Module 2

Introduction to Corda

Learning objectives

1. Understand that Corda has been designed to solve a **specific** business problem for **regulated financial institutions** and this is reflected in its architecture
2. Understand how to think ”the Corda way”
3. Understand the key concepts which underpin how Corda works

Agenda

1. The genesis of Corda
2. The Corda way of thinking
3. Corda key concepts

Recommended reading:

- Corda Non-Technical Whitepaper
- Corda Technical Whitepaper
- The Corda Way of Thinking blogpost
- https://docs.corda.net/key-concepts.html

Session 1

The genesis of Corda

The genesis of Corda

1. Why build Corda?
2. Design rationale

Why build Corda?

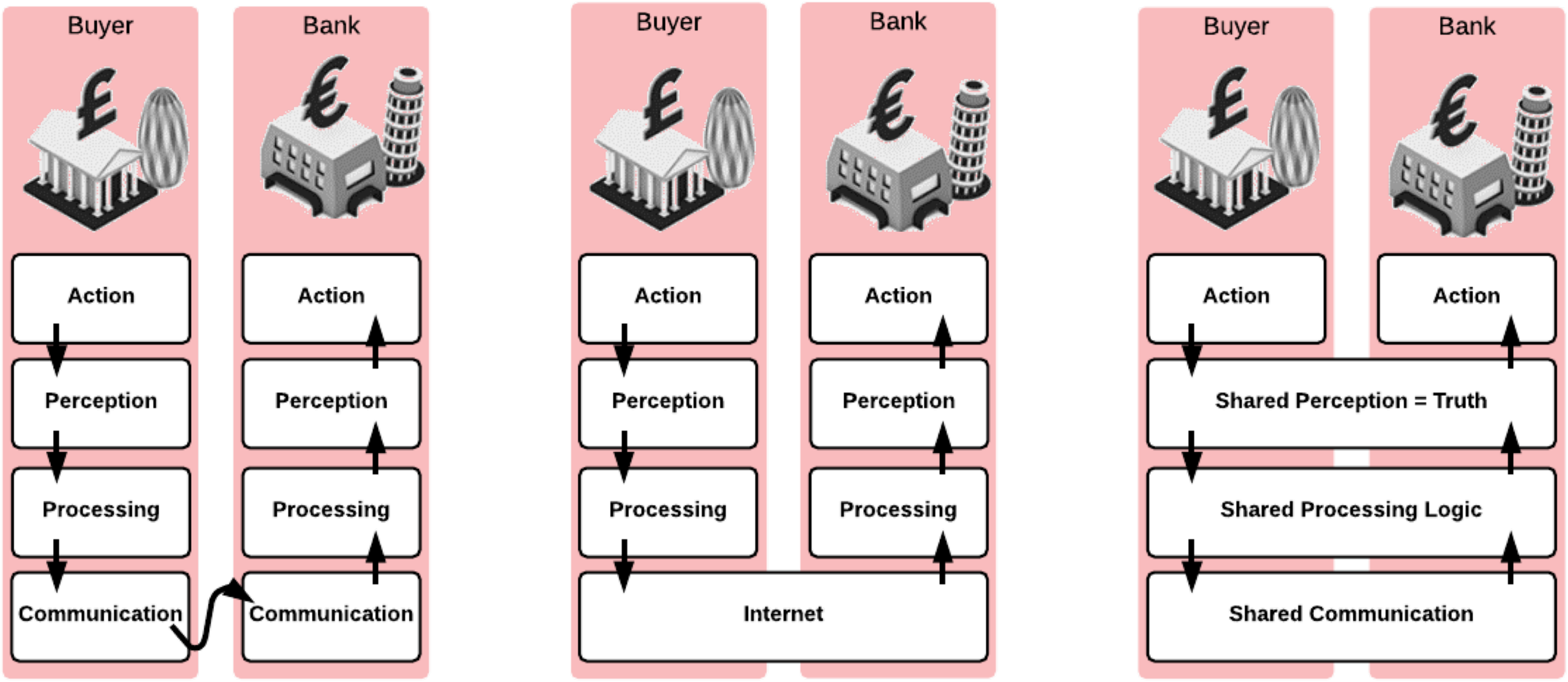
Mission objective

Requirements driven design

To establish the architecture for an **open**, **enterprise-grade**, **shared** platform for the **immutable** recording of financial events and execution of logic.

Back to basics

What problem are we trying to solve with distributed ledger technology?



Before the Internet

Now

After Shared Ledgers

Defining characteristics of distributed ledgers

Distributed ledgers are systems that enable parties who **don't fully trust** each other to form and maintain **consensus** about the existence, status and evolution of a set of shared facts.

Introducing Corda

Corda is a **distributed ledger platform** designed and built from the ground up to **record**, **manage** and **synchronise** agreements (legal contracts), designed for use by **regulated financial institutions**

Design rationale

Managing trade-offs

Designing the architecture of a distributed ledger platform is rooted in **managing a set of trade-offs**, primarily:

- Privacy and confidentiality
- Scalability
- Security
- Complexity
- Among others…

You cannot have your cake and eat it!

- Corda maintains the **optimal balance** of trade-offs for
  - the domain it is intended to operate within, and;
  - the business problems it is designed to solve
- Meanwhile, Corda also provides **flexibility** for developers to tweak some of these trade-offs to suit their requirements
- **Example:** pluggable consensus
- There are no **silver bullets**!

Permissioned / Permissionless

Permissioned network

Permissionless networks are inappropriate for most scenarios involving regulated financial institutions

No blockchain / Blockchain

No blockchain

When considering permissioned networks, the use of a blockchain is not required to facilitate consensus

Point-to-point/Broadcast

Point-to-point

On the grounds of confidentiality, we reject the notion that data should be broadcast to all participants or cumbersome pre-defined groups

Message queues / RPC

Message queues

Messaging queues tend to be more robust at the cost of complexity and extra infrastructure

Reliance on existing judicial systems / “Code is law”

Legal Prose

A key requirement for financial institutions was the ability to rely on courts of law in the case of conflicts

UTXO / Account model

UTXO Model

To maintain true immutability of the ledger, and make it possible to apply transactions in parallel

Re-use/Build

Re-use

Wherever possible, we use industry standard bank friendly libraries and technology instead of “reinventing the wheel”.

But Corda also offers flexibility

- Pluggable consensus
- Flexible transaction model
- States can contain arbitrary information
- Databases and message brokers

Summary

- Corda is designed to solve a range of problems for regulated financial institutions
- Corda exists because other available platforms did not satisfy the stated mission objective
- Building a DLT platform requires managing trade-offs
- Corda is opinionated but also facilitates developer flexibility

Session 2

Key concepts

Key concepts

Corda Key Concepts

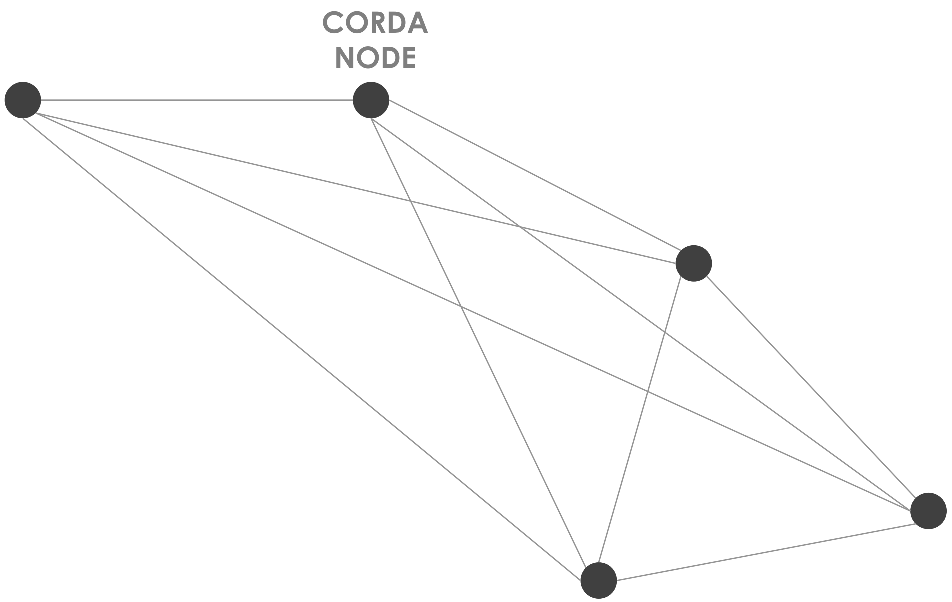
1. The Corda ledger
2. States
3. Transactions
4. Contracts
5. Legal prose
6. Commands
7. Timestamps
8. Attachments
9. Flows
10. Consensus
11. Notary services
12. Oracles
13. The Corda node and CorDapps
14. A Corda network

Before we start

- These slides introduce Corda key concepts one at a time
- New concepts build upon previously introduced concepts
- **If you have a question, it will likely be answered later on in the session!**
- **Example:** Uniqueness consensus which prevents "double spending" is introduced near the end of the session but is a clear concern from the beginning

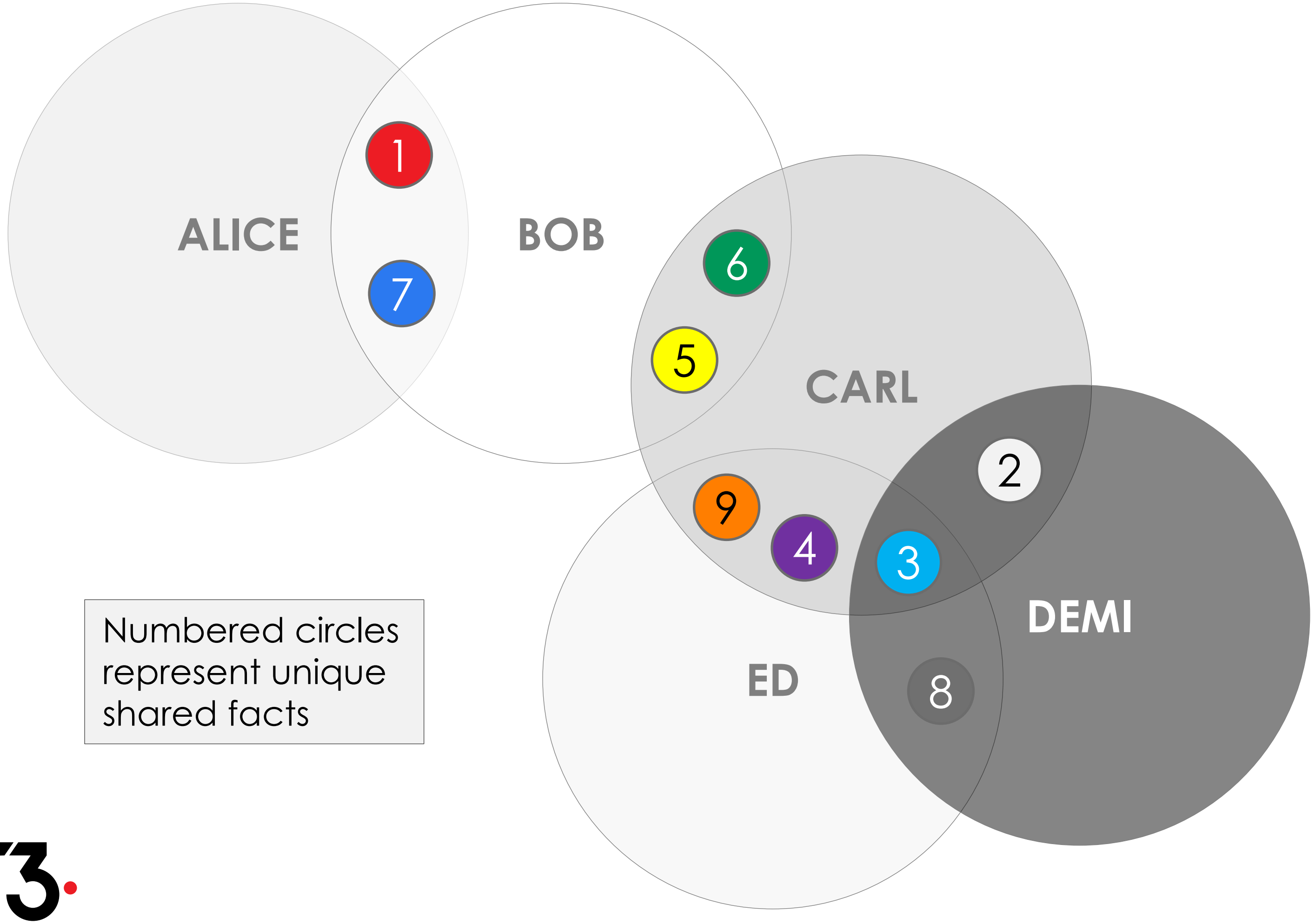
The Corda Ledger

A Corda network



- A Corda network is a **fully connected** graph
- **No global broadcast** or gossip network
- Communication occurs on a **point-to point basis** only
- Peers communicate using **AMQP/1.0** over **TLS**
- **Network map service** publishes list of peers
- Graph edges represent the **potential** to communicate, not persistent connections
- Think **Email** and **SMTP**

The Corda ledger



Numbered circles represent unique shared facts

The ledger from each peer's point of view is the union of all intersections with other network peers (some of which may be the empty set)

