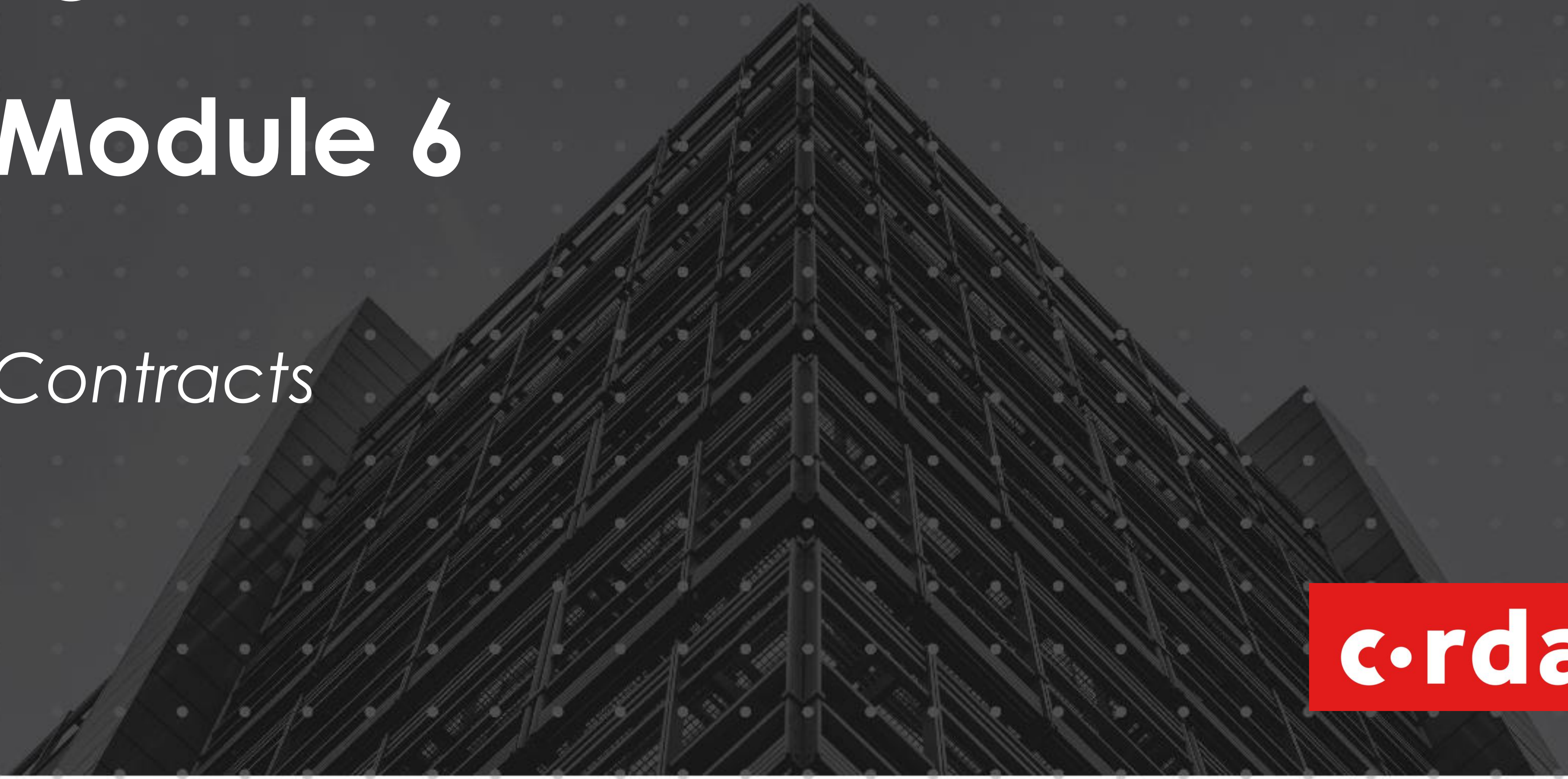
Module 6

Contracts

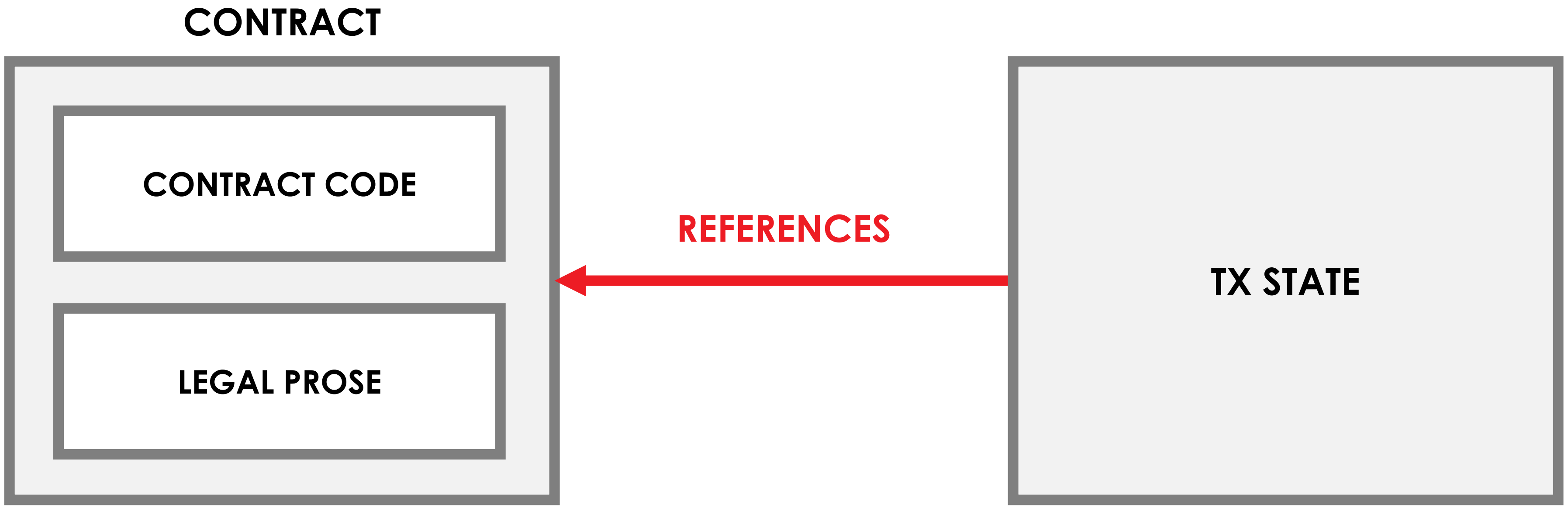


Learning outcomes

- Learn how contracts control the evolution of states
- Learn how a transaction's states are grouped for verification
- Learn the purpose of commands
- Learn how to design your own contract

Contracts

A contract is an object **referenced by a transaction state** that contains **legal prose** and **contract code** governing the state's evolution.



Contracts

All contracts must implement the `Contract` interface:

```
interface Contract {
    @Throws(IllegalArgumentException::class)
    fun verify(tx: LedgerTransaction)
}
```

Contracts

Contracts might optionally be annotated with `@LegalProseReference` annotation for a legal prose reference

The verify() method

The `verify()` method takes a `LedgerTransaction` as input and returns either:

- An exception if the supplied transaction is invalid according to the contract's rules
- `Unit` if the supplied transaction is valid

IMPORTANT: In verifying a transaction, the `verify()` method **ONLY HAS ACCESS** to the contents of `LedgerTransaction`.

LedgerTransaction

- `LedgerTransaction` has all the transaction's contents available for verification:

```
val inputs: List<StateAndRef>
val outputs: List<TransactionState<ContractState>>
val attachments: List<Attachment>
val commands: List<AuthenticatedObject<CommandData>>
val id: SecureHash
val notary: Party?
val signers: List<PublicKey>
val timeWindow: TimeWindow? = null
val type: TransactionType
val privacySalt: PrivacySalt
```

- It also has methods to easily extract these transaction elements

The simplest contract

The simplest possible contract would be defined as follows:

```
class SimplestContract: Contract {
    companion object {
       @JvmStatic
       val CONTRACT_ID = “com.example.Contract”
    }
    override fun verify(tx: LedgerTransaction) {
        // No constraints, so accepts anything.
    }

}
```

