Module 8

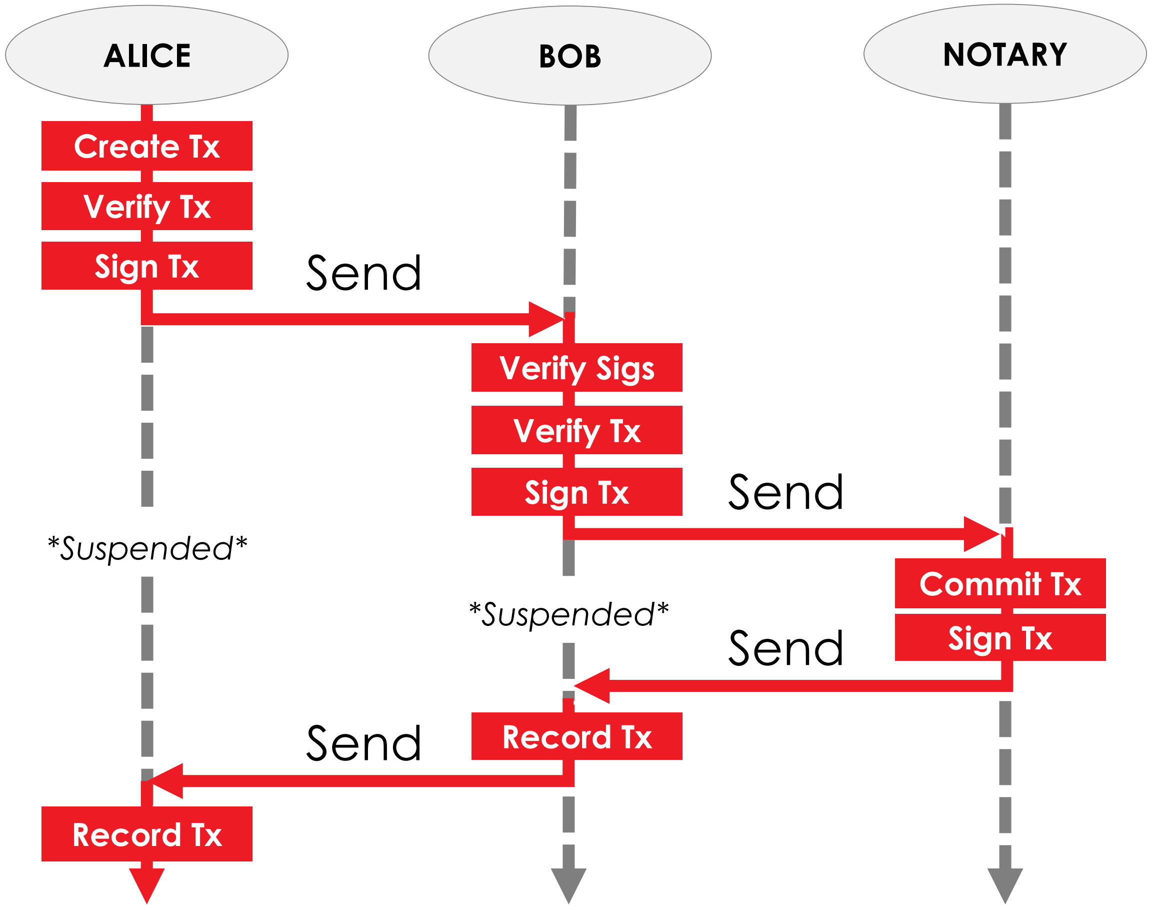
Flows

Learning outcomes

- Learn how flows allow the ledger update process to be automated
- Learn how flows are implemented in code
- Learn how to design your own flow

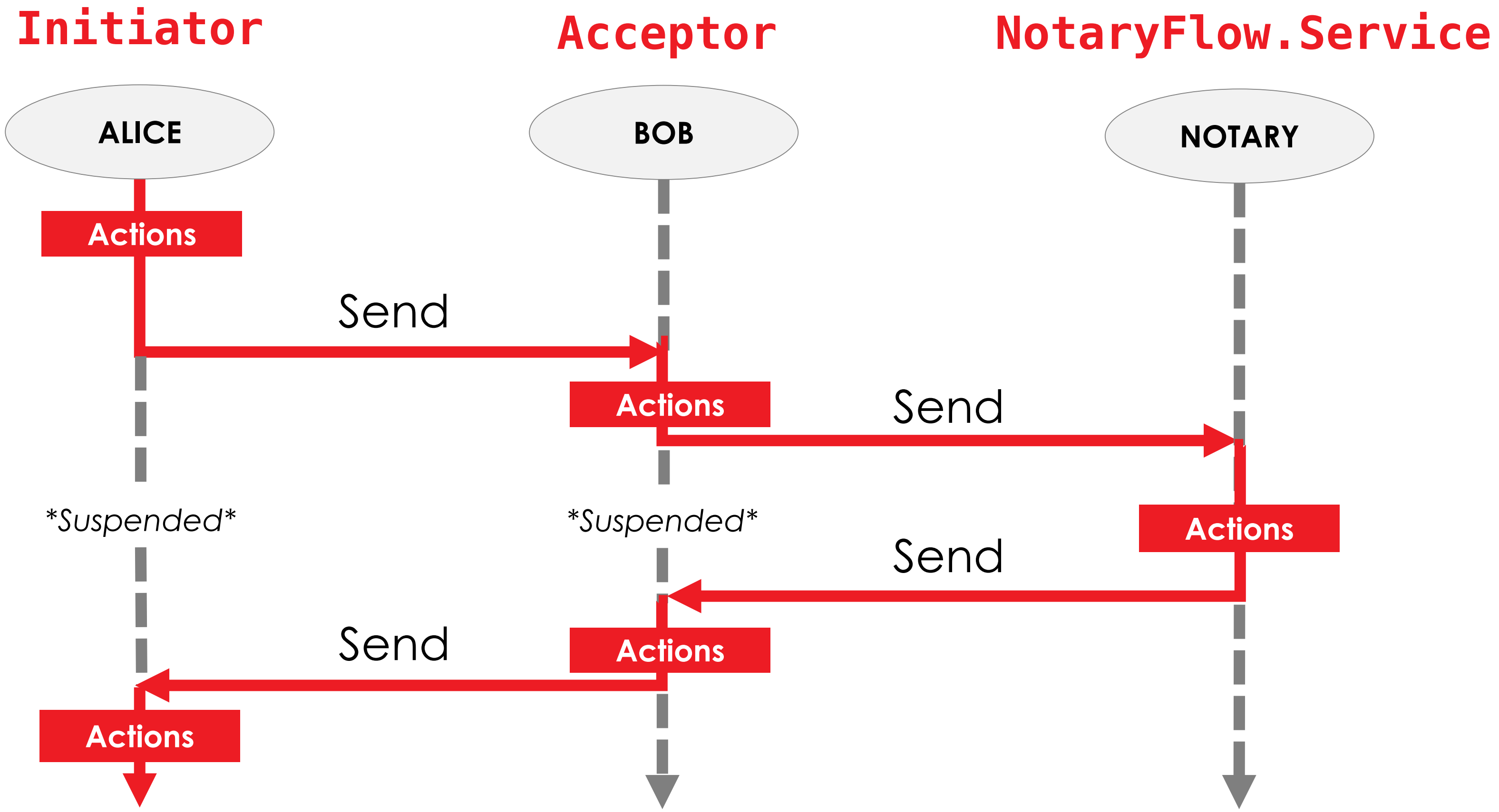
What is a flow?

