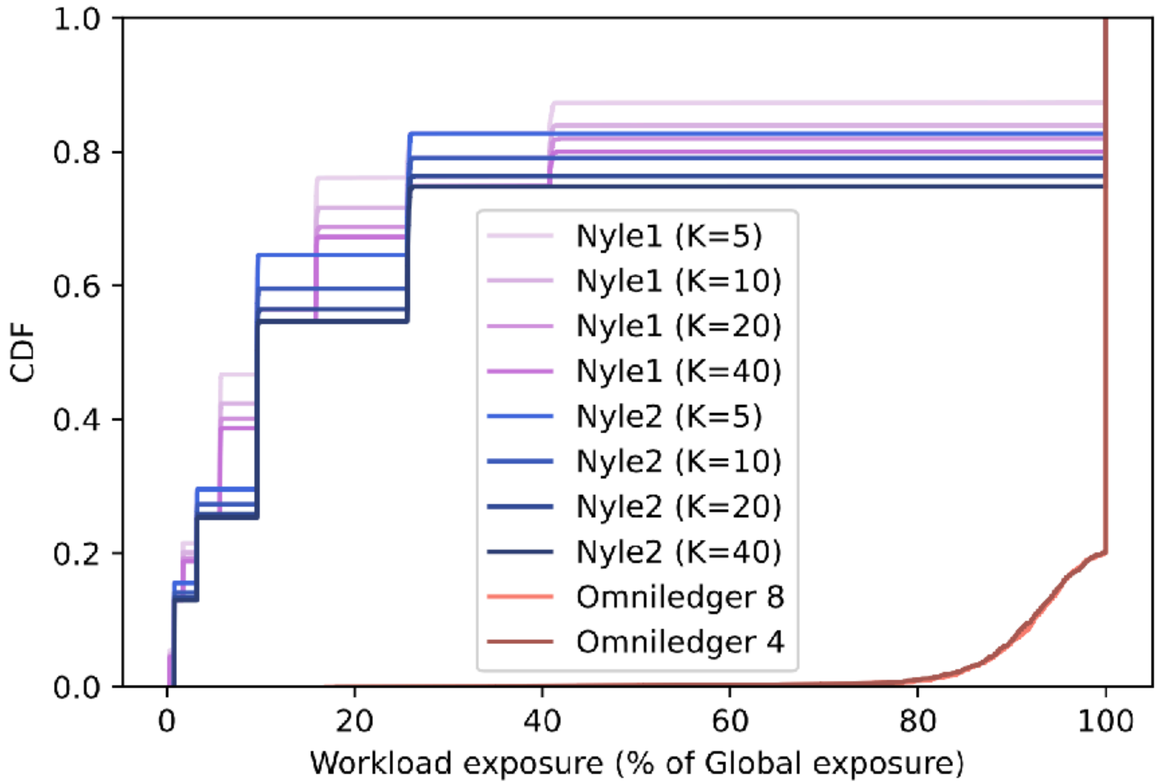
- **Nyle RTT-based autozoning**
  - **Nyle1**: More zones
  - **Nyle2**: Fewer zones

- **Omniledger***
  - **Omniledger4**: Shards of 80 nodes, each with 20 μshards
  - **Omniledger8**: Shards of 80 nodes, each with 10 μshards

* Eleftherios Kokoris-Kogias, Philipp Jovanovic, Linus Gasser, Nicolas Gailly, Ewa Syta, and Bryan Ford. OmniLedger: A Secure, Scale-Out, Decentralized Ledger via Sharding. In *39th IEEE Symposium on Security and Privacy (SP)*, 2018.

Simulation results

- Workload: 10000 random pairs with RTTs from a realistic trace-based distribution



Lower exposure is better, because it guarantees higher availability

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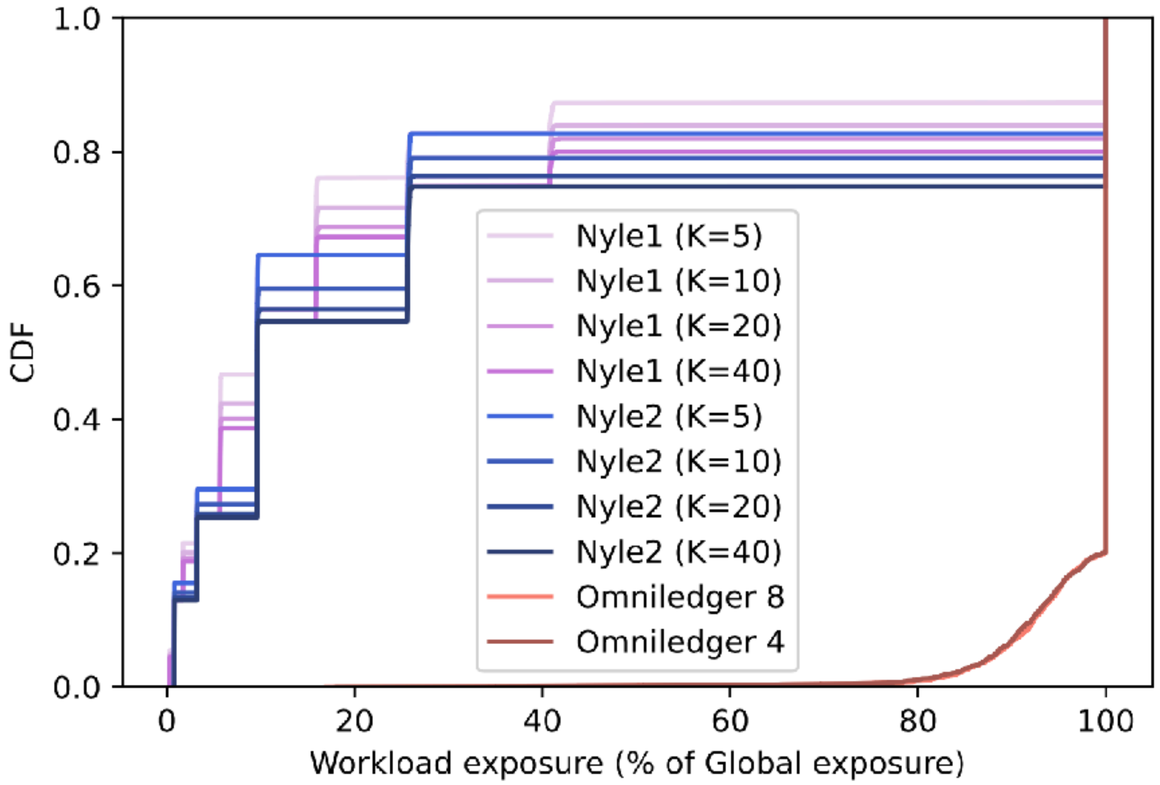

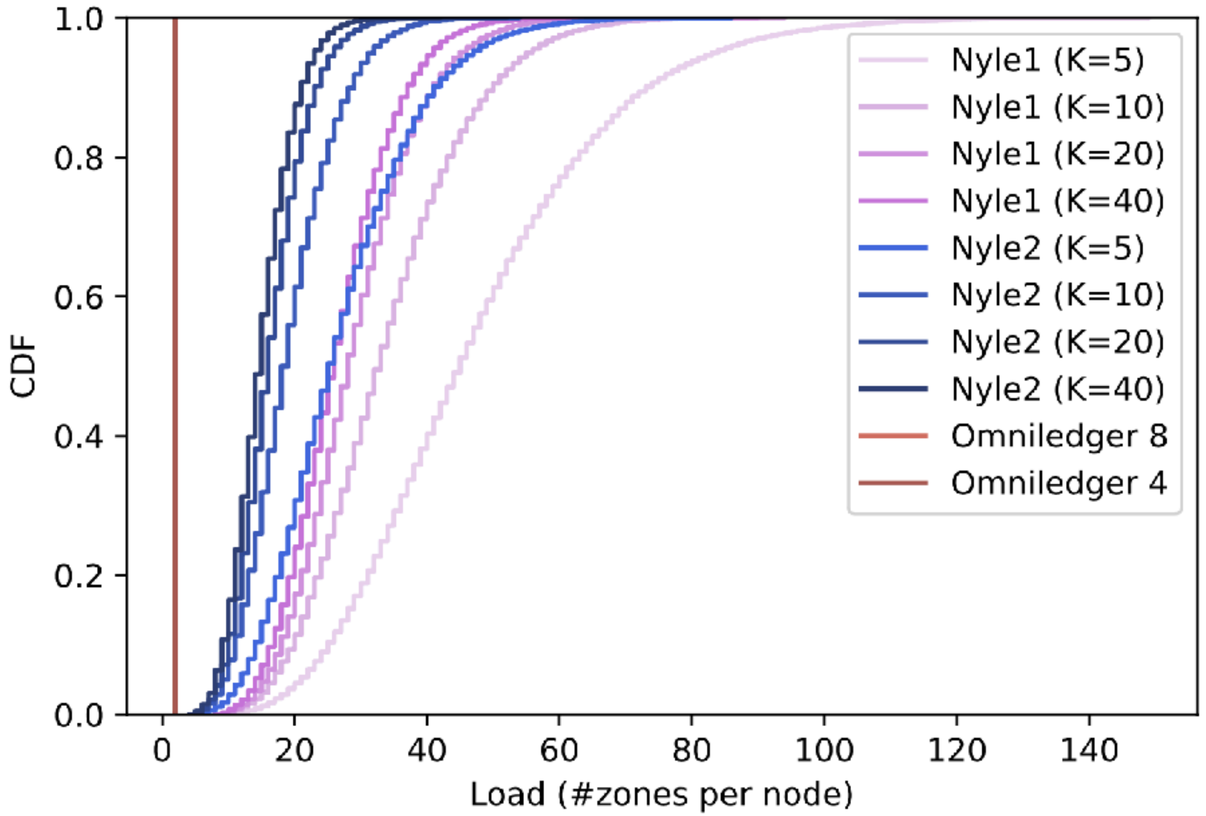

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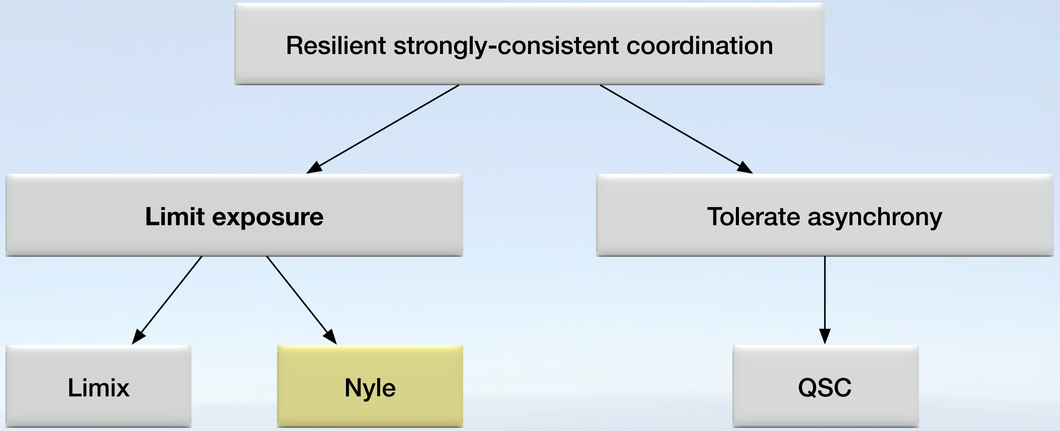

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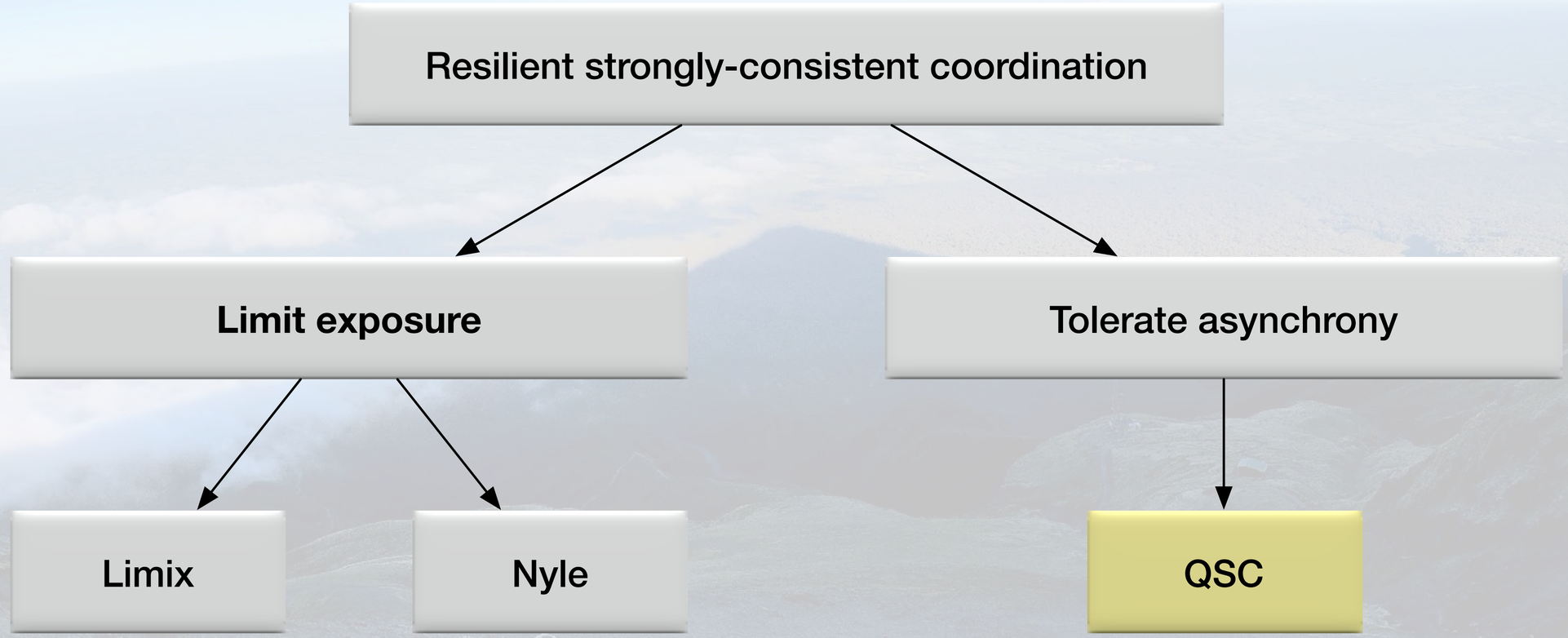
Nyle summary

- **Exposure-limiting architecture for BFT-style distributed ledgers**
  - Global zone is a secure finaliser, whereas local zones are opportunistic finalisers
- **Per-transaction user-controlled exposure**
- **Nyle significantly reduces exposure compared to Omniledger, at a 10x cost**

Thesis roadmap



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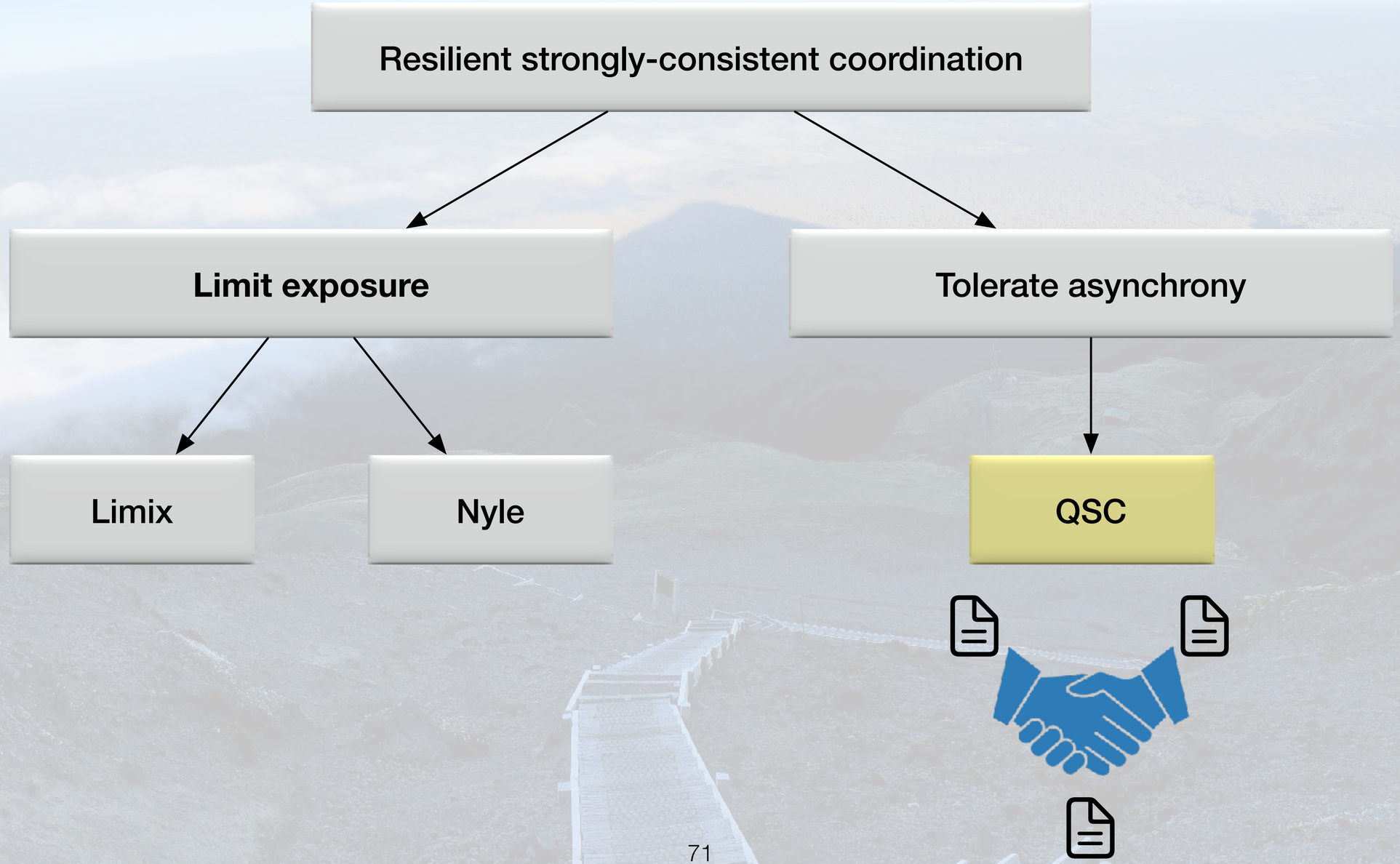
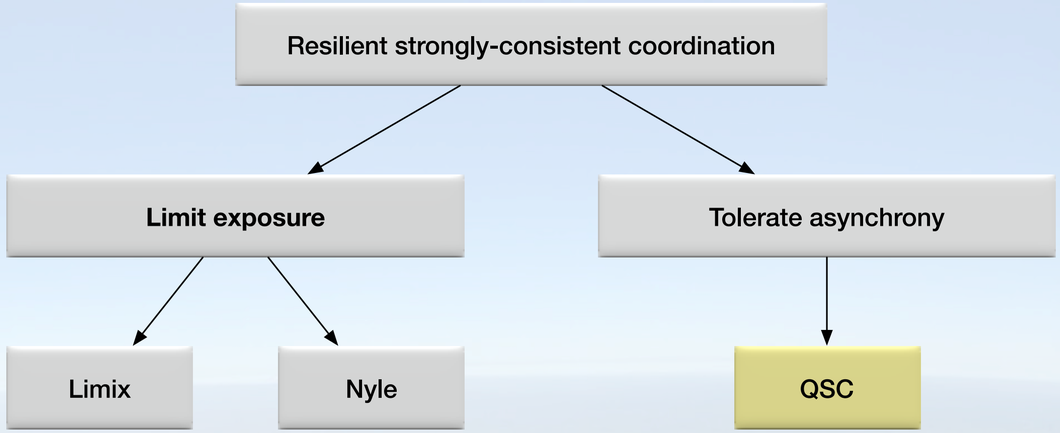


QSC roadmap



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- Asynchronous consensus designs
- QSC insights
- Threshold-synchronous broadcast
- The QSC algorithm
- Complexity and optimizations
- Summary

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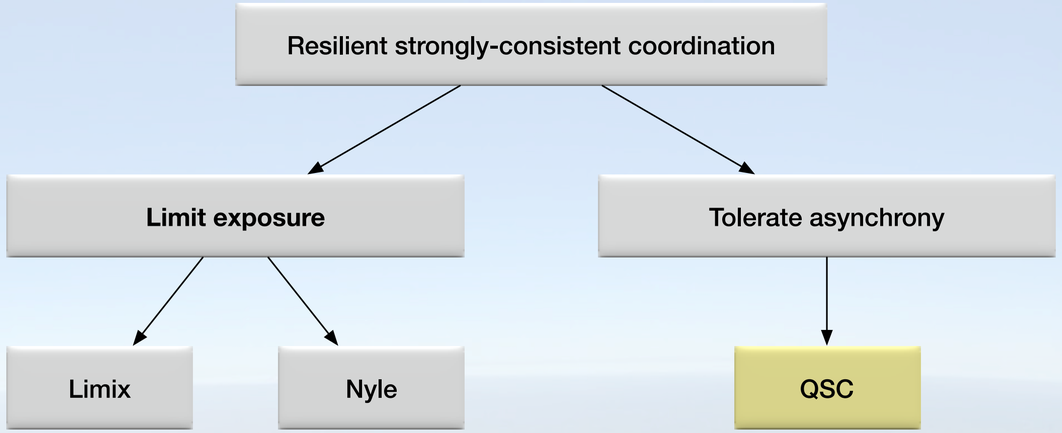

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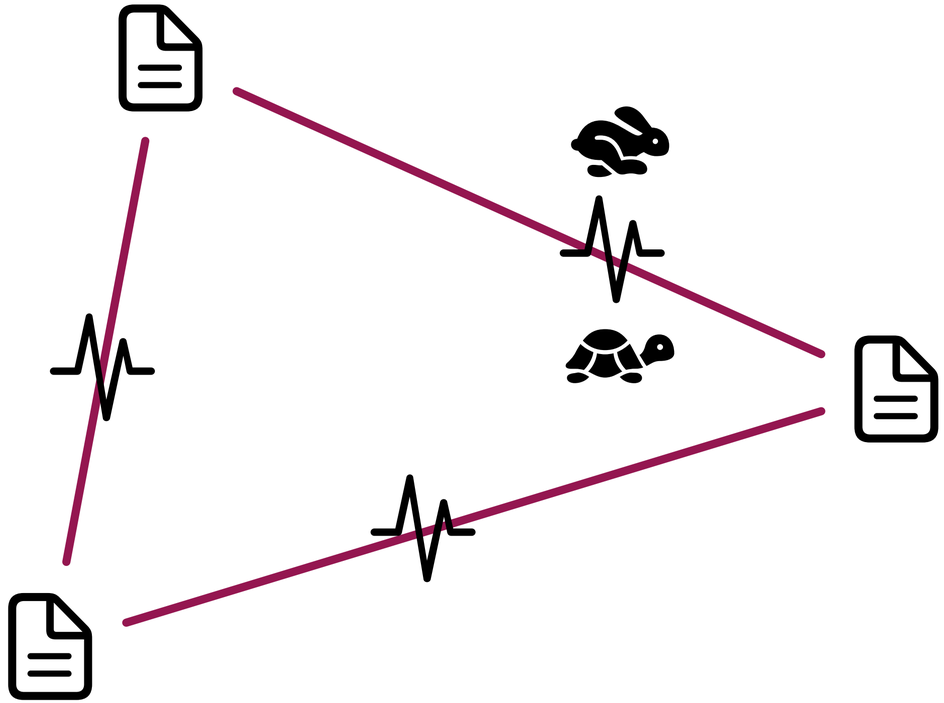
Coordination under asynchrony



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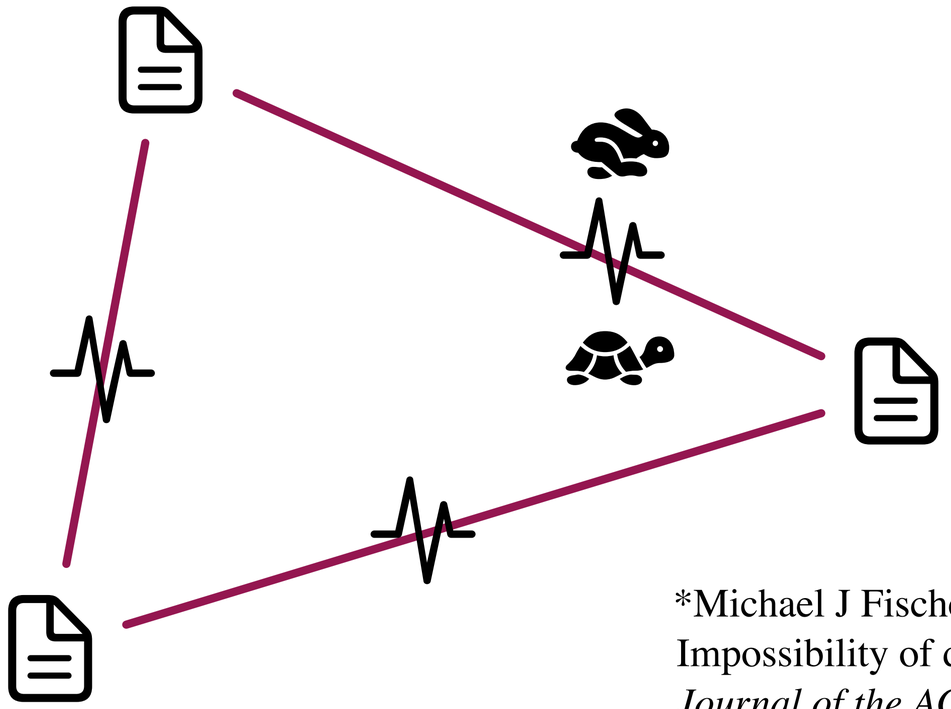

