On the Atomicity of Crosschain Transactions

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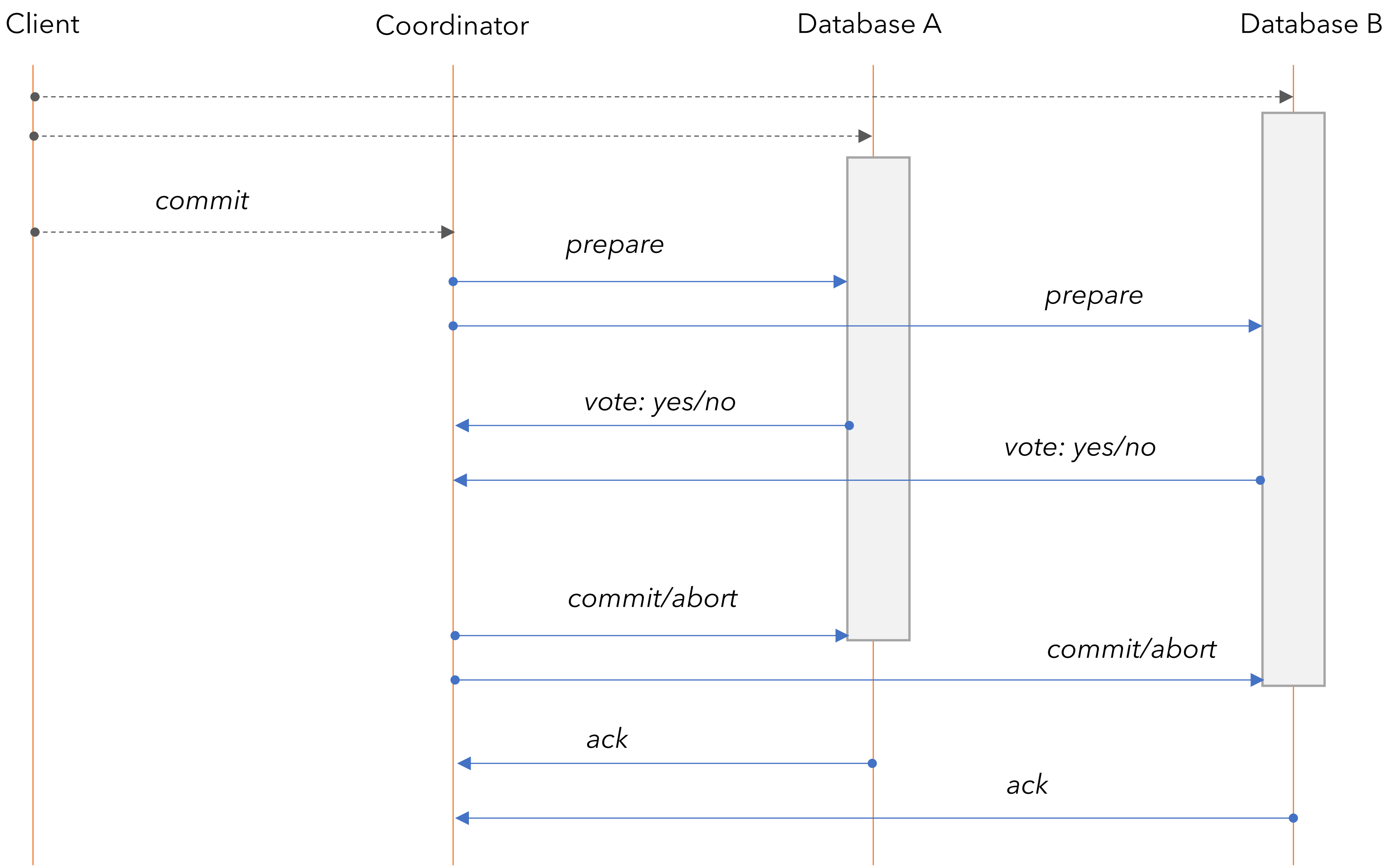
Atomicity in distributed transactions

- A distributed database transaction defines a unit of state change across two or more *data stores (shards, databases, partitions)*
- Examples:
  - Updating account balances across shards (transfer Alice -> Bob)
  - Flight, Hotel, Car (long lived transactions, spanning multiple DBs)
- Two important aspects:
  - Isolation: concurrency control (*SS2PL*)
  - Atomicity (*2PC, 3PC*)
- Atomicity is a property that guarantees that either all sub-transactions succeed, or neither does (all-or-nothing)