- Nodes communicate using structured sequences of messages called **flows**
- Flow steps are bilateral
- But any number of nodes can be involved in a single flow…
- …and be informed of the flow's completion and resulting ledger updates



Flow-logics

Each party in a flow runs its own **flow-logic**:



Flow-logics

- Flow-logics are subclasses of the `FlowLogic` class that describe the flow from a single node's point-of-view:

```
abstract class FlowLogic<out T>
```

- A flow-logic's actions are defined by overriding `FlowLogic.call`:

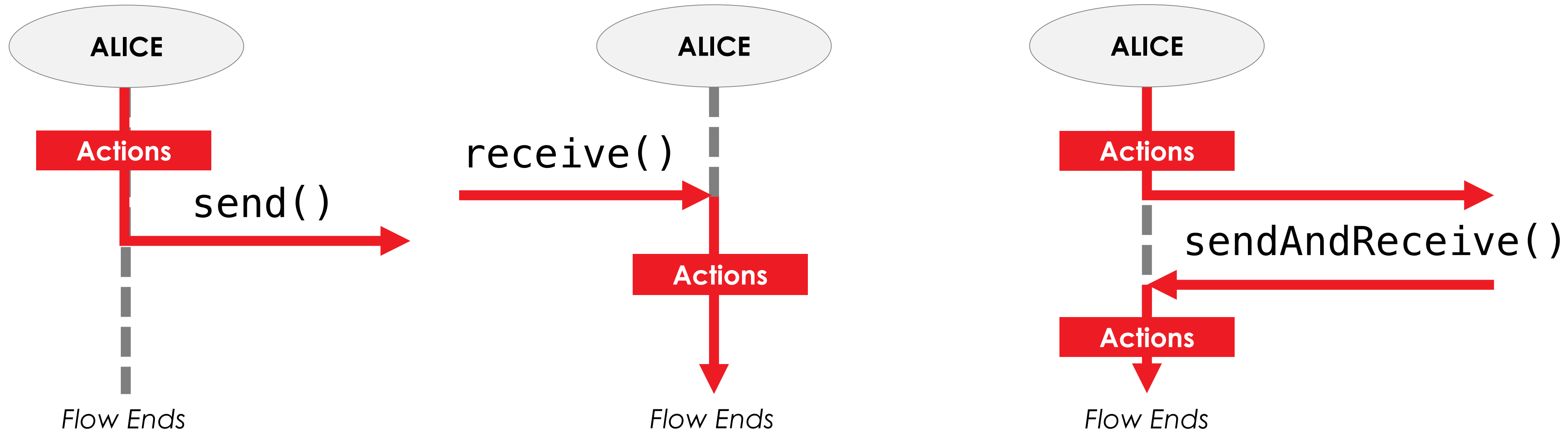
```
@Suspendable
@Throws(FlowException::class)
abstract fun call(): T
```

Services available to flows

- `call` can access the node’s other services via the node’s `ServiceHub`
- The services offered by the `ServiceHub` can be seen by inspecting `net.corda.core.node.ServiceHub`
- Some of the key services are:
  – `vaultService`, providing access to the node’s vault
  – `identityService`, allowing node identities to be looked up
  – `myInfo`, allowing the node to provide info about itself

Inter-party communication

Flow-logics within a flow can communicate in three ways:




```
send(
    otherParty: Party,
    payload: Any)
```

```
receive(
    receiveType: Class<R>,
    otherParty: Party)
```

```
sendAndReceive(
    receiveType: Class<R>,
    otherParty: Party,
    payload: Any)
```

Registering flows

- Flows must be annotated to indicate how they can be used:
- `@InitiatingFlow` – flows that can be started directly
- `@StartableByRPC` – flows that can be started via RPC
- `@InitiatedBy(FlowLogic.class)` – flows that can only be kicked off via messages from other flows

Invoking response flow-logics

- When the counterparty node receives a message from a given flow, it responds by:

1. Looking up the `FlowLogic` class that sent the message
2. If the `FlowLogic` class is registered as part of an `@InitiatedBy` annotation, the node initiates the registered response `FlowLogic`
3. Otherwise, the message is ignored

UntrustworthyData

- You cannot trust data received from other nodes – a counterparty could send you anything

- As a result, data received from other parties is wrapped in an **`UntrustworthyData`** instance:

```
class UntrustworthyData<out T>(
    private val fromUntrustedWorld: T)
```

- The underlying data is accessed using **`unwrap`**:

```
inline fun <R> unwrap(validator: (T) -> R) = validator(data)
```

unwrap()

- **unwrap()** takes a lambda checking the data received from the counterparty

- Example:

```
unwrap { tx ->
    // Check sigs and verify tx
    val wireTx = tx.verifySignatures(myKey, notaryKey)
    wireTx.toLedgerTransaction(serviceHub).verify()
    tx
}
```

Starting a flow

- Each node exposes a set of RPC (remote procedure call) operations to clients

- The **startFlowDynamic** RPC operation starts a flow-logic:

```
@RPCReturnsObservables
fun <T : Any> startFlowDynamic(
    logicType: Class<out FlowLogic<T>>,
    vararg args: Any?)
: FlowHandle<T>
```

- The flow-logic's **call** method is invoked, returning an observable that allows us to observe the flow's result

Flow session

- Interflow communications happen within a flow session
- Once created, flow session can and should be reused for all following communications
- Flow session can be initiated by invoking `initiateFlow(Party)`
- Flow session is injected through a constructor on the receiving side

ProgressTracker

- A flow-logic's progress is charted by overriding `FlowLogic.progressTracker`:

```
open val progressTracker: ProgressTracker? = null
```

- A `ProgressTracker` is constructed with a series of steps corresponding to the steps in the flow

```
class ProgressTracker(vararg steps: Step)
```

- And each `ProgressTracker.Step` is defined using a label:

```
open class Step(open val label: String)
```

- You advance through the progress-tracker steps using:

```
progressTracker.currentStep = myStep
```