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Deterministic consensus cannot guarantee progress (FLP impossibility result*)

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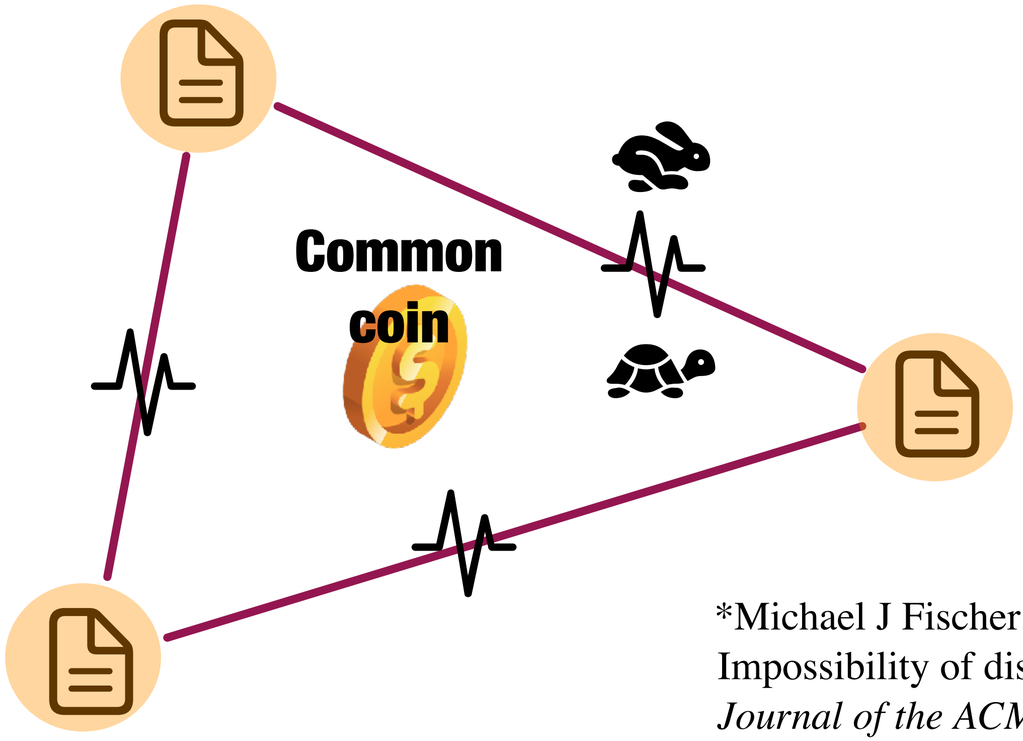

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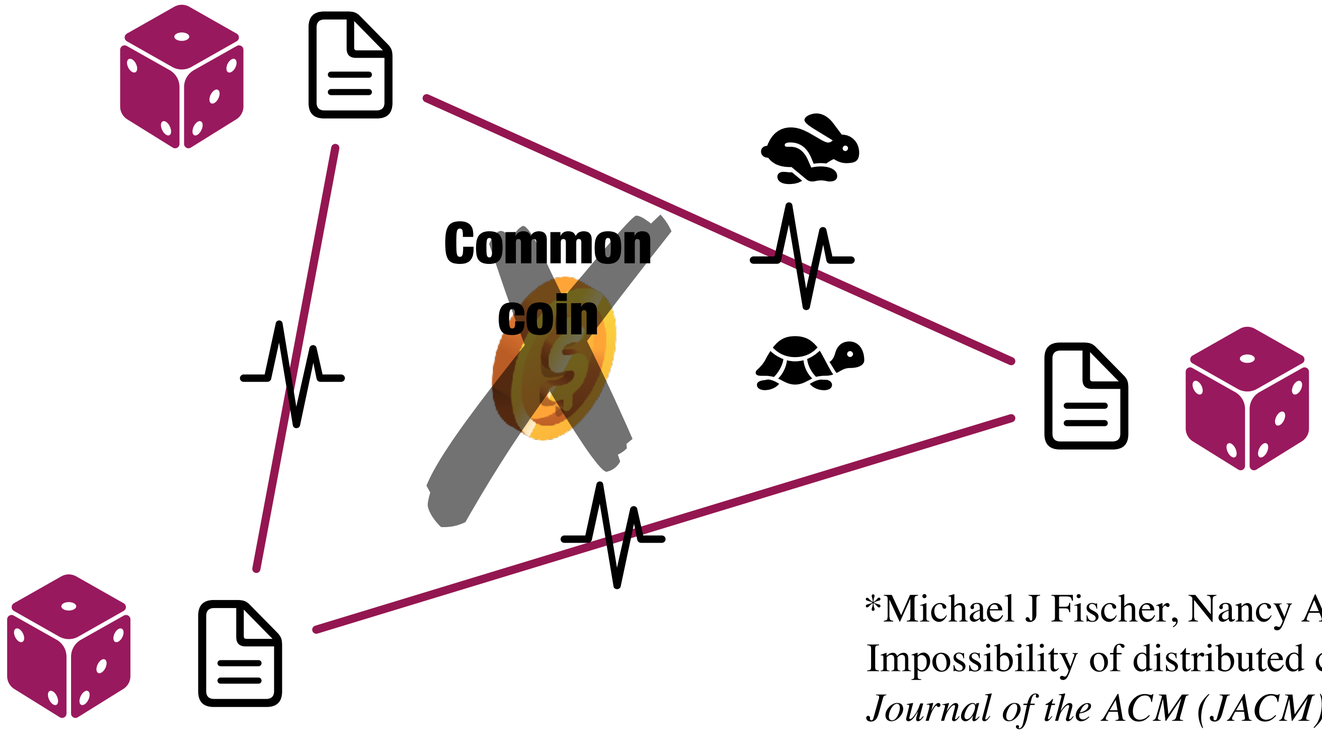

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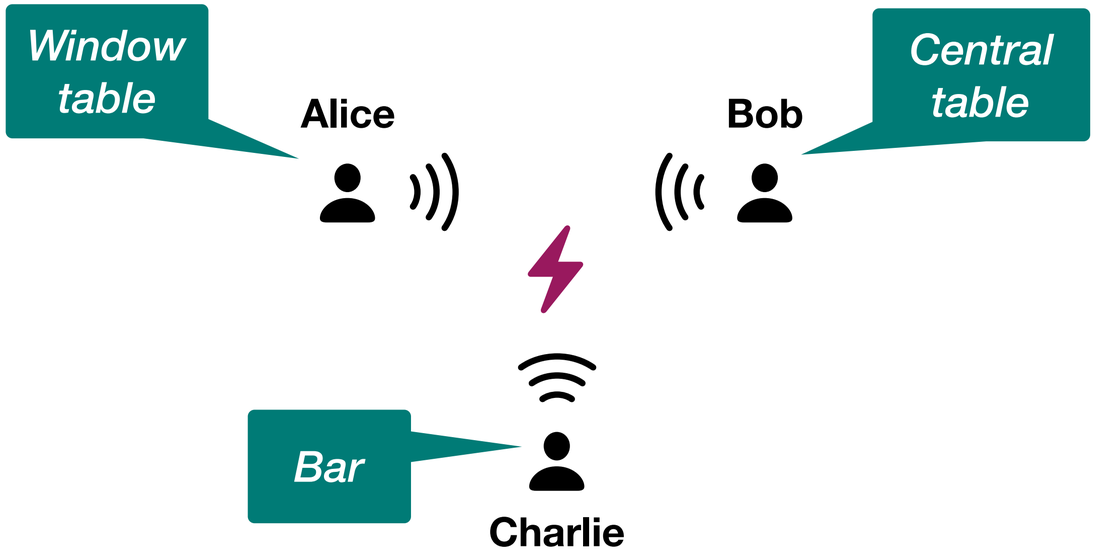
QSC: use private randomness (simpler) instead of a common coin

Consensus setup

- *“What table shall we sit at?”*
- **N** nodes, a minority **f** can fail by **crashing (fail-silent)**
- Each node proposes a value (multi-value consensus)
- Messages eventually delivered, but after a finite arbitrary delay

Goals



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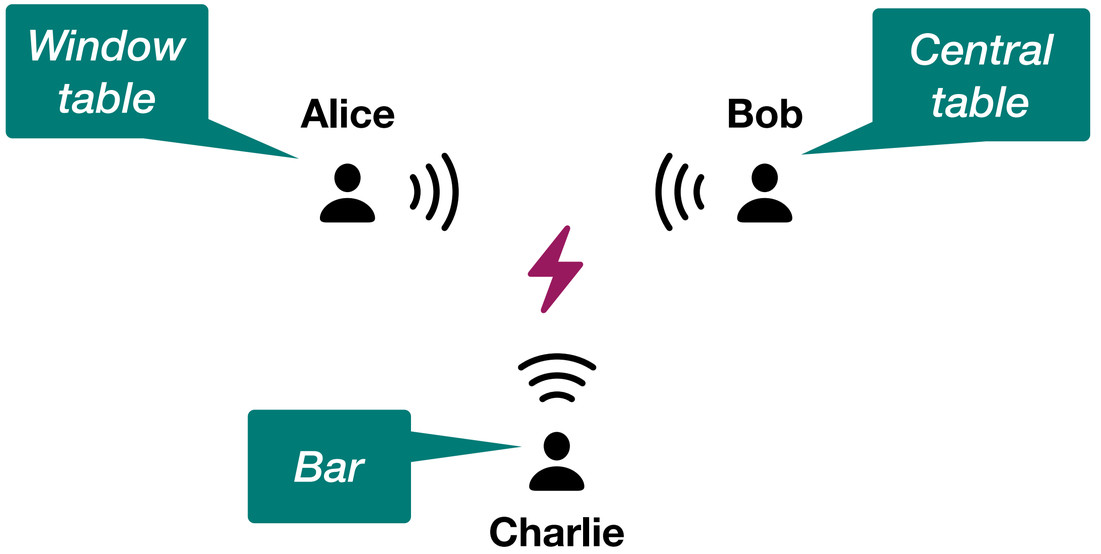
Goals

Termination: Every live node eventually decides

Agreement: No two nodes decide differently

Validity: The value decided is a proposed value

Integrity: No node decides twice



QSC roadmap

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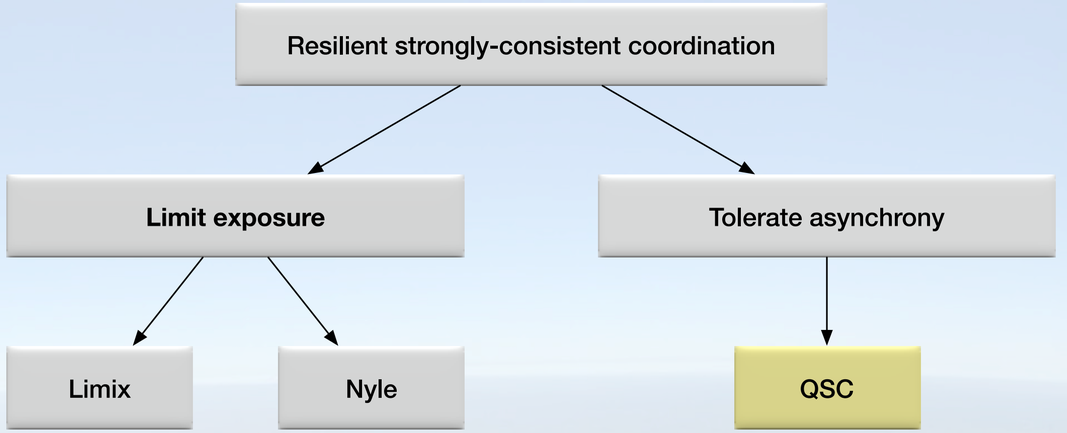

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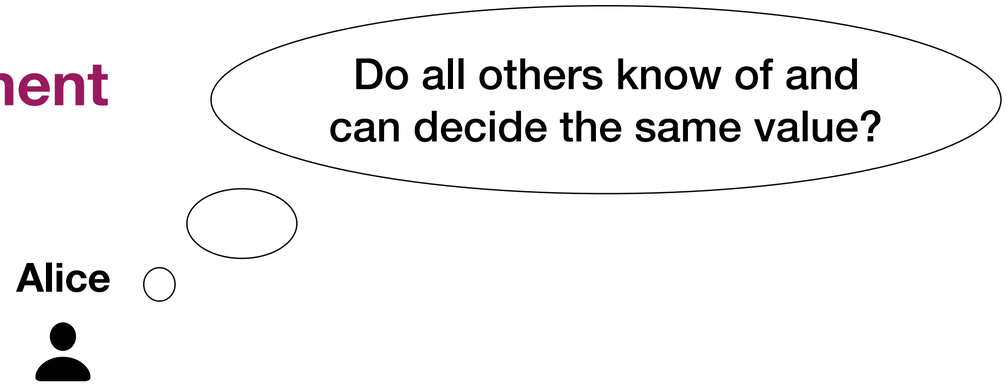

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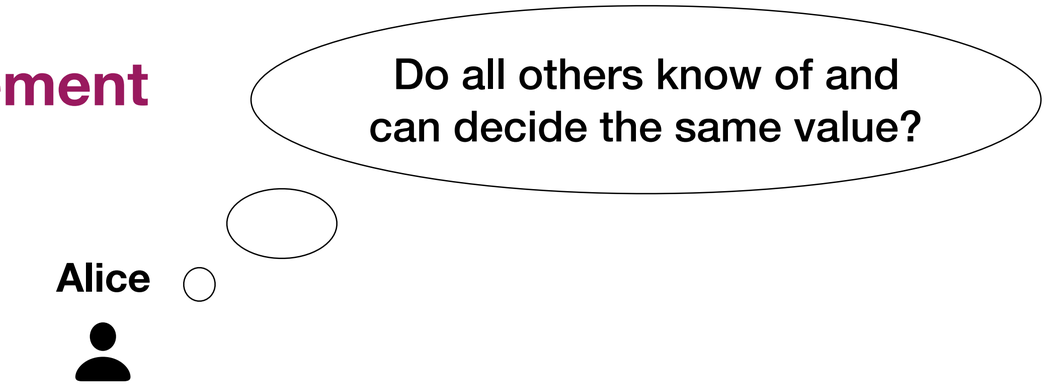
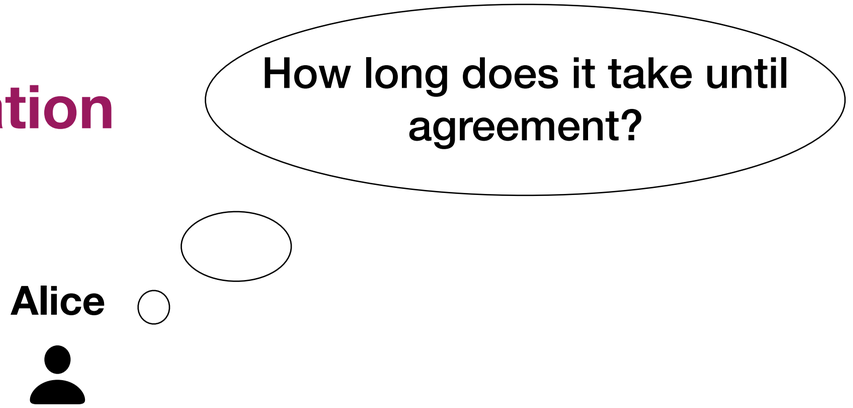
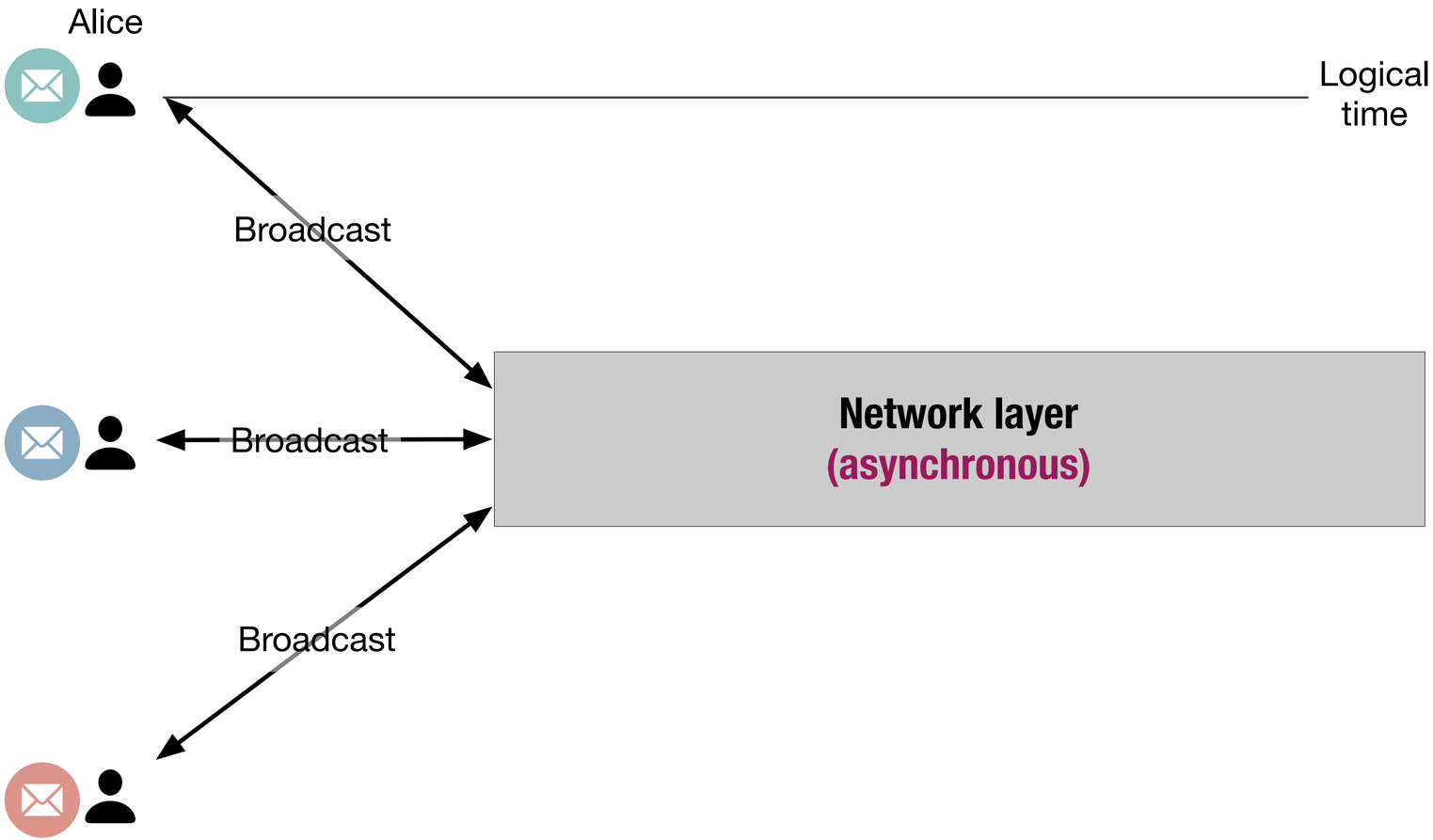


Termination



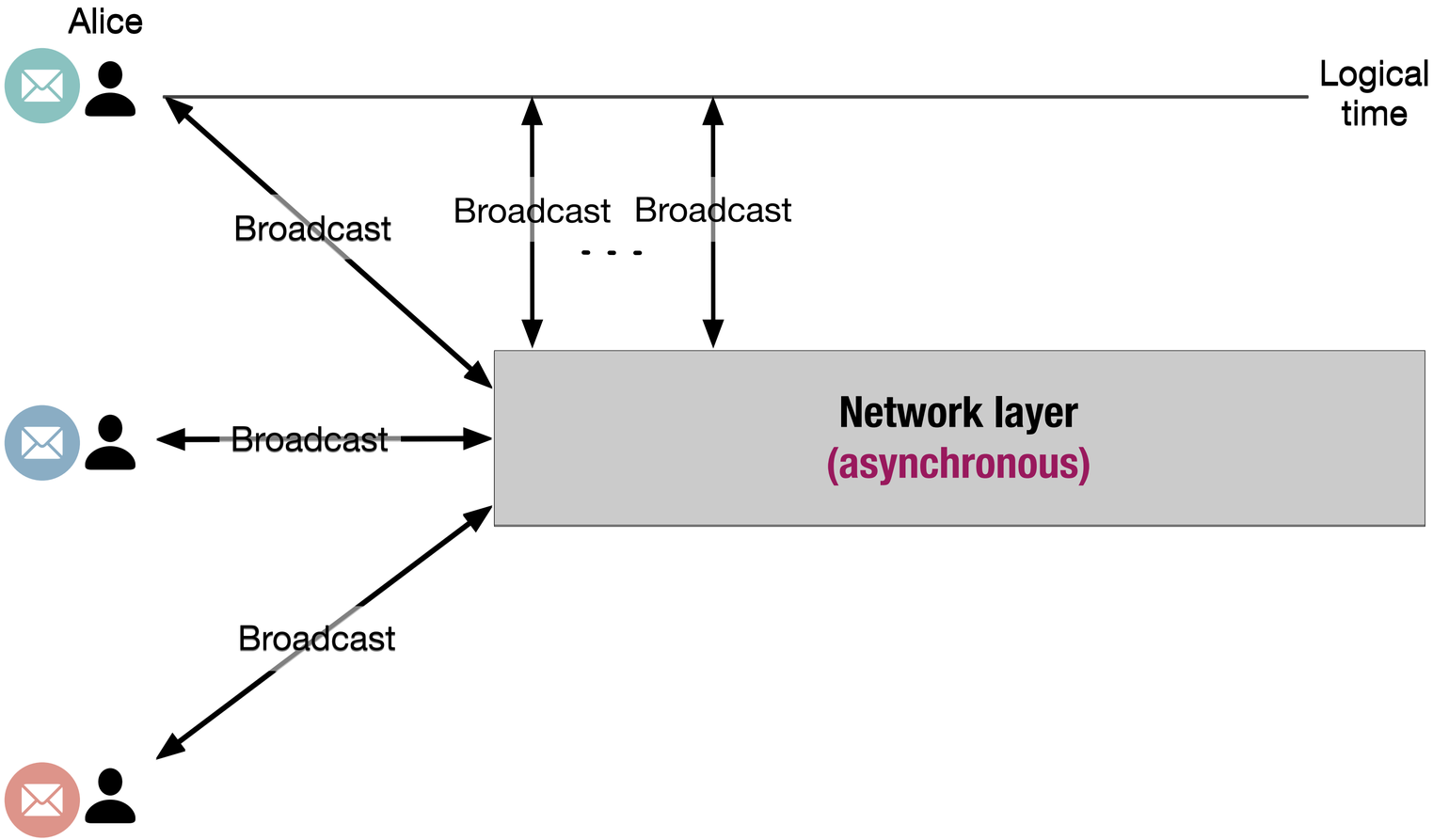
General steps



Exchange of information

Needed for validity

General steps



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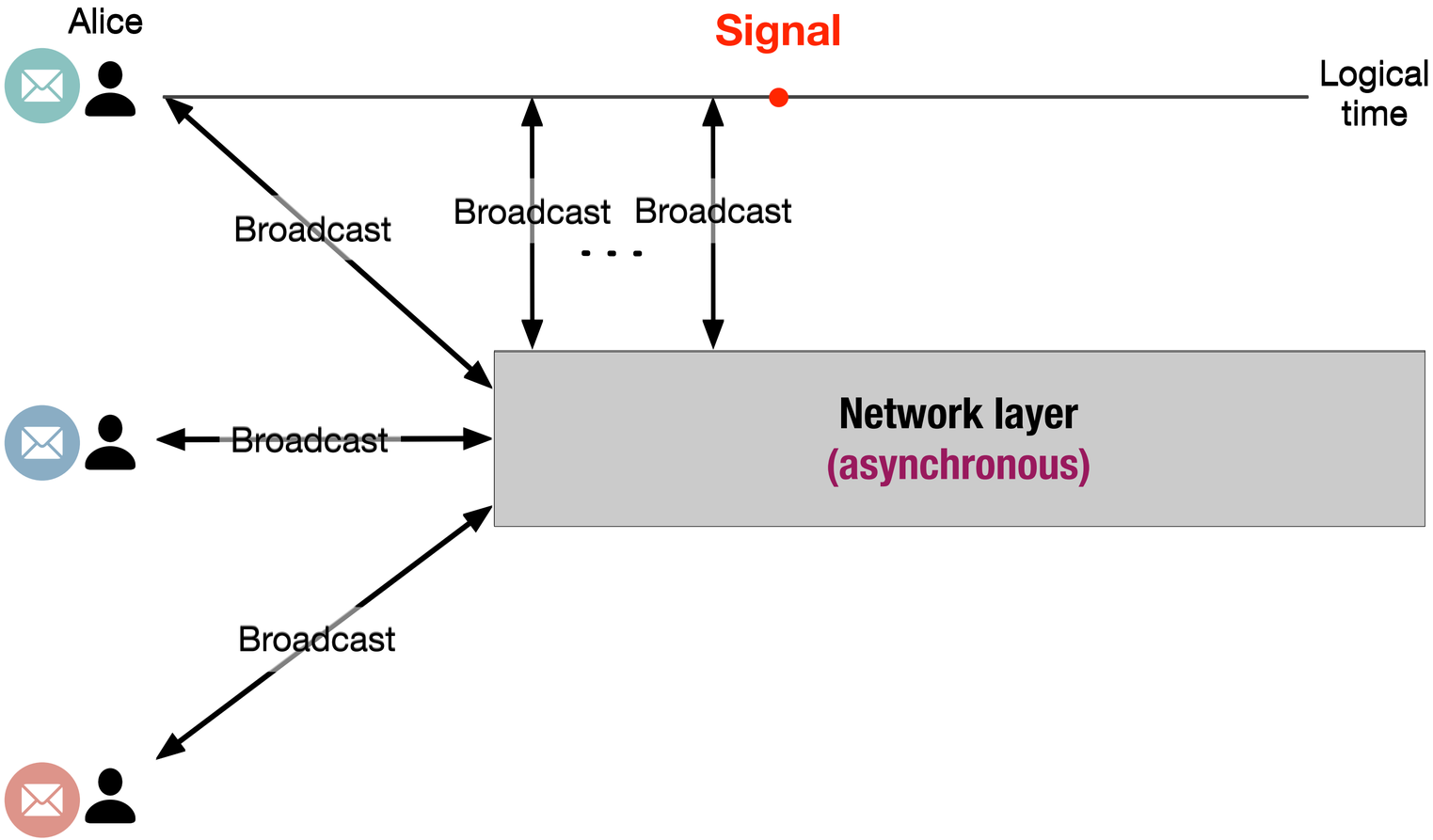