Two-phase Commit Protocol



Limitations

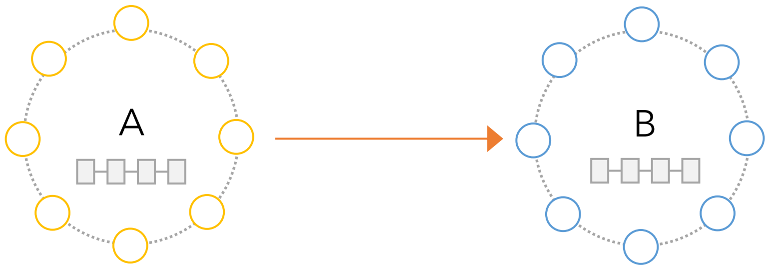
- Blocking Problem: Coordinators could crash, tying resources and blocking progress
- Database nodes could fail causing related problems
- Various mitigation strategies to improve fault tolerance
- Might require manual intervention
- Increases latency, Limits throughput and scalability

In practice:

- Within single administrative domain and often employed across homogenous systems
- For long-lived distributed transactions, approaches such as Saga patterns (with compensating transactions) are often employed in practice

Characterising Crosschain Communication

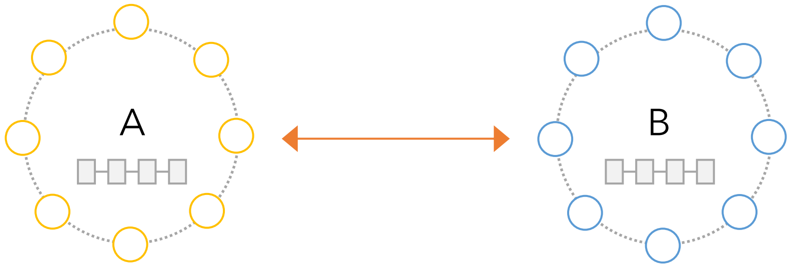
Interaction Patterns



A ⟶ B: state in B depends on state change in A

Example:

- Read balances of all token holders in one network and confer rights on another (DAOs…)



A ⟶ B *iff* B ⟶ A : state change in A and B needs to be synchronised. State in A changes if and only if corresponding state changes in B, and vice versa.

Example: *Trust-less* asset exchange between two or more parties.

Modes

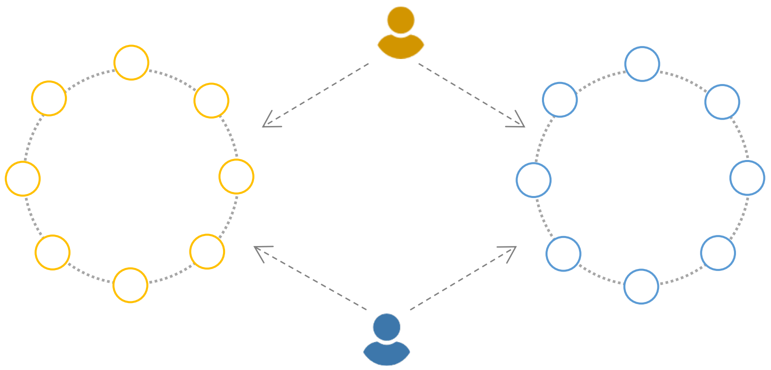
Asset Exchange

Asset Transfer

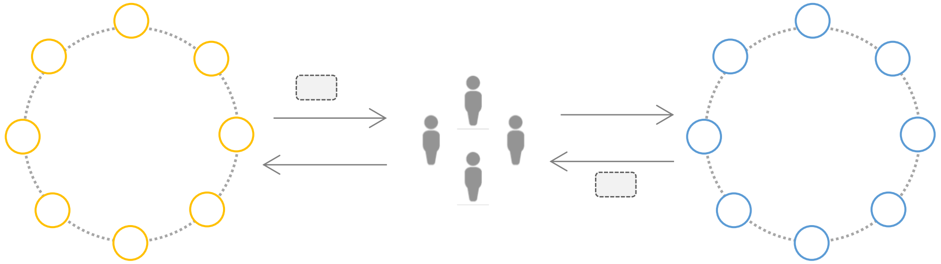
General Purpose crosschain Transactions

Characterising Crosschain Communication

Messaging Patterns



- Messages not directly exchanged between networks
- Coordinated by parties



- State change events Relayed across networks
- Relayed or Attested by a set of external parties/validators