ProgressTracker example

- An example `ProgressTracker` definition:

```
companion object {
    object GENERATING_TX : Step("Generating transaction.")
    object VERIFYING_TX  : Step("Verifying contract.”)
    …
    fun tracker() = ProgressTracker(
        GENERATING_TX, VERIFYING_TX, …)
}
override val progressTracker = tracker()
```

- The progress-tracker would then be updated using:

```
// Stage 1 – Generating a Transaction.
progressTracker.currentStep = GENERATING_TX
```

ProgressTracker output

These progress-tracker steps will be shown in the terminal:

```
"It's OK computer, I go to sleep after
twenty minutes of inactivity too!"

--- DEVELOPER SNAPSHOT ------------------------------------------------------------

Logs can be found in                  : /Users/joeldudley/Desktop/cordapp-tutorial/kotlin-source/build/nodes/NodeA/logs
Database connection url is            : jdbc:h2:tcp://10.163.199.132:61491/node
Node listening on address             : localhost:10004
Loaded plugins                        : com.example.plugin.ExamplePlugin
Node started up and registered in 22.42 sec

✅ Generating transaction based on new IOU.
✅ Verifying contract constraints.
✅ Signing transaction with our private key.
✅ Sending proposed transaction to recipient for review.
✅ Done
```

FlowException

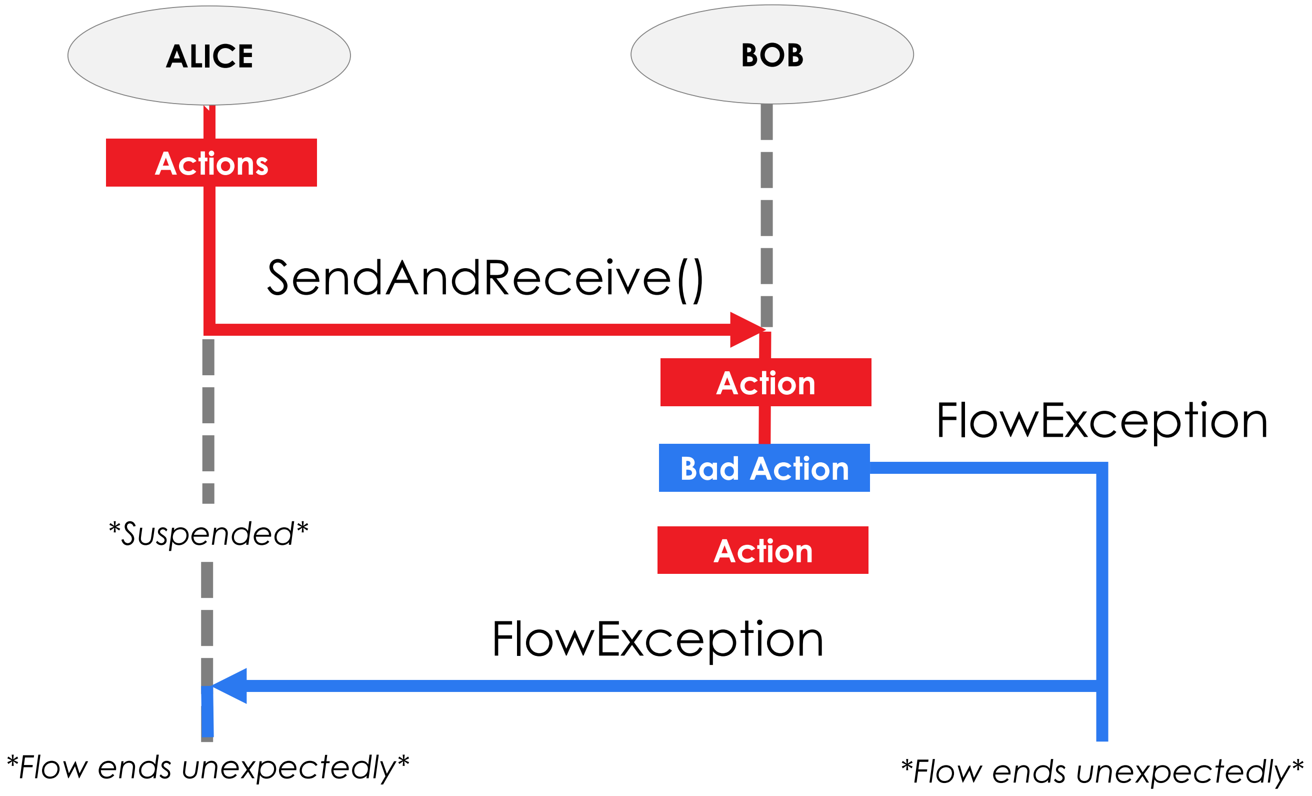
- Flows can throw a special kind of exception called `FlowException`:

```
open class FlowException @JvmOverloads constructor(
        message: String? = null, cause: Throwable? = null)
: Exception(message, cause)
```

- Unlike other exceptions, `FlowExceptions` are propagated to the flow's other active counterparties
- Parties can use `FlowExceptions` to let other parties know that they are not willing to proceed with the flow:
  - Signatures are not valid, or the transaction doesn't verify
  - The parameters of the deal are not as discussed
  - They are reneging on the deal…

FlowException diagram

`FlowExceptions` cause all participants' flows to end without executing any further steps:

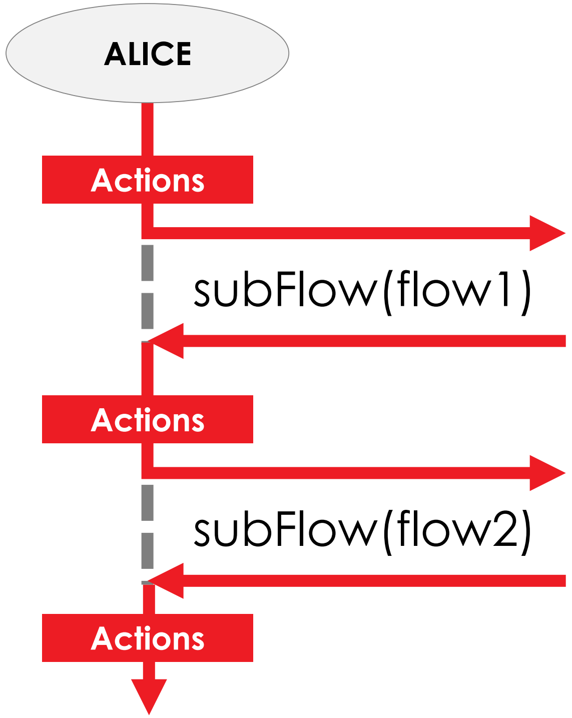


Subflows

- Within `call()`, a node can start additional *sub-flows*:

```
open fun <R> subFlow(
    subLogic: FlowLogic<R>)
: R
```