Exchange of information

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Wait for signal

A condition potentially useful for agreement

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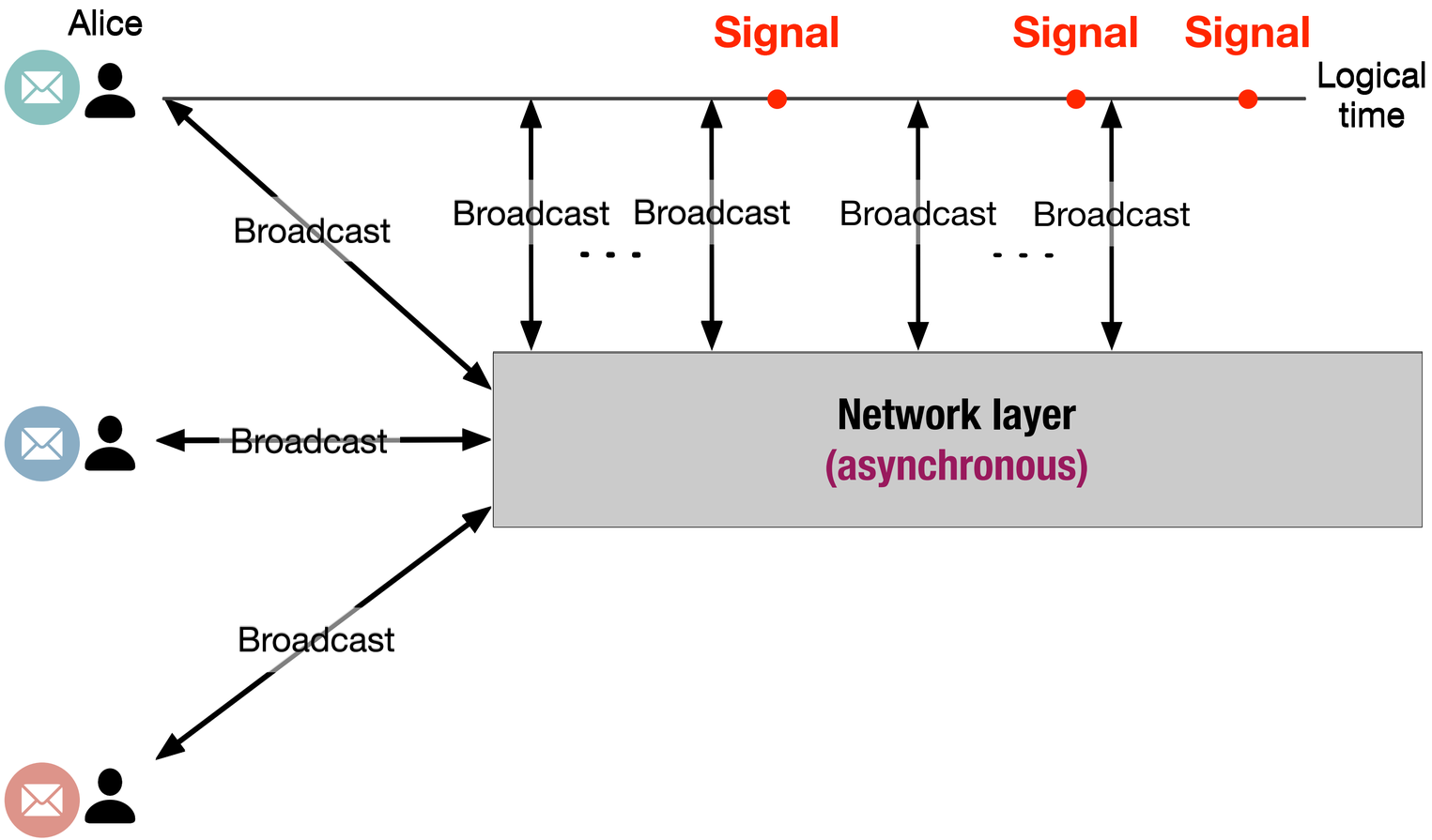

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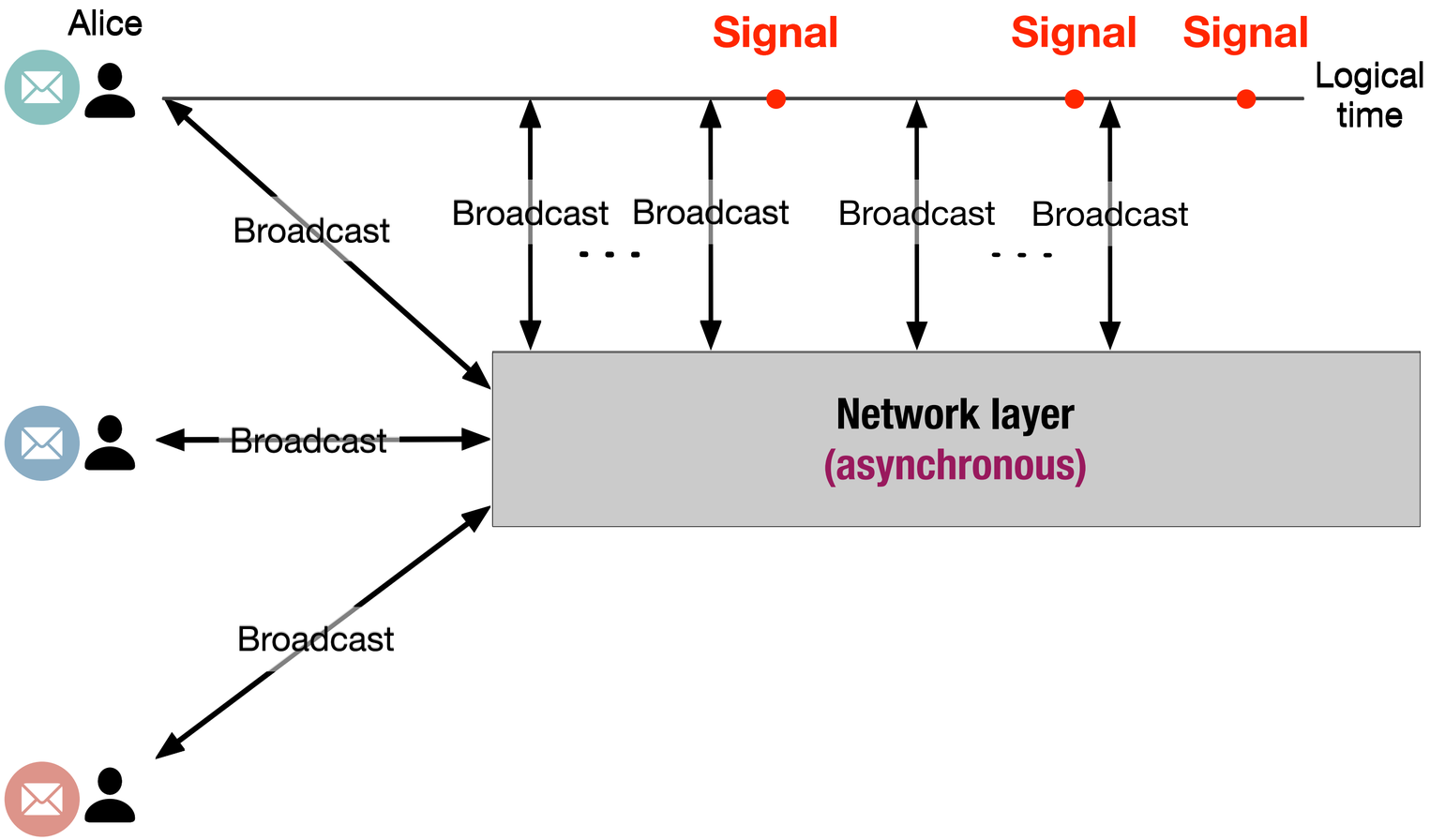

Exchange of information

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Termination

signal steps necessary to decide

What does the signal involve?

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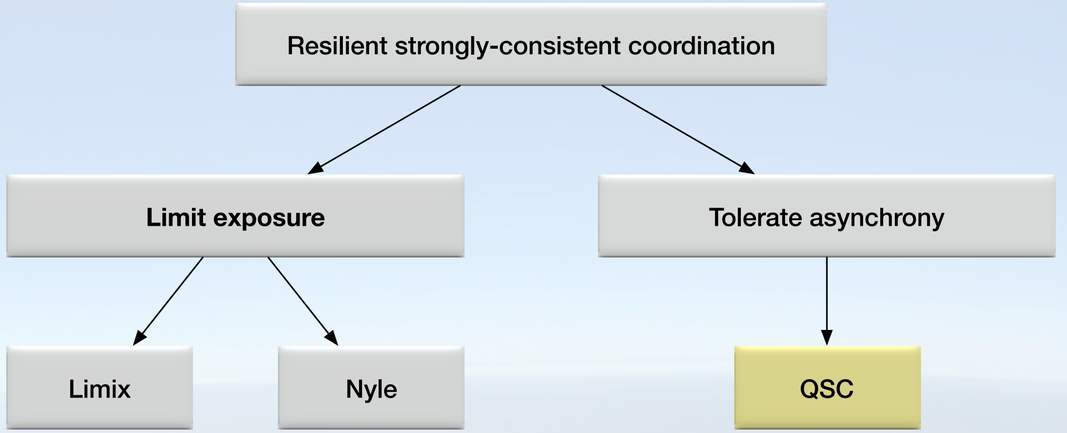

Binary consensus using common core*

Agree on 0 or 1

Exchange of information akin to voting

Use common core towards ensuring agreement

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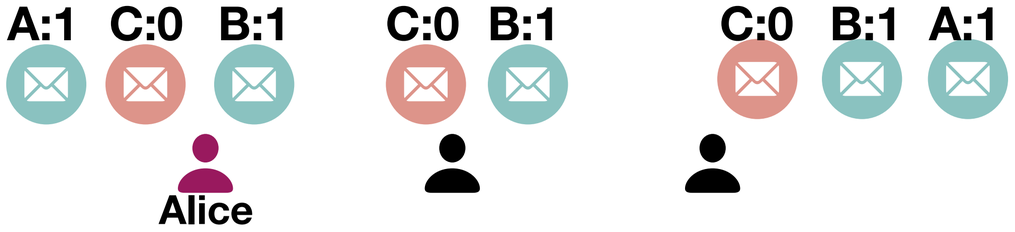

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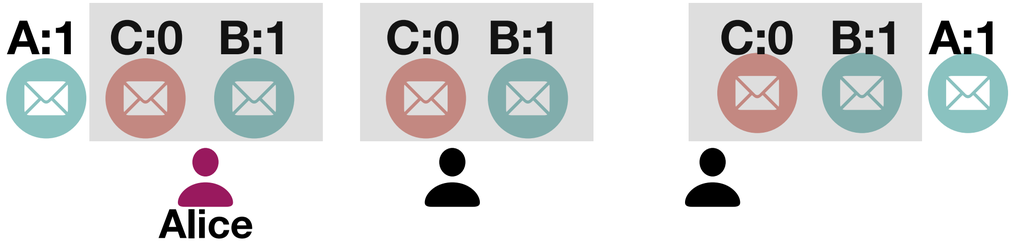

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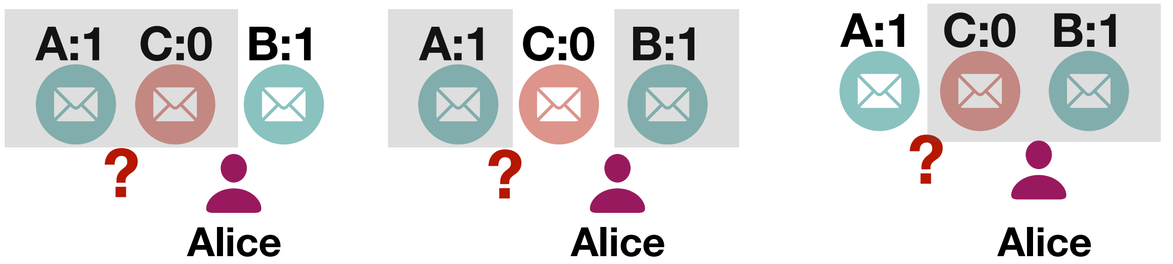

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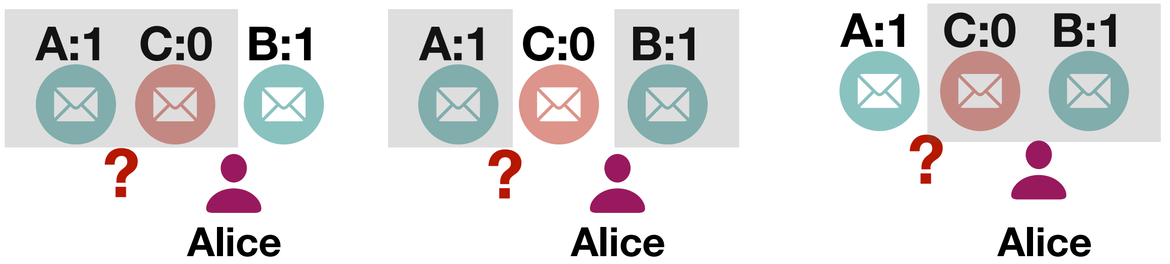

Signal

Common core and supermajorities

Falls back on **common coin**

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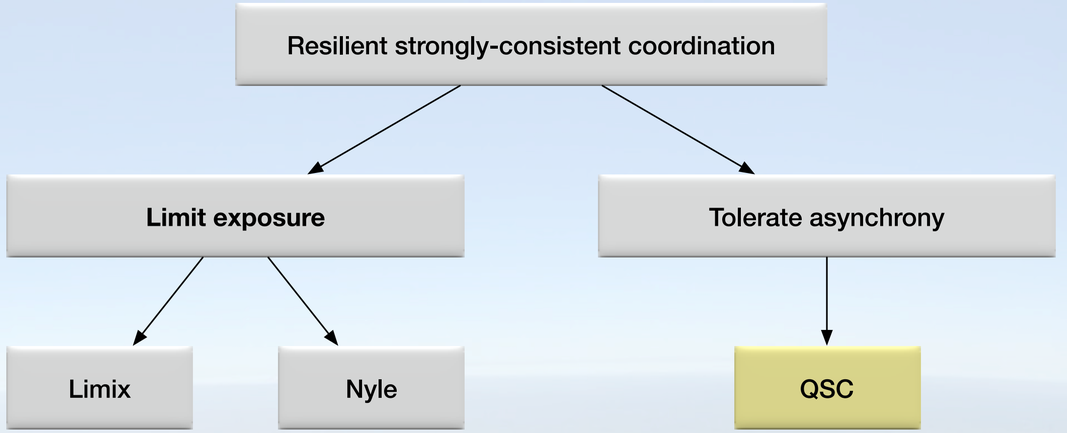

Consensus using reliable broadcast

Agreement on arbitrary values

Cannot use majority vote

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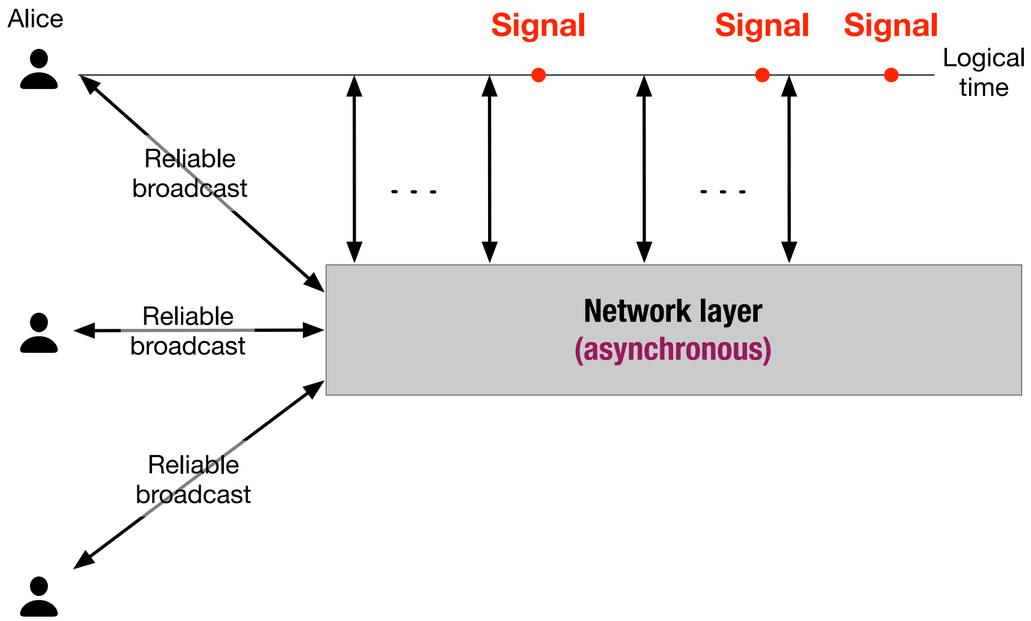
Use reliable broadcast

Eventually all live nodes receive the same proposals.
But when?



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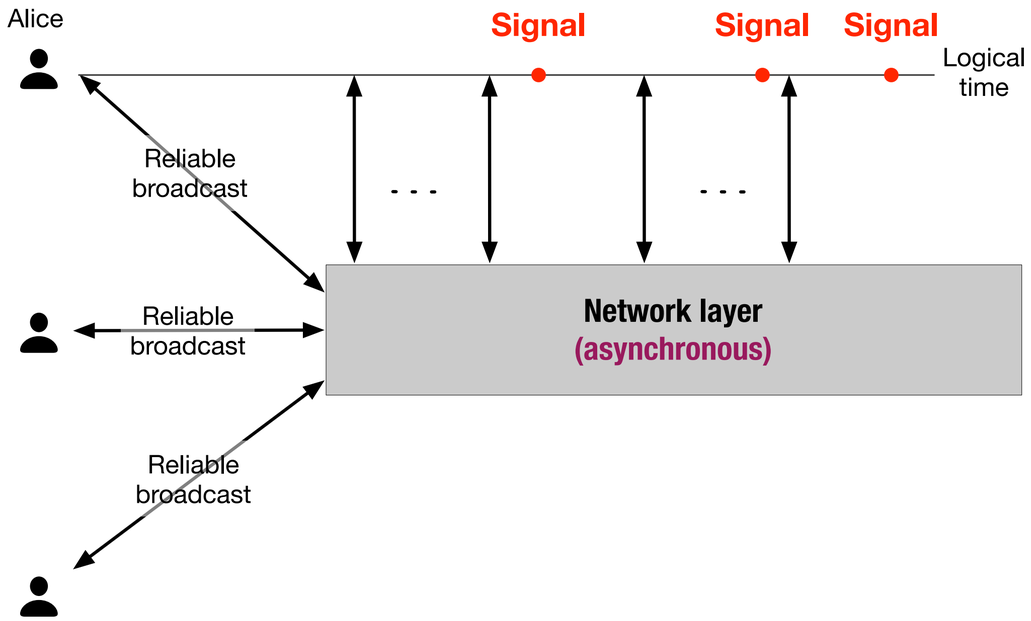
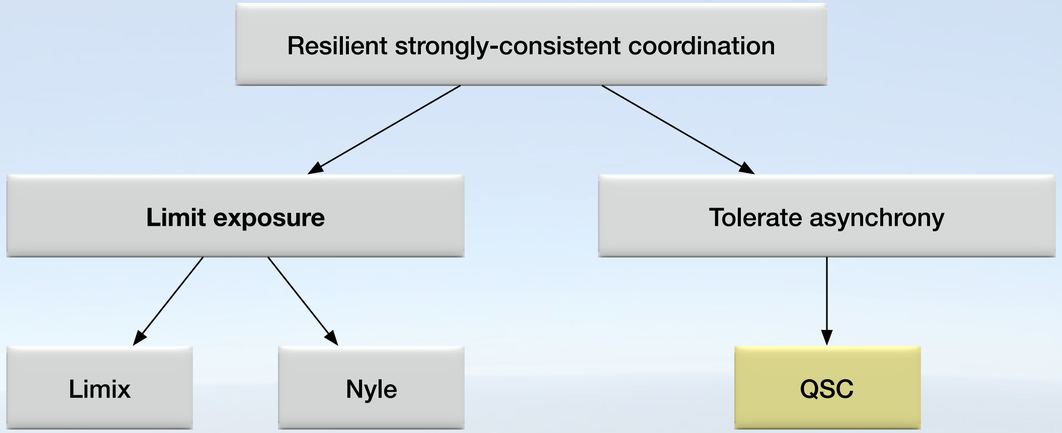
A possible signal

N binary consensus blocks



QSC roadmap



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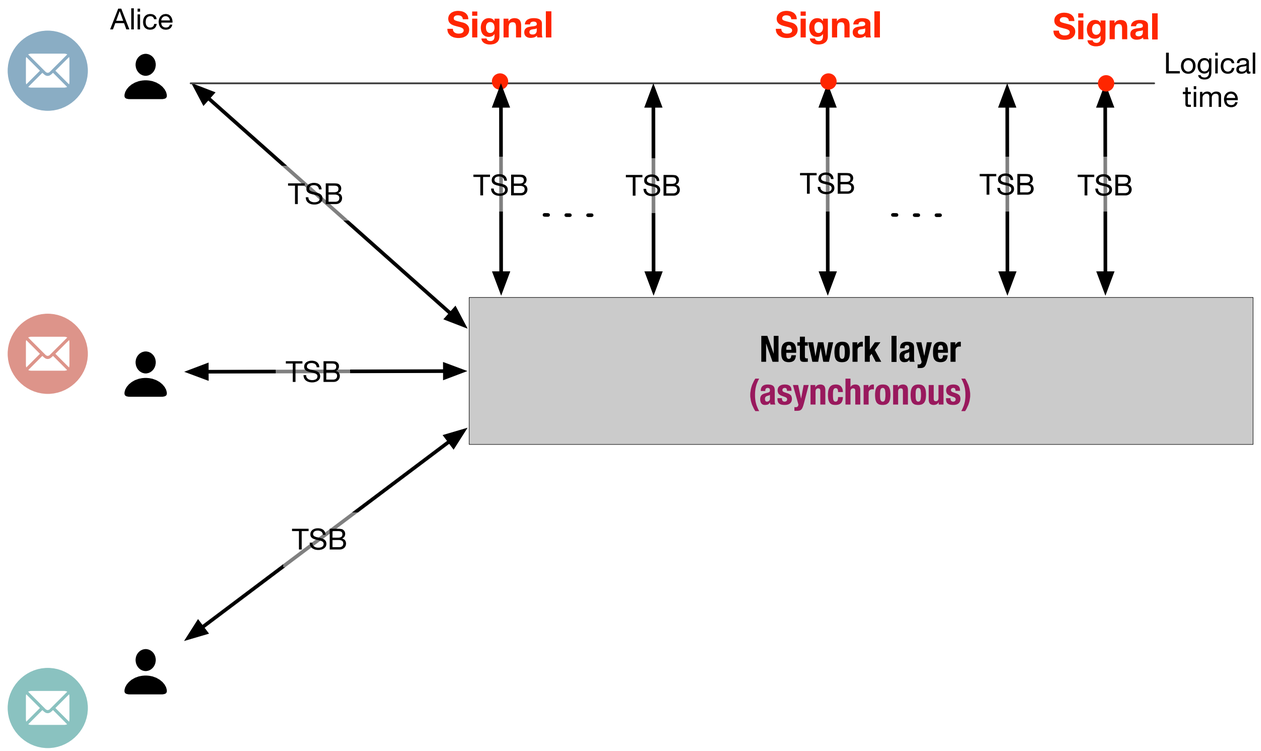