An example: Writing a verify function

- Let’s write a verify function for the following state:

```kotlin
data class NumberState(
    val number: Int,
    val alice: Party,
    val bob: Party,
    override val linearId: UniqueIdentifier =
UniqueIdentifier()
) : LinearState {
    override val participants
        get() = listOf(alice, bob)
}
```

The NumberContract

Our `NumberContract` will allow:

- The creation of new, positive-value `NumberStates`
- Adding non-negative amounts to existing `NumberStates`

These two possibilities correspond to two commands:

- Create
- Add

The NumberContract’s commands

```
class NumberContract: Contract {
    // contract id was omitted...

    interface Commands : CommandData {
        class Create : TypeOnlyCommandData(), Commands
        class Add : TypeOnlyCommandData(), Commands
    }

    override fun verify(tx: LedgerTransaction) {
        // verify() on next page...
    }
}
```

The NumberContract's verify function

```
fun verify(tx: LedgerTransaction) {

    val command = tx.findCommand<NumberContract.Commands> { true }

    when (command.value) {
        is Commands.Create -> { /* Create verification logic. */ }
        is Commands.Add -> { /* Add verification logic. */ }
        else ->
            throw IllegalArgumentException("Unknown command $command")
    }
}
```

verify code for Create command

```
is Commands.Create -> {
    requireThat {
        ”There are no inputs" using (tx.inputs.isEmpty())
        ”There is only one output" using (tx.outputs.size == 1)

        val out = tx.outputsOfType<NumberState>().single()
        ”Number must be positive" using (out.number > 0)
        ”The participants are distinct" using (out.alice != out.bob)

        val participantKeys = out.participants.map { it.owningKey }
        "All participants must be signers" using
                (command.signers.containsAll(participantKeys))
    }
}
```

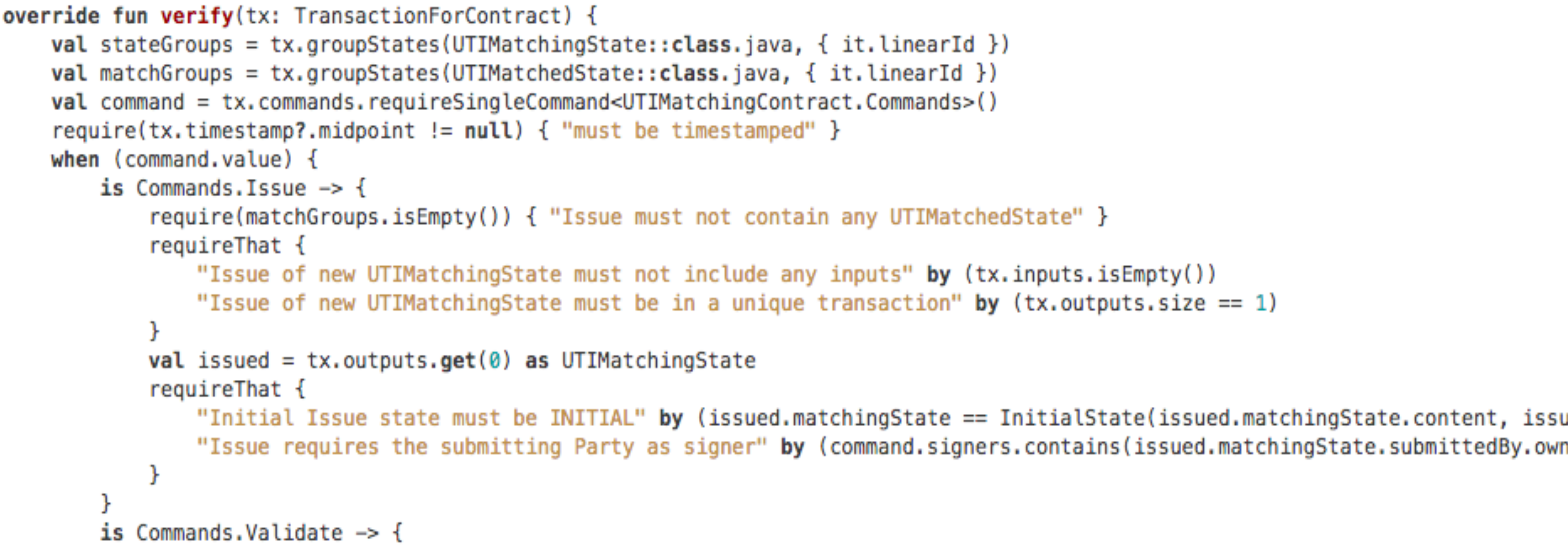
verify code for Add command

```
is Commands.Add -> {
    requireThat {
        ”There is only one input" using (tx.inputs.size == 1)
        ”There is only one output" using (tx.outputs.size == 1)

        val input = tx.inputsOfType<NumberState>().single()
        val out = tx.outputsOfType<NumberState>().single()
        ”Amount added is >0" using (input.number < out.number)
        ”The participants are distinct" using (out.alice != out.bob)

        val participantKeys = out.participants.map { it.owningKey }
        "All participants must be signers" using
                (command.signers.containsAll(participantKeys))
    }
}
```