Verification

- *Locally* verified state

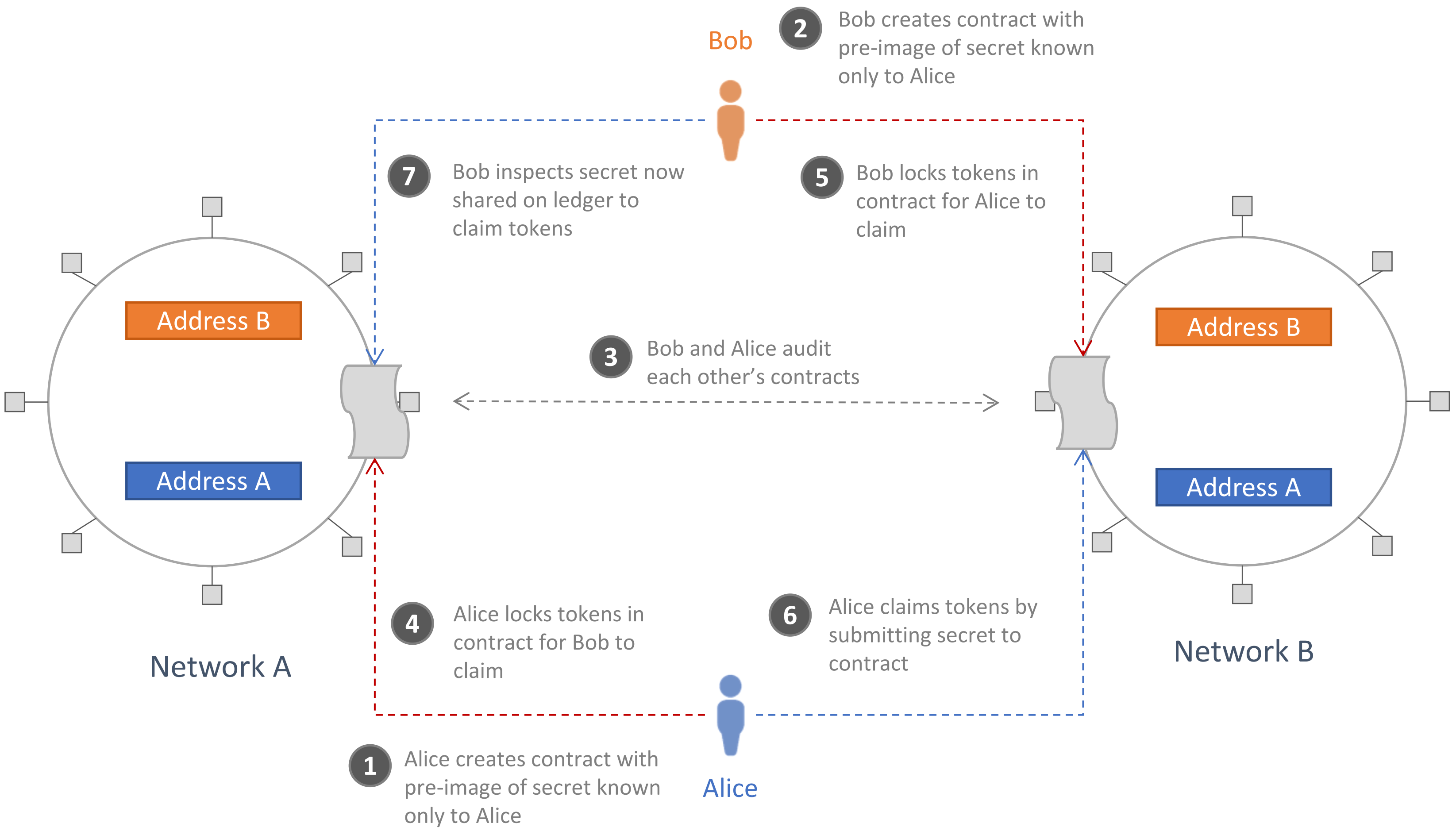
- *Natively*: Light-client headers
- *External*: A set of entities attest messages across chains (m-of-n scheme, proof-of-authority, stake …), optimistic/pessimistic