New primitive TSB
(threshold-synchronous broadcast)

QSC insights

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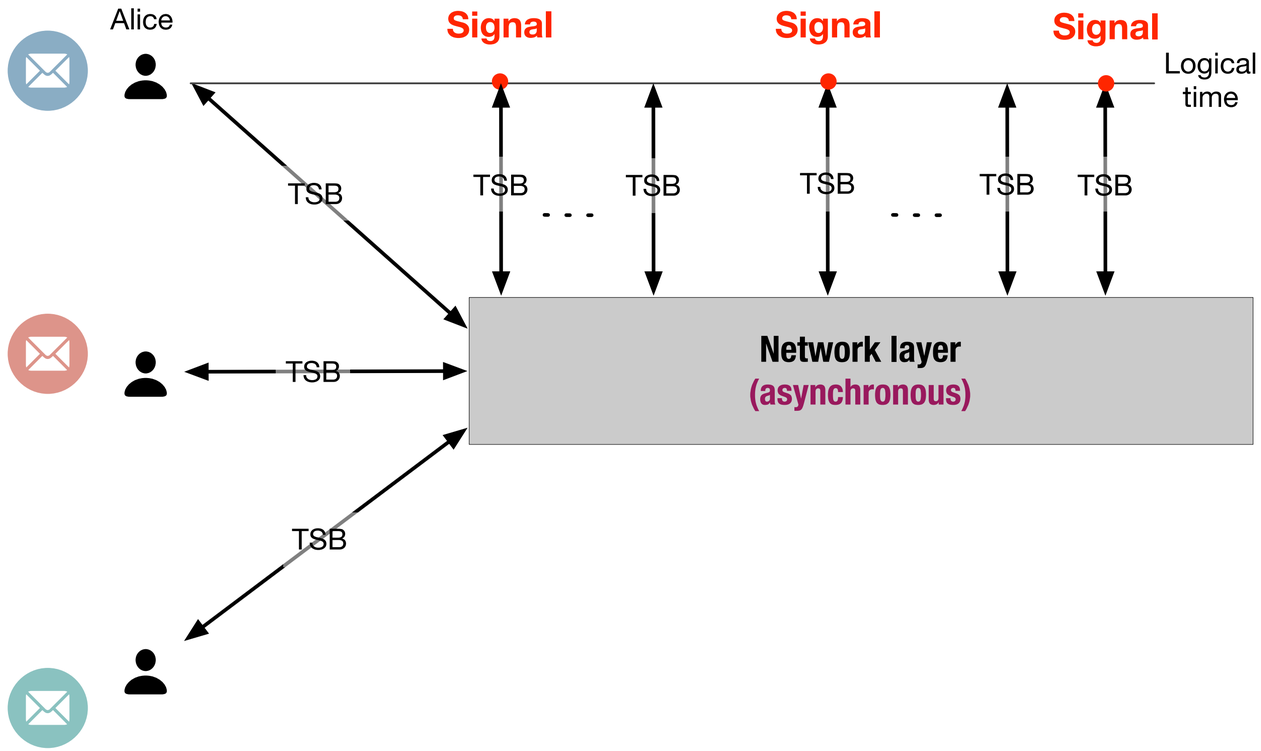

New primitive TSB (threshold-synchronous broadcast)

Unlike reliable broadcast, TSB also provides the **signal**

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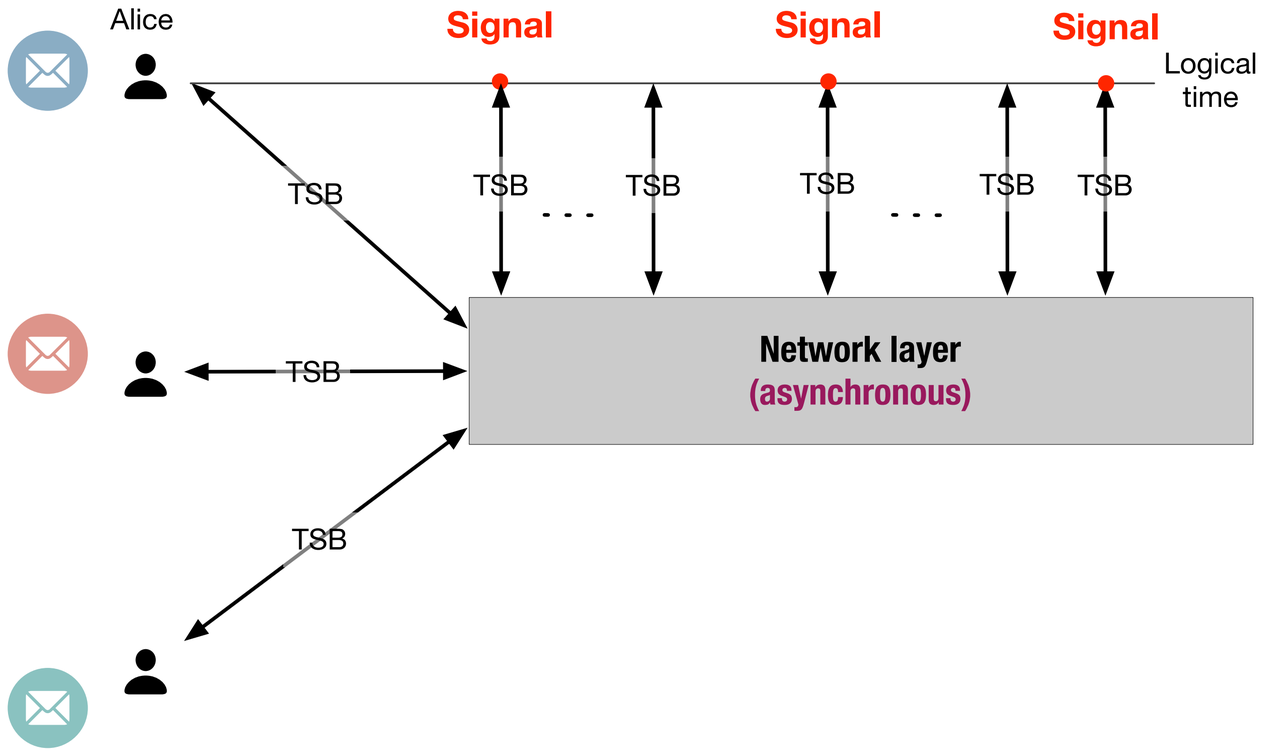

New primitive TSB (threshold-synchronous broadcast)

Unlike reliable broadcast, TSB also provides the **signal**

Unlike common core, TSB identifies specific values received by all

QSC insights

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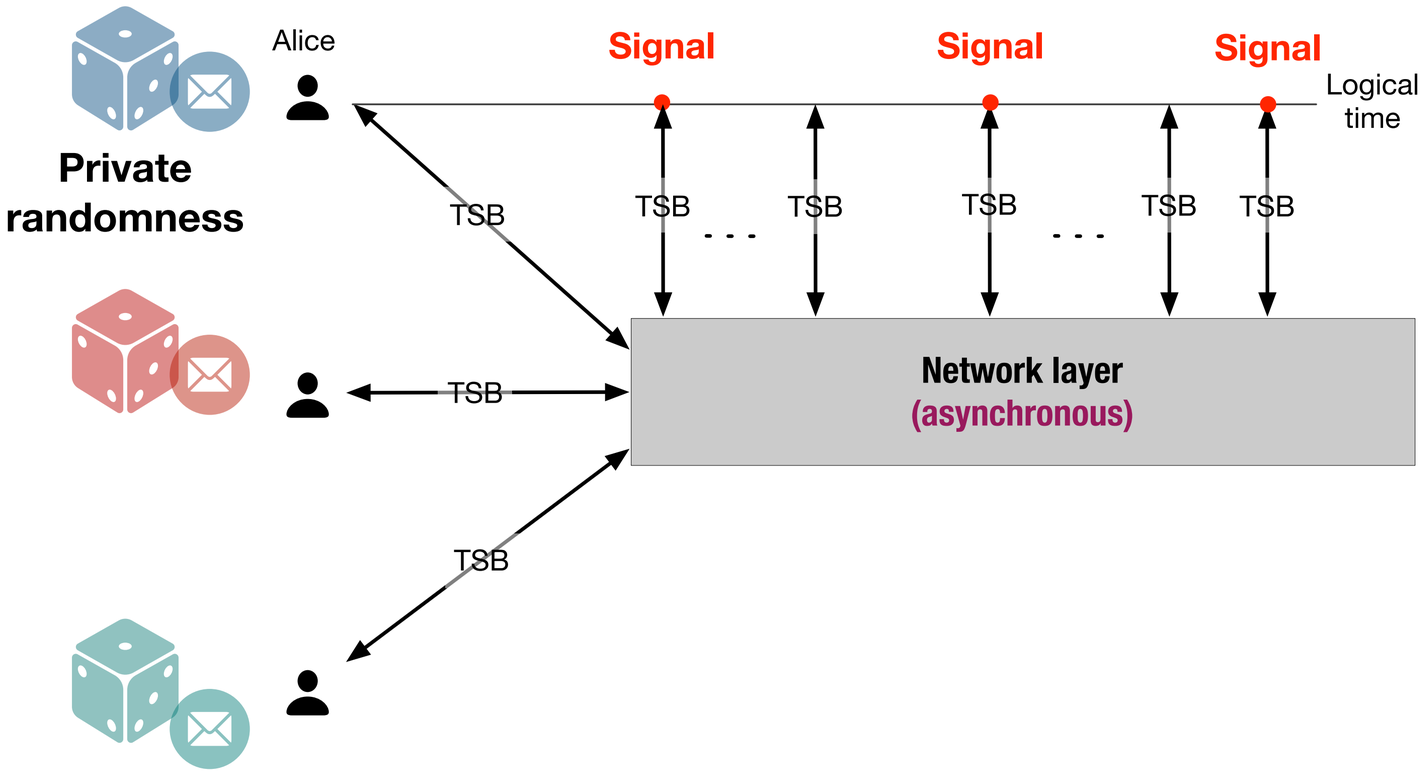
Without needing common coins
or binary consensus

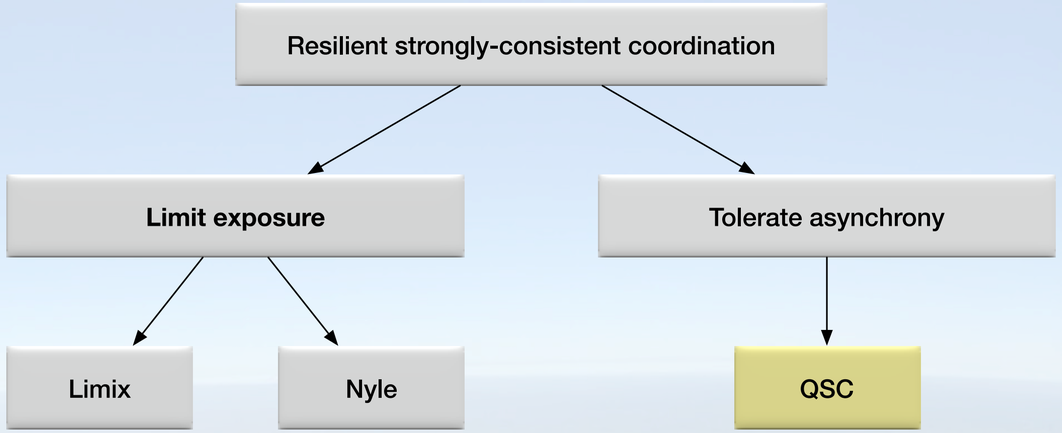


New primitive TSB (threshold-synchronous broadcast)

Unlike reliable broadcast, TSB also provides the **signal**

Unlike common core, TSB identifies specific values received by all

QSC roadmap



- Motivation and setup
- Asynchronous consensus designs
- QSC insights
- Threshold-synchronous broadcast
- The QSC algorithm
- Complexity and optimizations
- **Summary**

QSC summary

- **Crash-fault asynchronous consensus without common coins**
  - Uses node-private randomness
- **TSB: step-synchronous message delivery atop an asynchronous network**

Thesis roadmap

Resilient strongly-consistent coordination

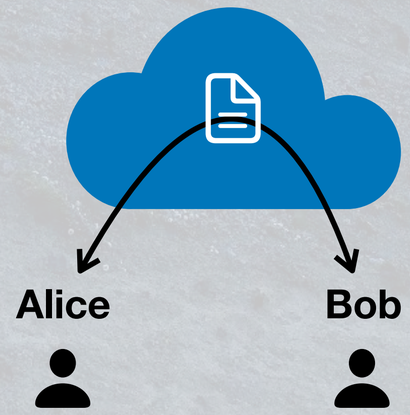
Limit exposure

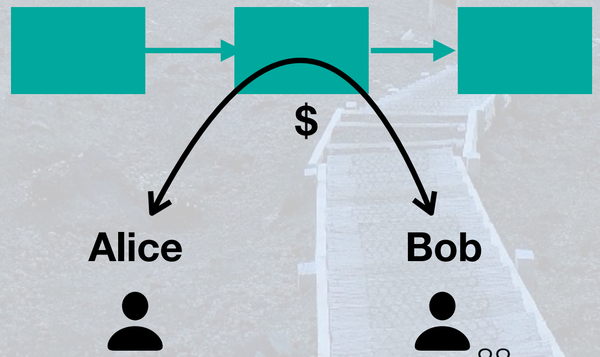
Tolerate asynchrony

Limix

Nyle

QSC





Conclusion

- **Resilience in strongly consistent coordination**
- **Limiting exposure results in systems resilient to distant failures**
  - Limix reduces exposure in metadata services for cloud systems
  - Nyle reduce exposure in BFT-style blockchains through a trust-but-verify approach
- **Tolerating network asynchrony could become more practical**
  - QSC solves asynchronous consensus for crash faults without requiring common coins

Backup slides

Limix: limit exposure to remote partitions

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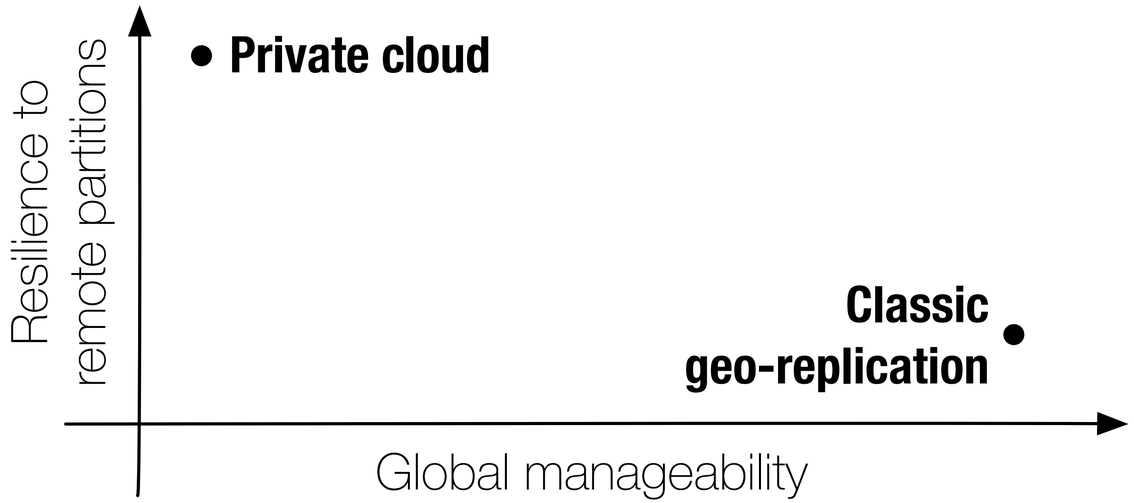
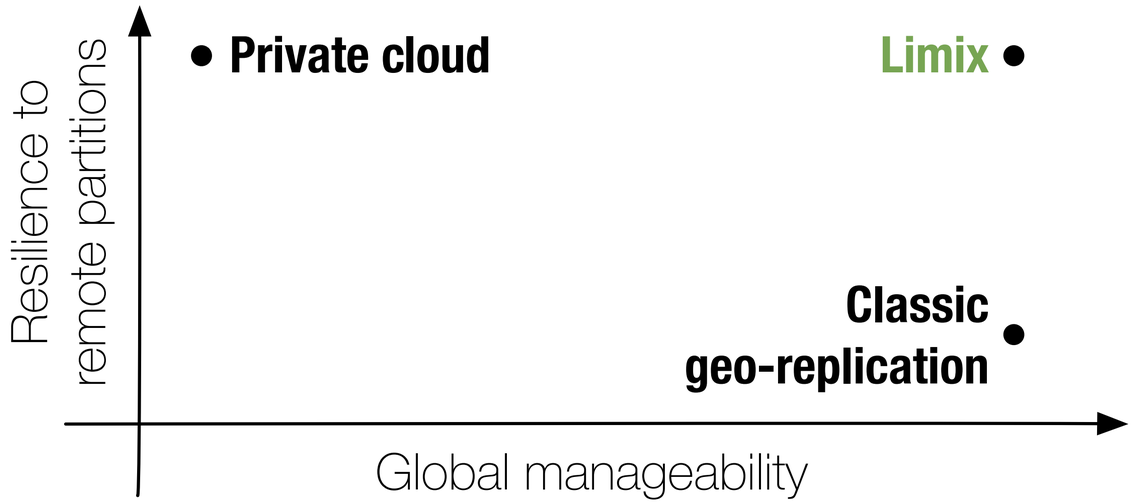
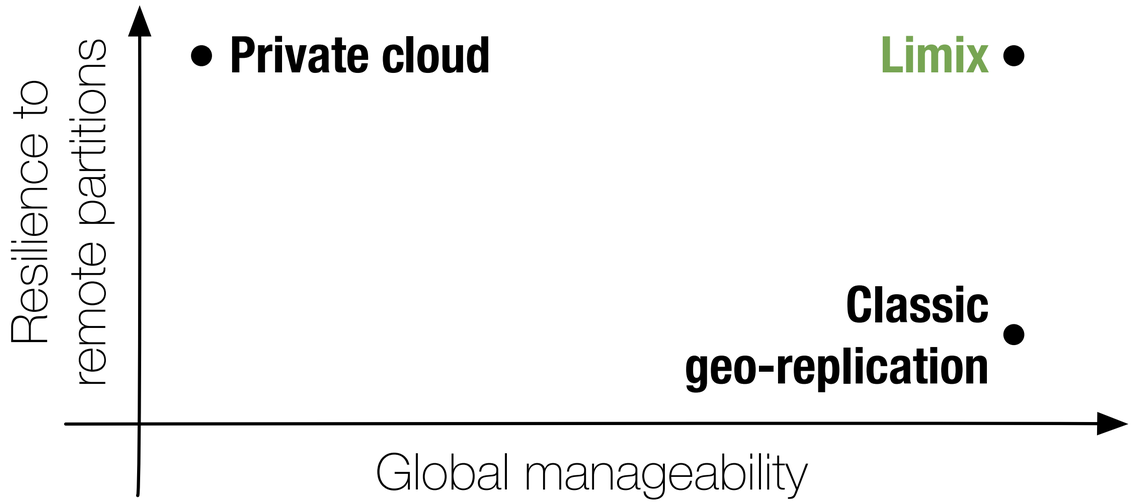
Limix: limit exposure to remote partitions



Limix: limit exposure to remote partitions

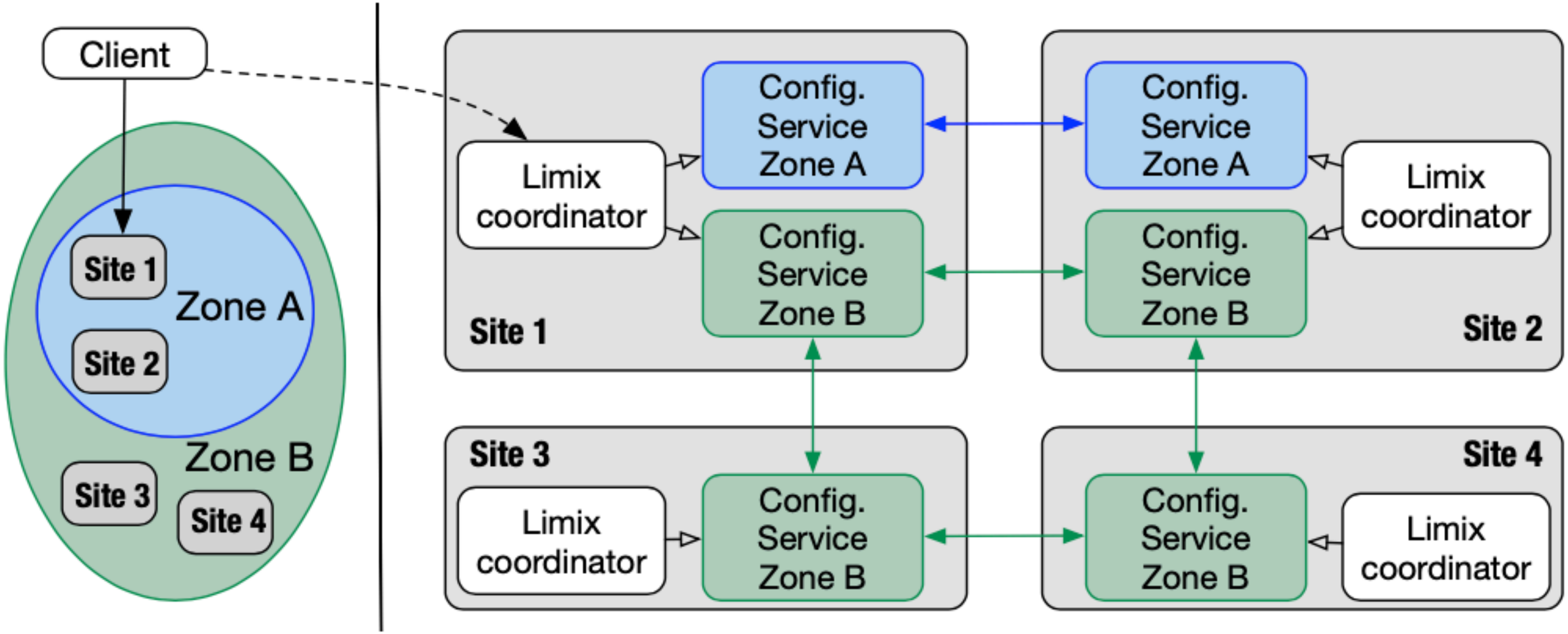


Limix: limit exposure to remote partitions



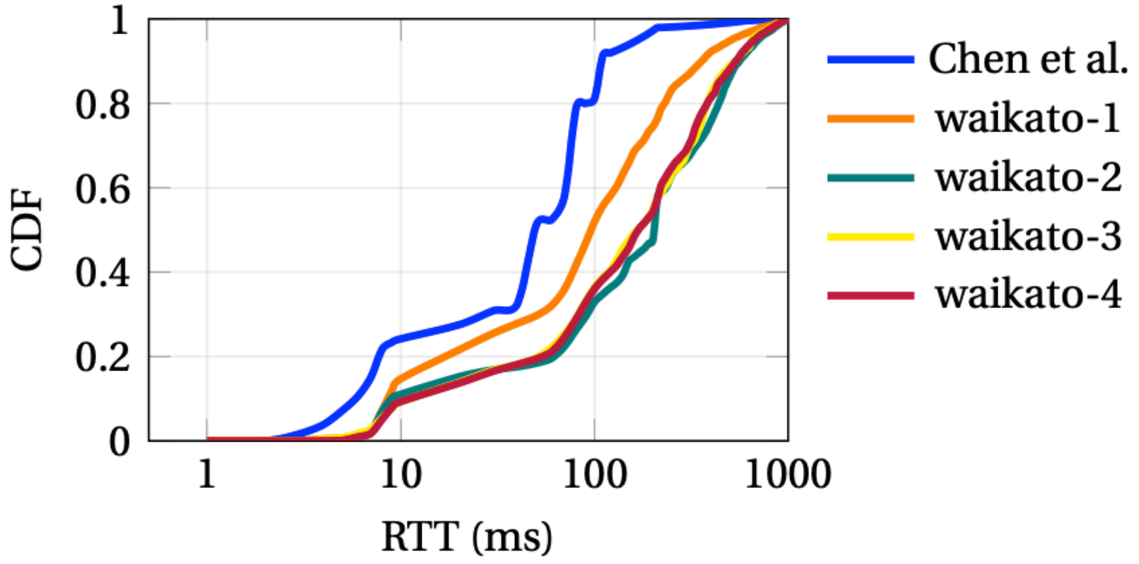
Goal: Limit metadata exposure for all users