ALICE = { 1 7 }

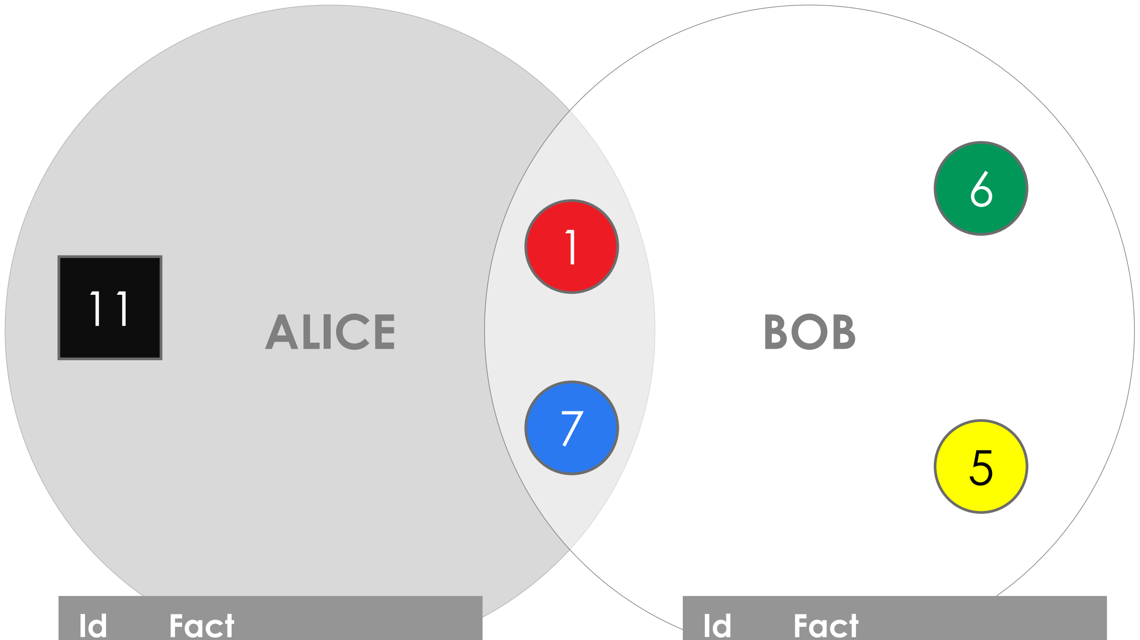
BOB = { 1 7 6 5 }

CARL = { 9 4 6 5 2 3 }

DEMI = { 2 3 8 }

ED = { 9 4 8 3 }

Anatomy of a bilateral ledger

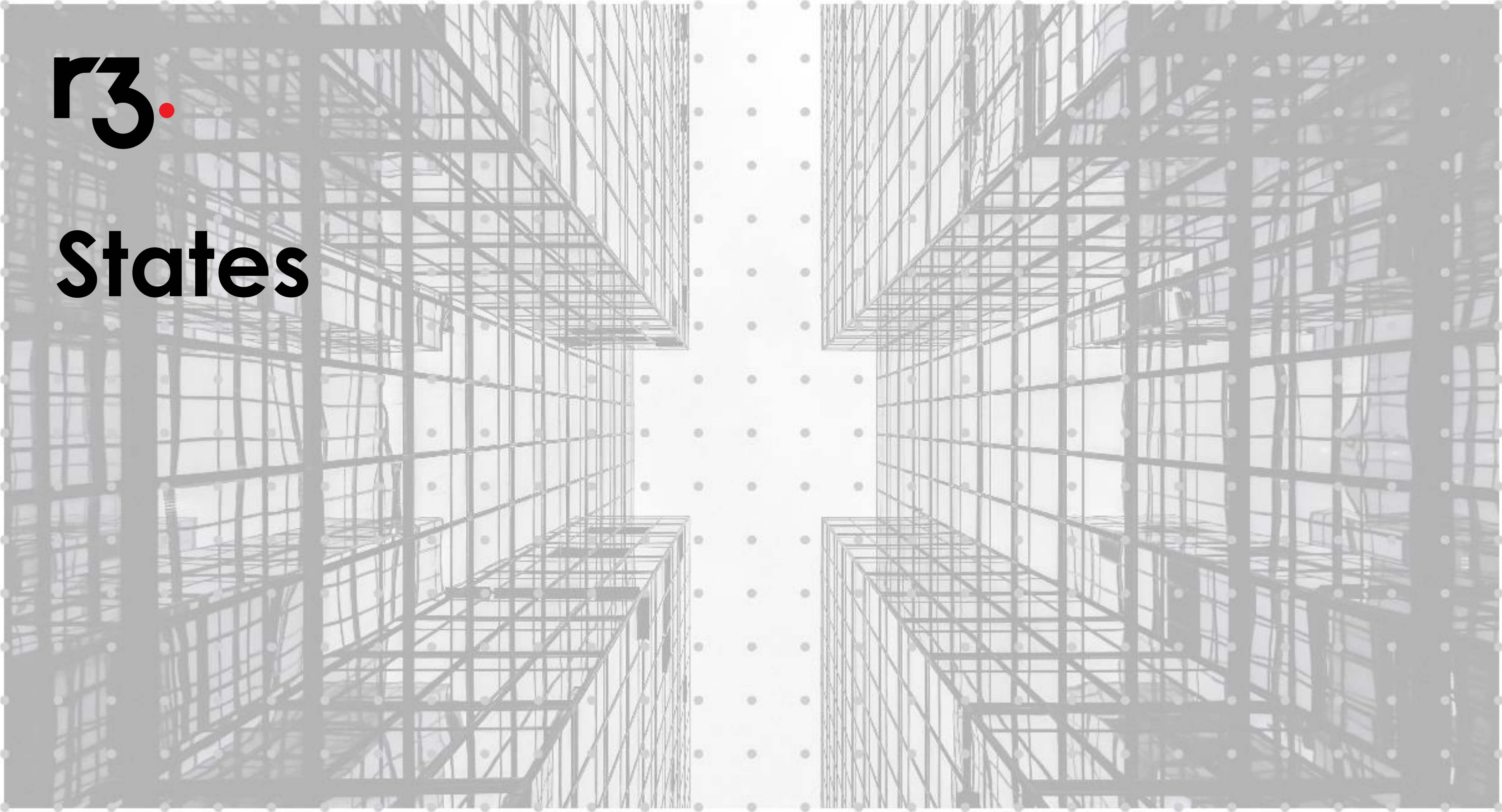


Id	Fact
1	"Much consensus"
7	"So bilateral"
11	"Wow ledger"

Id	Fact
1	"Much consensus"
6	"Very fact"
7	"So bilateral"
5	"amaze network"

- There is no "central ledger"
- Each network peer maintains a separate **vault** of facts
- Facts are like rows in a table
- All peers to a shared fact store identical copies
- Not all on-ledger facts have to be shared with other peers
- The black square **"11"** is an example of a on-ledger fact not shared with any peers

The Corda ledger is **subjective** from each peer's perspective



States

States represent (shared) facts

ALICE (IOUs)

Id	From	To	Amt	By	Penalty	Paid
1	Alice	Bob	£10	2017-03-31	20% daily	£0

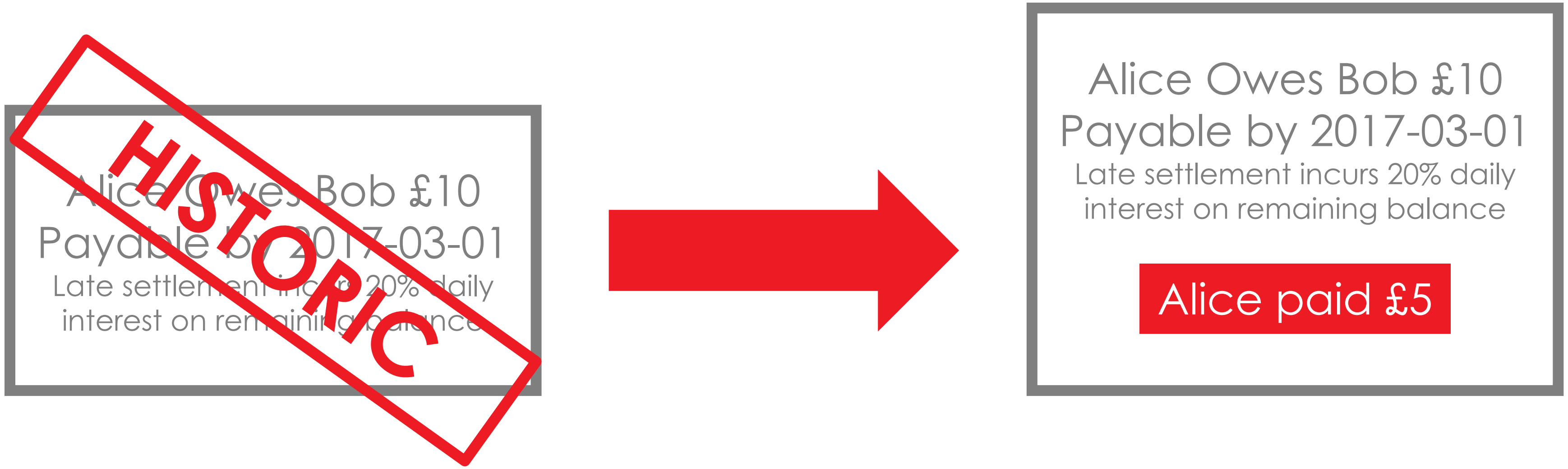
BOB (IOUs)

Id	From	To	Amt	By	Penalty	Paid
1	Alice	Bob	£10	2017-03-31	20% daily	£0

Alice Owes Bob £10
Payable by 01/03/17
Late settlement incurs 20% daily interest on remaining balance

Alice pays Bob £5

Alice settles £5 of a £10 IOU with Bob so she creates a new updated state to reflect this and marks the old one as historic



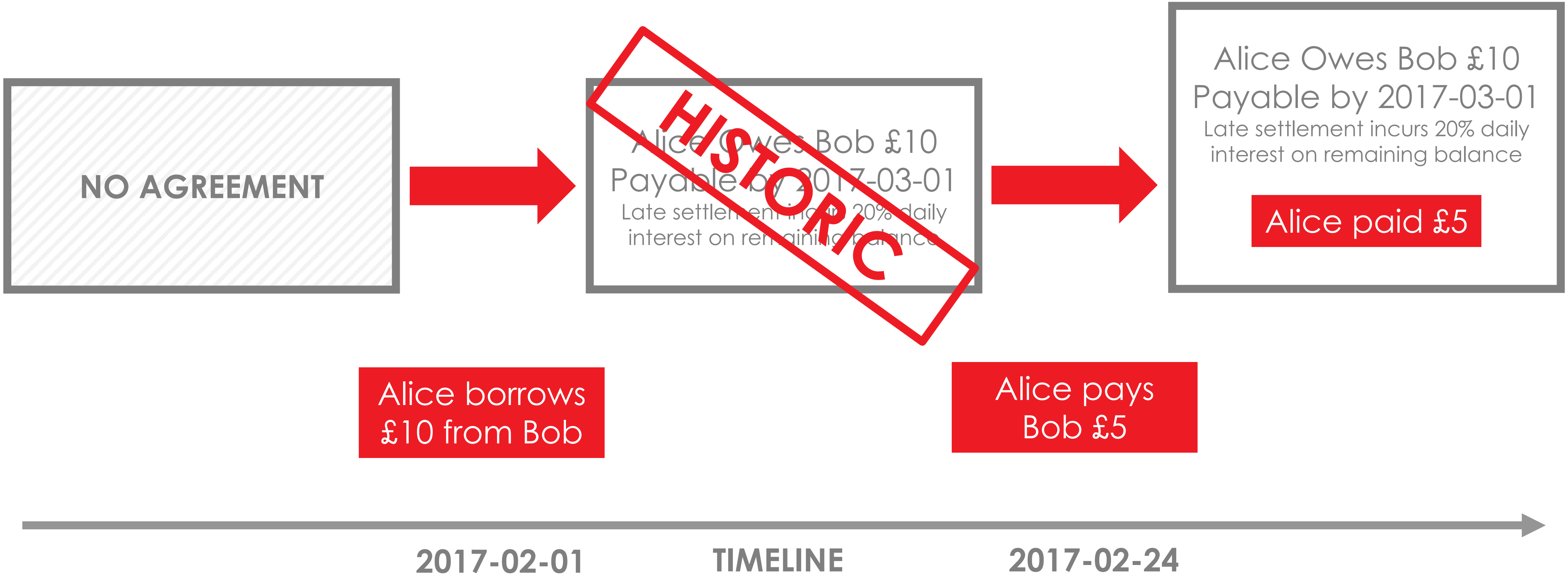
States can contain anything

- In Corda, states don't just represent digital cash
- The state model can be used to represent literally **anything**
- States are **statically typed** – an IOU state is always an IOU state

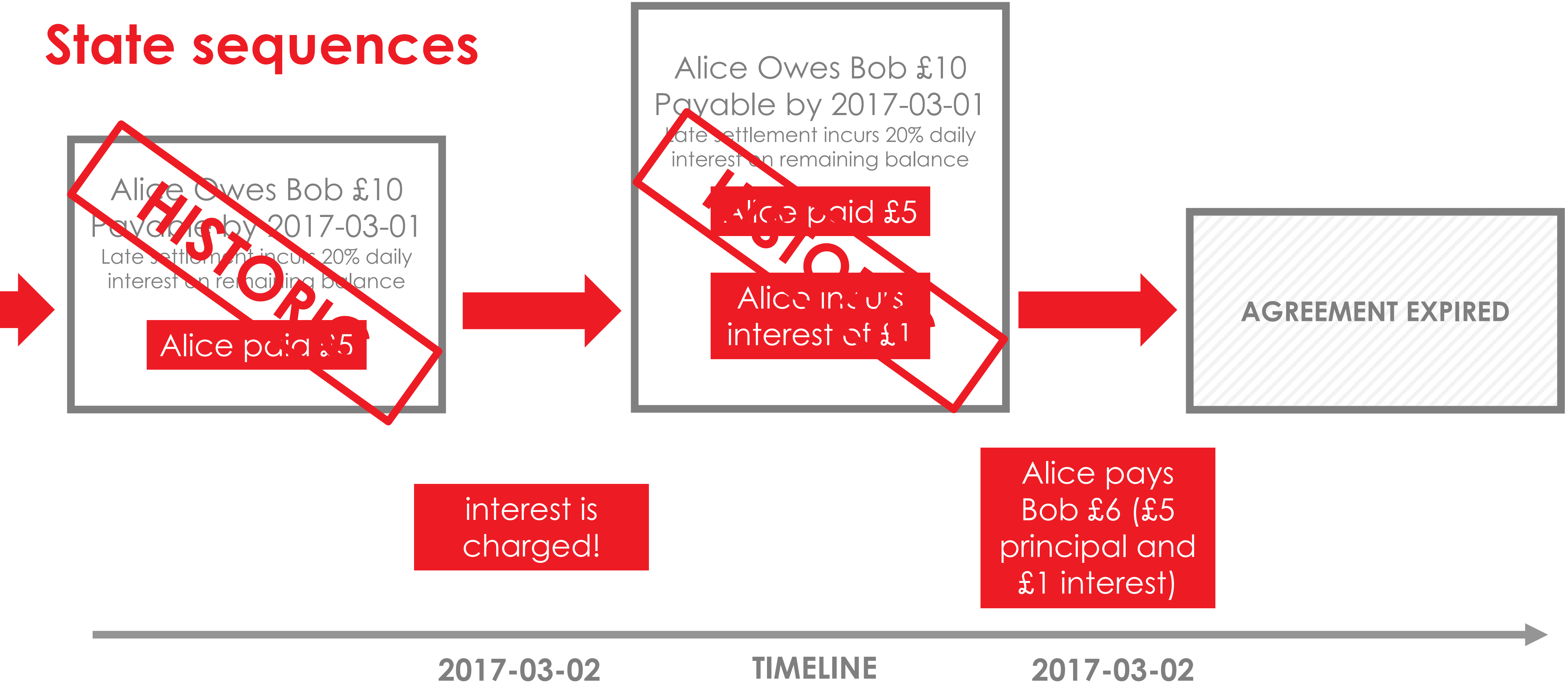
Bonds, Syndicated Loans, CDOs, CLOs, Reference Data, Invoices, Letter of Credit, Pu
Rate Swaps, Accounting Entries, Contract For Difference, Commercial Bank Credit,
ntations, Collateral, KYC Data, Credit Default Swaps, Bids/Offers, Personal Informatio

States are immutable objects that represent (shared) facts such as an agreement or contract at a specific point in time