verify() can be complex!



```
override fun verify(tx: TransactionForContract) {
    val stateGroups = tx.groupStates(UTIMatchingState::class.java, { it.linearId })
    val matchGroups = tx.groupStates(UTIMatchedState::class.java, { it.linearId })
    val command = tx.commands.requireSingleCommand<UTIMatchingContract.Commands>()
    require(tx.timestamp?.midpoint != null) { "must be timestamped" }
    when (command.value) {
        is Commands.Issue -> {
            require(matchGroups.isEmpty()) { "Issue must not contain any UTIMatchedState" }
            requireThat {
                "Issue of new UTIMatchingState must not include any inputs" by (tx.inputs.isEmpty())
                "Issue of new UTIMatchingState must be in a unique transaction" by (tx.outputs.size == 1)
            }
            val issued = tx.outputs.get(0) as UTIMatchingState
            requireThat {
                "Initial Issue state must be INITIAL" by (issued.matchingState == InitialState(issued.matchingState.content, issu
                "Issue requires the submitting Party as signer" by (command.signers.contains(issued.matchingState.submittedBy.own
            }
        }
        is Commands.Validate -> {
```

Contracts in summary

- Contracts decide which transactions are valid, and therefore control the evolution of states over time
- For verification, you only have access to the contents of `LedgerTransactionForContract`
- Commands provide additional information and are often used to fork the execution of `verify()`
- The `verify()` function can be quite complex

Practical

IOUContract

- In the `IOUContract.kt` template:
  - `legalContractReference` holds a hash of a dummy string
  - `verify` has an empty body
- Currently, the contract accepts every transaction (i.e. `verify` never throws an exception)
- We are now going to add constraints to control the evolution of `IOUState`s

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Step 1 – Contract Tests

Testing Contracts

- We test contract behavior using `LedgerDSL`
- `LedgerDSL` allows you to:
  - Create mock transactions
  - Test whether these are valid based on contract rules
- `LedgerDSL` also provides:
  - Dummy parties (`MINI_CORP`, `MEGA_CORP`…)
  - Dummy keys (`MINI_CORP_PUBKEY`…)

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LedgerDSL Syntax

- Corda's **NodeTestUtils** provide a **ledger** function, which takes a **LedgerDSL** lambda as an argument

- **LedgerDSL** exposes a **transaction** function, which takes a **TransactionDSL** lambda as an argument:

```
// Define your states, etc. here first.
ledger {
    transaction {
        // TODO: Test our transaction
    }
}
```

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TransactionDSL Syntax

- `TransactionDSL` is a mock transaction to which we can add inputs, outputs and commands:

```
…
transaction {
    input(INPUT_STATE) // An input state.
    output(OUTPUT_STATE) // An output state.
    command(KEYS, COMMAND) // A transaction command.
});
…
```