- Once a sub-flow starts, the parent flow is suspended until the sub-flow returns
- Subflows are used to:
  - Abstract away common flow tasks
  - Allow more than two nodes to communicate within a given flow

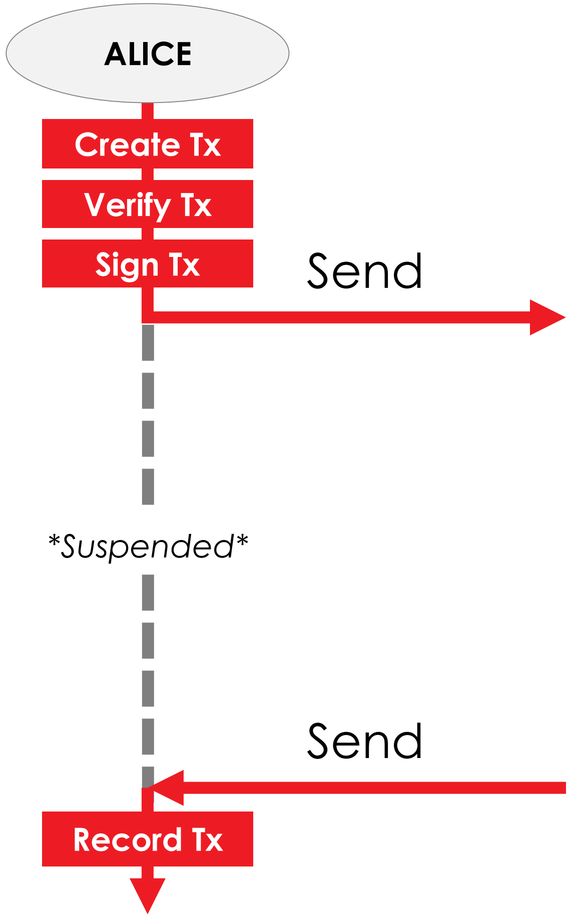


Built-in flows

- There are many useful built-in flows:
  - `FinalityFlow` notarizes and records a transaction
  - `SwapIdentitiesFlow` generates new identities with a party
  - `CollectSignaturesFlow` gathers all signatures on a transaction
  - `ResolveTransactionsFlow` walks the chain of transactions feeding into the current one, checking each for validity
  - `FetchDataFlow` retrieves data from peers
  - `FetchTransactionsFlow` retrieves transactions from peers
  - `NotaryChangeFlow` changes a transaction's notary
  - `TwoPartyDealFlow` a standard flow for creating two-party deals

Suspending flows

- Nodes need the ability to:
  - Handle millions of concurrent flows
  - Handle flows lasting for long periods of time
  - Survive restarts and upgrades
- To achieve this, flow-logics are regularly suspended and written to local storage:
  - When they are created
  - Whenever the network is called
  - While waiting on a counterparty
  - While waiting for human intervention



Writing a suspendable flow

- A flow-logic's **`call`** method is written in the normal blocking style:

```
override fun call(): SignedTransaction {
    // Prepare a transaction...
    flowSession.sendAndReceive(SignedTransaction,
otherParty, partialTx)
    // Handle the response…
}
```

- To allow it to be suspended, **`call`** must be marked with an **`@Suspendable`** annotation

- Any functions that **`call`** invokes must also be marked **`@Suspendable`**

Suspending a flow

- At compile time, `call`'s bytecode is automatically instrumented to be suspendable using the Quasar library[1]
- Once suspended, the flow is serialized using the Kryo framework[2]
- Other networking issues such as session management, message receipts and delivery retries are also abstracted away

[1] docs.paralleluniverse.co/quasar
[2] github.com/EsotericSoftware/kryo

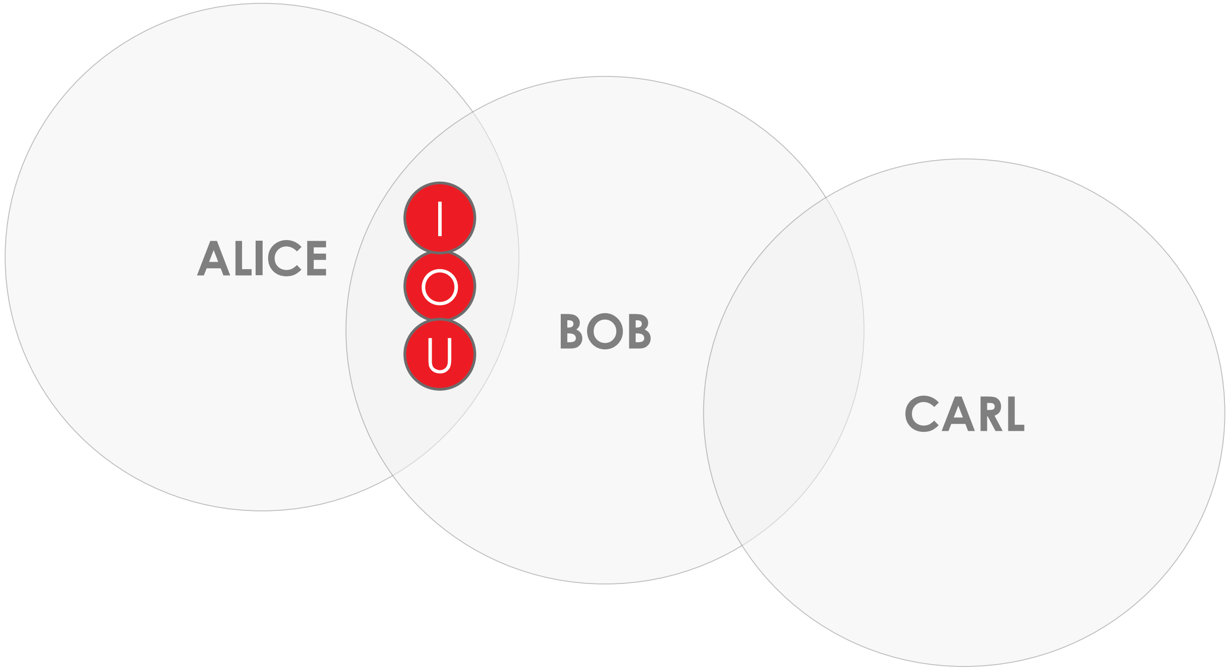
Flows in summary

- Flows allow nodes to communicate and agree on ledger updates
- Each flow is made up of two communicating, but untrusting, flow-logic subclasses
- Subflows are used to handle common tasks or create flows involving three or more parties
- Flows are suspended behind the scenes, allowing nodes to handle millions of concurrent flows

Practical

The Goal of the IOU Flow

- Our flow must allow Alice and Bob to agree the creation of IOUs
- …without Carl knowing about them