Limix architecture

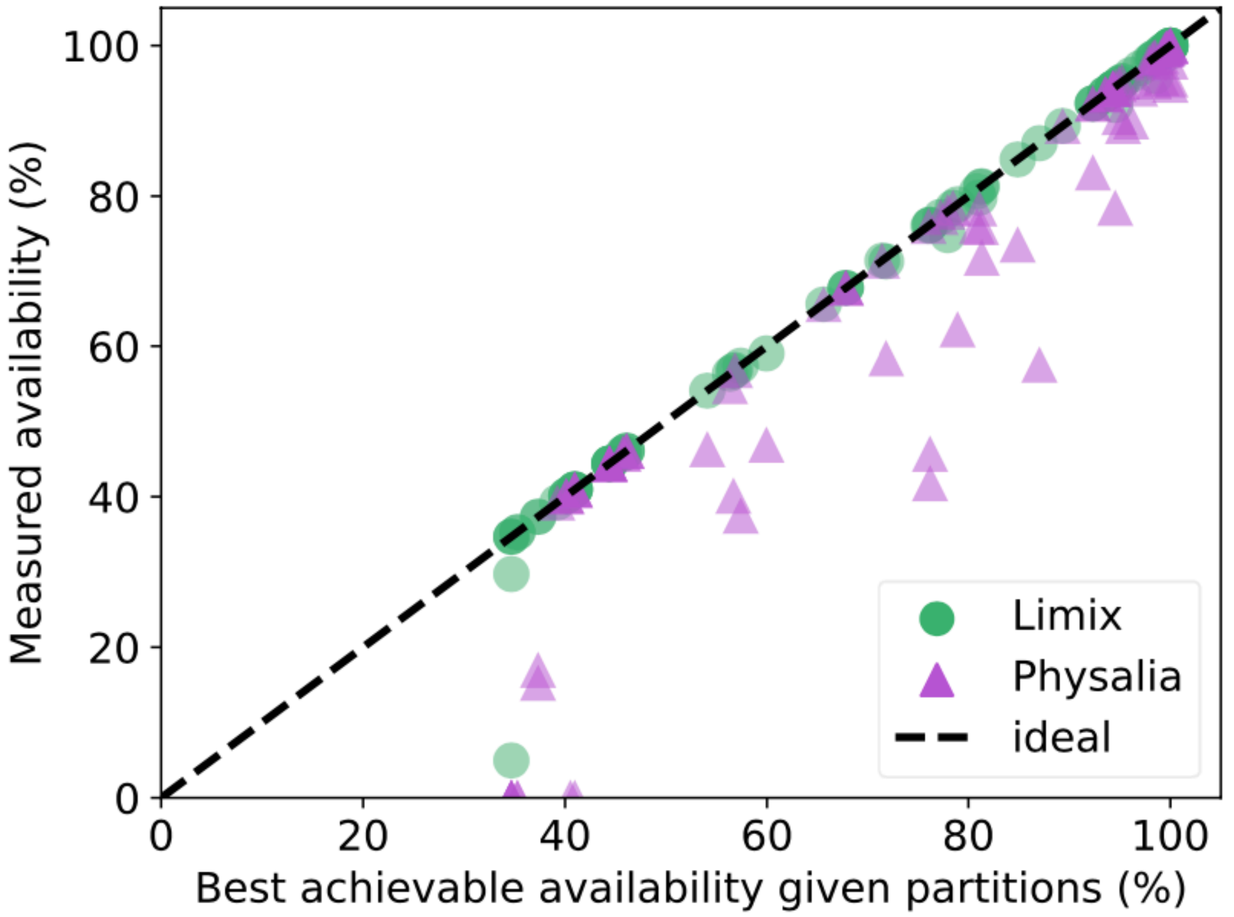


Limix realistic workload experiment

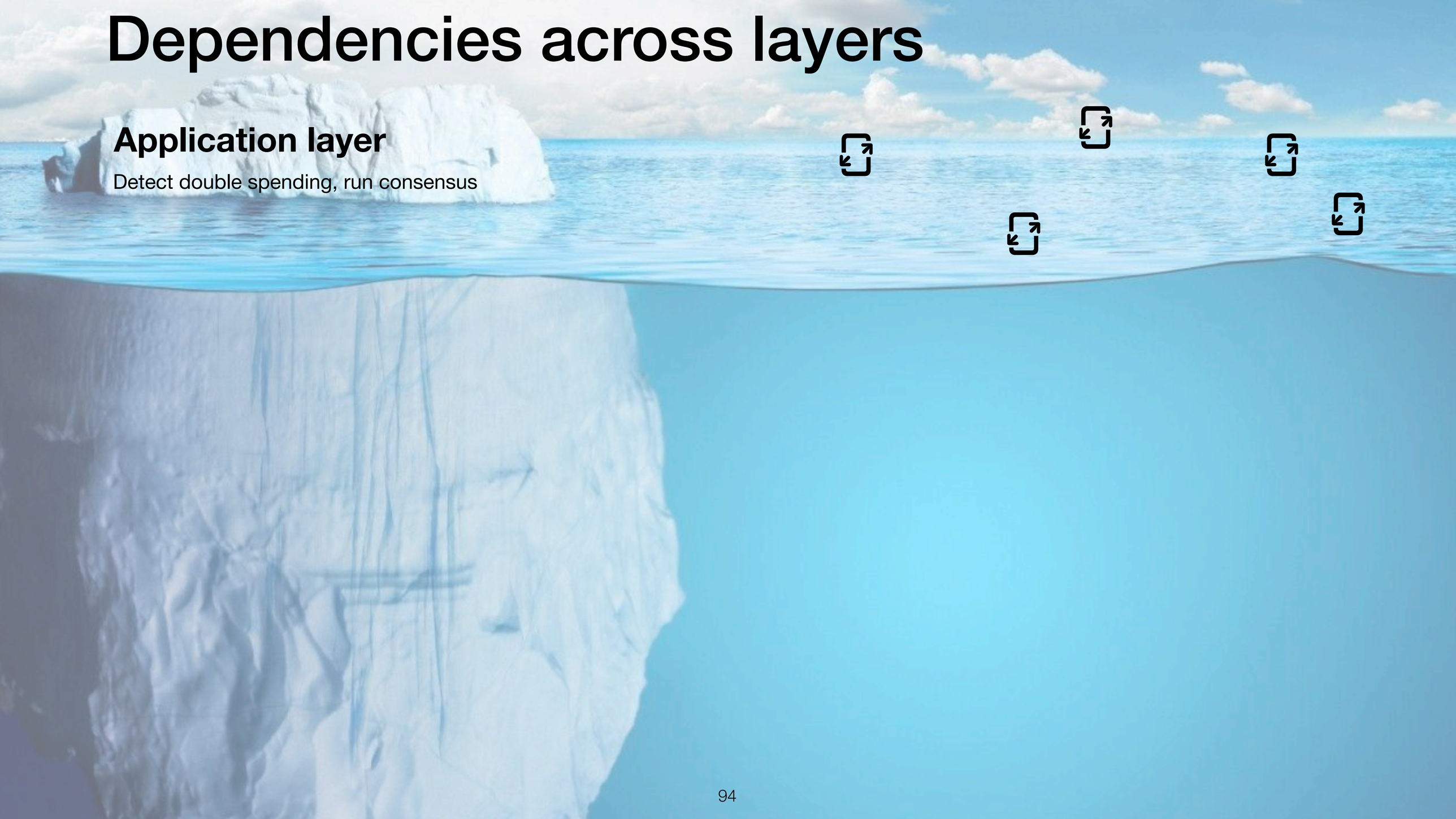
RTT between W-W pairs



Availability



Dependencies across layers



Application layer

Detect double spending, run consensus

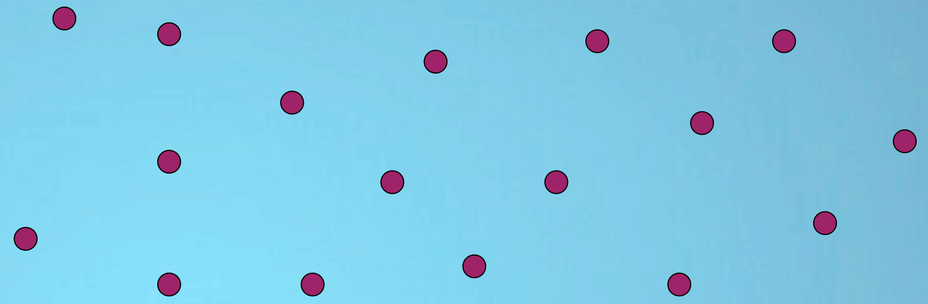
Dependencies across layers

Application layer

Detect double spending, run consensus

Validators layer

Ensure validator uptime, withstand Byzantine behaviour



Dependencies across layers

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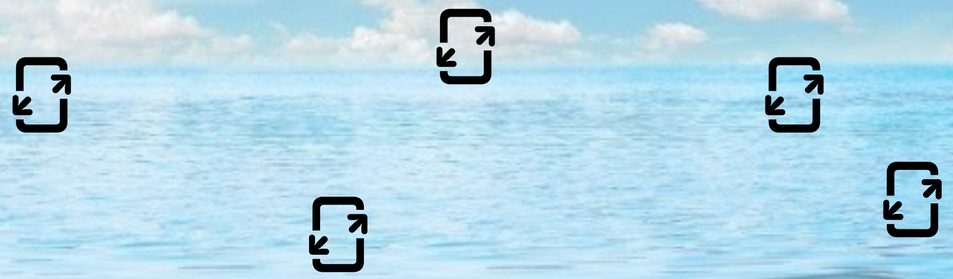

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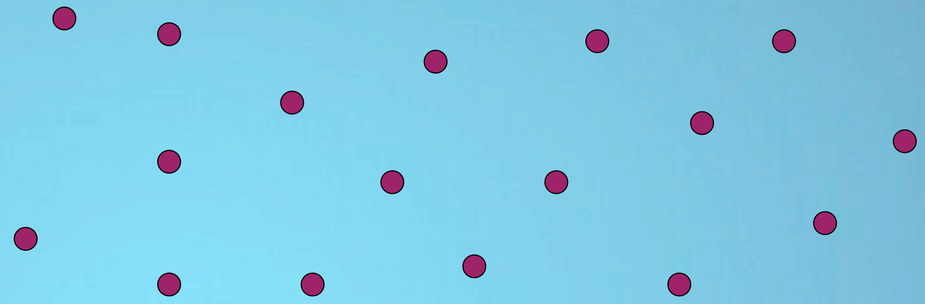


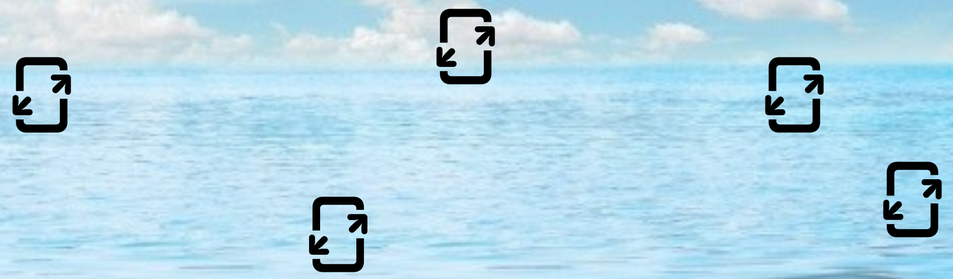
Interconnect layer

Correlated failures and attacks
Are validators up? From whose perspective?

Dependencies across layers

Application layer

Detect double spending, run consensus



Validators layer

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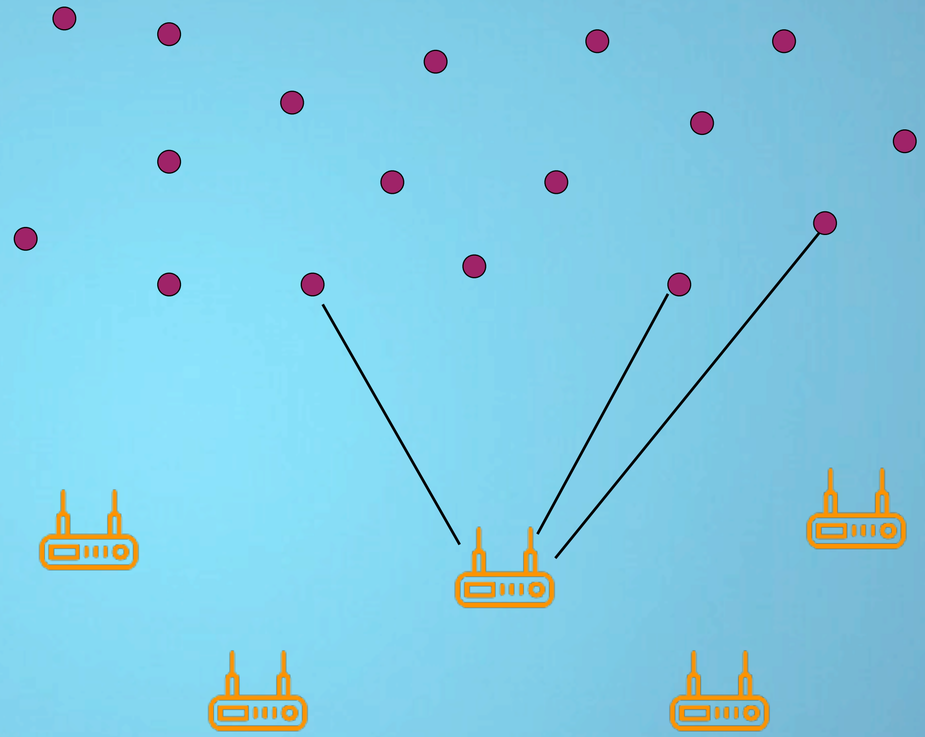

Interconnect layer

Correlated failures and attacks
Are validators up? From whose perspective?

Real-world resilience risks in blockchains

- Censorship / validators offline or slow ⇒ unavailability

Real-world resilience risks in blockchains

- Censorship / validators offline or slow ⇒ unavailability

Penalties

So far we have considered perfectly well-behaved validators, but what about validators that do not make timely head, source and target votes or do so slowly?

The penalties for missing the target and source votes are equal to the rewards the attestor would have received had they submitted them. This means that instead of having the reward

SLASHING

Slashing is a more severe action that results in the forceful removal of a validator from the network and an associated loss of their staked ether. There are three ways a validator can be

Nyle zoning

✓ **Challenge 1:**
Open membership resilient to Sybil attacks (globally < ⅓ Byzantine validators)

Solution:
Use existing* proof-of-work approaches

* Eleftherios Kokoris-Kogias, Philipp Jovanovic, Nicolas Gailly, Ismail Khoffi, Linus Gasser, and Bryan Ford. Enhancing Bitcoin Security and Performance with Strong Consistency via Collective Signing. In *Proceedings of the 25th USENIX Conference on Security Symposium*, 2016.

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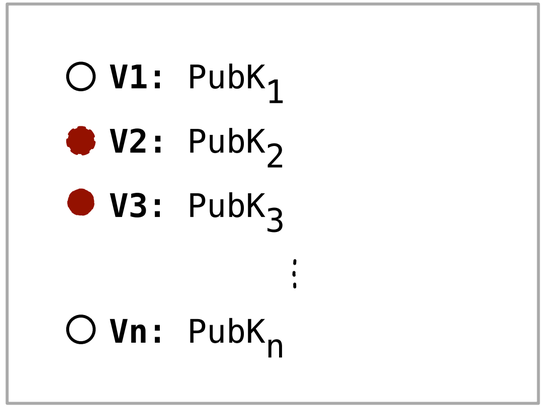

Honest validator

Compromised validator

* Eleftherios Kokoris-Kogias, Philipp Jovanovic, Nicolas Gailly, Ismail Khoffi, Linus Gasser, and Bryan Ford. Enhancing Bitcoin Security and Performance with Strong Consistency via Collective Signing. In *Proceedings of the 25th USENIX Conference on Security Symposium*, 2016.

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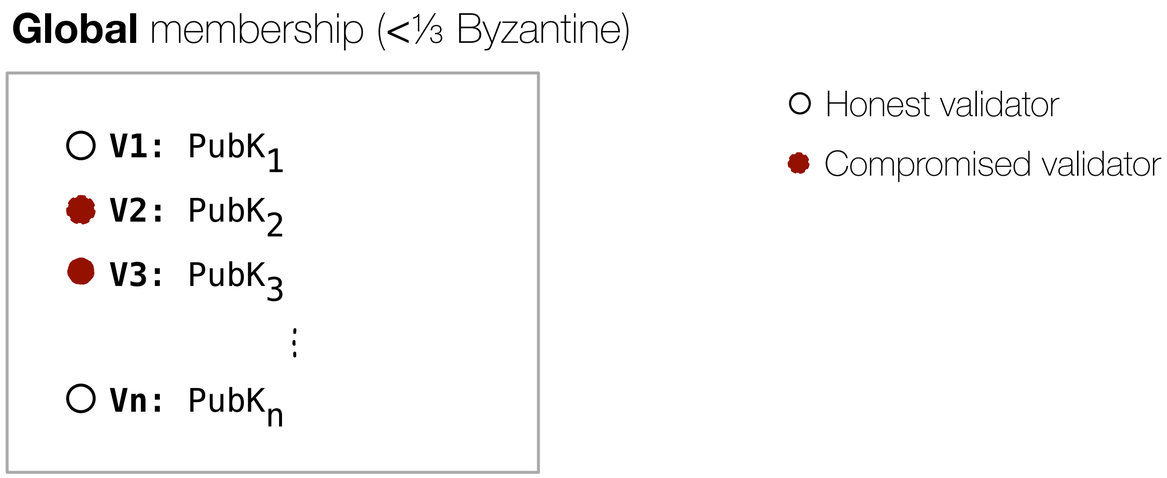

X **Challenge 2:**
Validator joins two disjoint zones

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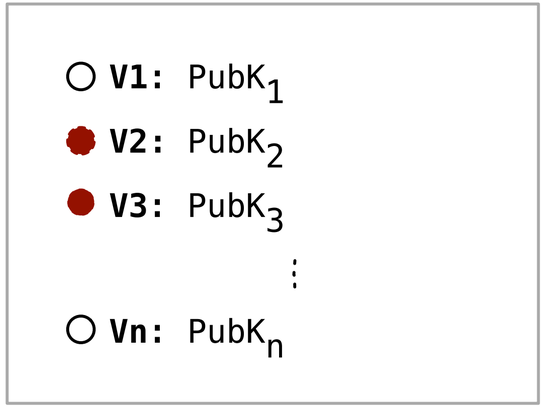

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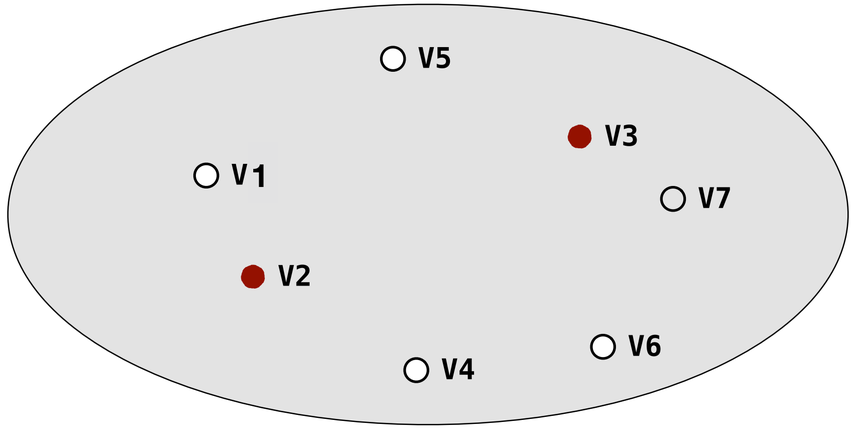

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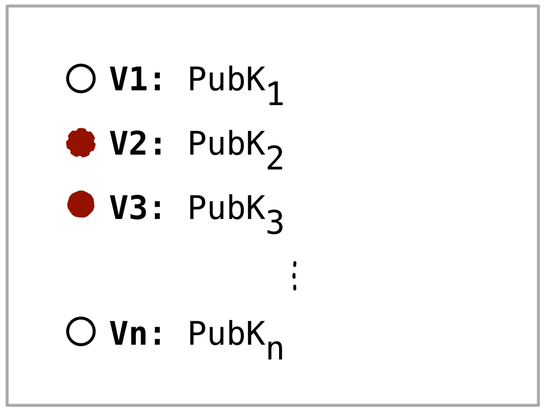

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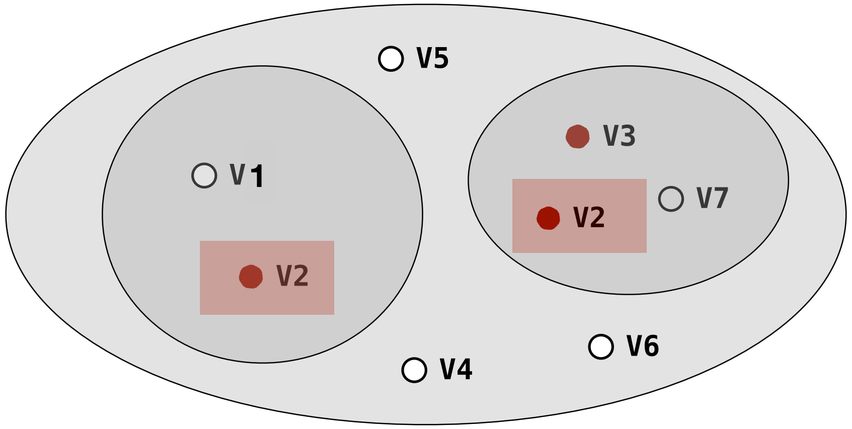

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Solution:
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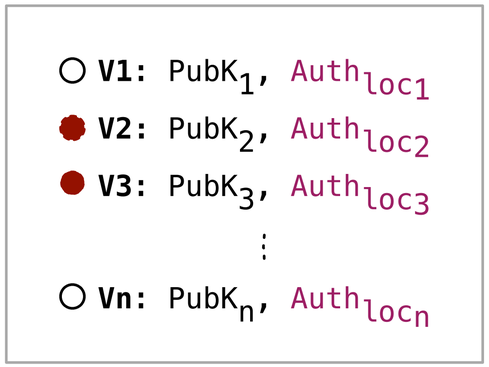
✓ **Challenge 2:**
Validator joins two disjoint zones

Solution:
Validators make a location claim

Global membership (<⅓ Byzantine)



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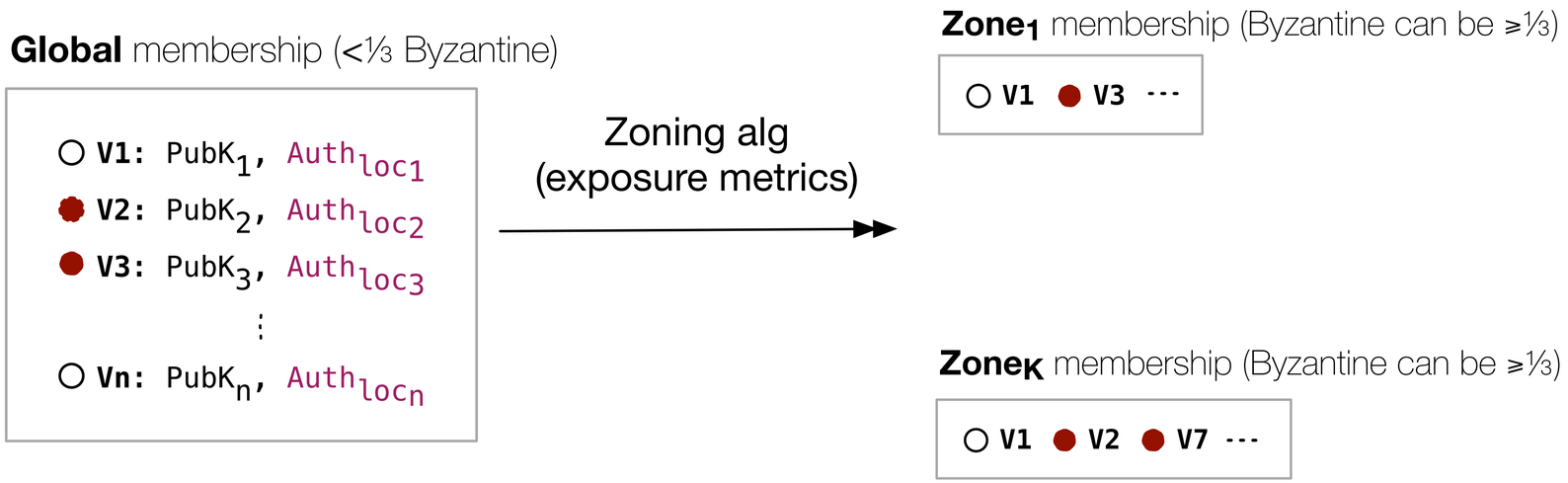