Atomic Crosschain transaction

- Atomicity: ensure that either all sub-transactions in a crosschain transaction occur or none does
- Challenges
  - More failure scenarios: Byzantine faults
  - Finality guarantees (probabilistic, deterministic – instant or eventual)
  - Who coordinates transactions (Transaction parties, bridge intermediaries)?
  - Incentive alignment and stability under dynamic environments (asset volatility, changing gas prices etc.)
  - Transaction costs of multi-step coordination
  - Bridge hacks (de-pegging of assets…)
- Atomic Commit Protocols:
  - Properties: Safety, Liveness
  - Desired Properties: Fairness, Trust-lessness, Throughput, Asynchrony, Privacy

Contract Patterns for Asset Exchange

Hashed Time-Lock Contracts (HTLC) - Crosschain Atomic Swaps



Fund locking

- To initialise an asset exchange, it is common for one or both parties to first lock up funds with a fund-withholding party on his or her own blockchain.
- Temporary fund locking ensures the locked fund cannot be use for other purposes while the exchange is being executed.
- This scheme is often used with a specified timeout to provide flexibility for reclaiming locked funds if the exchange does not take place.

Execution

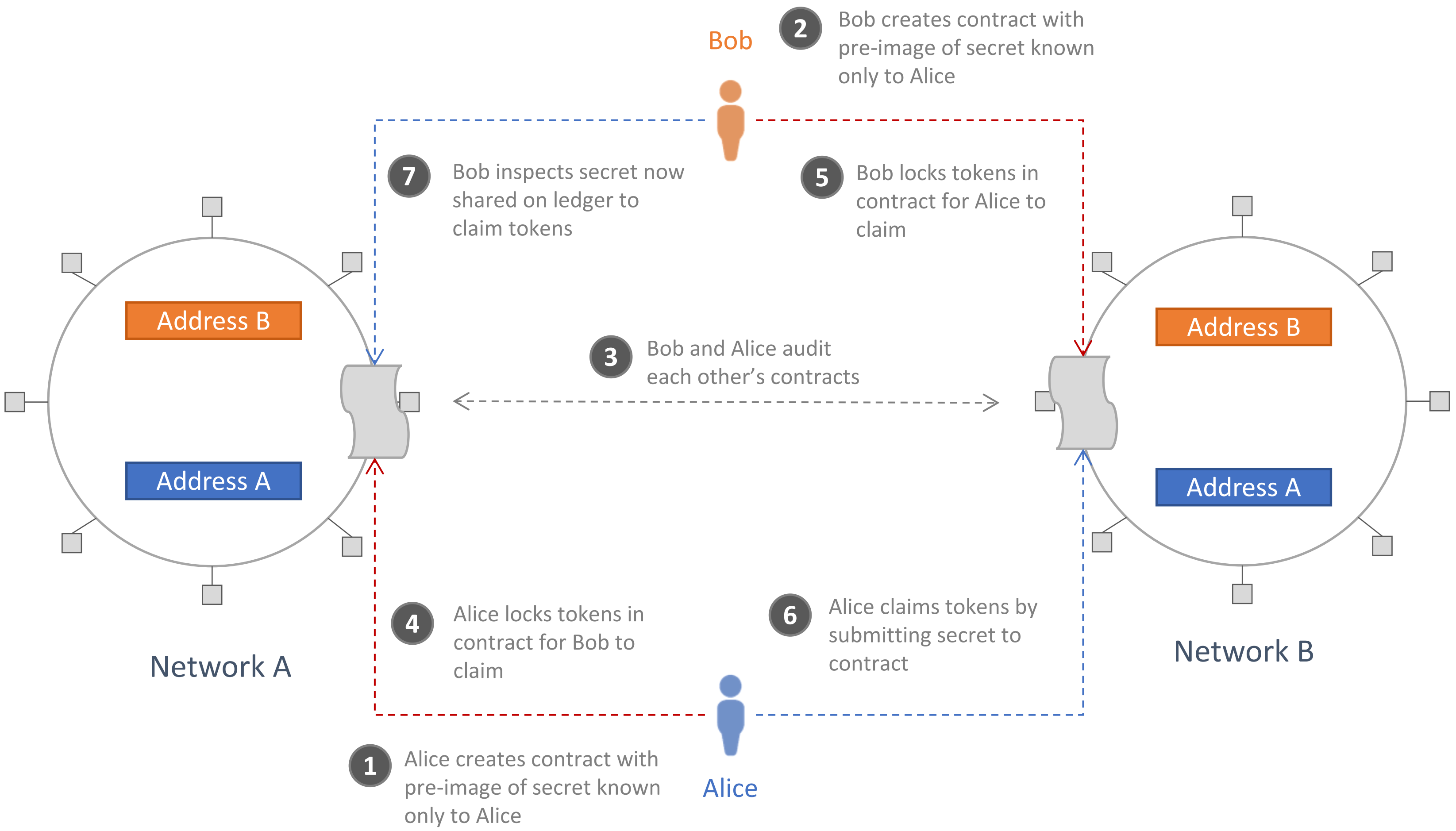
- In general, the execution requires a pair of transactions to occur on both blockchains
- The execution of the exchange can be carried out by users themselves, or through other trusted third parties.