- We can then assert whether the contract is valid or not (with a specific message):

```
…
transaction {
    input(INPUT_STATE) // An input state.
    output(OUTPUT_STATE) // An output state.
    command(KEYS, COMMAND) // A transaction command.
    failsWith(FAILURE_MSG) // Assert transaction failure.
    verifies() // Assert transaction success.
}
…
```

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Step 2 – The Create Command

Command Recap

- Remember that commands play two roles in a transaction:
  - Parameterizing the running of a `Contract`'s `verify` function
    - *e.g. executing different constraints for issuances vs. transfers*
  - Attaching signatures to transactions
- We will define a `Issue` command that is only used to attach signatures to IOU transactions
- We will require this command in every transaction involving an `IOUState`

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Adding the Command

- We will define the **Issue** command inside the **Commands** interface which has been provided inside **IOUContract**:

```
class Create : TypeOnlyCommandData(), Commands
```

- We also need to require the **Issue** command in the **verify** function:
  - Within **verify**, we access a transaction's commands using **tx.commands**
  - We retrieve the command's type using **Command.value**

- Refer to the unit test instructions for more details

The Command Test - Implementation

Goal	Require the Issue command in valid transactions
Where?	test/contract/IOUIssueTests.kt Contract/IOUContract.kt
Steps	1. Uncomment the `mustIncludeIssueCommand` test 2. Run the test using the "`Kotlin – IOU Transaction Tests`" run config 3. Modify IOUContract.kt to make the tests pass
Key Docs	N/A

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Adding the Constraint - Solution

Goal	Impose a constraint on the command type in `IOUContract.verify`
Steps	• Check that there is only one command • Check that it is of type `IOUContract.Commands`

Code	`val command =`
	`    tx.commands.requireSingleCommand<IOUContract.Commands>()`

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Step 3 – Further Constraints

Constraint Types

There are three broad types of constraints:

- Constraints on the attributes of the shared facts
  – e.g. no cash states over USD10,000, max 100 items per order…

- Constraints on the types of transactions that are valid
  – e.g. transaction inputs value == transaction outputs value…

- Constraints on the signers of a transaction
  – e.g. a purchase order must be signed by the buyer…

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Design Brainstorm

- What additional constraints should we impose on our IOUs to achieve the desired behaviour?

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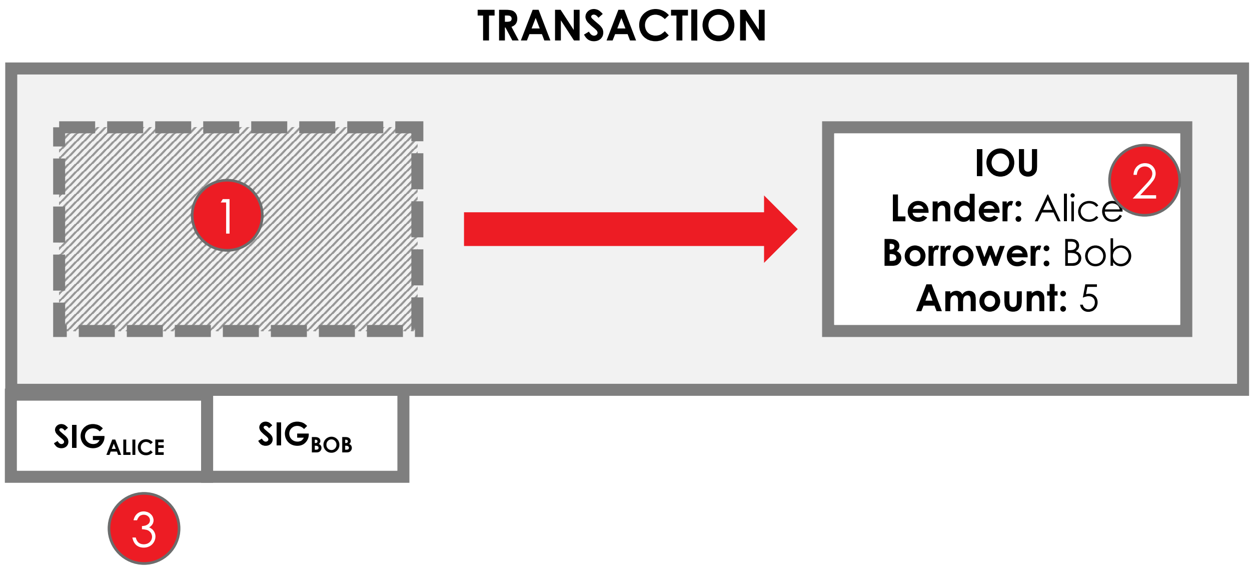
IOU Creation Behavior