State sequences



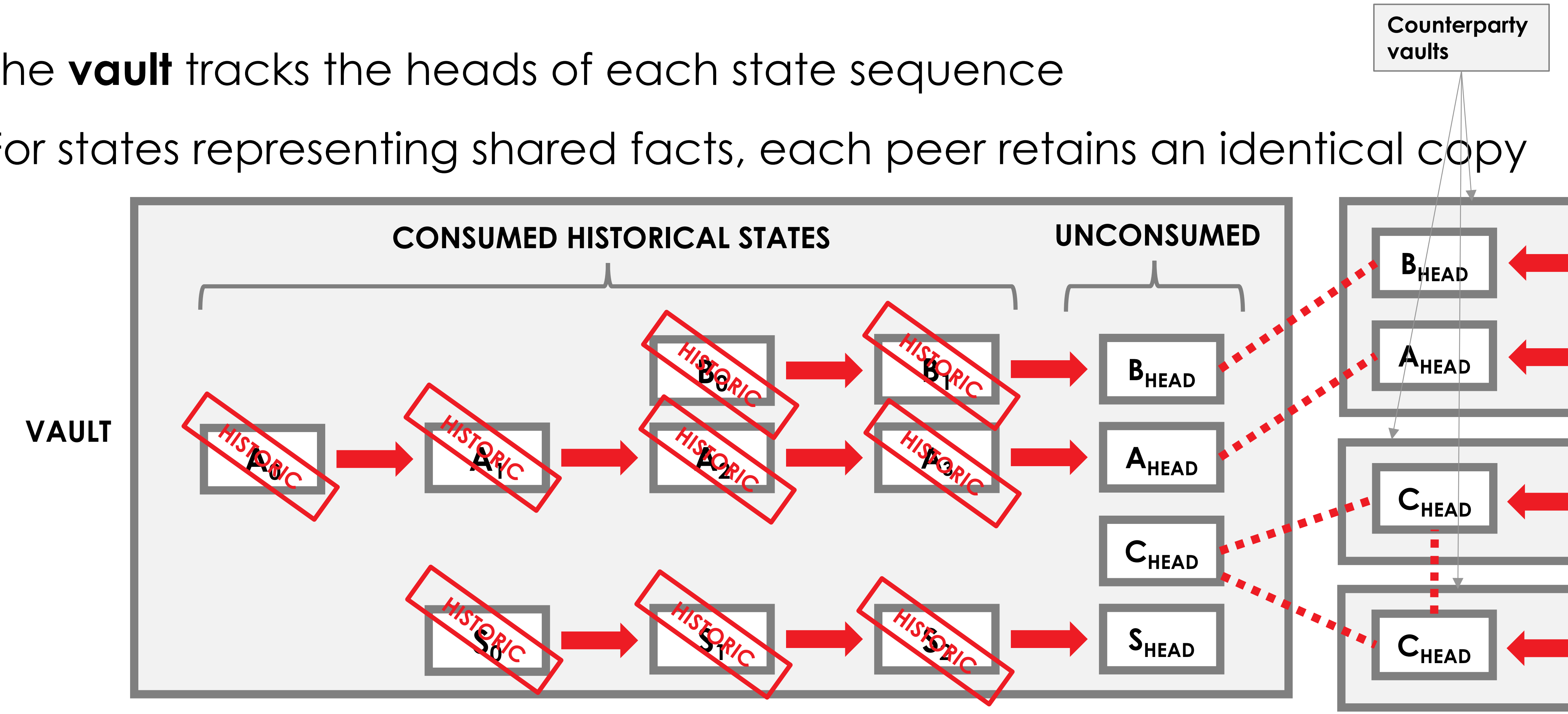
State sequences



The life-cycle of a shared fact or agreement over time is represented by a state sequence

The vault tracks state sequence heads

- The **vault** tracks the heads of each state sequence
- For states representing shared facts, each peer retains an identical copy

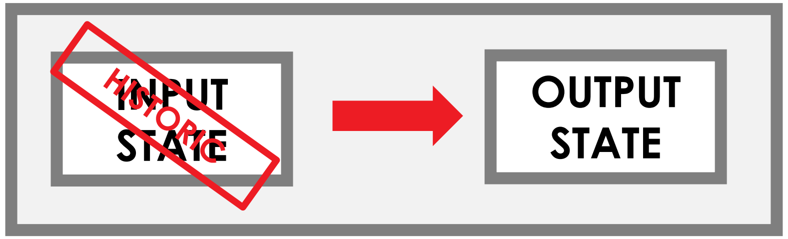


The ledger from each peer's point of view consists of all the state sequence heads (or non-historic states) tracked in the **vault**

Transactions

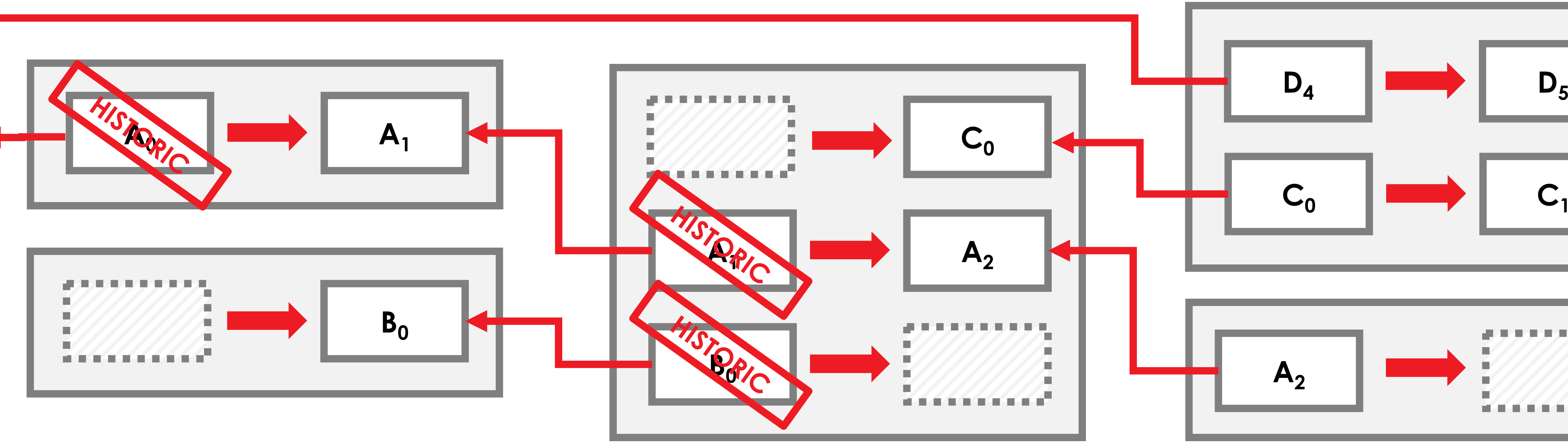
Transactions

- We introduce transactions as **atomic units of change** to update the ledger
- Transactions reference zero or more input states and create zero or more output states
- The newly created output states replace the input states which are marked as historic



Transactions can be arbitrarily complex

Transactions may combine issuances, updates and exits.



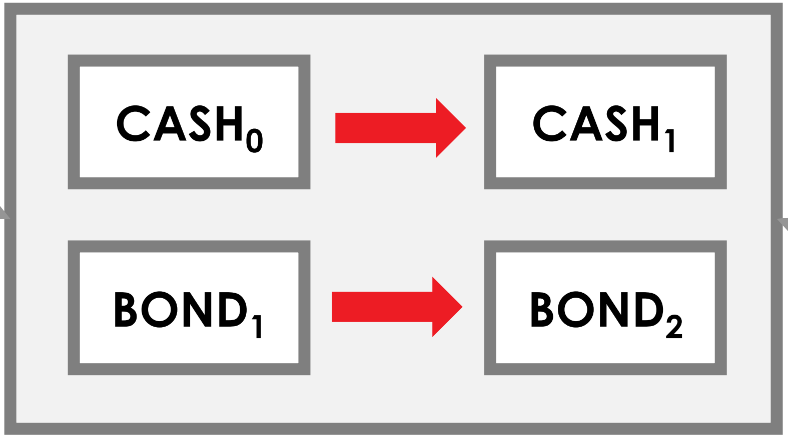
Transactions can be arbitrarily complex

Transactions can contain states of many types.

Or this transaction could represent a delivery versus payment of some cash for a bond

1) Cash is paid from the buyer to the seller
2) The bond is moved from the seller to the buyer

TRANSACTION

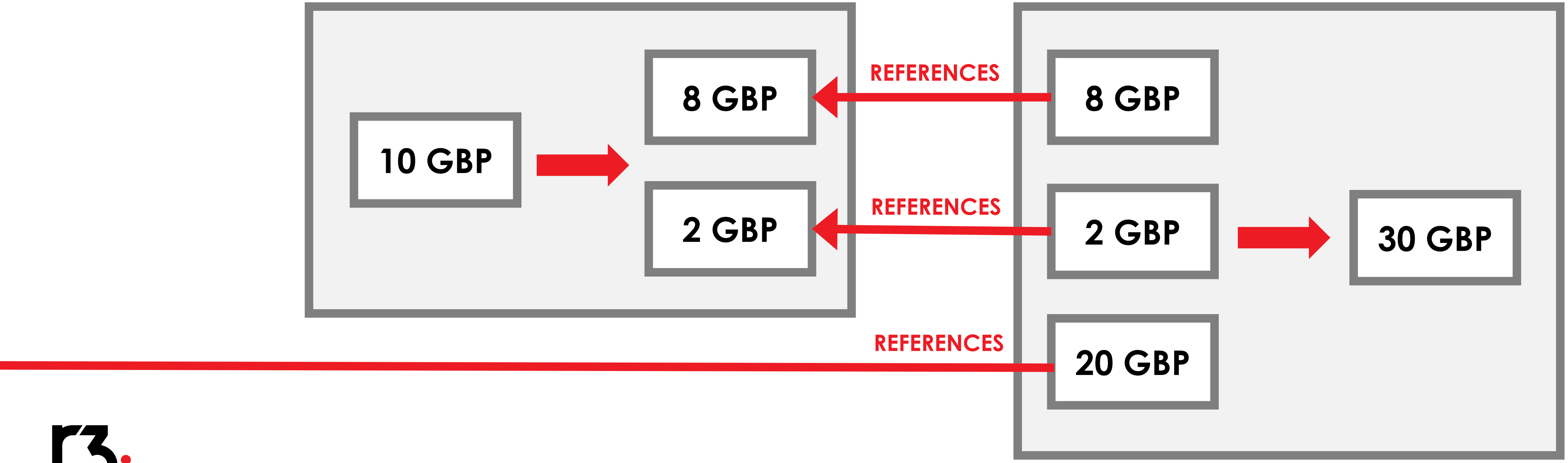


This transaction could represent a coupon payment on a bond:

1) Cash is paid from the bond issuer to the bond owner.
2) The bond shared fact is updated to reflect the coupon payment

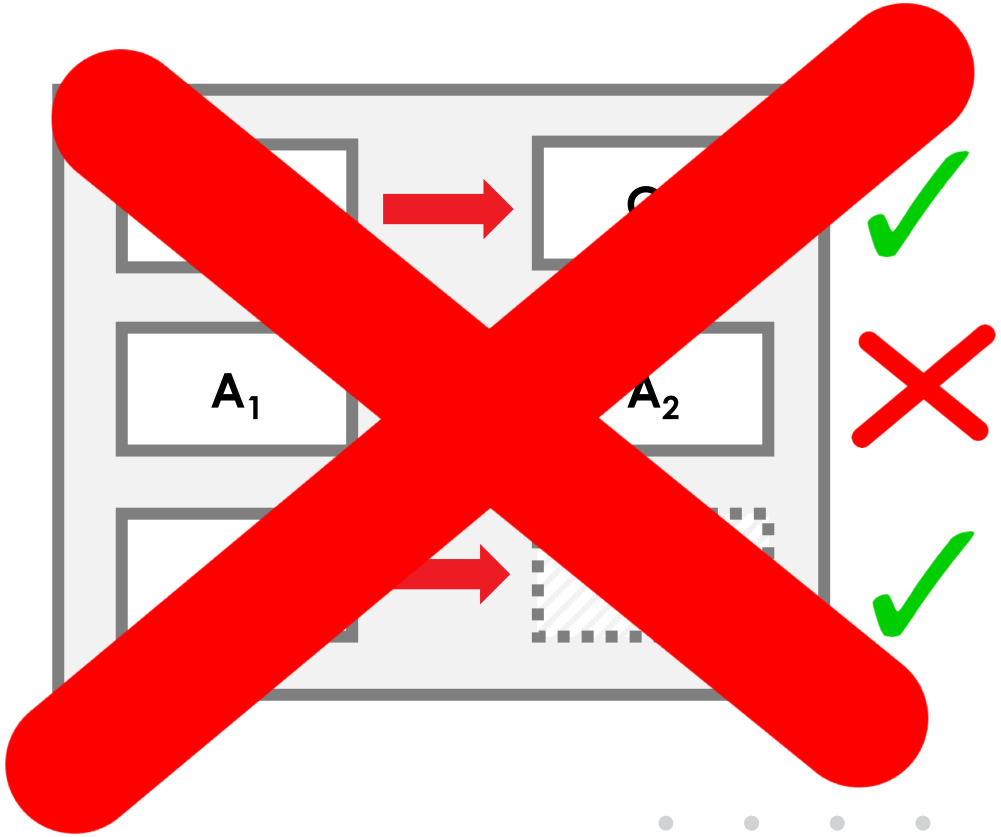
Transactions can split and merge states

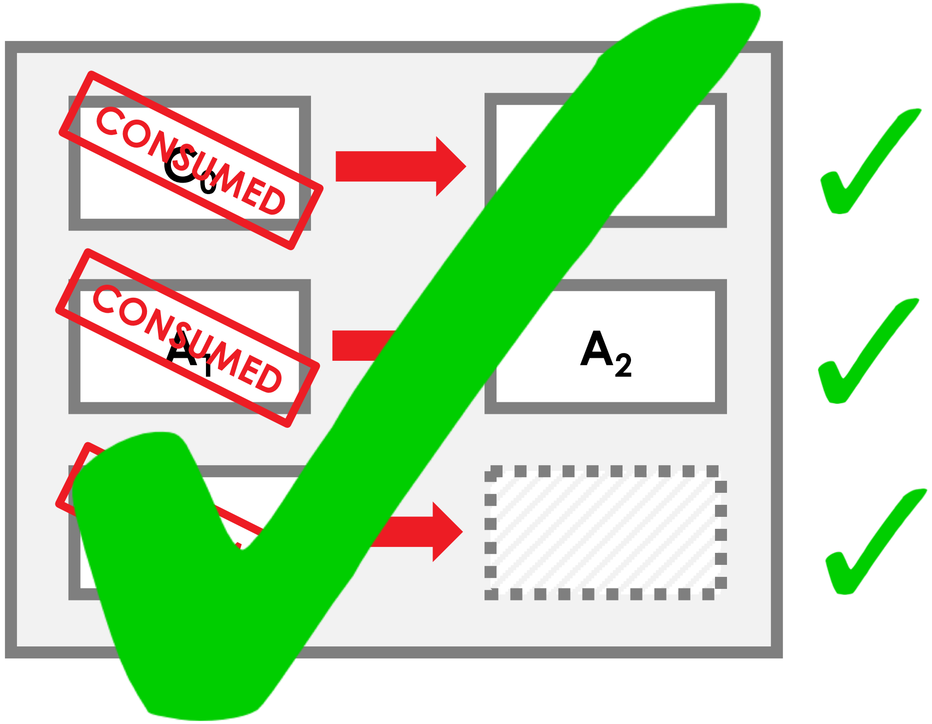
Transactions can also split and merge states representing fungible assets.



Transactions are atomic

A Transaction in Corda is an **indivisible** and **irreducible** set of changes such that either **all** occur, or **nothing** occurs.