Refund

- For protocols that are initialised with a temporary fund-locking, the locked funds can usually be reclaimed by the initial owner after a specified timeout.

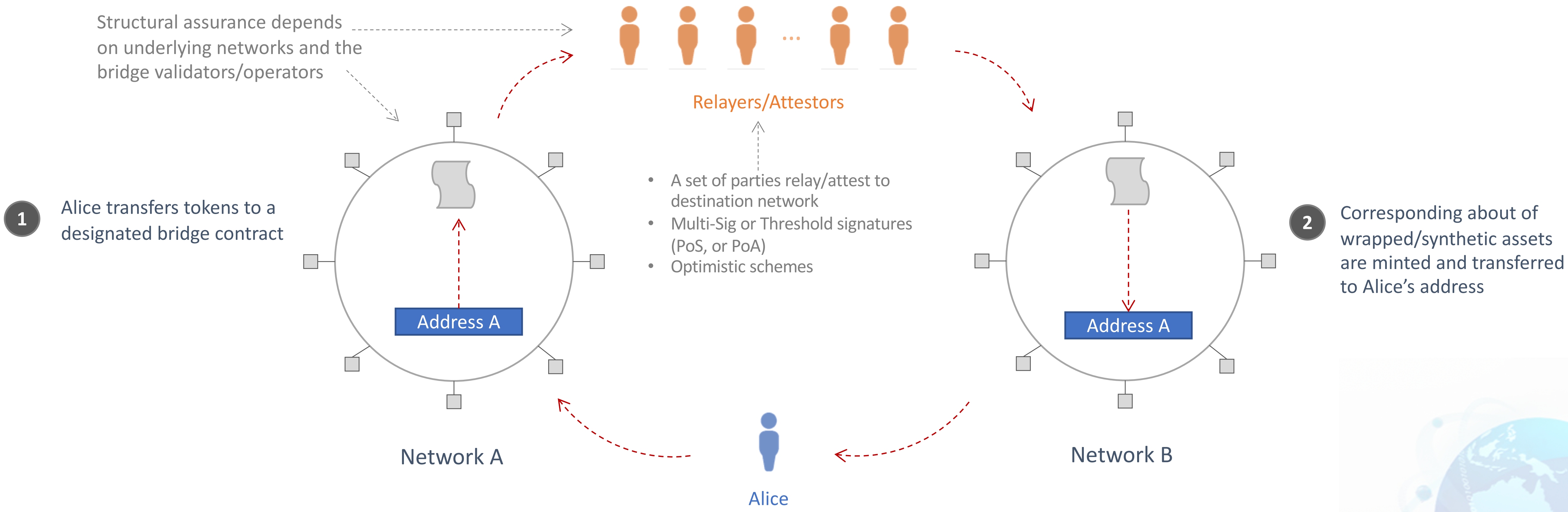
Contract Patterns for Asset Exchange

Hashed Time-Lock Contracts (HTLC) - Crosschain Atomic Swaps



- Assumption:
  - All parties have to be online. One party failing could break atomicity.
  - Hash function compatibility
- Problems:
  - Free-option problem and griefing
  - Latency
  - Parties have to be online
  - Not very generalisable beyond asset exchange scenarios
- Numerous works have improved different aspects of the protocol:
  - Addressing the free option-problem (pricing, fractionalising…)
  - Reducing synchrony requirements
  - Extension to multi-party, multi-asset exchanges
  - Extensions to support networks that do not support hashlock or timelock primitives
  - Improve privacy
- In practice, difficult to use at scale