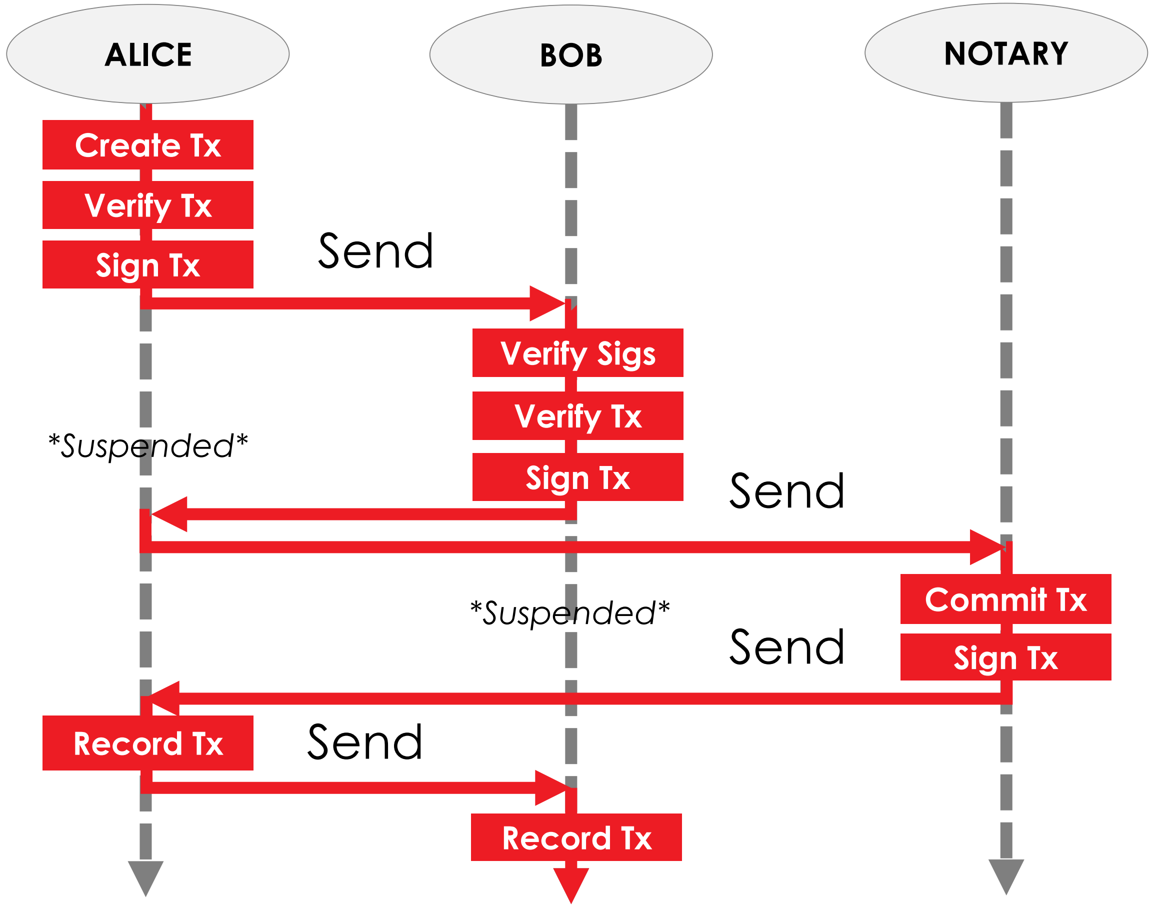


Design Brainstorm

- What steps need to happen in a flow intended to create a new IOU?
- How should they be ordered?
- How should they be spread between participants?
  - Lender
  - Borrower
  - Notary

The IOU Flow

- `IOUIssueFlow`, our IOU creation flow:



Key Considerations

- `IOUIssueFlow` involves three parties:
  - The `Lender`
  - The `Borrower`
  - A notary
- `IOUIssueFlow` proceeds in three stages:
  1. The borrower party builds a new transaction and signs it
  2. The lender receives the partially-signed transaction, signs it, and sends it back to the borrower
     - This is handled by `SignTransactionFlow`
  3. The notary notarises the tx, and the other parties record it
     - This is handled by `FinalityFlow`

Step 1 – Flow Tests

Flow Recap

- Our IOU issue flow is made up of two `FlowLogic` subclasses:
  - `IOUIssueFlow`
  - `IOUIssueFlowResponder`
- A node starts a flow by invoking its `call` method
- Flows are checkpointed at various points during their execution, so `call` must be marked `@Suspendable`

The Flow Testbed

- Corda also provides a testing framework for flows
- The framework allows flows to be quickly tested using a mock network with mock nodes (with no spin-up time):

```
@Before
fun setup() {
    net = MockNetwork()
    val nodes = net.createSomeNodes(2)
    a = nodes.getPartyNodes[0]
    b = nodes.getPartyNodes[1]
    net.runNetwork(-1)
}
```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Simulating Flows

- Flows are asynchronous, so instead of returning a value now, they return a `Future` – a placeholder for their eventual value

- Within a flow test, we obtain the `Future` representing the result of the flow's execution:

```
val flow = ExampleFlow.Initiator(state, b.info.legalIdentity)
val future = a.services.startFlow(flow).resultFuture
```

- We simulate the running of the network:

```
net.runNetwork()
```

- We can then retrieve the output of the flow:

```
future.get()
```

Writing Flow Tests

- We can test that a flow will throw an exception:

```
assertFailsWith<TransactionVerificationException> {
    future.getOrThrow()
}
```

- Or we can retrieve the flow's output and run assertions against it:

```
val signedTx = future.getOrThrow()

assertEquals(signedTx.sigs.size(), 2)
```

Our First Flow Test

- In our design, the `IOUIssueFlow` should return a `SignedTransaction`
- It does so by:
  1. Building a transaction
  2. Signing the transaction to convert it into a `SignedTransaction`
- We will test for this by requiring the party's signature on the `SignedTransaction` returned by `IOUIssueFlow`

VerifySignatures()

- Our test uses `SignedTransaction`'s `verifySignaturesExcept` method:

```
verifySignaturesExcept(vararg CompositeKey allowedToBeMissing)
```

- Be careful with `verifySignaturesExcept`:
  - Its parameter is the list of signatures that it SHOULDN'T verify
  - In our case, that's the signatures of the `Lender` and the `notary`, since we are only gathering a signature from the `Borrower` for now

Running the Flow Tests

- Flows require the Quasar fiber framework
  - This allows them to be suspended and resumed