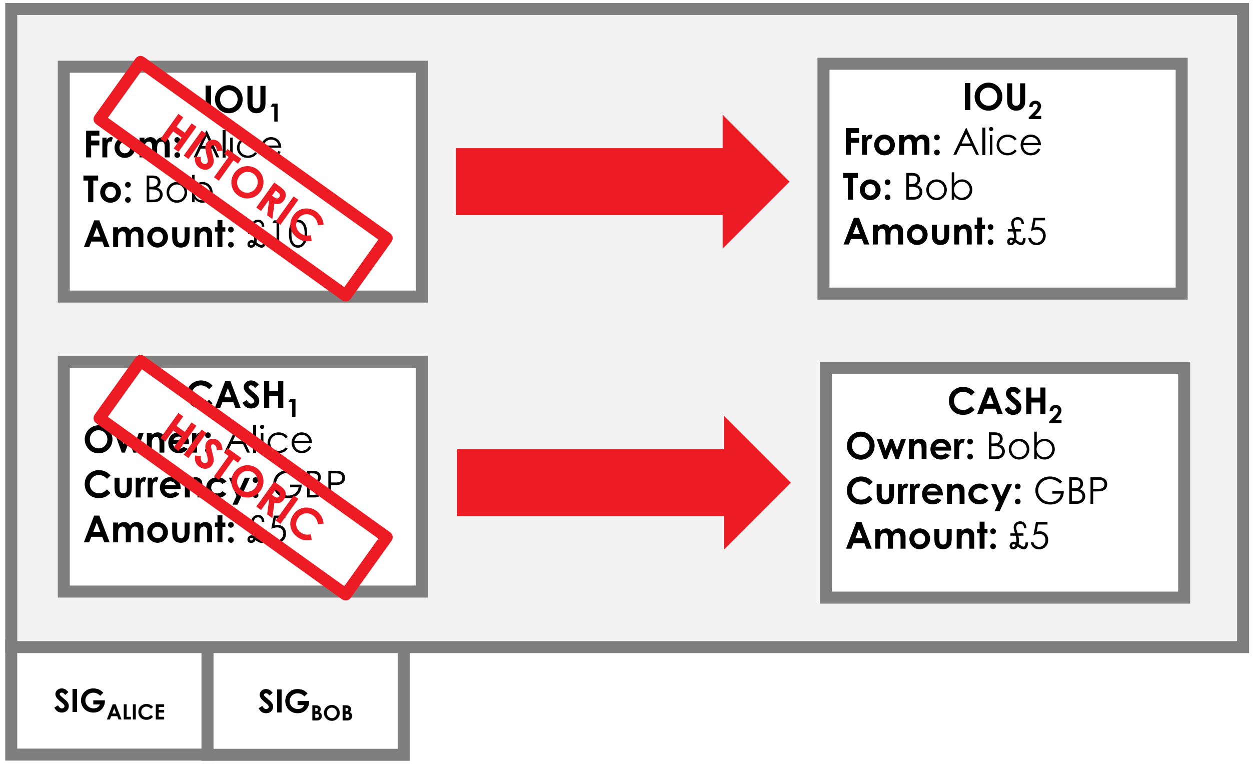




Transactions are an atomic set of changes to update the ledger

Committing transactions

Example: Alice partially settles an IOU with Bob.



The transaction is currently unsigned and is thus **uncommitted**.

Alice signs. As the transaction is only partially signed, it is still **uncommitted**.

Bob signs. The transaction is now **fully signed** by the required peers and can be **committed**.

Transactions are committed and update the ledger only when signed by all required peers

Uncommitted transactions are proposals to update the ledger

Committed transactions are immutable

Transactions are not instructions

- Transactions are **not** instructions which require action
- Instead, transaction creators **calculate an updated ledger** which is reflected by the output states
- The output states **are** the updated ledger!
- **In other words:** Corda transactions state **what** the updates are as opposed to **how** to calculate the updates

Transaction proposals **require verification** which is performed separately to transaction creation

Transactions in summary

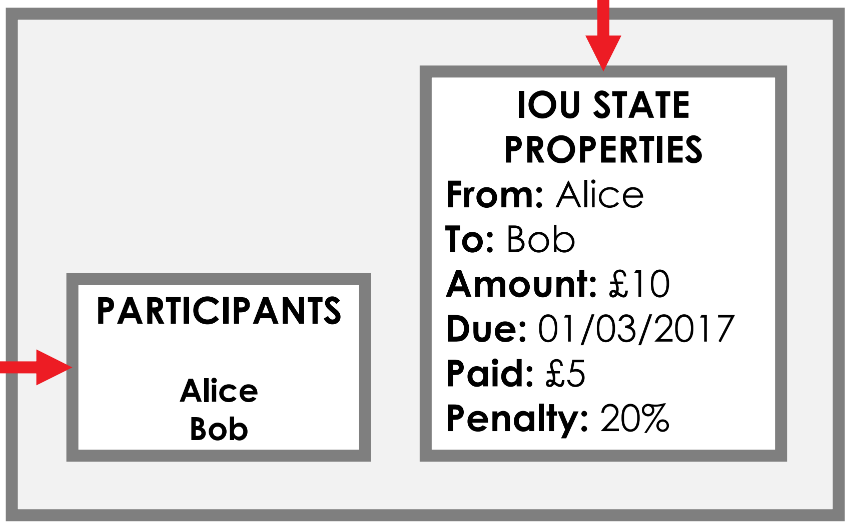
1. Any peer may create a transaction proposal
2. Transaction proposals are uncommitted by default
3. Before a transaction proposal is committed it must first be **digitally signed** and then **verified** by all required peers on a need-to-know basis
4. Once a transaction is committed it marks the input state references as historic and creates new output states reflecting an updated ledger

Contracts

A closer look at state objects…

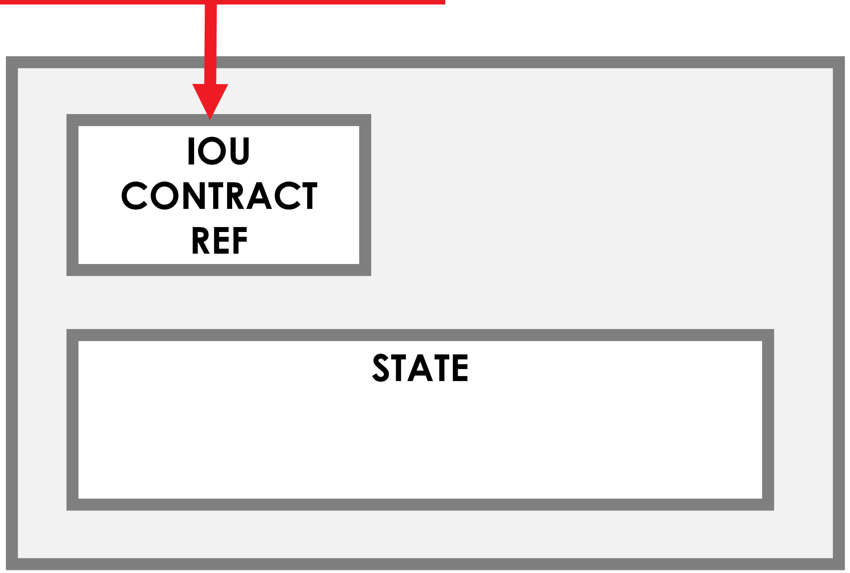
Properties reflect the state of an agreement or contract at a specific point in time

Participants lists the peers who can consume this state in a transaction



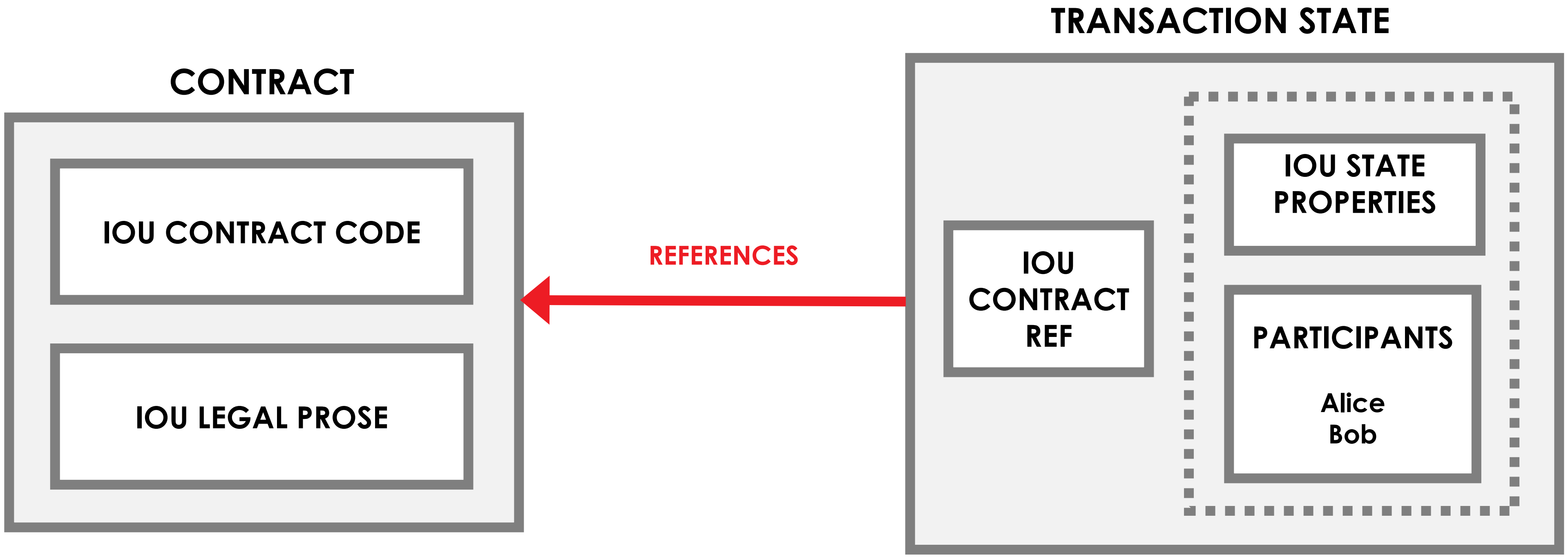
Transaction states

Contract ref point to a contract which defines the verification function



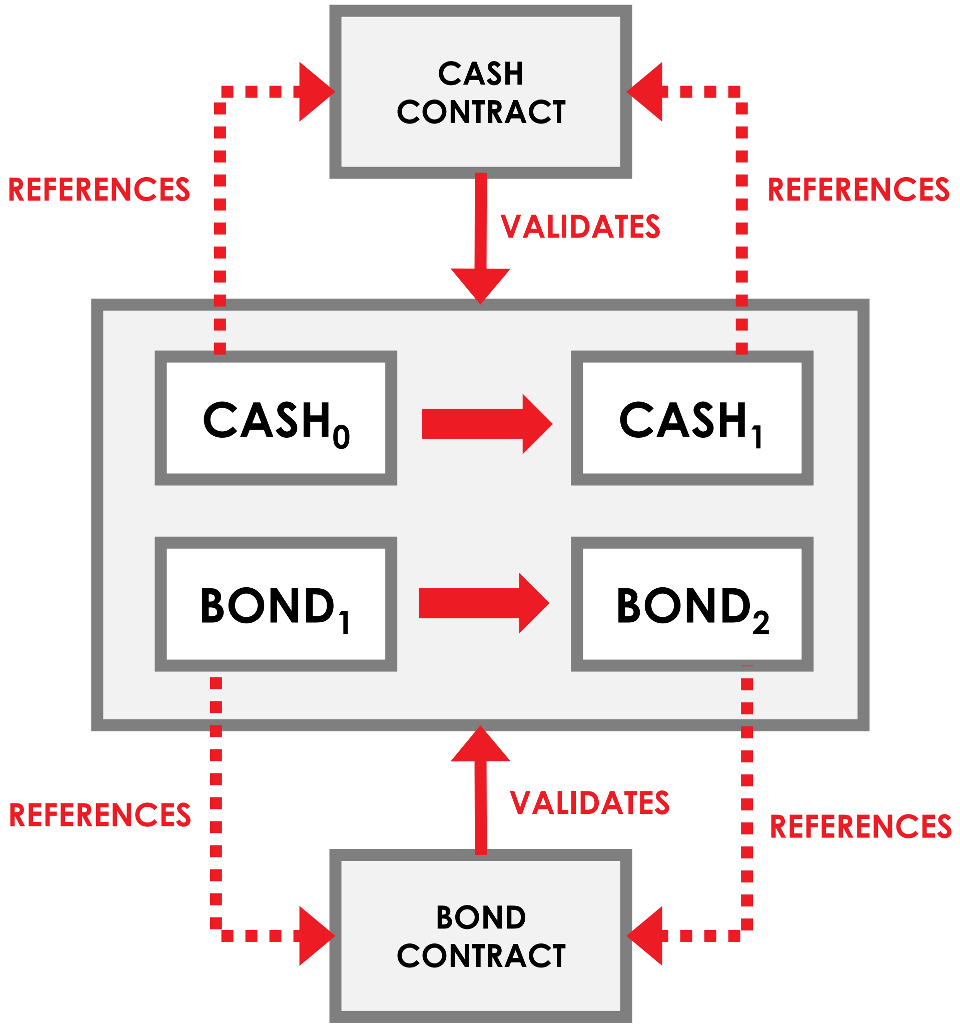
Contracts

Corda mandates that each state inside a transaction must reference a contract



Contracts

- As transactions may contain multiple state types, multiple contracts can be referenced in a transaction
- The Corda platform will use all referenced contract code to verify a (proposed) transaction



Contract code

The **verification function** is defined in the **contract code**.

The function **takes a transaction as a parameter** and either **throws an exception** if the transaction fails verification, or **returns nothing** if the transaction verifies.

```
fun verify(tx: Transaction): Unit
```

In Kotlin, **`Unit`** is a type with only one value: the **`Unit`** object. This type corresponds to the **`void`** type in Java/C.

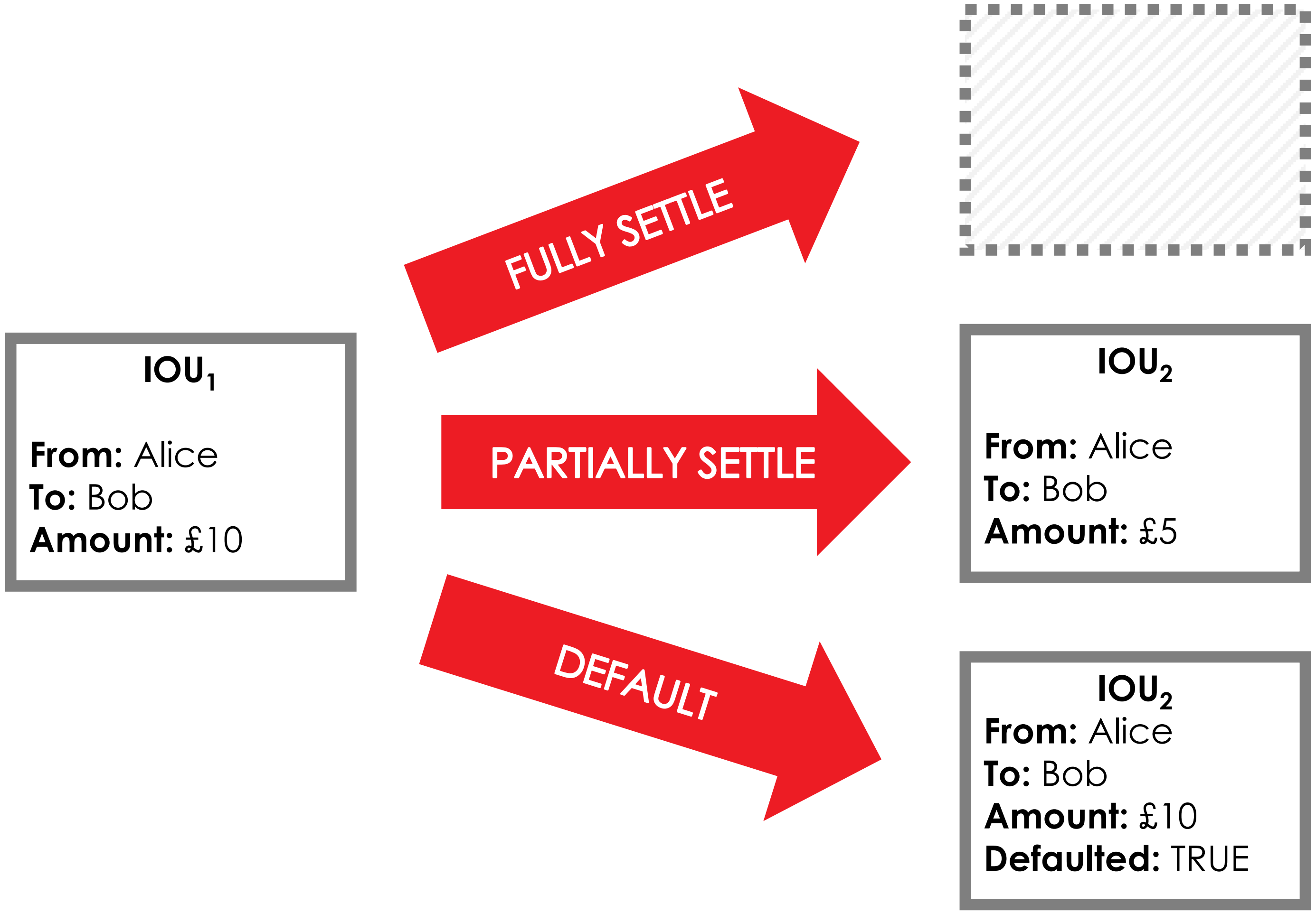
Contract code

```
// Transaction must have zero inputs.
tx.inputs.size() == 0
// Transaction must have one output.
tx.outputs.size() == 1
// The lender cannot be the borrower.
tx.outputs[0].lender != tx.outputs[0].borrower
// The output state must contain an amount > 0.
tx.outputs[0].amount > 0
```