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Solution:
Use existing proof-of-work approaches

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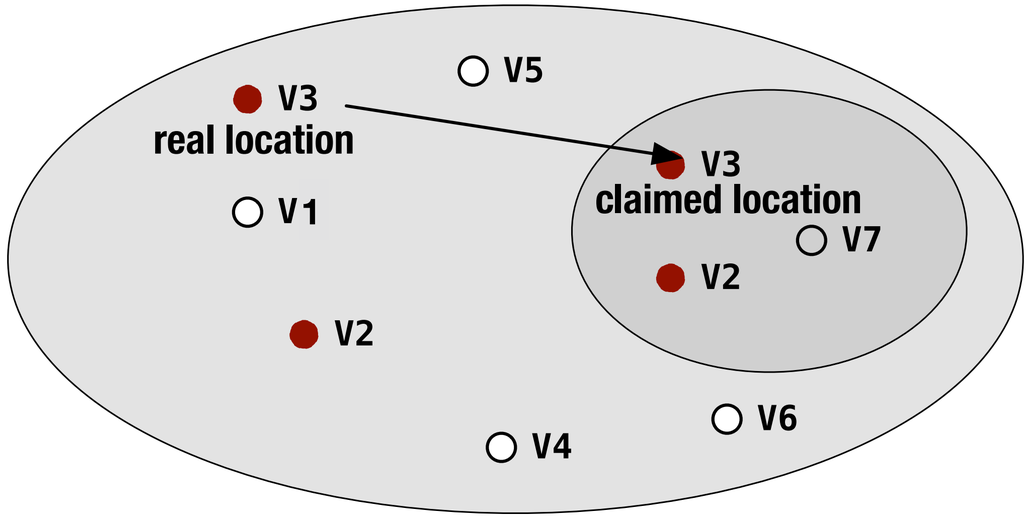
Validator joins two disjoint zones

Solution:
Validators make a location claim

X **Challenge 3:**
Compromised validator makes bogus location claim



Nyle zoning

√ **Challenge 1:**
Open membership resilient to Sybil attacks (globally < ⅓ Byzantine validators)

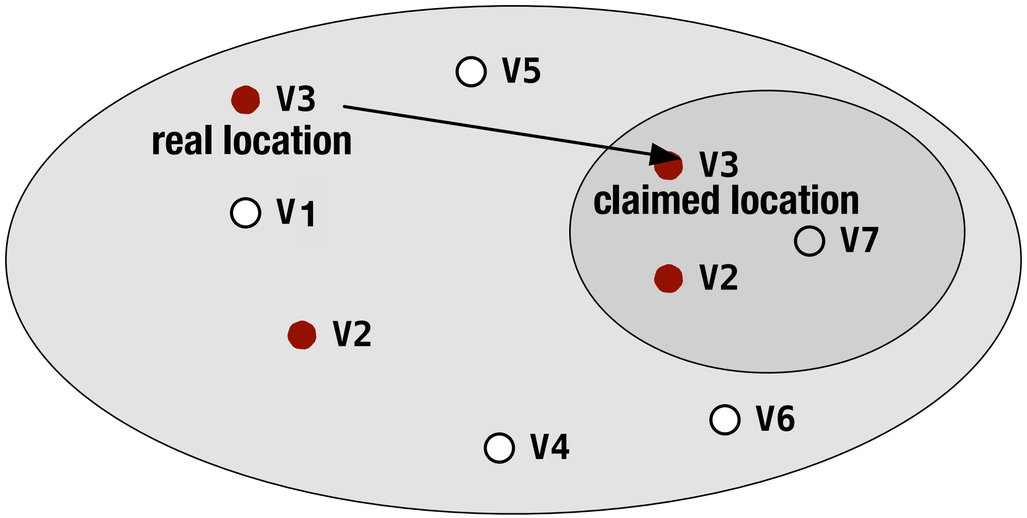
Solution:
Use existing proof-of-work approaches

√ **Challenge 2:**
Validator joins two disjoint zones

Solution:
Validators make a location claim

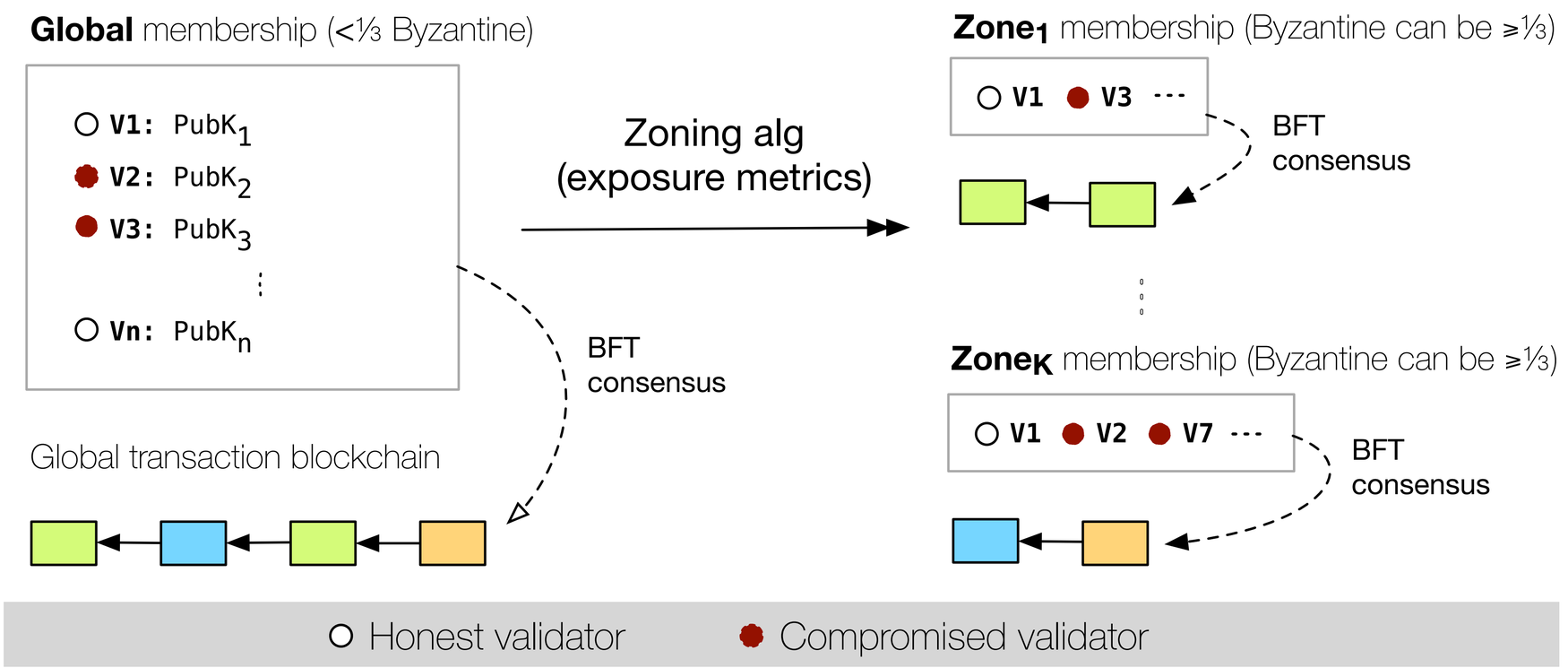
√ **Challenge 3:**
Malicious validator makes wrong location claim

Solution:
Validate location claims via existing mechanisms*



* Katharina Kohls and Claudia Diaz. VerLoc: Verifiable localization in decentralized systems. In *USENIX Security Symposium (USENIX Security)*, 2022

Nyle zoning


Global membership (<⅓ Byzantine)
V1: PubK1
V2: PubK2
V3: PubK3
Vn: PubKn
Zoning alg
(exposure metrics)
BFT
consensus
Global transaction blockchain
Zone1 membership (Byzantine can be ⩾⅓)
V1 V3 ---
BFT
consensus
ZoneK membership (Byzantine can be ⩾⅓)
V1 V2 V7 ---
BFT
consensus
Honest validator
Compromised validator

Nyle transaction validation security

#	Participant honest(✓) / compromised(×) / unknown(∗)				Nyle property guarantee yes(✓) / no(×) / N/A [reason]						
					Safety			Liveness*			Exposure
	Sender	Recv	CLZ	SEZ	Sender	Recv.	Zones	Sender	Recv.	Zones	
1.	✓	*	✓	✓	✓	✓	✓	✓	✓	✓	SEZ
2.				×		✓[S2]			✓[L1]		Global
3.	✓	*	×	✓	✓[S1]	✓	✓	✓[L2]	✓	✓[L2]	SEZ
4.				×		✓[S2]			✓[L1,L2]		Global
5.	×	*	✓	✓	N/A	✓	✓	N/A	✓	✓	SEZ
6.				×		✓[S4]			✓[L1]		Global
7.	×	*	×	✓	N/A	✓[S3]	✓[S3]	N/A	✓	✓[L1,L3]	SEZ
8.				×		✓[S3]			✓[L1]		Global

Reason ID	Description
S1	The sender can forward an already validated transaction to cancel CLZ history rewrite.
S2	The transaction should be accepted, the receiver detects the bogus reject of a compromised SEZ.
S3	Zones and receiver notified of double spending by the Global zone.
S4	The transaction must not be accepted, the receiver detects the bogus accept of a compromised SEZ.
L1	The Global zone eventually replies with an authentic validation.
L2	The sender replaces a censoring CLZ via a CLZ transfer (Section 3.6).
L3	The zones contact the Global zone to intervene if the CLZ is unresponsive.

Binary consensus using common core

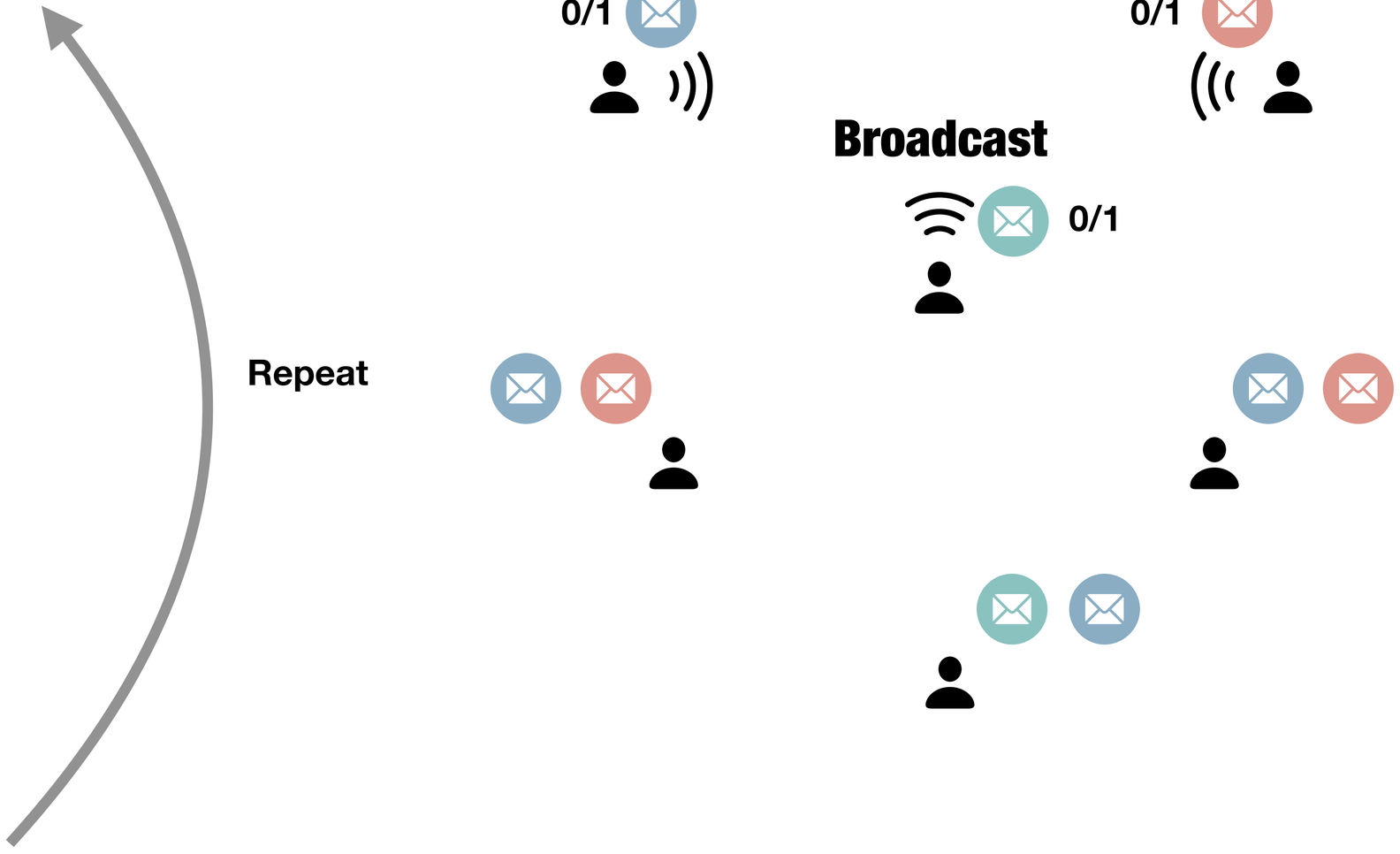
Exchange of information

Voting

Wait for N-f

Can I decide?
If not, how do I continue?

Observe a majority vote?



Consensus using reliable broadcast

Agreement on arbitrary values

Cannot use majority vote

Use reliable broadcast

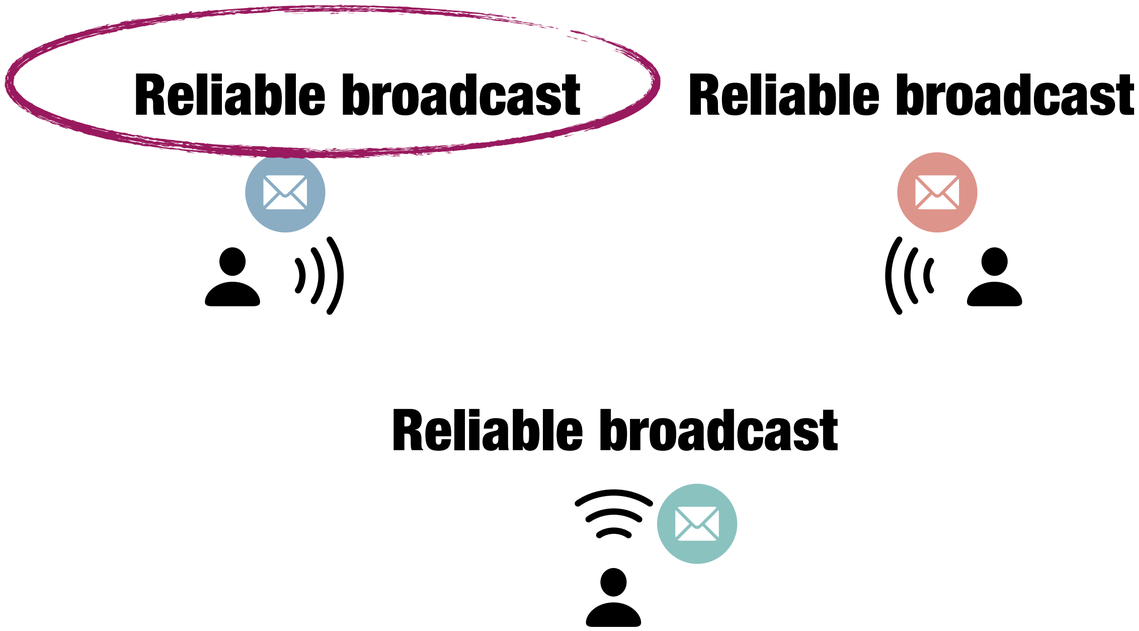
Eventually all live nodes receive the same proposals. But when?

Different signals possible

A multi-valued common coin
N blocks of binary consensus

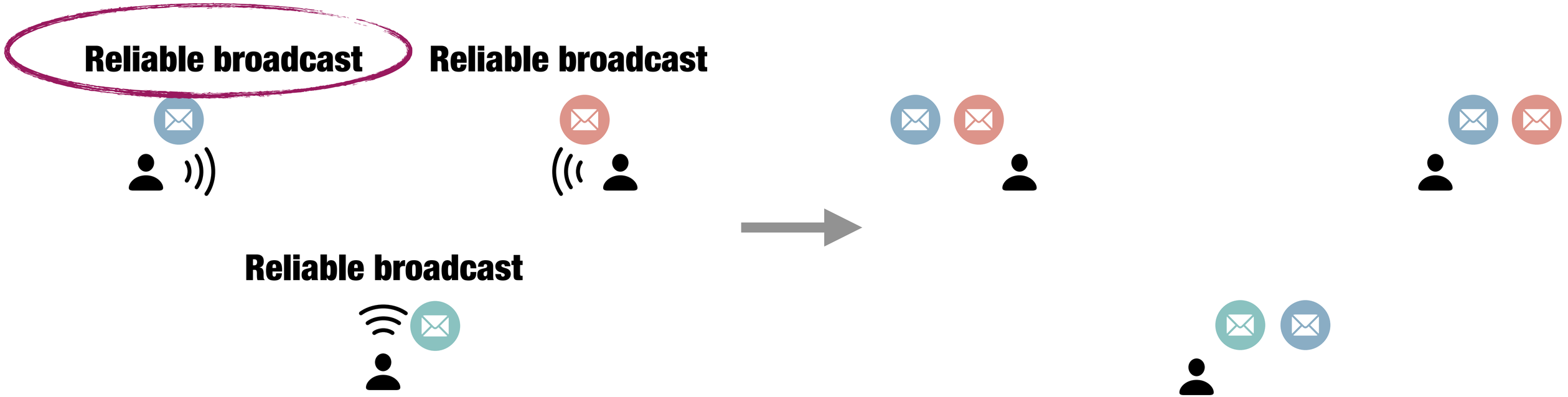
Consensus with common coins and reliable broadcast

Validity



Consensus with common coins and reliable broadcast

Validity



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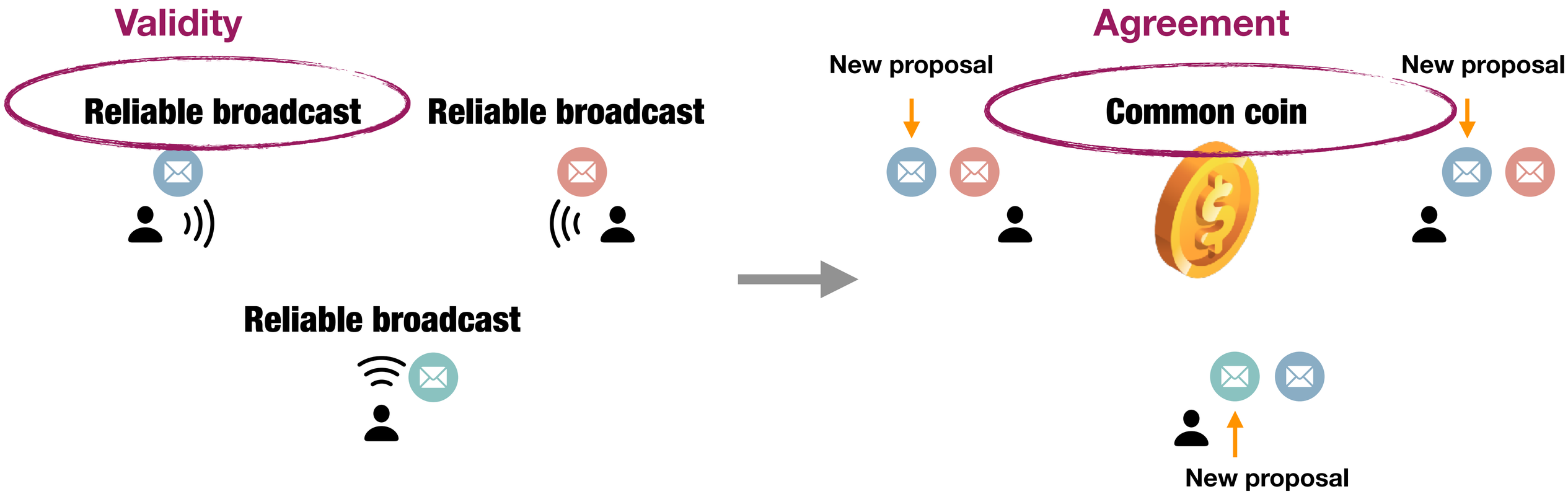
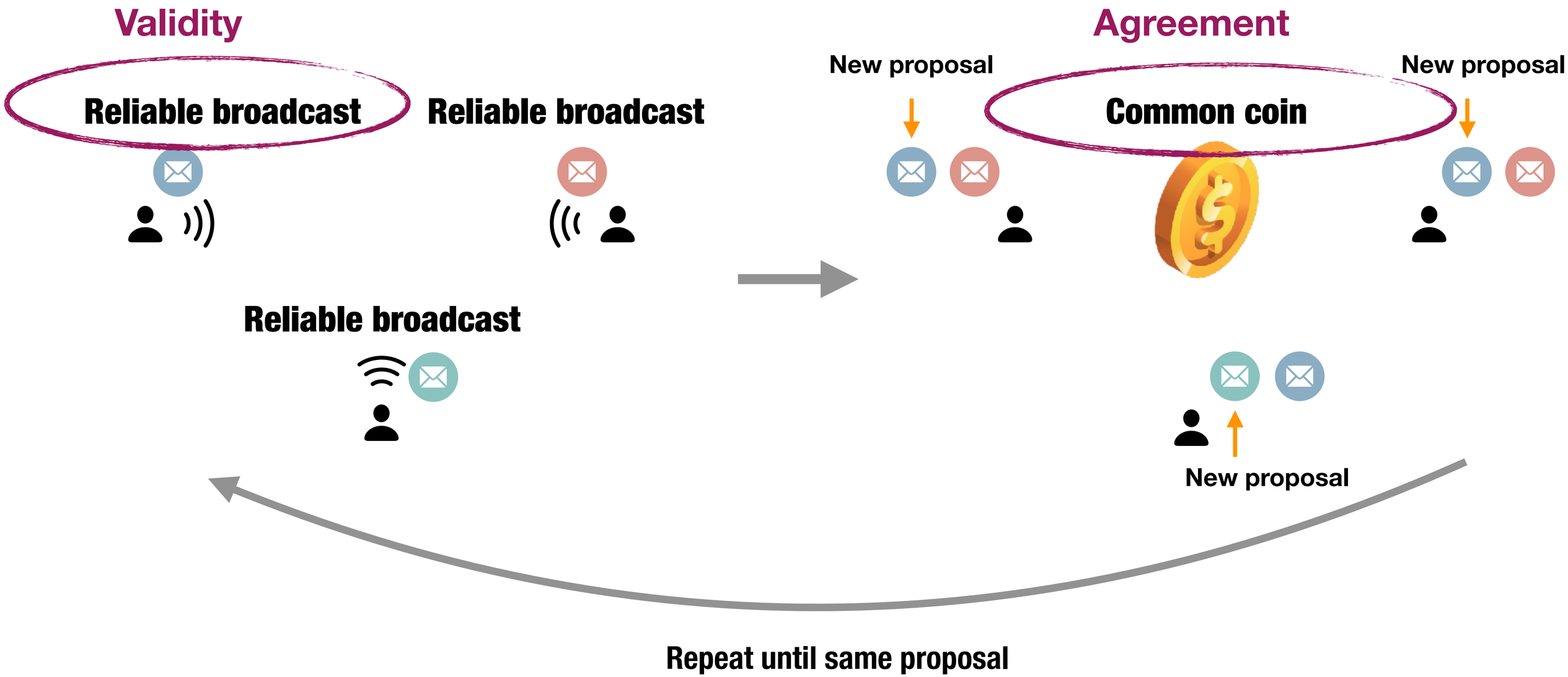