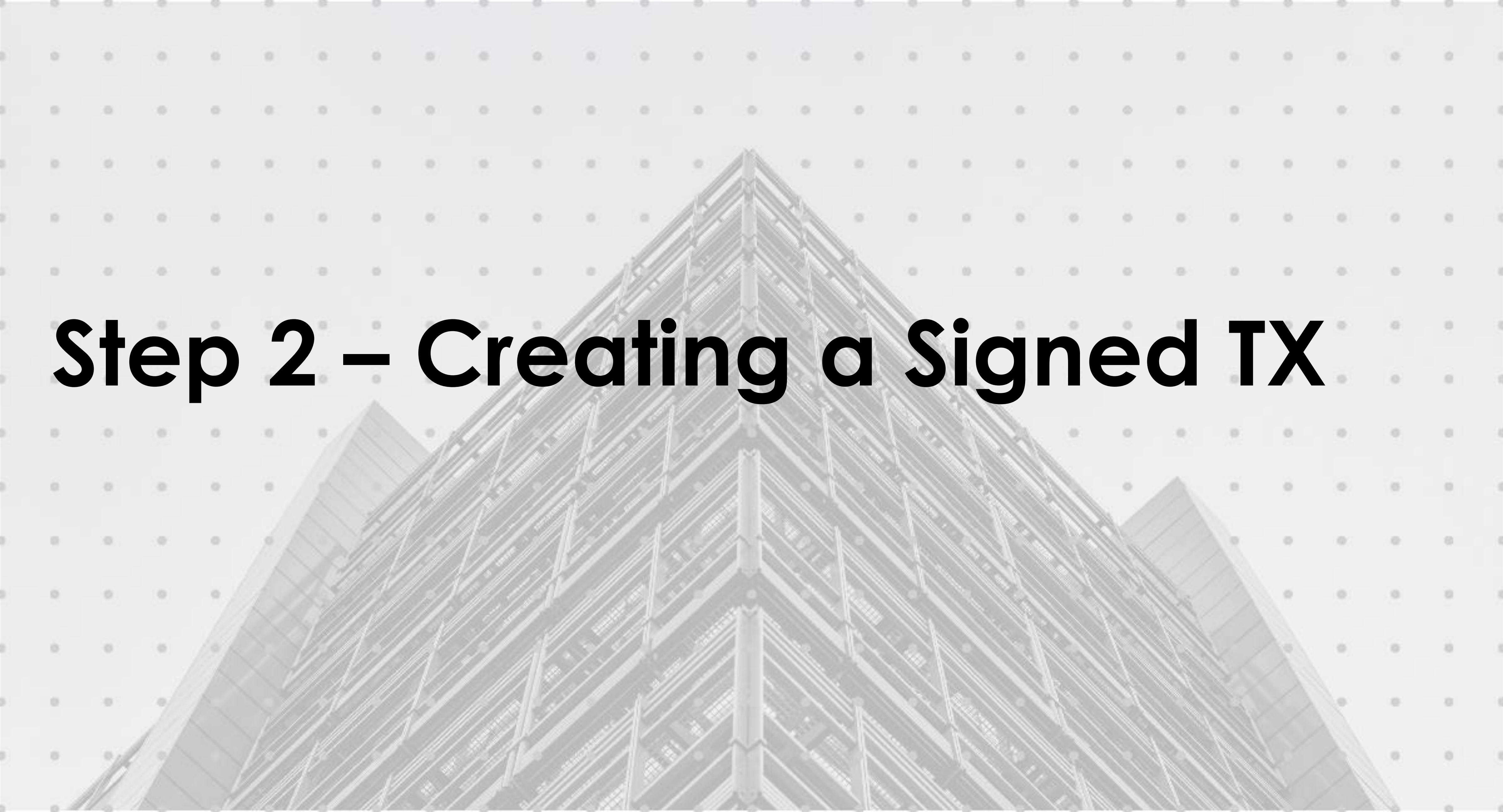
- If you tests do not run due to an "instrumentation error" then add the following VM options to the default JUnit test runConfiguration:

```
-ea -javaagent:./lib/quasar.jar
```

Our First Flow Test - Implementation

Goal	Run the flow test for the borrower's signature
Where?	flows/IOUIssueFlowTests.kt
Steps	1. Uncomment the `flowReturnsCorrectlyFormedPartiallySignedTransaction` test 2. Run the test, using the Green arrow to the left of the test name 3. The test should fail. 4. Use the instructions provided above to write a flow to make the test pass – it WON'T, yet. We've got more work to do.
Key Docs	https://docs.corda.net/flow-testing.html

Step 2 – Creating a Signed TX



Creating a SignedTransaction

- To create a valid `SignedTransaction`, we need to:
  1. Get a reference to a notary
  2. Create a command
  3. Create a `TransactionBuilder`
  4. Add the `Issue` command and `IOUState`
  5. Convert the `TransactionBuilder` into a `SignedTransaction` by signing the builder

Choosing a Notary

- Let's start by choosing a notary
- Within `call`, you can use the `ServiceHub` to access the node's services, include the network map
- To retrieve a notary, we use:

```
serviceHub
    .networkMapCache
    .notaryIdentities.first()
```

Choosing a Notary - Implementation

Goal	Retrieve the notary for the transaction
Where?	IOUIssueFlow.kt
Steps	1. Write the code to obtain a reference to the notary who will notarize the transaction
Key Docs	N/A

Choosing a Notary - Solution

Goal	Retrieve the notary's identity in `call`
Steps	• Get a reference to the `ServiceHub` object • Retrieve the list of notaries • Extract the first (and only) notary from the list • Retrieve its identity
Code	`val notary = serviceHub .networkMapCache .notaryIdentities.first()`

```
val notary =
    serviceHub
    .networkMapCache
    .notaryIdentities.first()
```

Creating a Command

- Next, we need to create our transaction's **`Command`**
- **`Command`**s associate **`CommandData`** with a set of signers:

```
Command(
    cd: CommandData,
    requiredSigners: List<CompositeKey>
);
```

- We are going to use the **`Issue ComandData`** class we defined earlier
- The lender and the borrower will be the signers

Creating a Command - Implementation

Goal	Instantiate a `Issue` command
Where?	IOUIssueFlow.kt
Steps	1. Write the code to instantiate a `Issue` command
Key Docs	N/A

Creating a Command - Solution

Goal	Create a `Issue` command instance in `call`
Steps	• Construct the `Command` object using: • The `IOUContract.Issue` `CommandData` subclass • The list of the `IOUState`'s `participants`

Code	`val issueCommand = Command(`
	`IOUContract.Commands.Issue(),`
	`state.participants.map { it.owningKey });`

Building the Transaction

- We create the transaction itself using the `TransactionBuilder` class
- `TransactionBuilder` is initialised with the following syntax:

```
TransactionBuilder(notary = notary)
```

- We add items to the `TransactionBuilder` using `withItems`, which takes a variable-length list of:
  - `StateAndRefs` (input state references)
  - `ContractStates` (output states)
  - `Commands`

Building a Transaction - Implementation

Goal	Construct the transaction
Where?	IOUIssueFlow.kt
Steps	1. Write the code to create a `TransactionBuilder` with: • The selected notary • The `Issue` command • The IOU state
Key Docs	N/A