The **contract code** is a “pure” function executed in a deterministic environment, on a need-to-know basis which verifies transactions

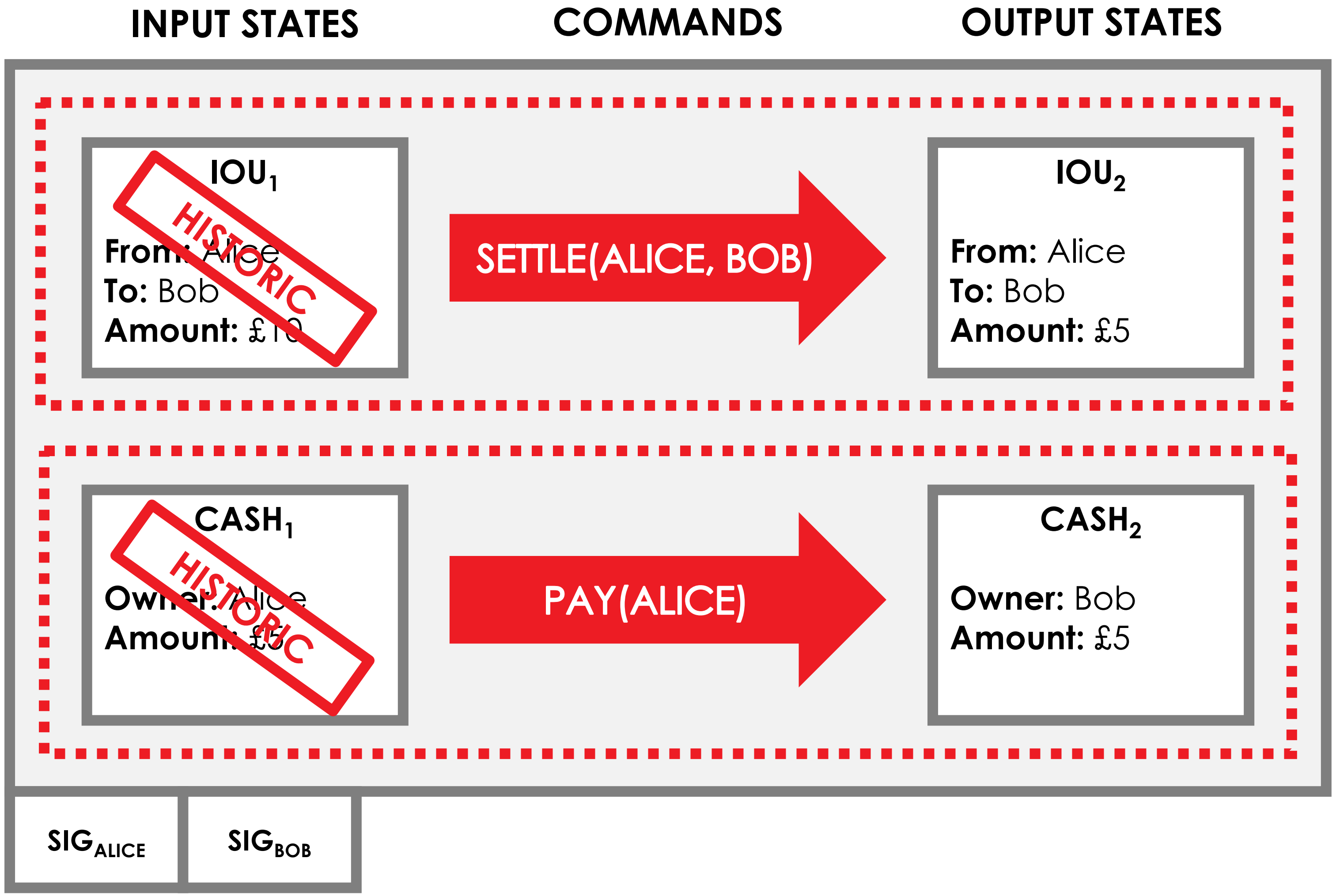
Commands

States can evolve in multiple ways



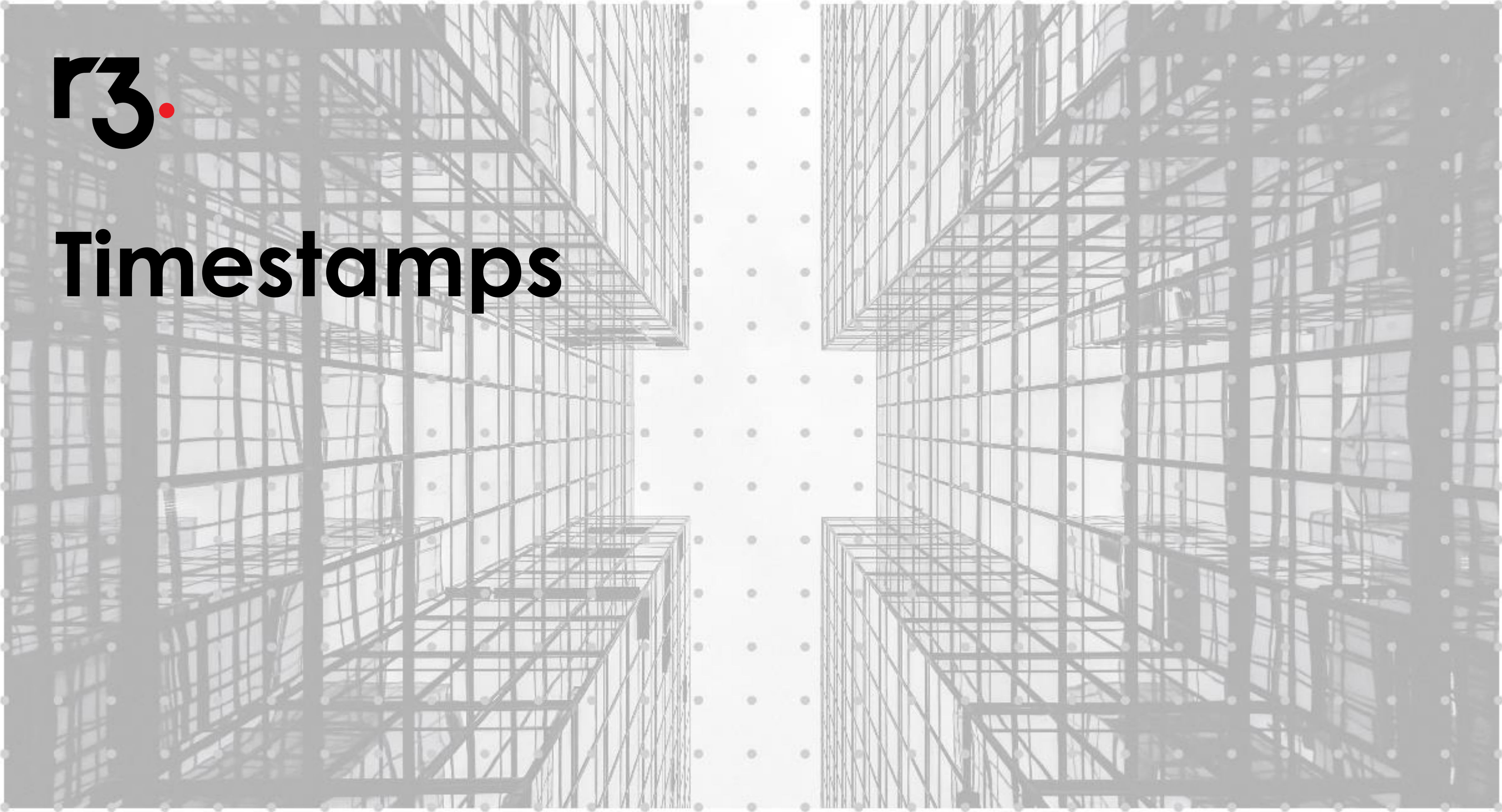
Commands

Alice settles £5 of a £10 debt with Bob, so creates a transaction proposal



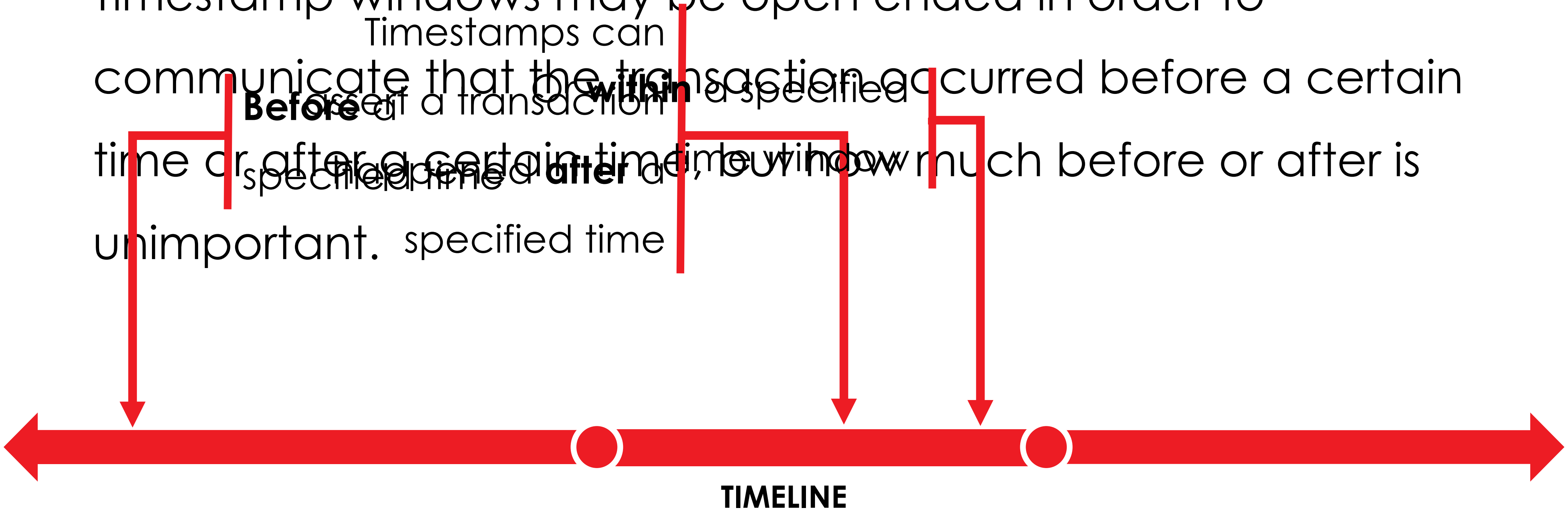
Commands parameterise transactions hinting to their intent and specify the required signers via a list of public keys

Timestamps



Timestamps

Timestamp windows may be open ended in order to communicate that the transaction occurred before a certain time or after a certain time, but how much before or after is unimportant.



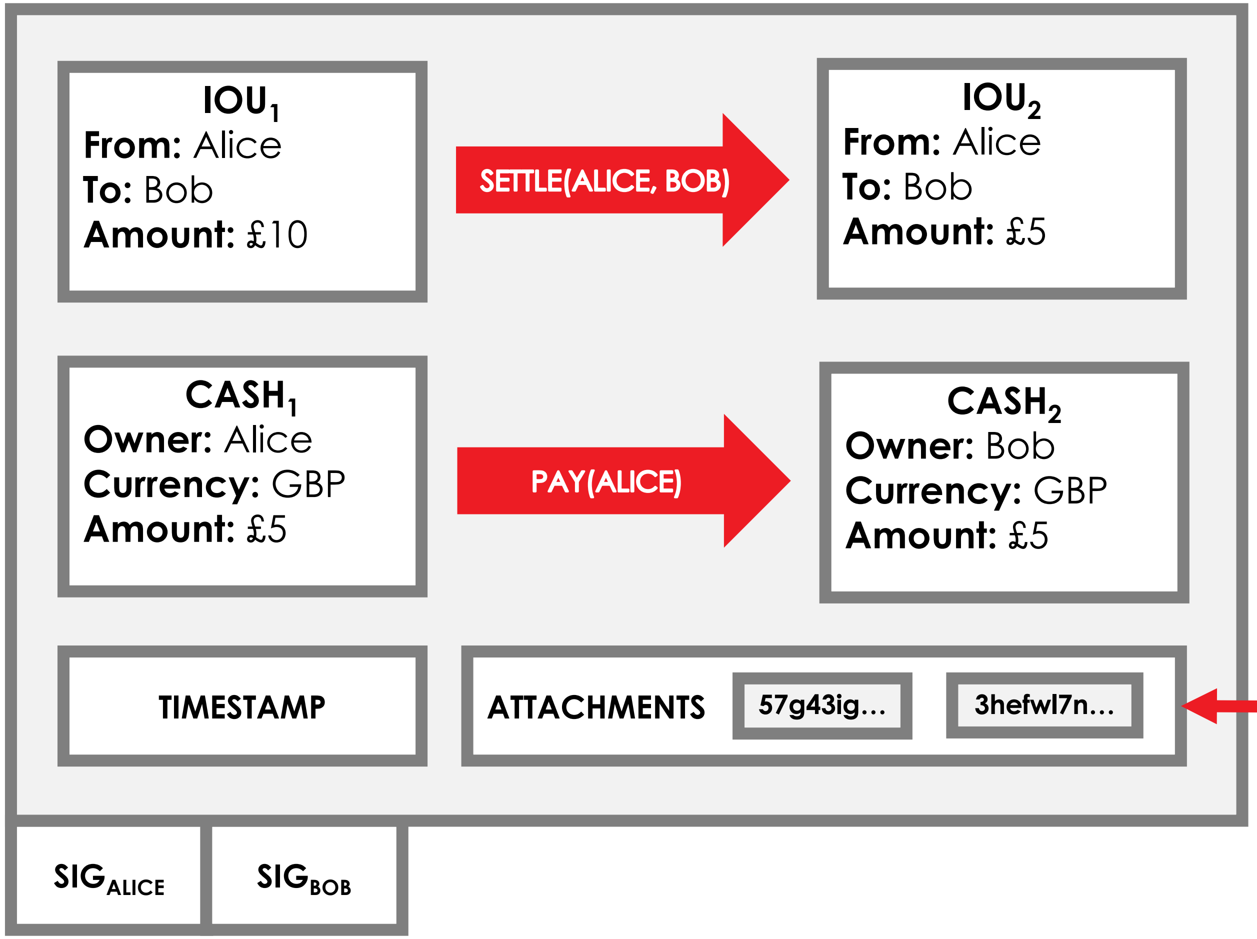
Timestamps assert that a transaction happened within a specified time window