- Transactions creating `IOUState`s should behave as follows:
  1. No inputs
  2. One output
  3. Signatures from both parties

- `IOUContract` must embody these constraints



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IOU Creation Constraints

- We can enforce this behaviour with the following using:
  - `mustIncludeIssueCommand`
  - `valueMustBePositive`
  - `transactionMustHaveNoInputs`

    i.e. IOUs can be transferred
  - `transactionMustHaveOneOutput`

    i.e. only one IOU per transaction
  - `senderMustSignTransaction`
  - `recipientMustSignTransaction`

    i.e. both parties must agree to the transaction

Step 3 – Tx-Level Constraints

Transaction-Level Tests

- We need two transaction-level constraints:
  - `issueTransactionMustHaveNoInputs`
  - `issueTransactionMustHaveOneOutput`

- A note on `issueTransactionMustHaveOneOutput`:
  - A mistake would be to test this transaction by passing in no outputs and no inputs
  - With no outputs (and no inputs), there are no states, and thus no contract code to execute, so the transaction can't fail!
  - Instead, we'll test the transaction by giving it two outputs

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Transaction-Level Constraints - Implementation

Goal	Implement the constraints that transactions must have a single output and no inputs
Where?	contract/IOUContract.kt, inside the `verify` method test/transactions/IOUIssueTests.kt
Steps	1. Uncomment the following tests: • `issueTransactionMustHaveNoInputs` • `issueTransactionMustHaveOneOutput` 2. Run the test 3. Modify IOUContract.kt to make the tests pass
Key Docs	N/A

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Transaction-Level Constraints - Solution

Goal	Constrain the number of inputs (0) and outputs (1) in `IOUContract.verify`
Steps	- Test the sizes of the input and output arrays - Make sure the contract error messages match those in the tests

Code	`"No inputs should be consumed when issuing an IOU."`
	`    using tx.inputs.isEmpty()`
	
	`"Only one output state should be created when issuing an IOU.”`
	`    using (tx.outputs.size == 1)`