Building the Transaction - Solution

Goal	Create a **TransactionBuilder** with the **IOUState** and **Issue** command

Steps	• Create a new **TransactionBuilder** using the notary's identity
	• Add two items to the transaction:
	    • The **TransactionState** with **IOUState** and a reference to **IOUContract**
	    • The **Issue** command

Code	`val builder = TransactionBuilder(notary = notary)` `builder.withItems(state, issueCommand)`

Signing a Transaction

- We now need to convert the `TransactionBuilder` into a `SignedTransaction`:
  - TransactionBuilder is a mutable transaction-in-construction
  - SignedTransaction is immutable because it has been signed

- You sign the builder using the ServiceHub, which has access to the node's keypair:

```
val signedTx = serviceHub.signInitialTransaction(builder)
```

Flow Return Types

- Each flow-logic returns a value of a specific type from its `call` method
- To change a flow-logic's return type, you must:
  - Change the generic type of the FlowLogic it inherits from
  - Annotate `call` with the desired return type
- In our case, we need to modify our flow-logic to return a `SignedTransaction`

Signing a Transaction - Implementation

Goal	Return the transaction signed by the `Initiator`
Where?	IOUIssueFlow.kt
Steps	1. Write the code to create and return a `SignedTransaction` 2. Run the `flowReturnsCorrectlyFormedPartiallySignedTransaction` test 3. The test should finally pass!
Key Docs	N/A

Signing a Transaction - Solution

Goal	Sign the in-construction transaction to generate a `SignedTransaction`
Steps	• Sign the `TransactionBuilder` to convert it into a `SignedTransaction`
Code	`val ptx = serviceHub.signInitialTransaction(builder)`

Step 3 – Verifying the TX

Verifying a Transaction

- Before sending the transaction to the counterparty, the `Initiator` also needs to verify it
- We want to verify our transaction **BEFORE** signing it, to ensure that we're not signing an invalid transaction
- We verify the `TransactionBuilder` by invoking its `verify` function
- `verify` will invoke the contract logic of every input and output, without checking required signatures

Verifying a Transaction - Implementation

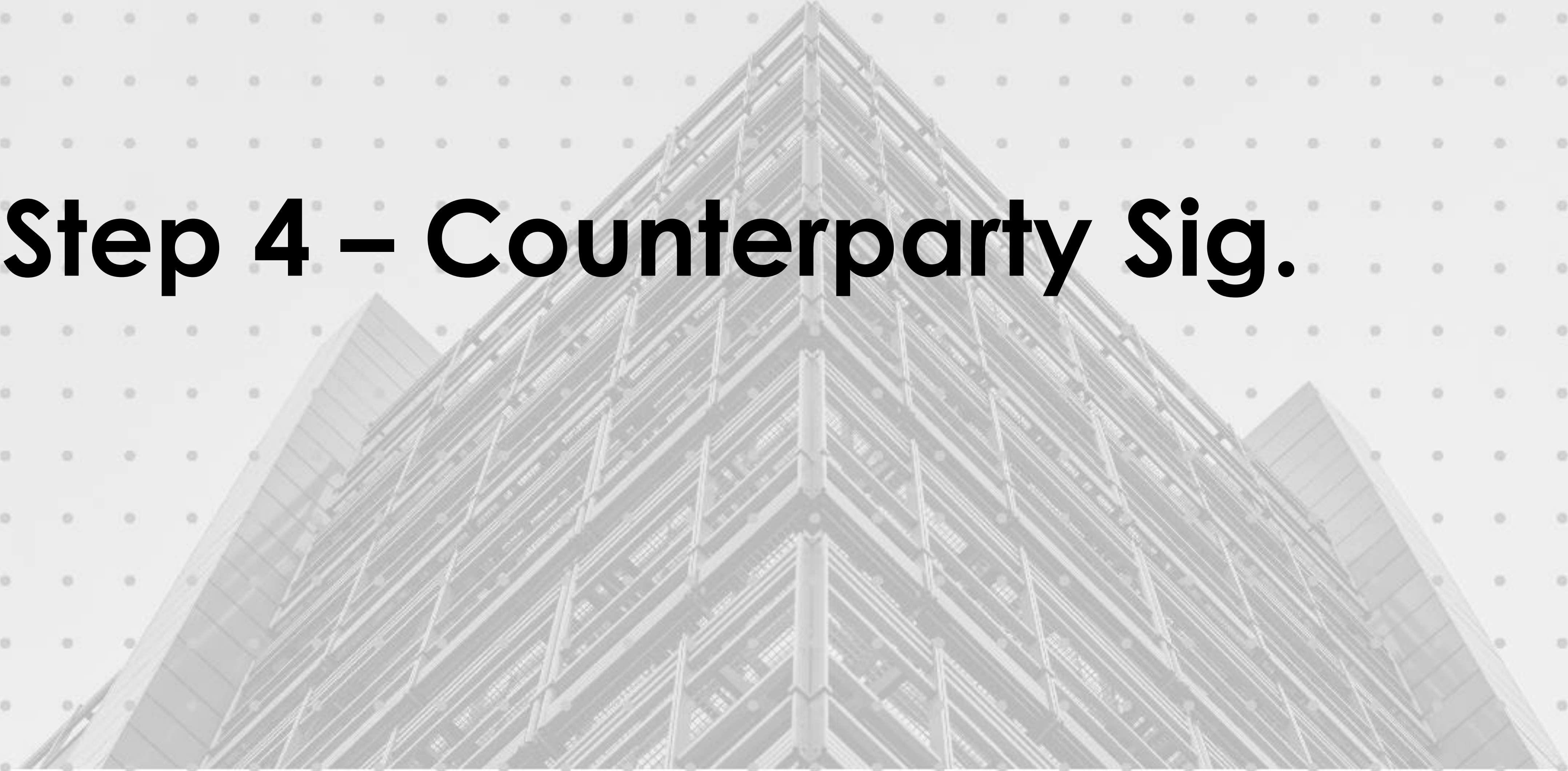
Goal	Make the `Initiator` verify the transaction
Where?	flow/IOUIssueFlow.kt, **after** creating the `TransactionBuilder`, but **before** signing it test/flows/IOUIssueFlowTests.kt
Steps	1. Add the transaction verification code to the `IOUIssueFlow.call` method
Key Docs	N/A

Verifying a Transaction - Solution

Goal	Verify the `SignedTransaction`
Steps	• Call the `TransactionBuilder`'s `verify` method
Code	see below

```
override fun call(): SignedTransaction {
    …
    builder.verify()
    …
}
```

Step 4 – Counterparty Sig.