Contract Patterns for Asset Transfer



Asset Exchanges in Practice (Liquidity Pools)

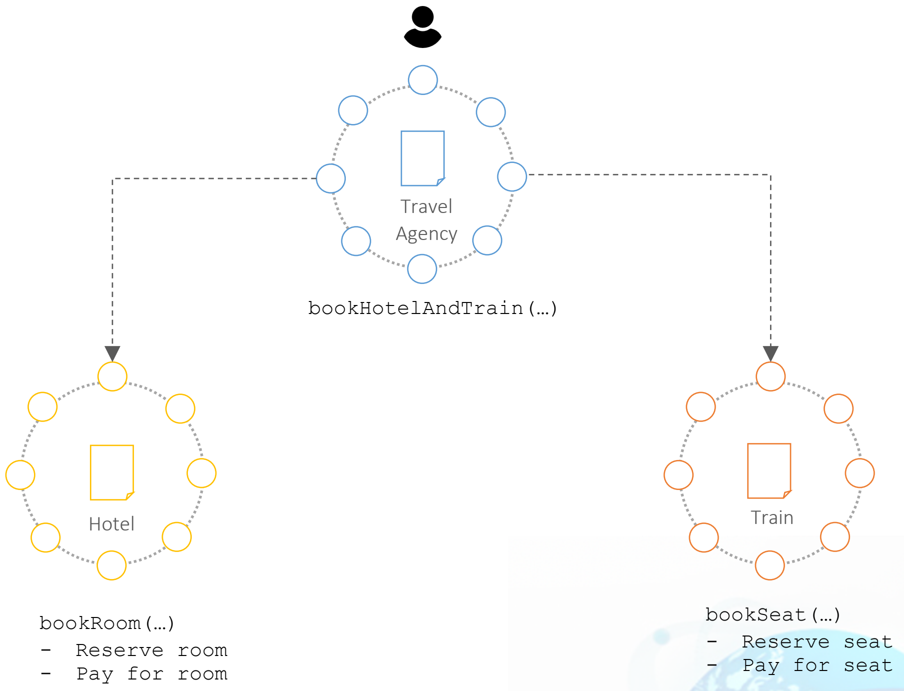
- Single-asset liquidity pool maintained on each chain
- Asset exchange semantics built on top of asset transfer mechanics
- User seeking to acquire token X on network A for corresponding token Y on network B
    1. Locks X on network A
    2. Message of the locked asset is relayed to destination
    3. User is either a) issued synthetic token which is a claim to an amount in the pool b) directly given the corresponding tokens
- Various failure scenarios
    - Relaying crosschain messages could fail across chains, or delayed (crash, gas spikes etc.)
    - Liquidity in the destination chain might no longer be available
    - User funds could be locked for extended periods, waiting for failure scenario to resolve
    - Costly and time consuming for user to refund transactions
    - Manual admin interventions

Failure Scenarios of non-atomic models

- State updated in one source chain but not in destination
- Failure could occur for a number of reasons
  - Failure of intermediary bridge validators (relayers/attestors)
  - Failure of destination transaction for various reasons (e.g. not enough liquidity in pool)
  - Change in economic costs of completing transaction (e.g. gas price spikes in destination, asset price volatility)
- Atomicity in crosschain in practice:
  - Protocol Guaranteed Atomicity (increase security and resilience, reduce trust assumptions)
  - Externally coordinated "*atomicity*" (exposes users to various failure scenarios, which are often remediated through trusted operators/admins…)