Attachments

Attachments

- Transactions can also contain a number of **attachments**
- Attachments are **zip files** and identified by **hash**
- Attachments are **referenced** within a transaction, but not included in the transaction itself
- Attachments are intended for data on the ledger that multiple peers may wish to **reuse over and over again**
- A transaction creator chooses which files to attach

Attachments



Attachments are added by transaction creators and identified by hash within the transaction

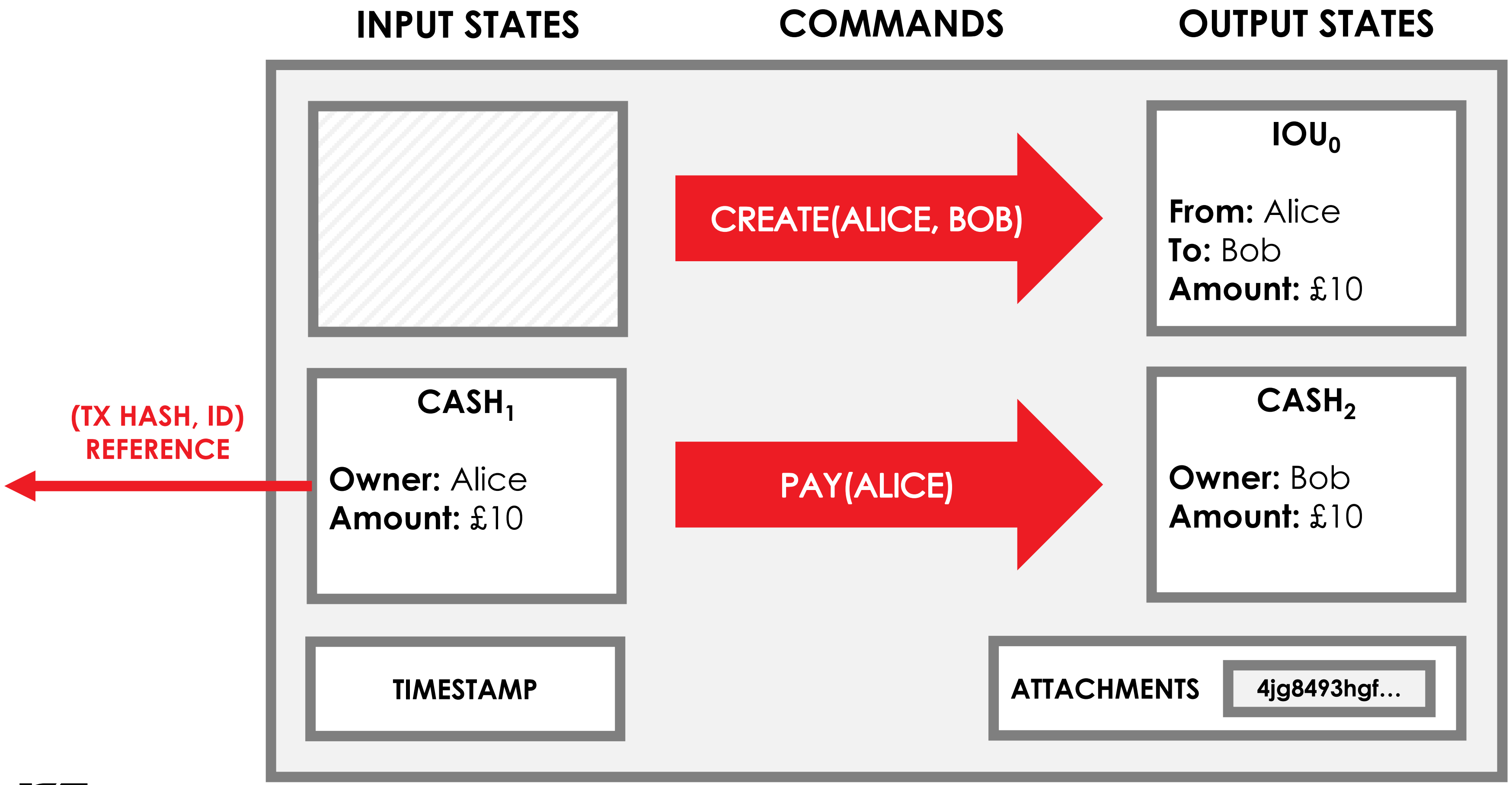
Attachments

Attachments may contain:

- **Contract code** and associated **state definitions** (.class files)
- **Legal prose** template and parameters
- **Data files** which support the contract code e.g. currency definitions, public holiday calendars or financial data

Attachments are zip files referenced in a transaction by hash but not included in the transaction itself

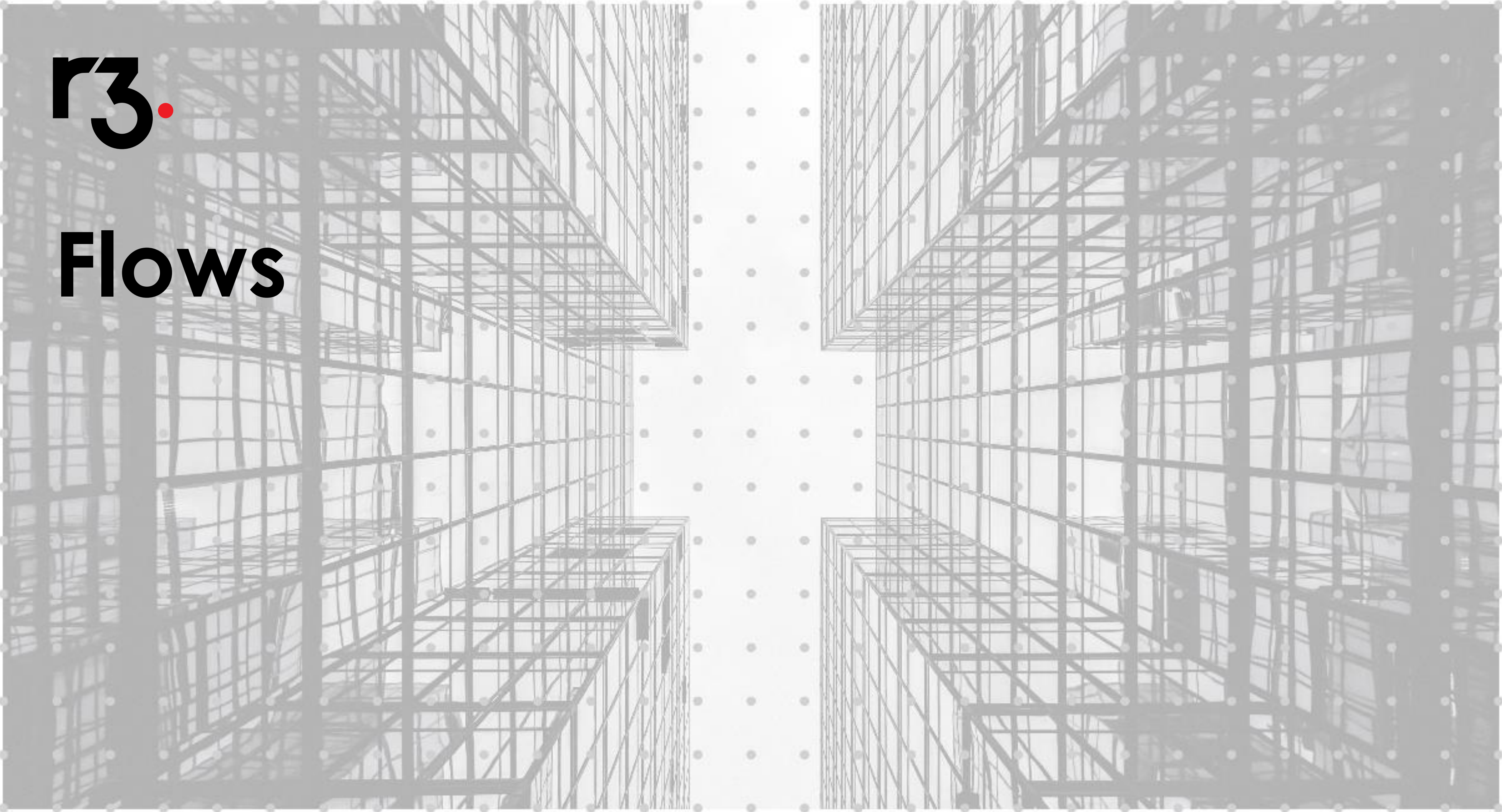
Creating a transaction proposal



sign the transaction

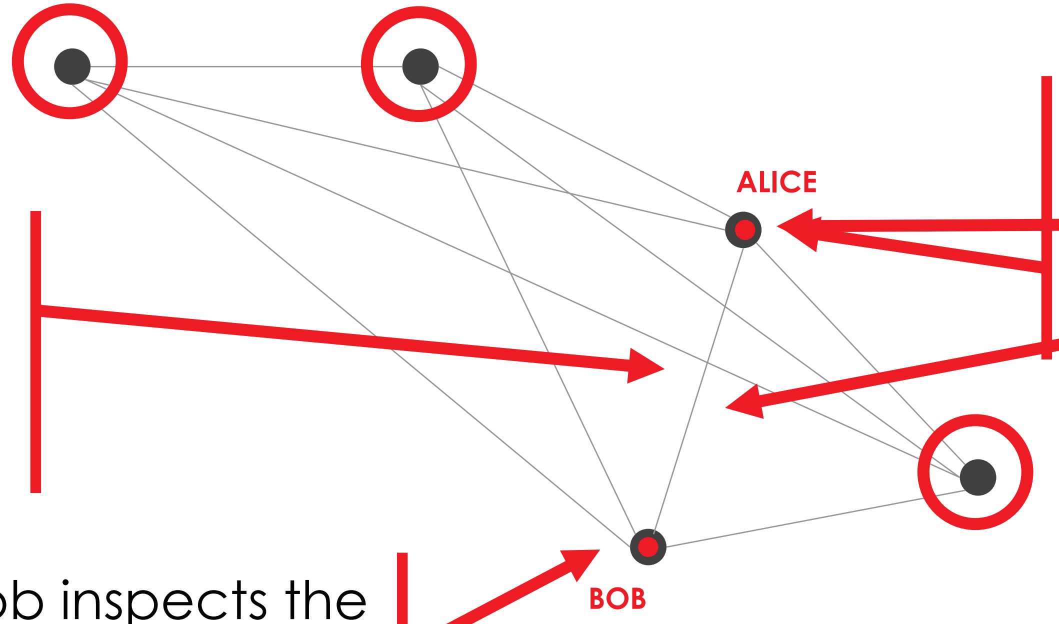
Transactions summary

- Transactions are an atomic set of changes
- Transactions contain zero or more input and output states
- States are grouped by type
- Transactions contain one or more commands
- Transactions can contain a timestamp
- Transactions can contain zero or more attachments
- Transactions are proposed and then subsequently signed and verified by the required peers



Flows

Alice and Bob agree upon an IOU



1. Alice creates a new transaction proposal and signs it

2. Alice sends the proposal and her signature to Bob

3. Bob inspects the proposal, verifies it and then signs it

4. Bob sends back the transaction and his signature to Alice

5. Alice verifies the transaction and checks Bob's signature

Uninvolved peers do not receive any of Alice's or Bob's transactions

You can write blocking code that never blocks!

```
// Alice
tx = new Tx()
peer = “Bob”
sig = sign(tx)
payload = (tx, sig)
res = sendAndReceive(payload, peer)
check(res.sigB)
verify(res.tx)
commit(res.tx)
```

When calling the network Alice’s fibre is **suspended** and **serialised to disk** (or check-pointed). If Alice’s node fails or restarts, she can deserialise the fibre and continue the flow when her node reboots

Check-pointed

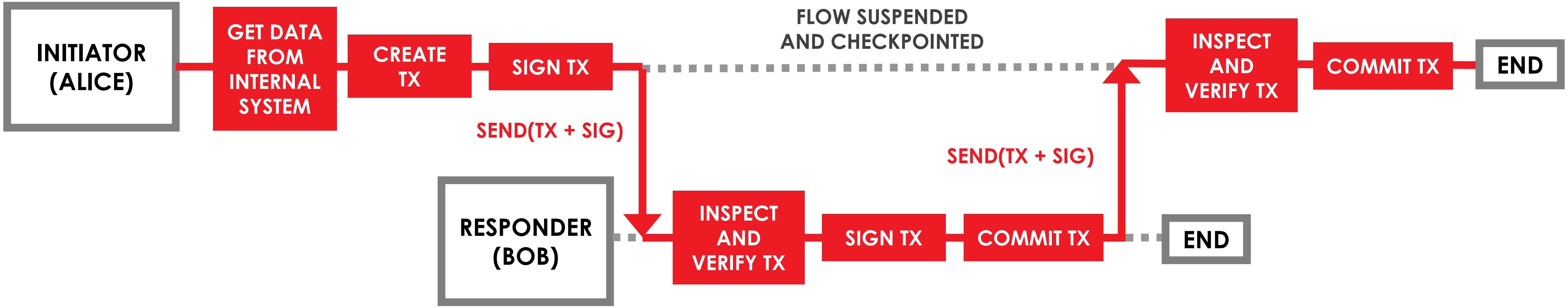
```
// BOB
peer = “Alice”
Res = receive(peer)
check(res.sigA)
verify(res.tx)
sigB = sign(res.tx)
payload = (res.tx, sigB)
send(payload, peer)
commit(res.tx)
```

Bob’s flow is check-pointed here

… and here

The two party deal flow

This is the flow Alice and Bob use to agree upon an IOU, in Corda it can be called as a sub-flow.



Flows are light-weight processes used to coordinate the complex multi-step, multi-peer interactions required for peers to reach consensus about shared facts

Consensus

Two types of consensus

Peers reach consensus over transactions in two ways:

Verification consensus	**Uniqueness consensus**

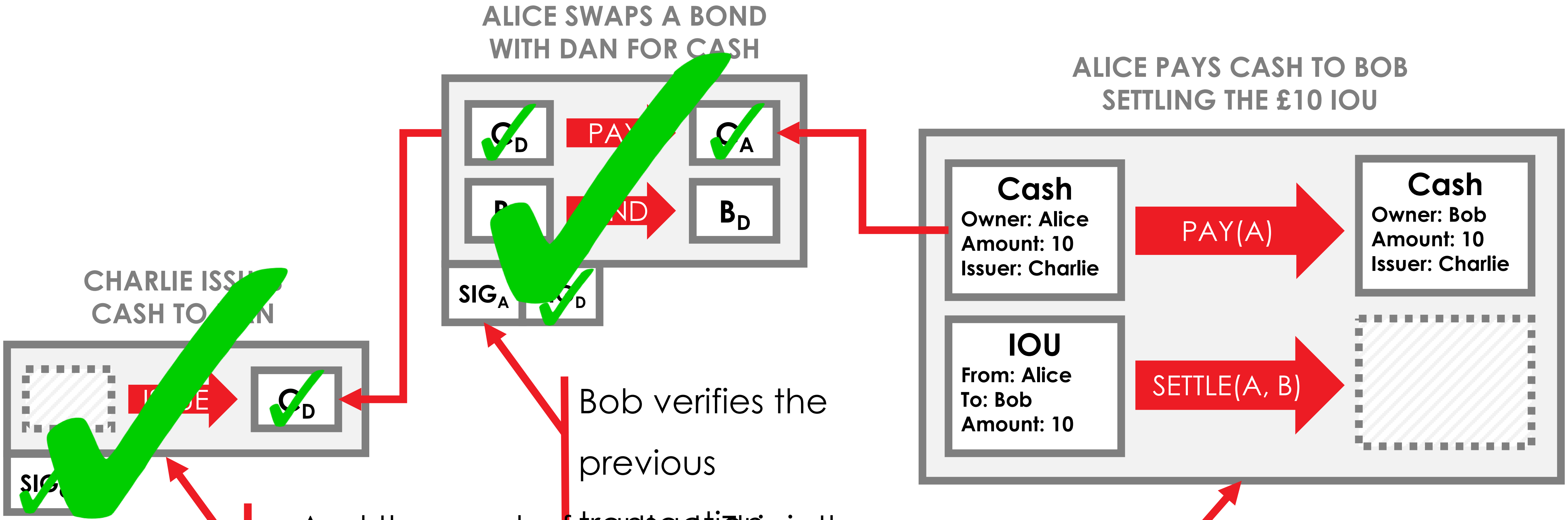
Verification consensus

In Corda, verification consensus involves peers reaching certainty that a transaction:

1. **is signed by all required peers** listed in the commands
2. **satisfies the constraints** defined by the contracts pointed to by the input and output states

However there is an additional step required…

Verification consensus



Bob verifies the previous transaction

... And the one before that! This is the issuance transaction and it was signed by Charlie, so the Cash is a valid claim!