Flow Communication

- IOU creation also requires communication with the other party in the flow
- We can use the pre-built `SignTransactionFlow` to collect the signatures from the required counterparties for us
- It takes a `SignedTransaction` (already signed by the calling node) as a parameter and returns a `SignedTransaction` with all the collected counterparty signatures
- This flow allows you to ignore the details of the back-and-forth communication required to collect all the signatures, thus simplifying your flow

SignTransactionFlow

- `SignTransactionFlow(stx: SignedTransaction)` does two things:
  - Verifies the transaction and our signature
  - Collects, adds and verifies all the signatures from required counterparties
    - An exception is thrown if any signatures are missing or invalid
- `SignTransactionFlow` is invoked using `subFlow(fl: FlowLogic)`

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SignTransactionFlow- Implementation

Goal	Send the `SignedTransaction` from the `Initiator` to the `Acceptor` and back
Where?	flow/IOUIssueFlow.kt test/flows/IOUIssueFlowTests.kt
Steps	1. Uncomment the `flowReturnsTransactionSignedByBothParties` test 2. Test should fail 3. Modify IOUIssueFlow.kt to make the test pass
Key Docs	N/A

SignTransactionFlow- Solution

Goal	Send the `SignedTransaction` to the other `Party` for signing
Steps	1. Review the `SignTransactionFlow` 2. Use the the `SignTransactionFlow`, which takes a `SignedTransation` as a parameter and returns a `SignedTransction`
Code	`val stx = subFlow(CollectSignaturesFlow(ptx))`

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Step 5 – Finalizing the TX

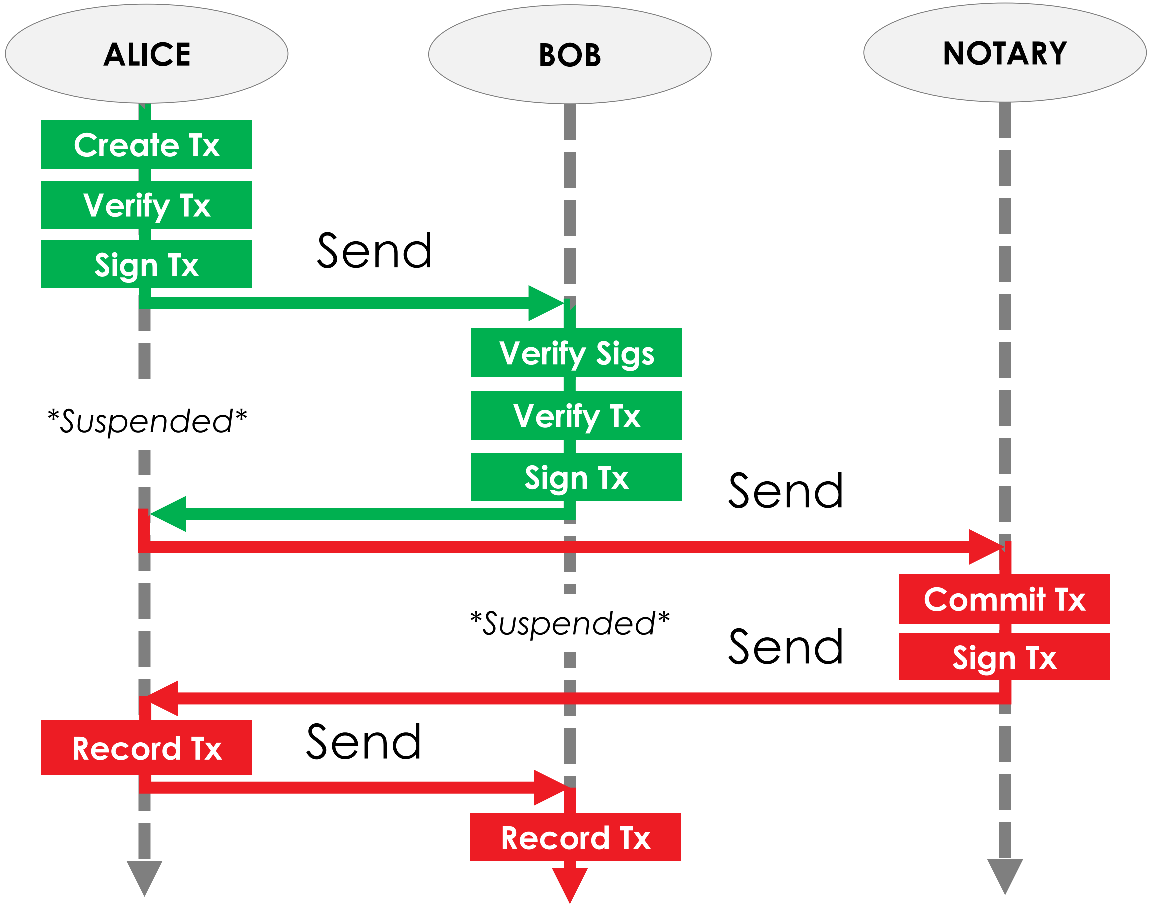
Transaction Finalization Test

- The valid, signed IOU transaction now needs to be notarized and recorded in every participant's vault
- We will test this by ensuring that the state returned by the Initiator's flow matches the state recorded in both nodes' vaults
- We can access the transactions in a node's vault using the following syntax:

```
nodeName
    .services
    .validatedTransactions
    .getTransaction(id: SecureHash)
```

Transaction Finalization

- The finalization process involves another 7 steps!



FinalityFlow

- Fortunately, we can use Corda's built-in `FinalityFlow` here to finalize the transactions
- `FinalityFlow(stx: SignedTransaction, participants: Set<Party>)` does two things:
  - It notarizes a transaction
  - It records the transaction in every participant's vault
- `FinalityFlow` is invoked from the `Acceptor`'s `FlowLogic` using `subFlow(fl: FlowLogic)`

Finalizing a Transaction - Implementation

Goal	Notarize and record the transaction in every participant's vault
Where?	flow/IOUIssueFlow.kt test/flows/IOUIssueFlowTests.kt
Steps	1. Uncomment the following tests: `flowRecordsTheSameTransactionInBothPartyVaults` 2. The tests should fail 3. Modify IOUIssueFlow.kt to make the tests pass
Key Docs	N/A

Finalizing a Transaction - Solution

Goal	Notarize the transaction and record it in the participants' vaults
Steps	• Invoke the FinalityFlow • Return the resulting fully-signed SignedTransaction

Code	`val ftx = subFlow(FinalityFlow(stx))`
	
	`return ftx`

Over to you!

There are two more flows to complete!

Follow the instructions in
`IOUTransferFlow` and `IOUSettleFlow`

Checkpoint – Progress So Far

Our progress so far

- We now have a flow allowing parties to issue and agree on new IOUs
- But we have no way of interacting with our nodes to get them to run these flows
- We will solve this by adding a REST API to our nodes
- But first, we're going to examine how we deploy and run the nodes that will be executing our CorDapp