Consensus with common coins and reliable broadcast



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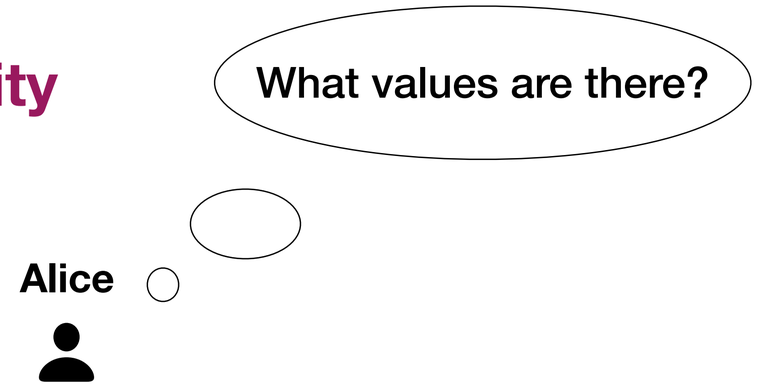
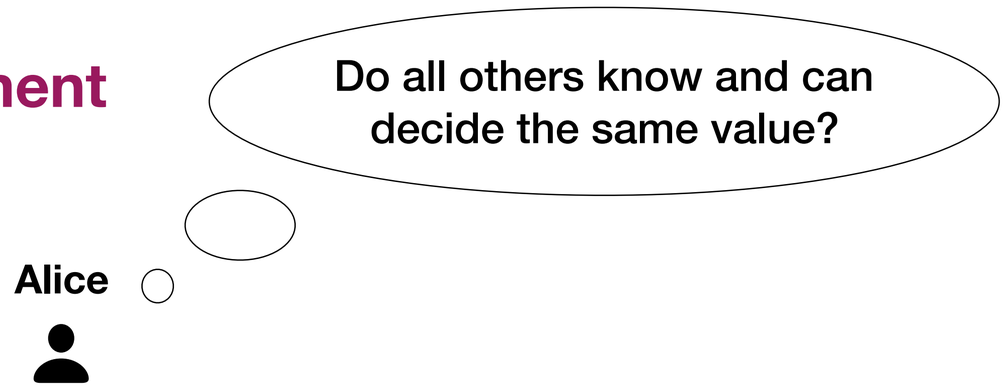
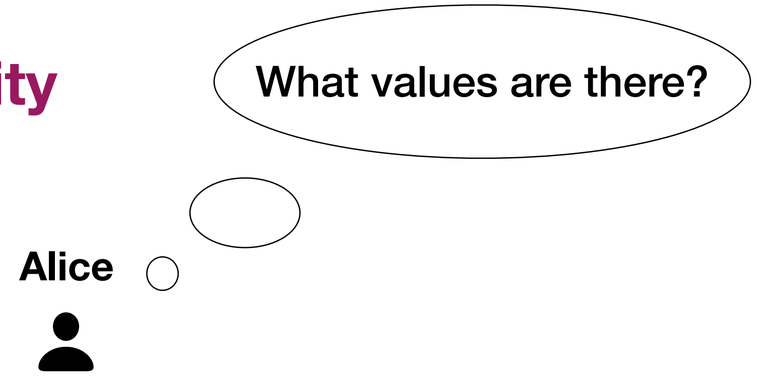


Agreement

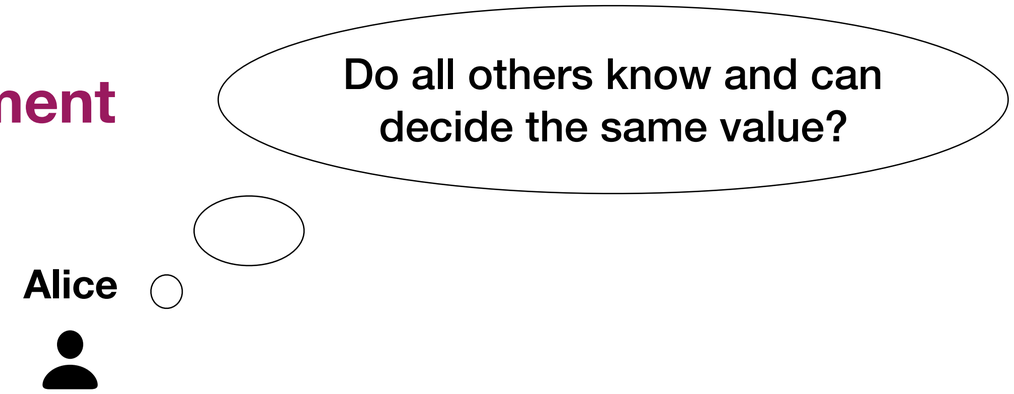


QSC insights

Validity



Agreement



QSC insights

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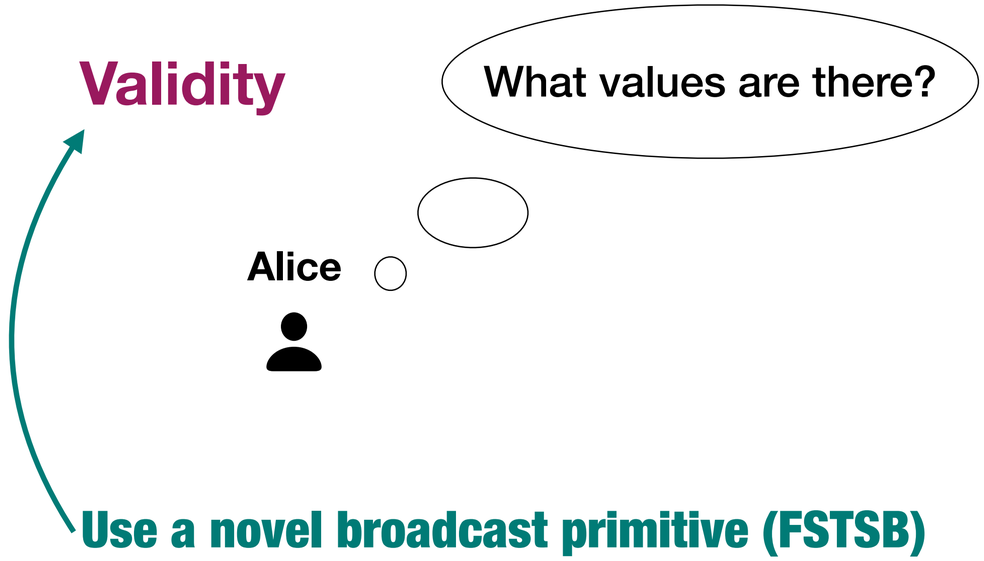
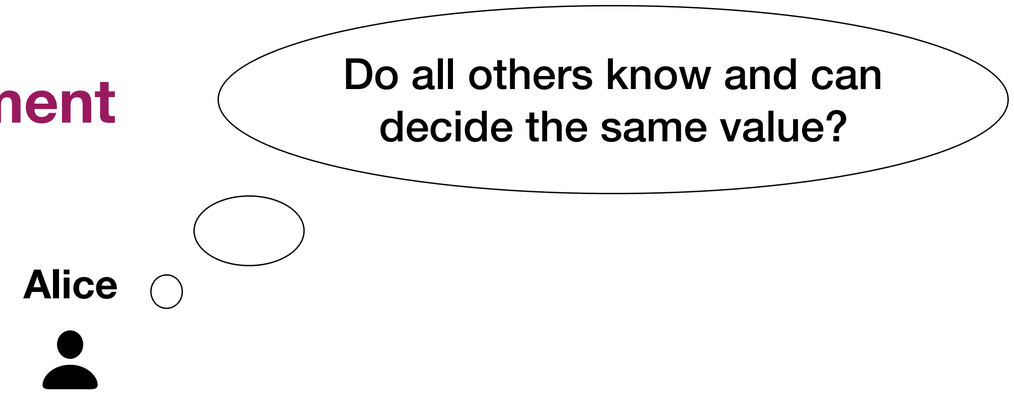


Use a novel broadcast primitive (FSTSB)

Agreement



QSC insights

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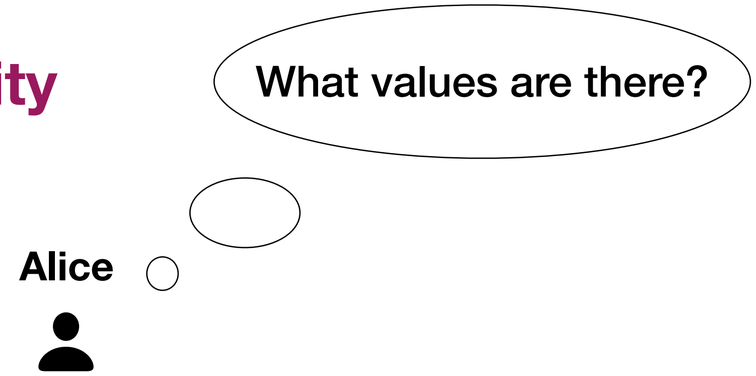
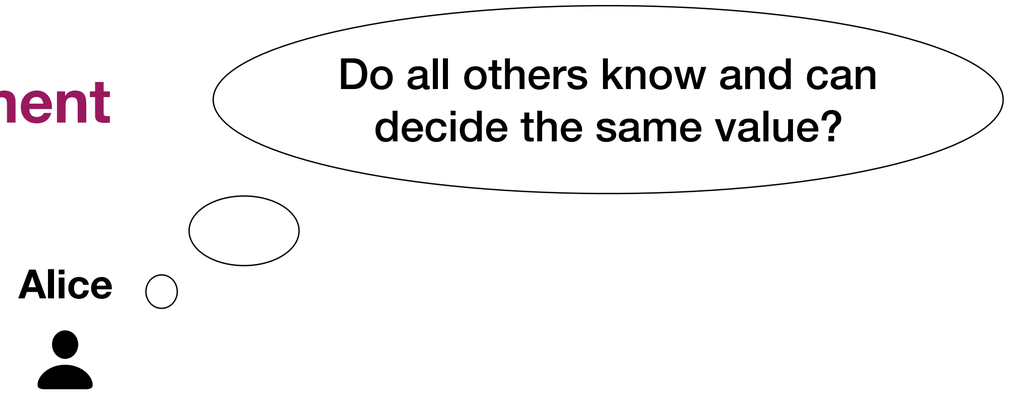


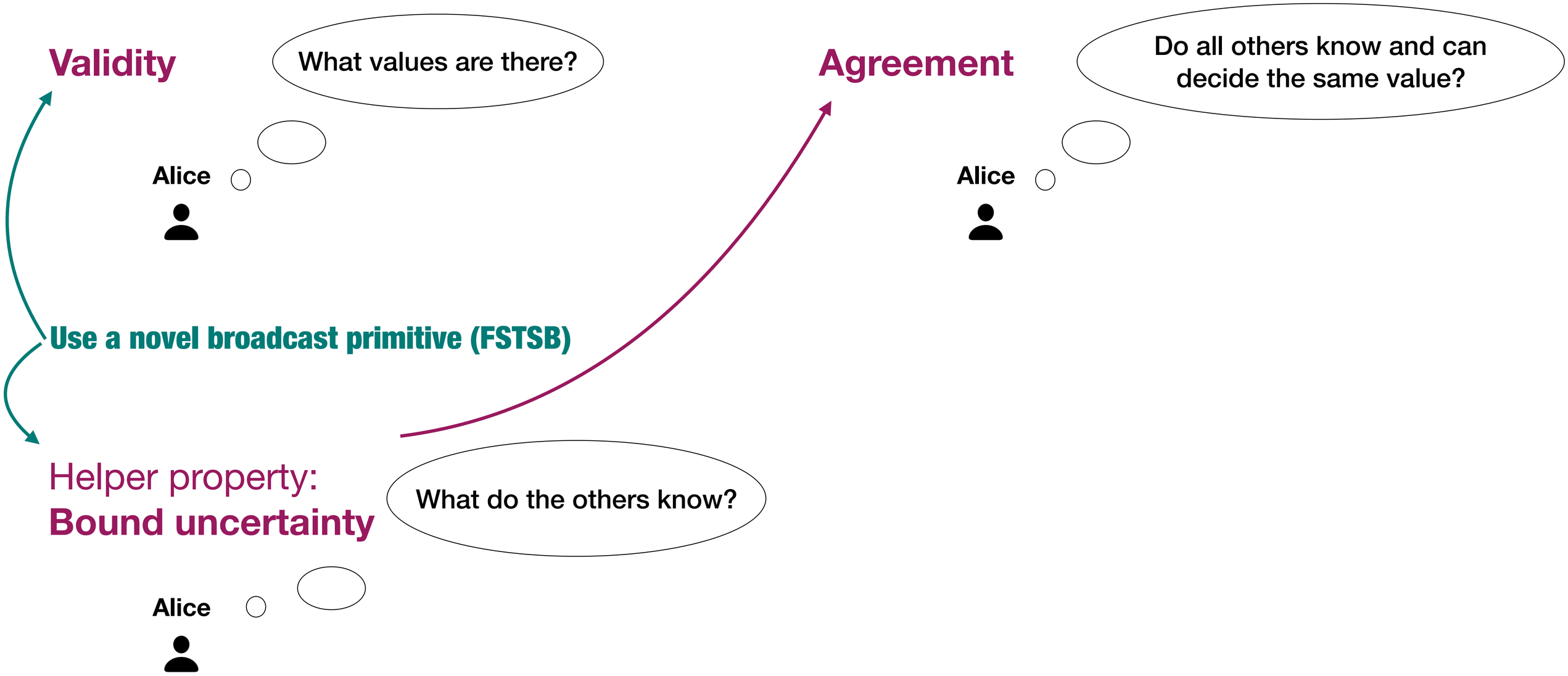
Agreement



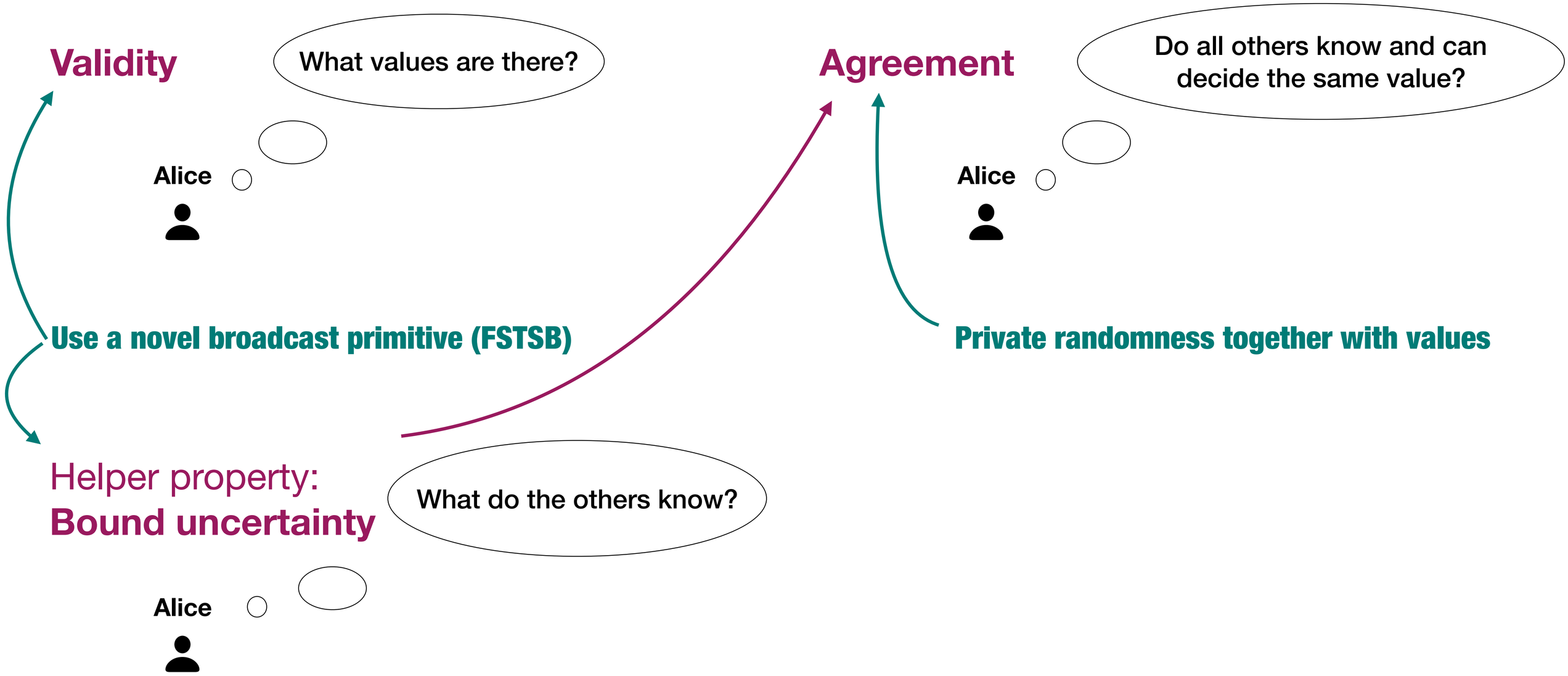
Use a novel broadcast primitive (FSTSB)

Helper property:
Bound uncertainty

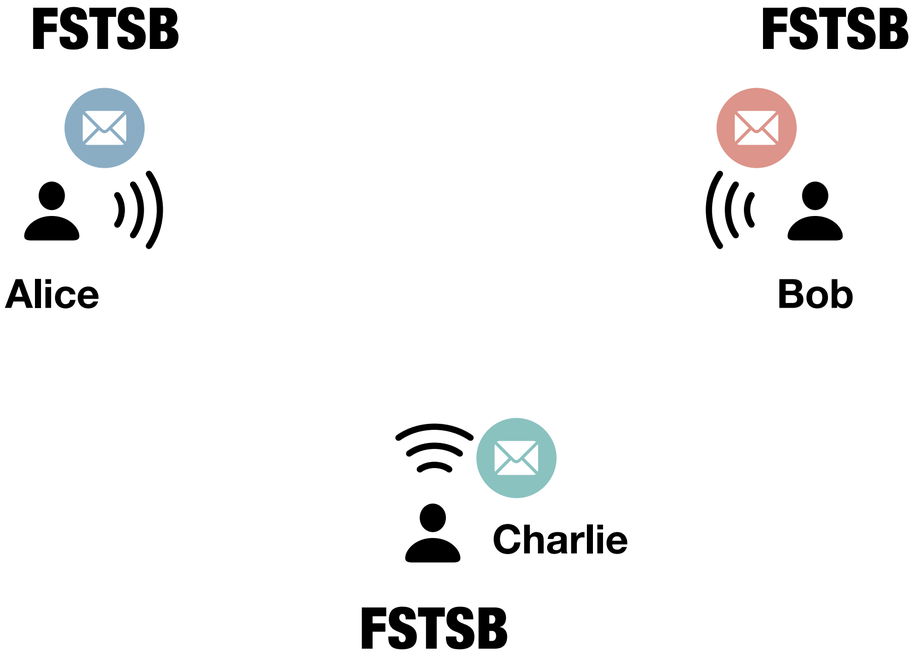
QSC insights



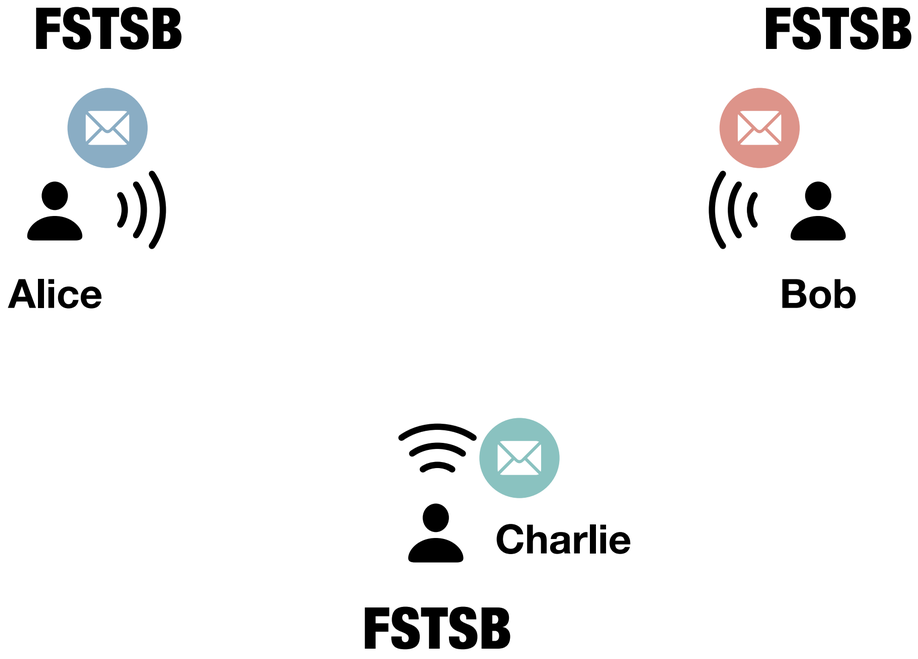
QSC insights



Validity



Validity



- No other proposal is ever introduced

Validity

Alice

Bob

FSTSB

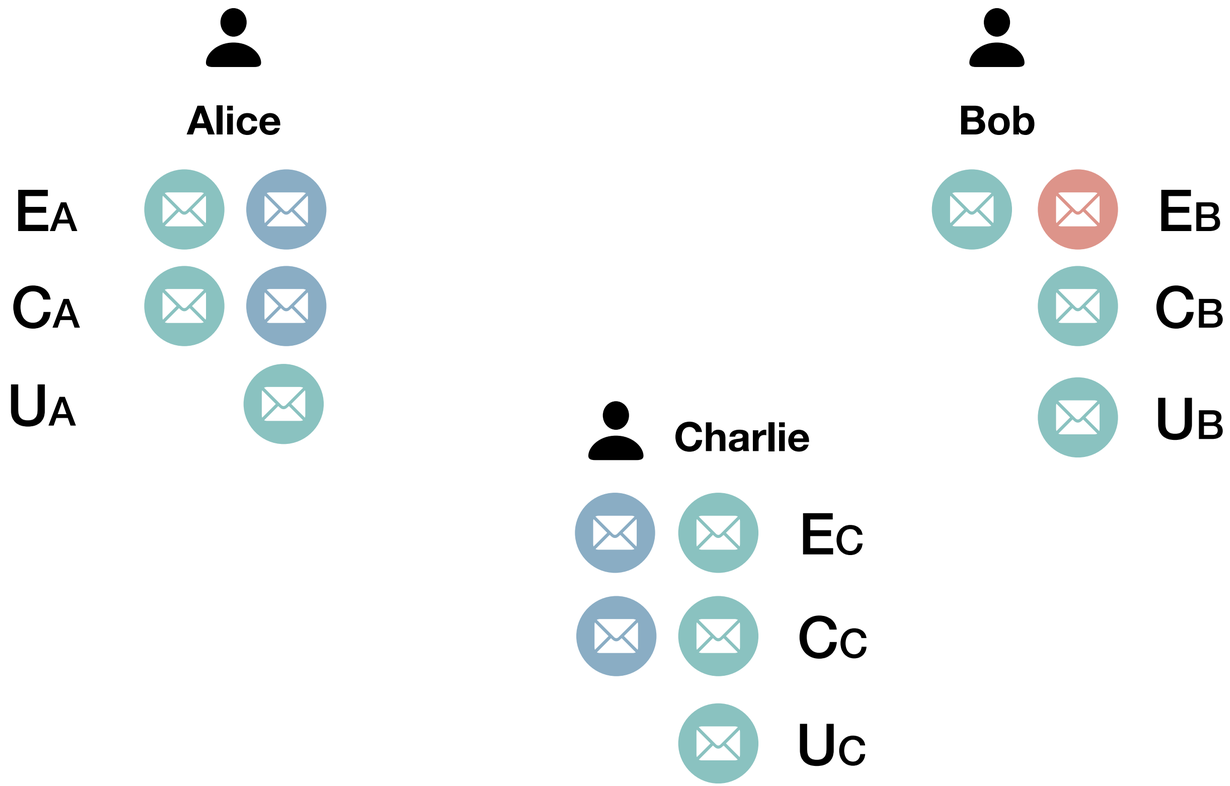
- No other proposal is ever introduced
- Though random values change