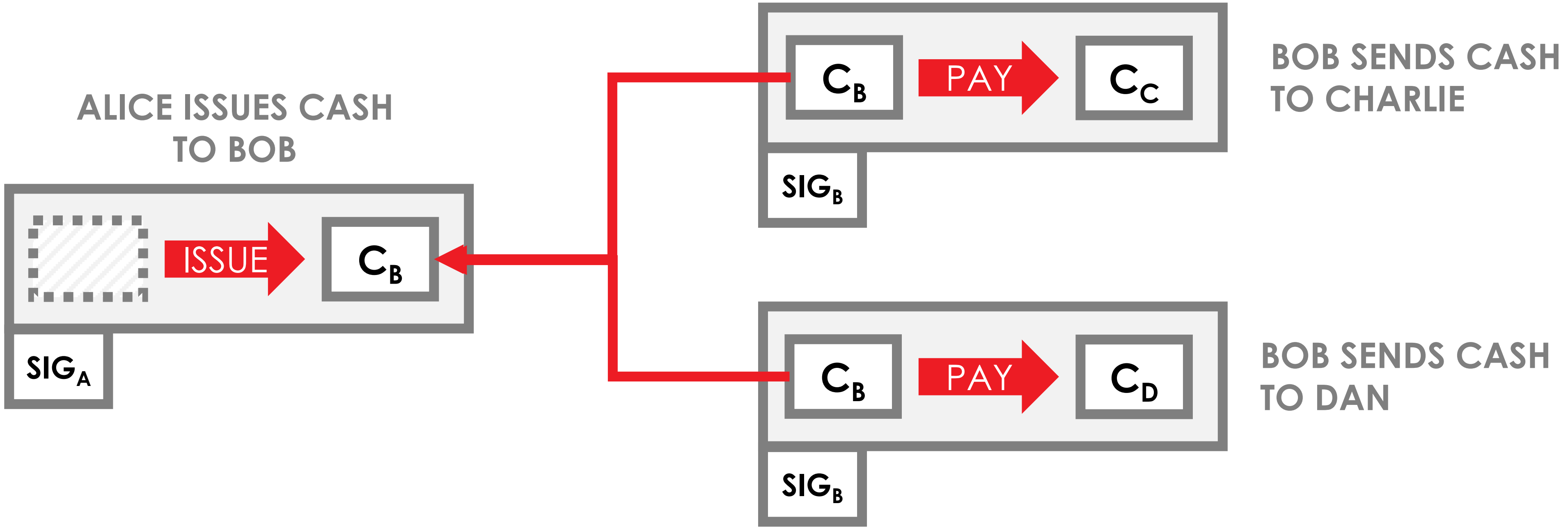
Alice presents Bob with a transaction

r3.

Verification consensus involves reaching certainty that a transaction (and all its dependencies) is signed by all required peers and satisfies the constraints in the contract code

Uniqueness consensus

By now you have probably realised that without uniqueness consensus a nefarious actor can **use the same cash input state reference in multiple transactions. How do we stop this?**



Uniqueness consensus involves peers reaching certainty that the **output states created in a transaction** are the **unique successors** to the **input states referenced** by that transaction

Notary services

Notary services track used states

In simple terms, notaries **maintain a map** keyed with input state references:

```
Key: (Transaction ID, Output Index)
Value: (Transaction ID, Input Index, Requesting Peer)
```

The map values indicate the **ID** of the transaction which **used the state as an input and marked it as historic**, as well as the **identity of the requesting peer.**

Notary services workflow

When a proposed transaction is sent to a notary service the notary **checks if any of the input state references are already in the map** and one of two things may happen:

1. If any are in the map, the notary **throws an Exception** and notes that there is a conflict
2. If none are in the map then the notary **adds each input state** to the map and **signs** the proposed transaction

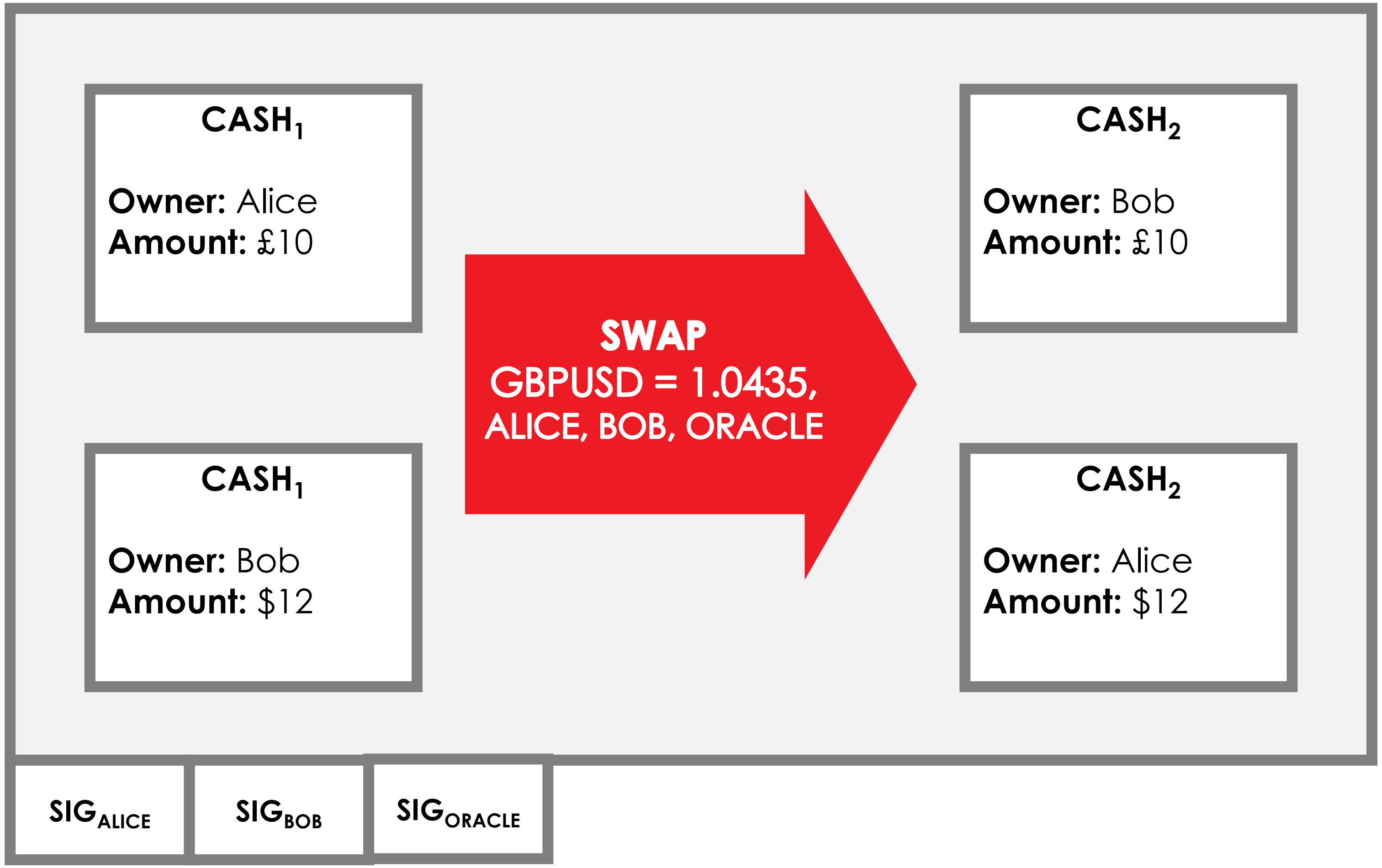
Notaries provide uniqueness consensus

Oracles

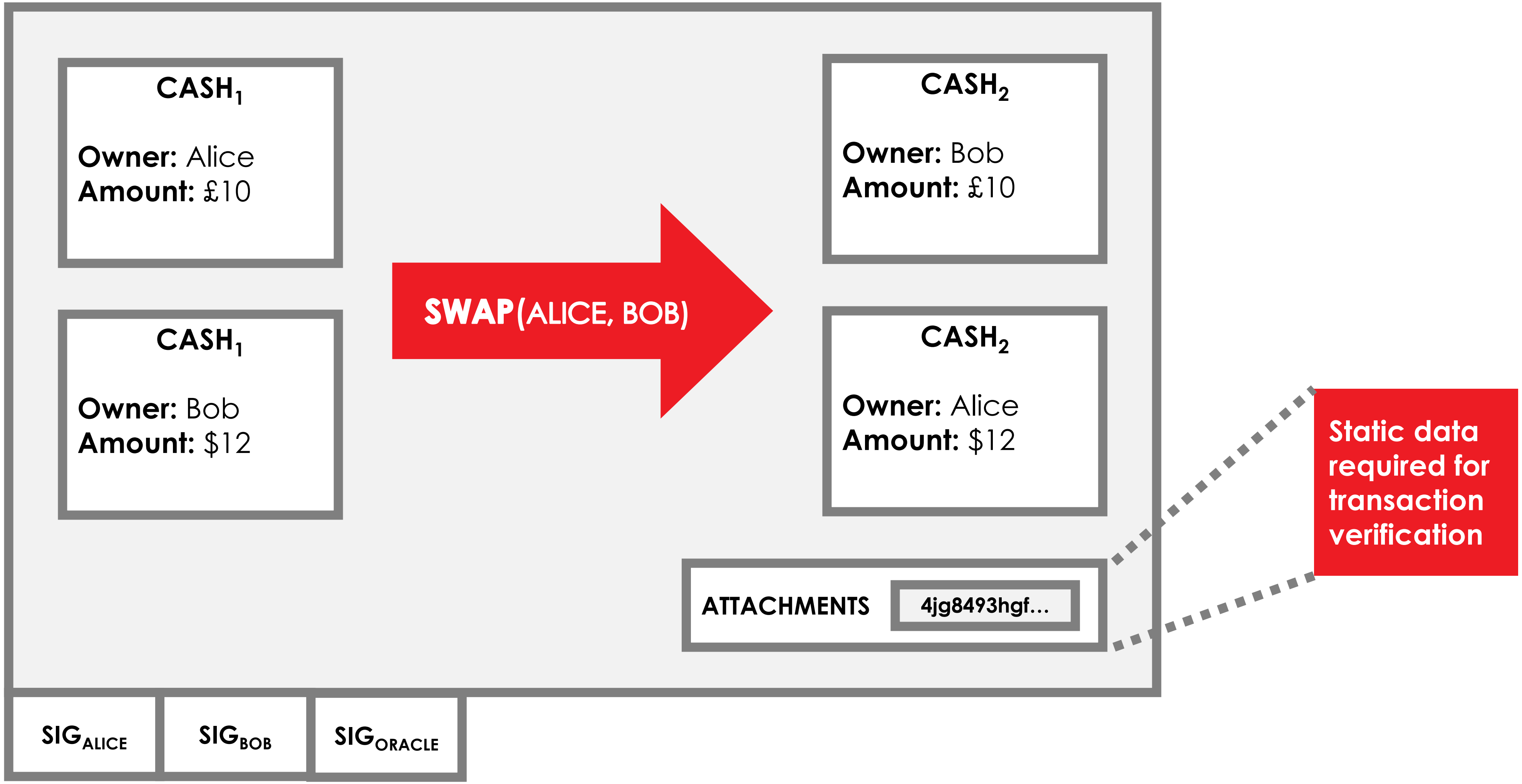
Oracles

- An oracle is a **source of data or calculations**, which has been accepted by multiple peers as **authoritative**, **binding** and **definitive** for an agreed set of values or range of calculations
- The oracle may source its data from **external observations** or calculate its results based on inputs received from **on-ledger states or attachments**

Embedding external data in commands



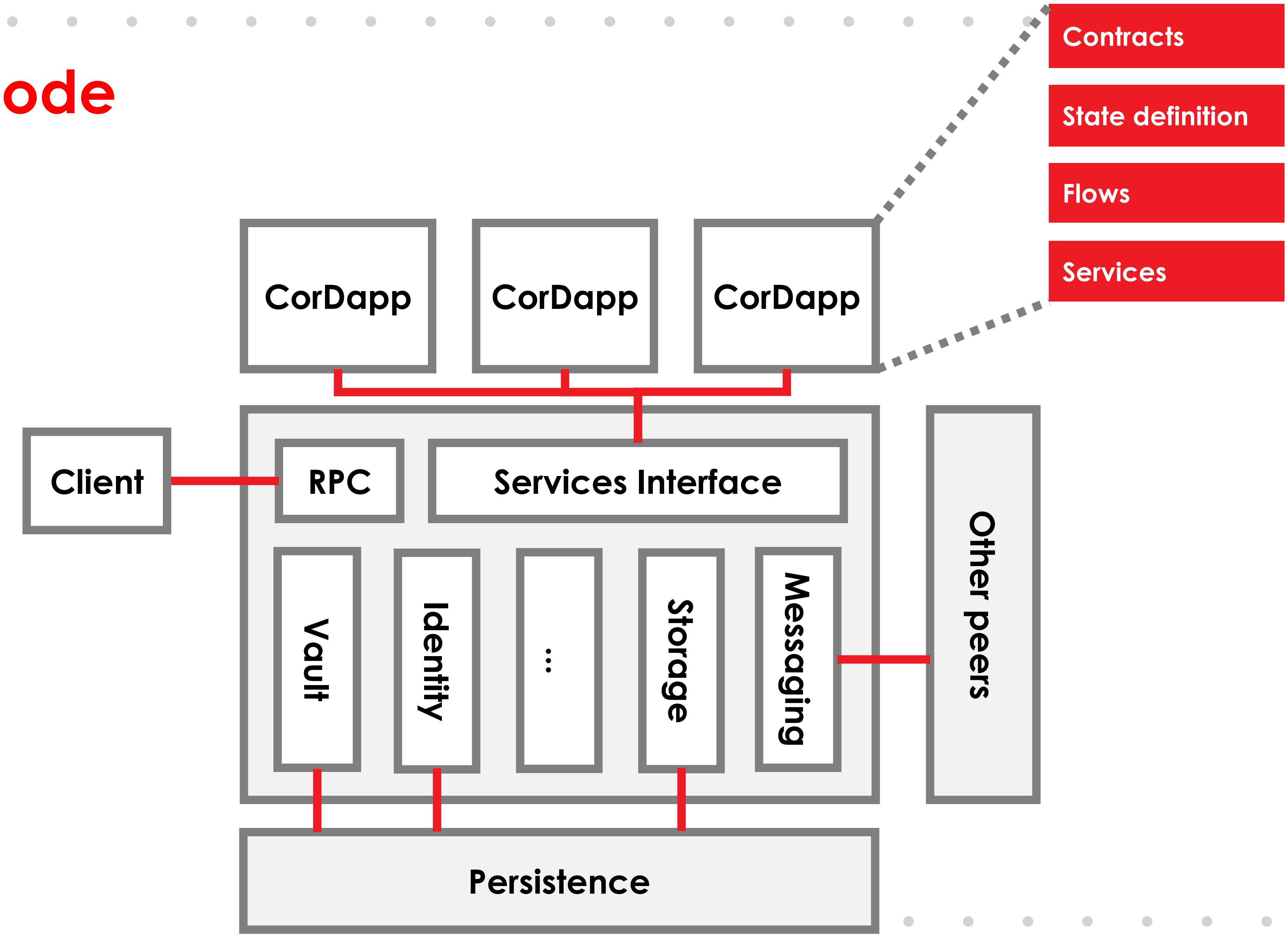
Embedding data in attachments



Oracles are an authority that attests to (and may also provide) off-ledger facts needed to verify transaction proposals