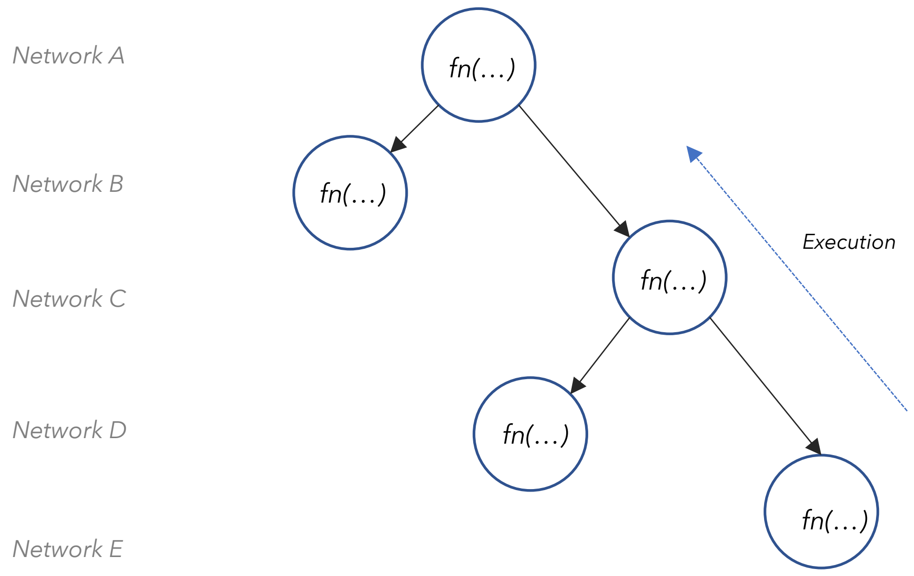
General Purpose Atomic Transactions

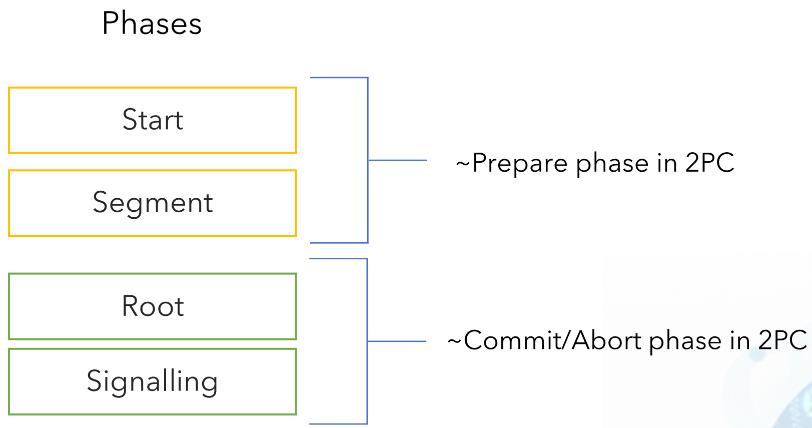
- Address more complex crosschain application interaction scenarios
- Crosschain transactions spanning multiple chains, performing general function calls
- The need for atomicity in this context grows as failure scenarios leading to inconsistent crosschain states could be difficult to remediate
- Challenges of protocol enforced atomicity
  - How do we ensure atomicity of arbitrary state changes?
  - What type of isolation guarantees need to be offered?
  - Who coordinates transactions? Can they perform all legs of a transaction and are they incentivised to do so?
  - How do we reason about incentive alignments across all parties?
  - What application-context independent assumptions can be made?
  - What are the costs?



GPACT Protocol

- The General Purpose Atomic Crosschain Transaction (GPACT) protocol is a call tree commitment scheme that provides atomic crosschain function calls across an arbitrarily deep call tree*
- *Example: Orchestrate global trade workflow spanning different networks (trade finance, trade logistics, provenance, payments identity/KYC networks etc.*





** Peter's talk covers GPACT and incentivisation in crosschain communication in greater depth*

Conclusion

- Most crosschain transaction scenarios conceptually involve coordinated state change across networks, requiring atomicity
- In practice however, these properties are not guaranteed by most crosschain protocols. This introduces various failure scenarios requiring trusted actors for remediation
- Such trusted actors in bridge design are often the source of security vulnerability, as seen in recent hacks
- Protocol enforced atomicity, could increase resilience and security, and reduce trust requirements
- As adoption of crosschain protocols grows, and more complex crosschain use-cases emerge, the need for atomicity guarantees could become more salient
- Whether the limitations of current atomic protocols can be overcome to offer viable, cost-effective and scalable alternatives to non-atomic approaches is to be seen.