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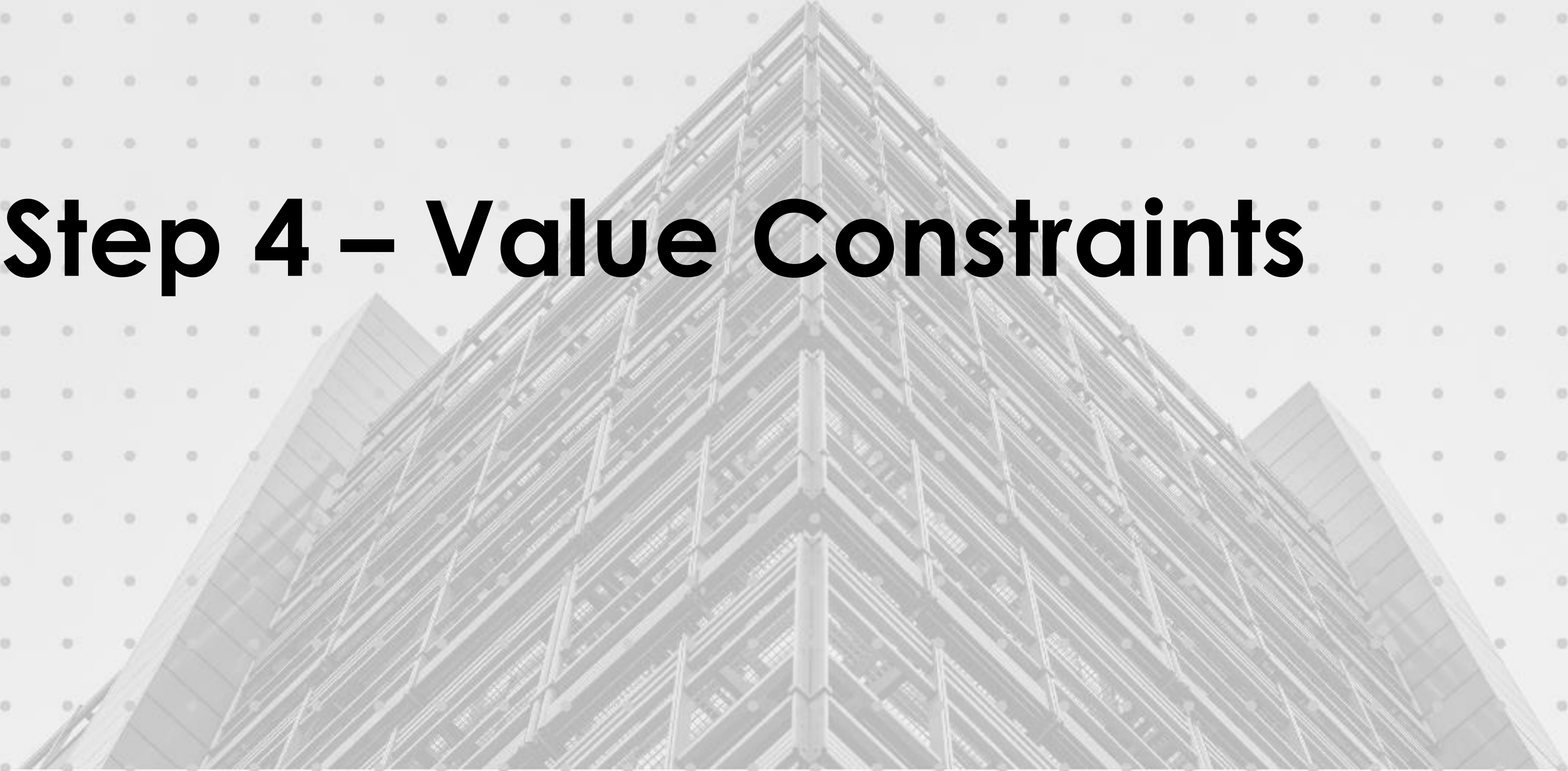
Step 4 – Value Constraints



IOU Value Constraint

- We are now going to update our contract code to prevent the creation of negative-valued IOUs

- Constraints are written using the `Requirements` DSL:

```
override fun verify(tx : LedgerTransaction) {
    requireThat {
        FAILURE_MSG using BOOLEAN_TEST
        FAILURE_MSG using BOOLEAN_TEST
    }
}
```

- The transaction's inputs and outputs are available as `ContractState` arrays via `tx.inputs` and `tx.outputs`

- The `ContractState` array must then be cast to the actual input/output state type(s)

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IOU Value Constraint - Implementation

Goal	Impose an "IOU value must be non-negative" constraint
Where?	IOUContract.kt, inside the `verify` function
Steps	• Uncomment the `cannotCreateZeroValueIOUs` test • Run the test • Modify IOUContract.kt to make the test pass: • Use the syntax on the previous page to create a `requireThat` block • Retrieve the output `ContractState` from the transaction • Cast the output to an `IOUState` • Write a constraint that this output cannot be negatively-valued
Key Docs	N/A

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IOU Value Constraint - Solution

<table>
<tr><td><b>Goal</b></td><td>Impose “IOU value must be non-negative” constraint in <code>IOUContract.verify</code></td></tr>
<tr><td><b>Steps</b></td><td>• Extract the output <code>ContractState</code> and cast it to <code>IOUState</code>
• Obtain the <code>IOUState</code>’s value using <code>IOUState.amount</code>
• Write a failure message matching the message in the test</td></tr>
<tr><td><b>Code</b></td><td><pre>
override fun verify(tx: TransactionForContract) {
    …
    requireThat {
        val iou = tx.outputstates.first() as IOUState
        "A newly issued IOU must have a positive amount." using
            (iou.amount > Amount(0, iou.amount.token))
    }
}
</pre></td></tr>
</table>