The Corda Node

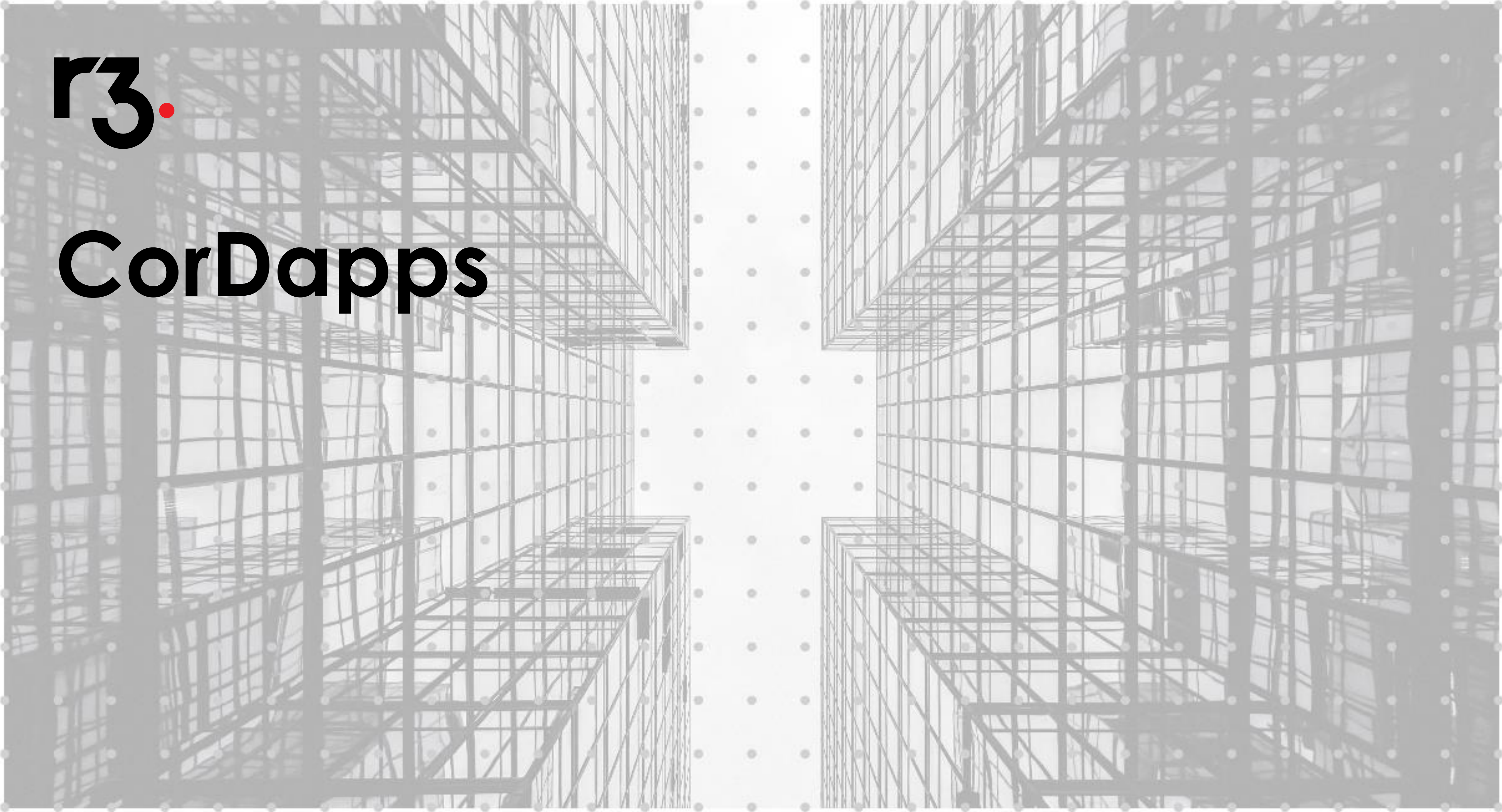
A Corda node



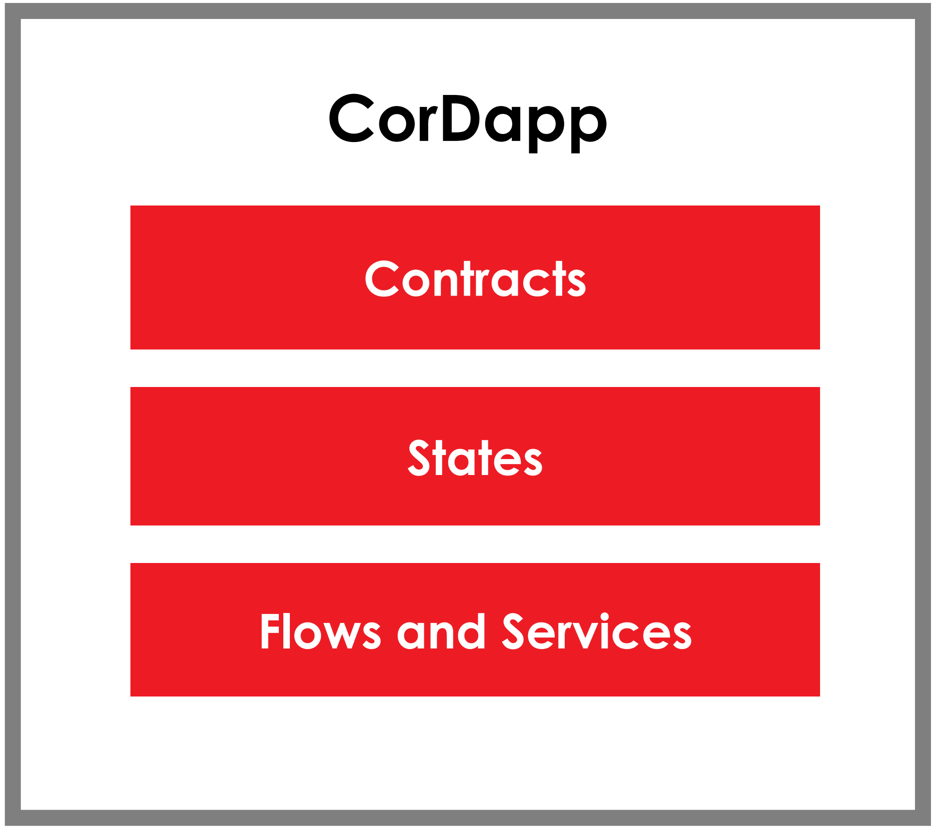
Contracts
State definition
Flows
Services
CorDapp
CorDapp
CorDapp
Client
RPC
Services Interface
Vault
Identity
...
Storage
Messaging
Other peers
Persistence

A Corda node implements a collection of services required to participate in a Corda network

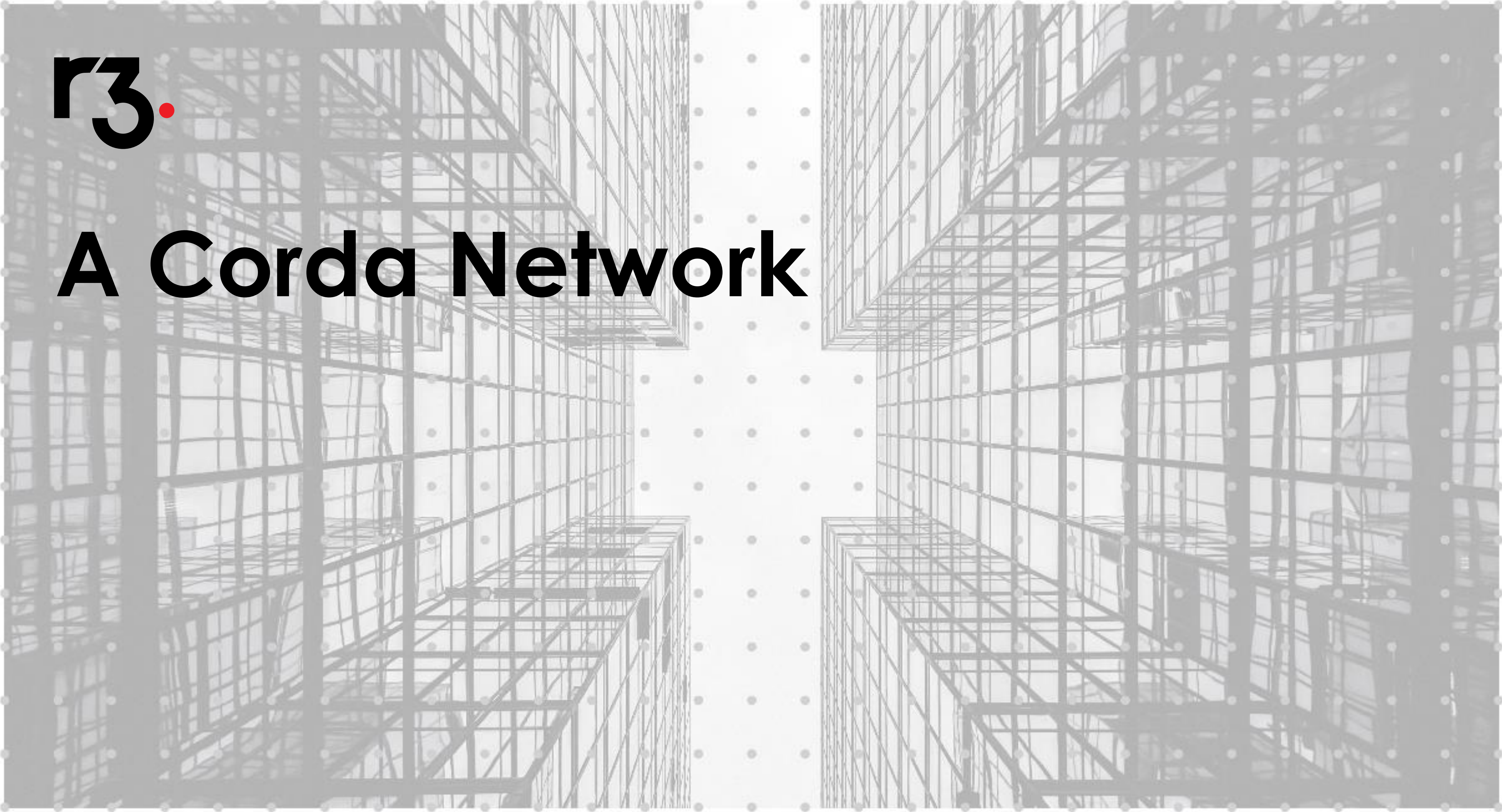
CorDapps



CorDapps

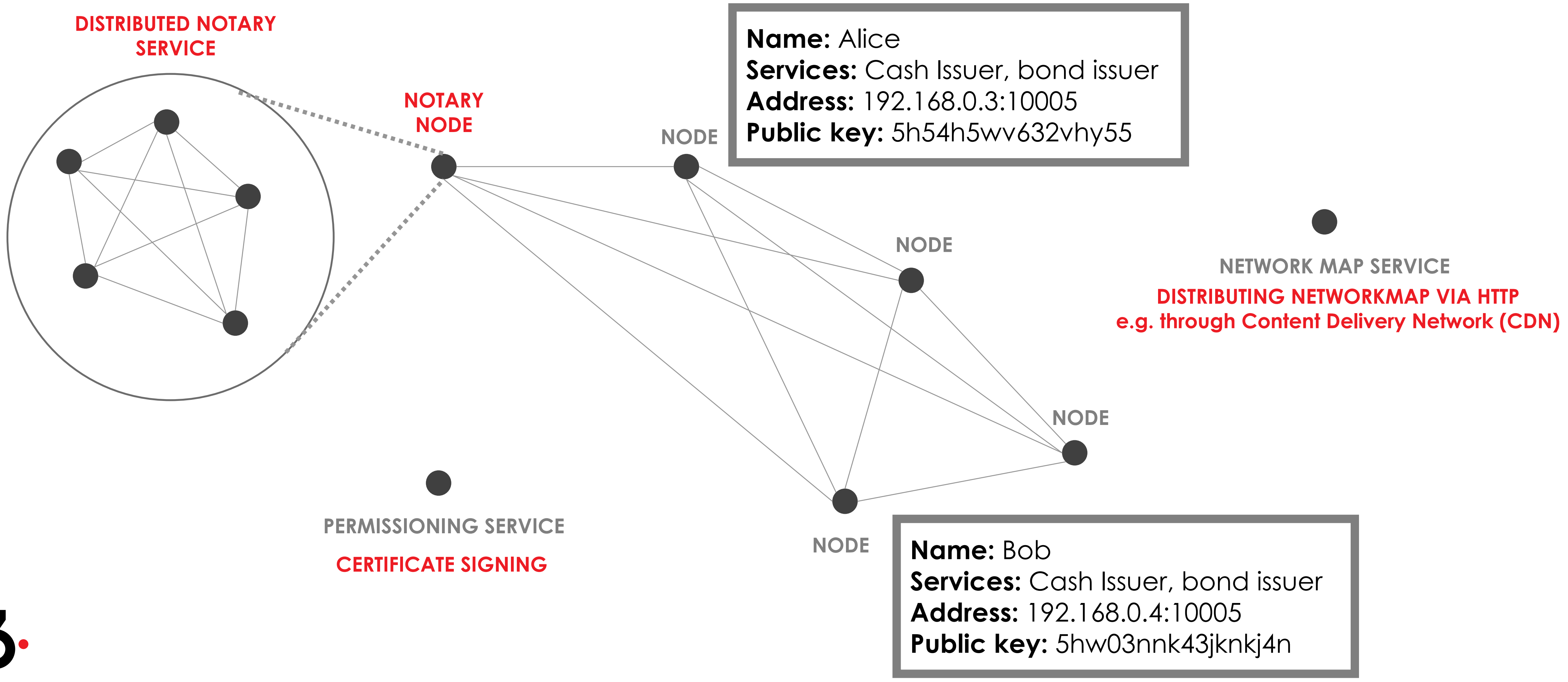


CorDapps are Corda node extentions which comprise the states, contracts and flows required to implement some specific business logic



A Corda Network

A Corda network



A Corda network comprises:

- A doorman
- An external network map service
- Two or more Corda nodes
- Zero or more oracles
- One or more notary services

Summary

Corda Key Concepts

1. The Corda ledger
2. States
3. Transactions
4. Contracts
5. Legal prose
6. Commands
7. Timestamps
8. Attachments
9. Flows
10. Consensus
11. Notary services
12. Oracles
13. The Corda node and CorDapps
14. A Corda network

Learning objectives

1. Understand that Corda has been designed to solve a specific business problem for regulated financial institutions and this is reflected by its architecture
2. Understand how to think "the Corda way"
3. Understand the key concepts which underpin how Corda works