Bounding uncertainty by approximating others' knowledge

FSTSB ⇒ sets E,C,U

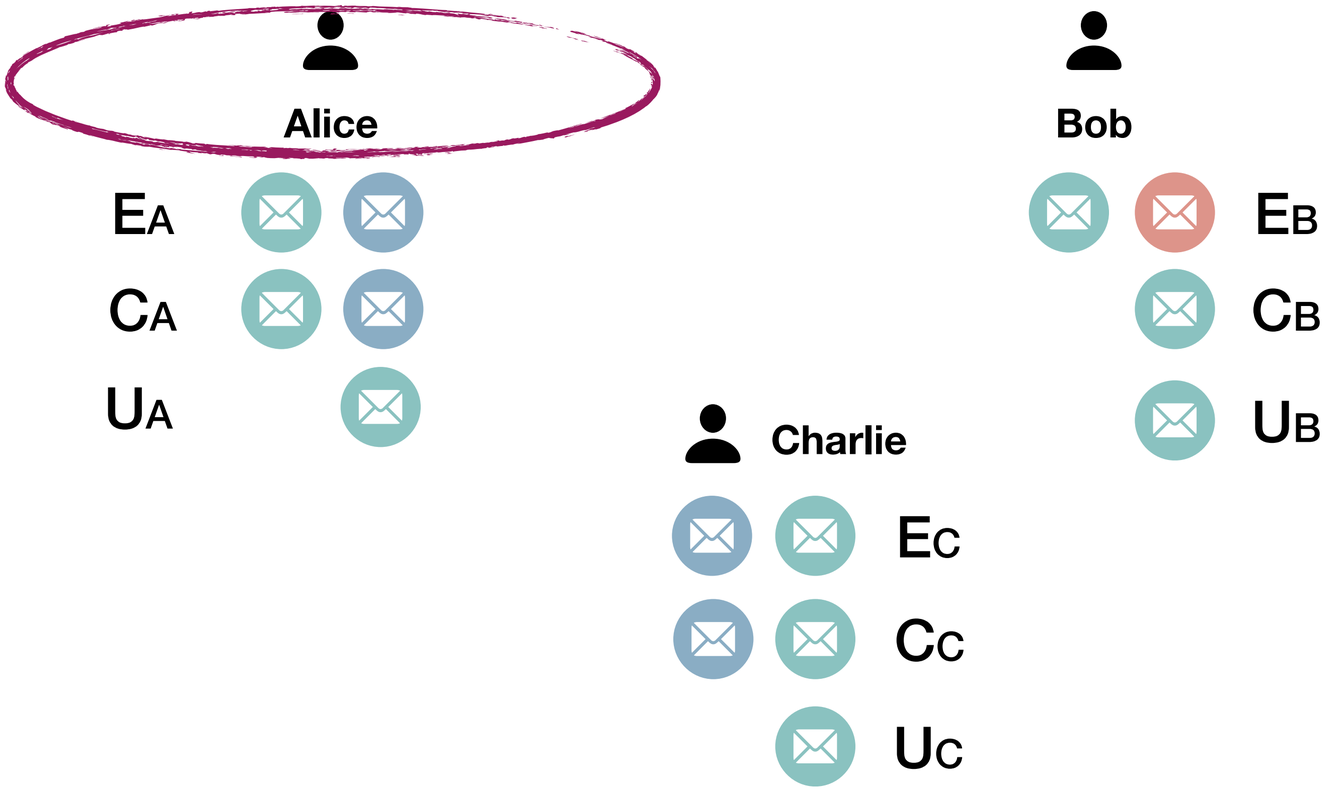
Bounding uncertainty by approximating others' knowledge

FSTSB ⇒ sets E,C,U



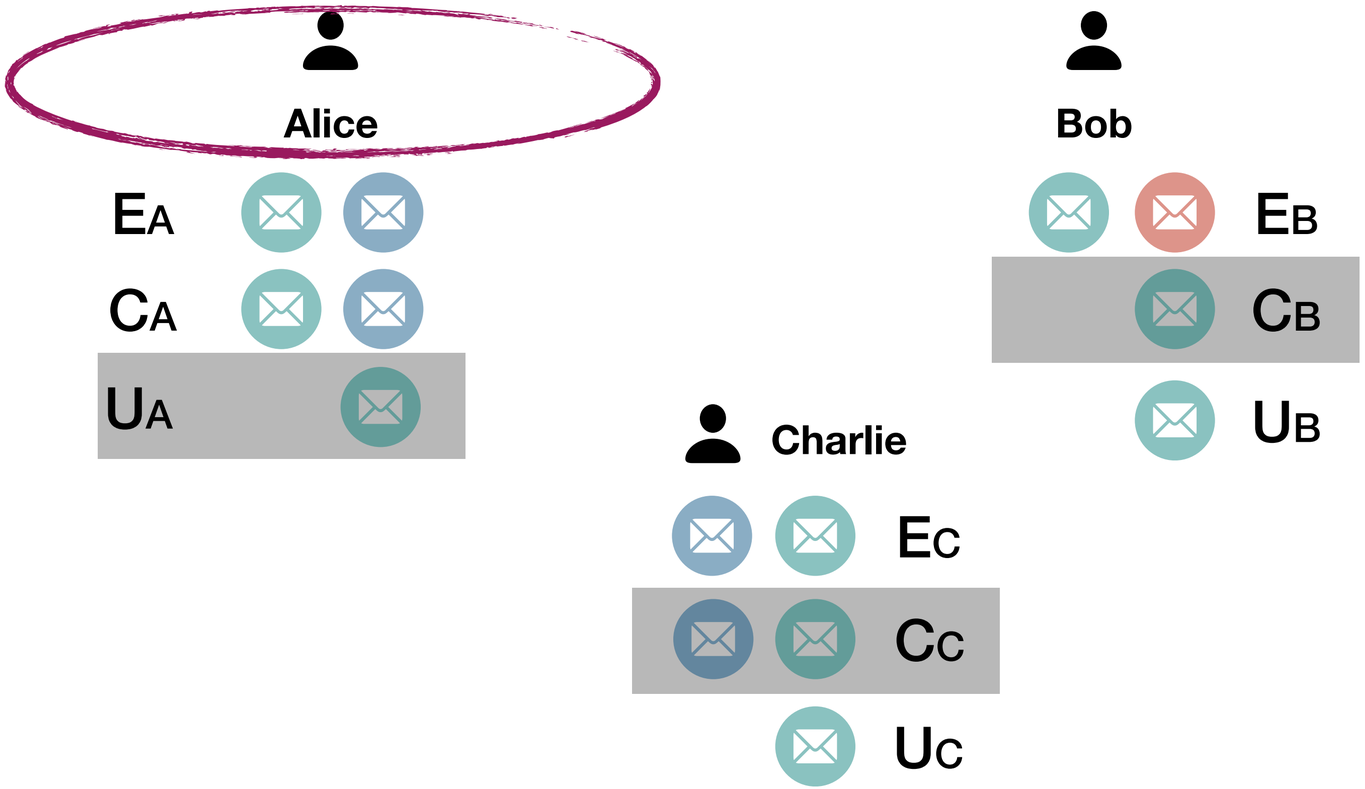
Bounding uncertainty by approximating others' knowledge

FSTSB ⇒ sets E,C,U



Bounding uncertainty by approximating others' knowledge

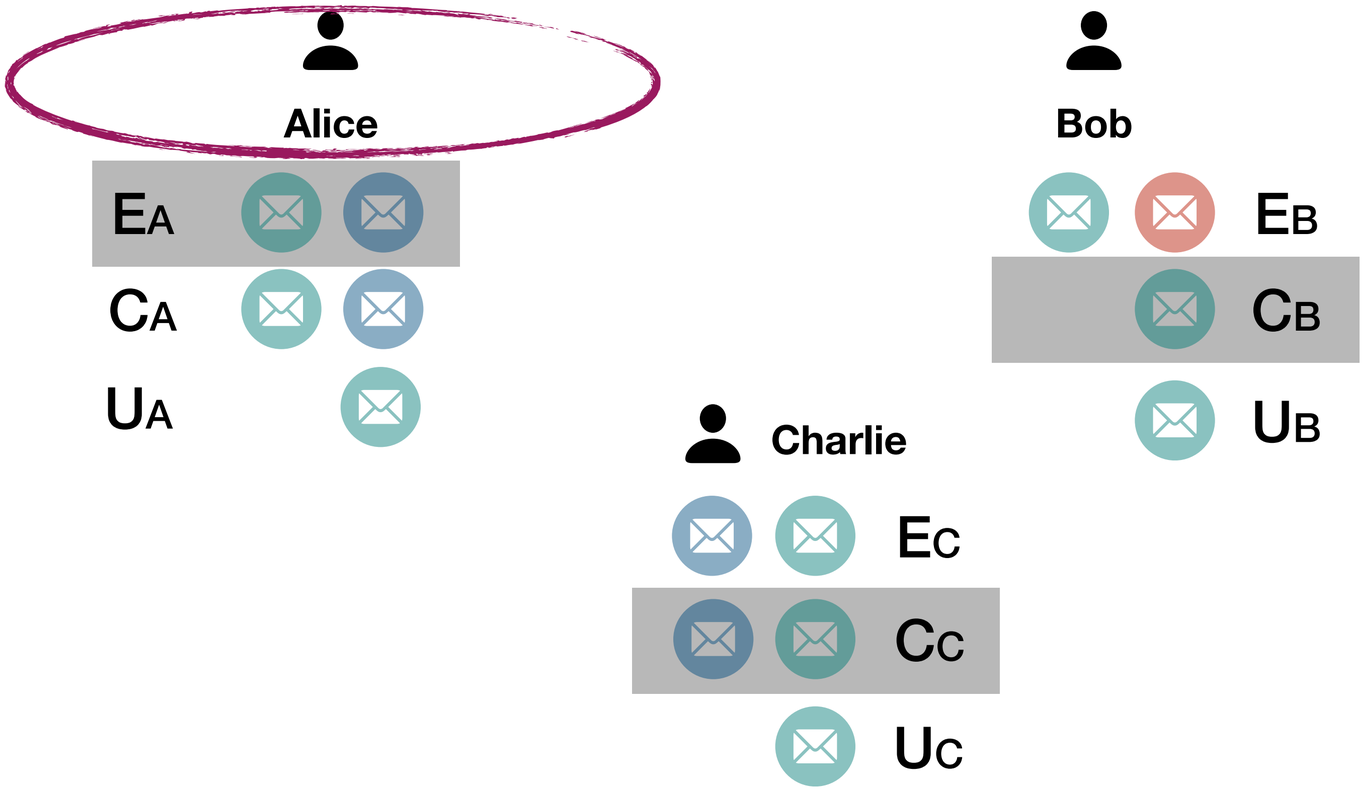
FSTSB ⇒ sets E,C,U



$C_{\text{any-other}} \supseteq U_{\text{Alice}}$

Bounding uncertainty by approximating others' knowledge

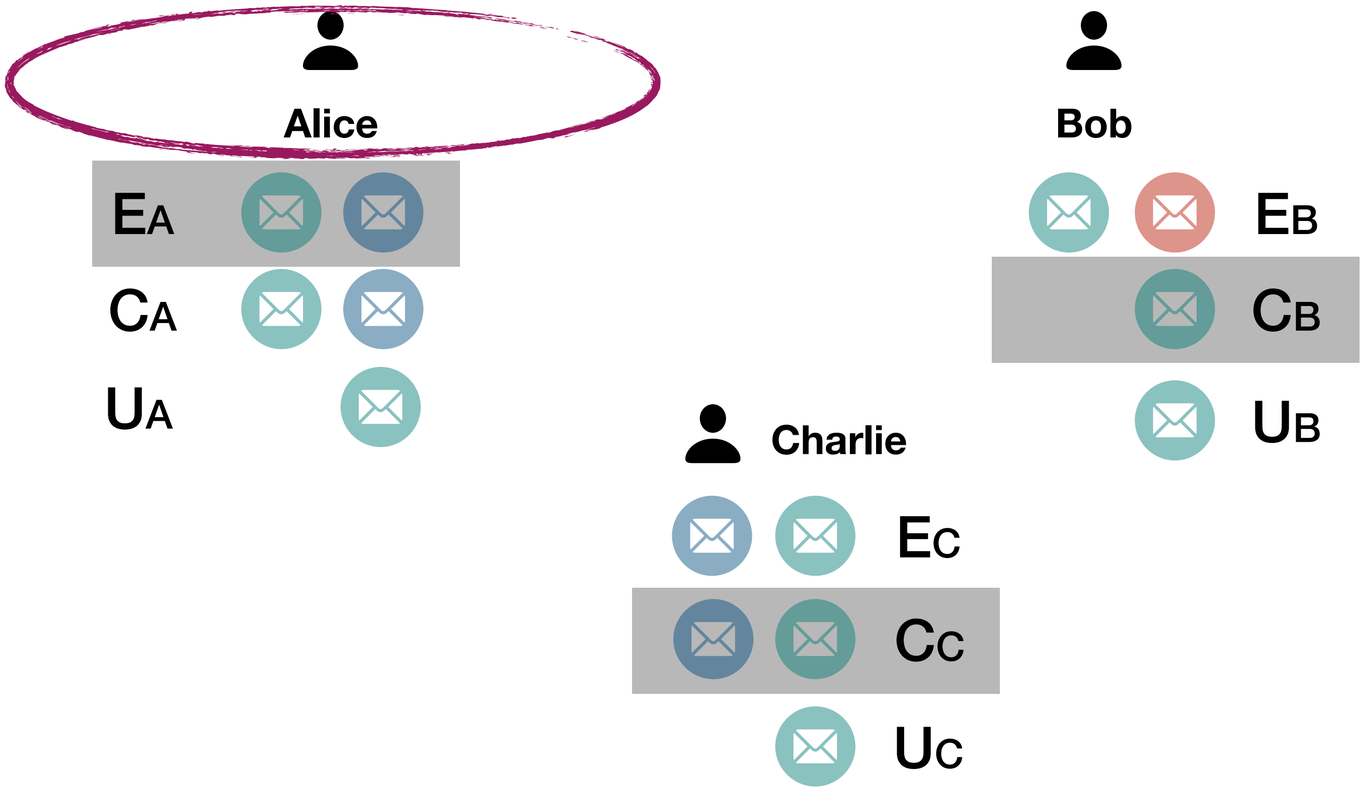
FSTSB ⇒ sets E,C,U



$C_{\text{any-other}} \supseteq U_{\text{Alice}}$

Bounding uncertainty by approximating others' knowledge

FSTSB ⇒ sets E,C,U



Bounding uncertainty by approximating others' knowledge

FSTSB ⇒ sets E,C,U

Alice

Bounding uncertainty by approximating others' knowledge

FSTSB ⇒ sets E,C,U

Alice

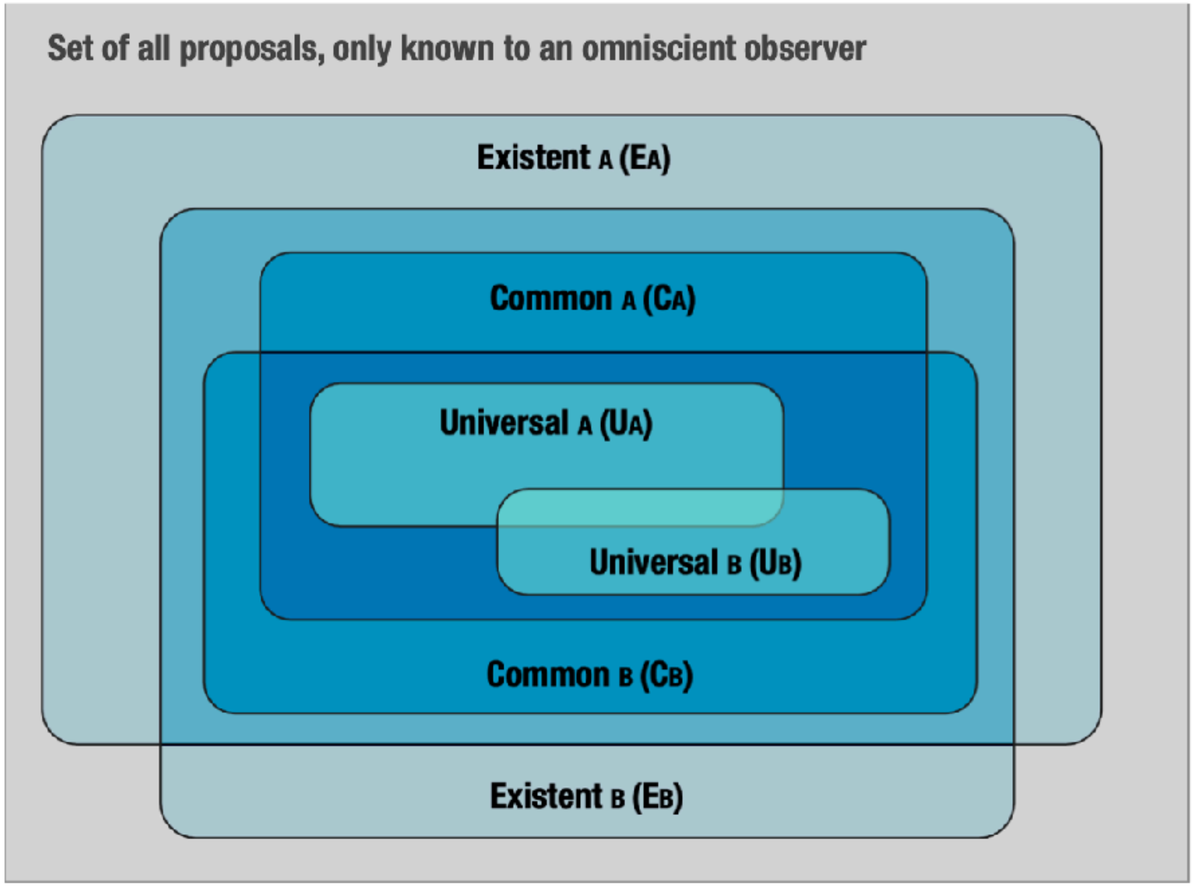
$$\mathbf{E}_{\text{Alice}} \supseteq \mathbf{C}_{\text{any-other}} \supseteq \mathbf{U}_{\text{Alice}}$$

Bounding uncertainty by approximating others' knowledge

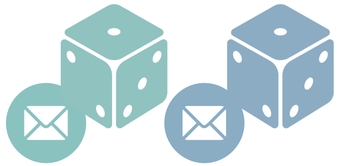
FSTSB ⇒ sets E,C,U

Alice

$E_{Alice} \supseteq C_{any\text{-}other} \supseteq U_{Alice}$



Agreement



$\mathbf{E}_{\text{Alice}} \supseteq \mathbf{C}_{\text{any-other}} \supseteq \mathbf{U}_{\text{Alice}}$

Agreement

E Alice ⊇ **C** any-other ⊇ **U** Alice

Agreement

$$\mathbf{E}_{\text{Alice}} \supseteq \mathbf{C}_{\text{any-other}} \supseteq \mathbf{U}_{\text{Alice}}$$

Highest priority $\overset{?}{=}$ Highest priority

Agreement

$$\mathbf{E}_{\text{Alice}} \supseteq \mathbf{C}_{\text{any-other}} \supseteq \mathbf{U}_{\text{Alice}}$$

Highest priority $\overset{?}{=}$ Highest priority

Y: Decide that value

Agreement

$$E_{\text{Alice}} \supseteq C_{\text{any-other}} \supseteq U_{\text{Alice}}$$

Highest priority $\overset{?}{=}$ Highest priority

Y: Decide that value

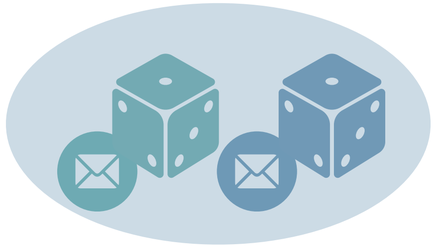
$$E_{\text{any-other}} \supseteq C_{\text{Alice}} \supseteq U_{\text{any-other}}$$

Agreement

$$E_{\text{Alice}} \supseteq C_{\text{any-other}} \supseteq U_{\text{Alice}}$$

Highest priority $\stackrel{?}{=}$ Highest priority

Y: Decide that value



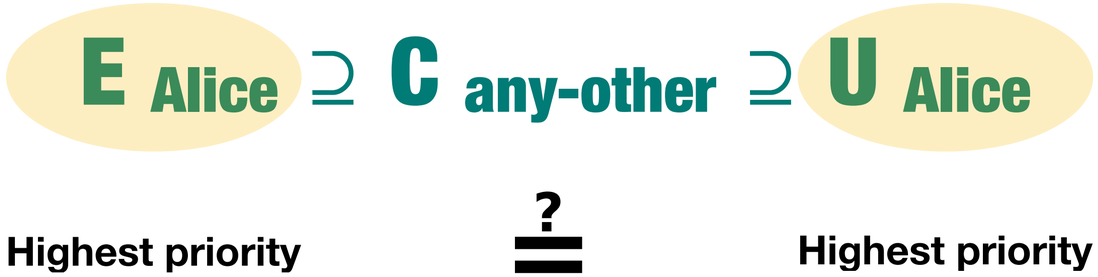
$$E_{\text{any-other}} \supseteq C_{\text{Alice}} \supseteq U_{\text{any-other}}$$

N: Continue with highest priority

Agreement

$$\mathbf{E}_{\text{Alice}} \supseteq \mathbf{C}_{\text{any-other}} \supseteq \mathbf{U}_{\text{Alice}}$$

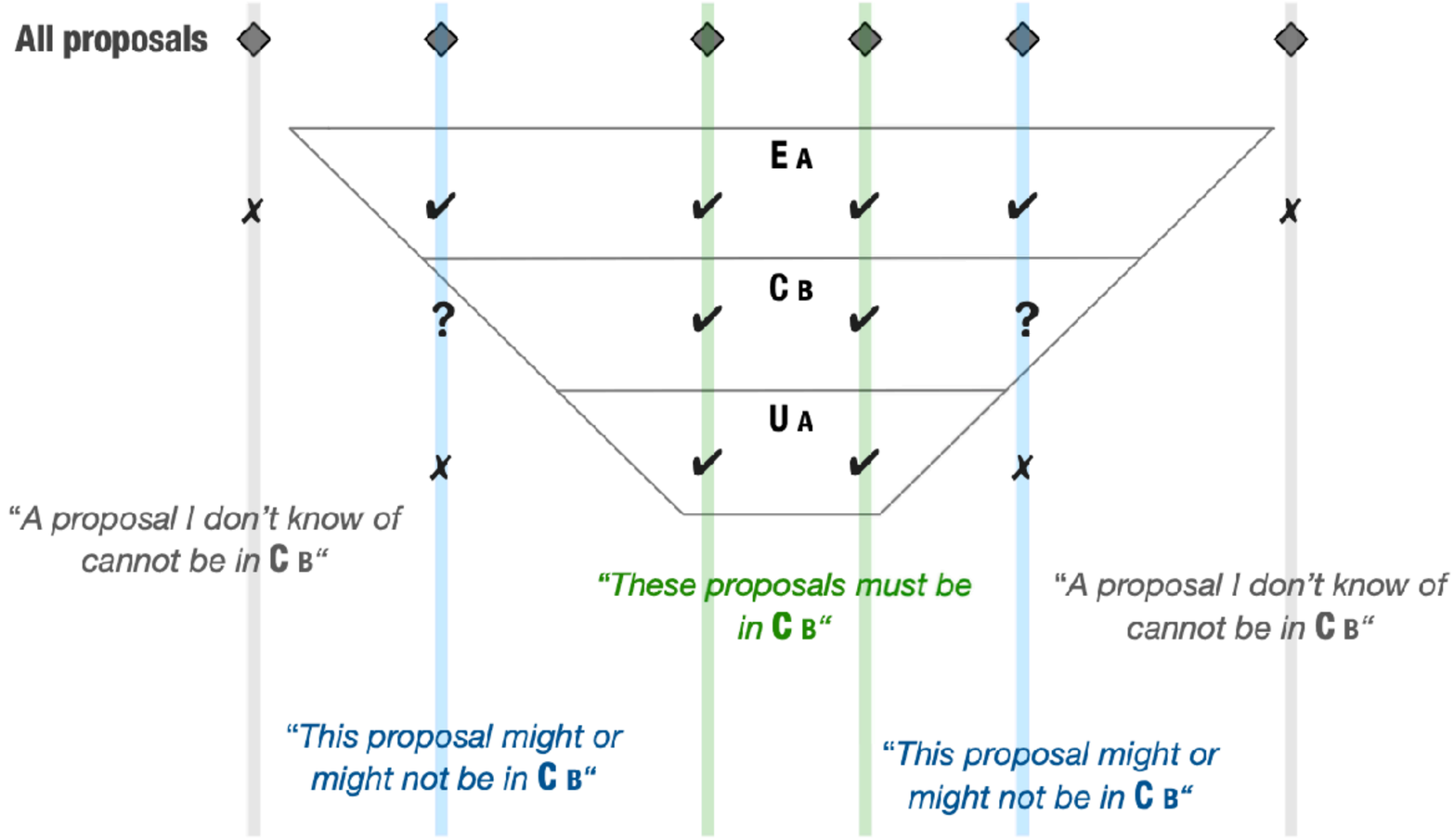
Agreement


E Alice
⊇
C any-other
⊇
U Alice
Highest priority
?
Highest priority

Agreement

$E_{Alice} \supseteq C_{any\text{-}other} \supseteq U_{Alice}$

Highest priority $\overset{?}{=}$ Highest priority



Agreement

Continue with highest priority

$E_{\text{Alice}} \supseteq C_{\text{any-other}} \supseteq U_{\text{Alice}}$

Highest priority $\overset{?}{=}$ Highest priority