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Step 5 – Signer Constraints

Signer Tests

- The final constraint is to check for the correct public keys in the transaction:
  - `lenderAndBorrowerMustSignIssueTransaction`
- We don't add public keys to transactions directly – we attach them to commands instead

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Signer Constraints - Implementation

Goal	Implement the constraints requiring the participants to sign the transaction
Where?	• test/contract/IOUIssueTests.kt • contract/IOUContract.kt
Steps	1. Uncomment and run the following test: • `lenderAndBorrowerMustSignIssueTransaction` 2. The tests should fail 3. Modify IOUContract.kt to make the tests pass: • Use the `Command.signers` method • Access a transaction's participants using `tx.participants`
Key Docs	N/A

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Signer Constraints - Solution

Goal	Impose a constraint on the required signatures in **`IOUContract.verify`**
Steps	• Extract the command from the transaction • Compare the command's signers to the transaction's participants

Code	`"Both lender and borrower together only may sign IOU issue transaction." using`
	`    (command.signers.toSet() ==`
	`        iou.participants.map { it.owningKey }.toSet())`

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There's more...

There is one more test to finish – you're on your own!

`lenderAndBorrowerCannotBeTheSame()`

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Step 6 – Another Command

The Transfer Command

- IOU creation/evolution is now controlled by a set of rules:
  - Non-zero IOUs only
  - IOUs can only be created (not transferred or destroyed)
  - IOU creation transactions must have:
    - *No inputs*
    - *One output (the new IOU)*
  - IOU creation requires sender and recipient signatures

- Let's write another command, `Transfer`, that will allow the IOU's recipient to transfer it to another party

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Design Brainstorm

- What contract constraints should we impose to model the behaviour of transferring an IOU?

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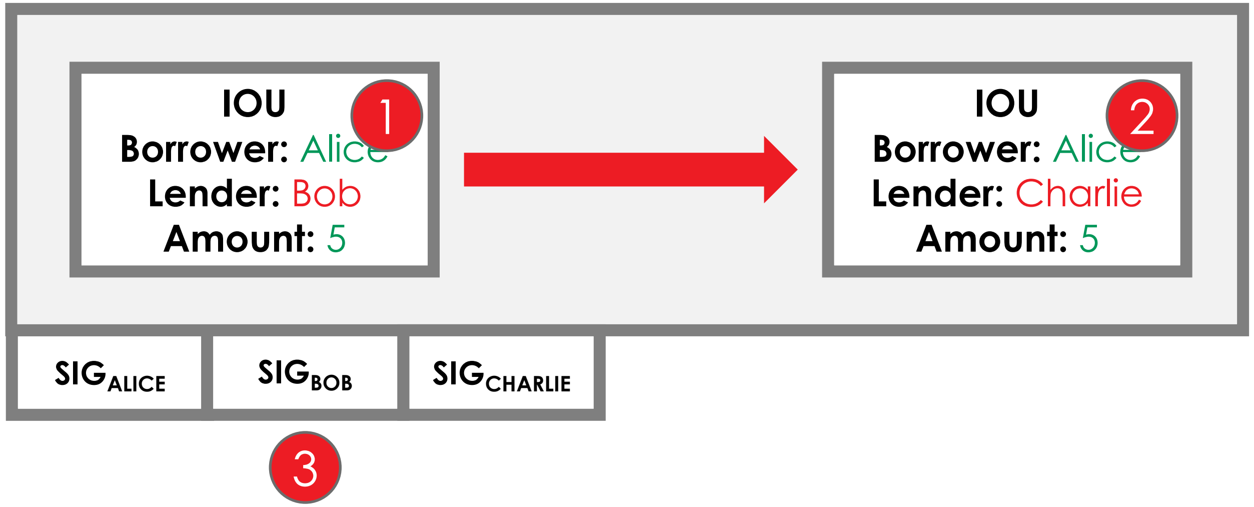
Transfer Command Design

- Transactions transferring `IOUState`s should behave as follows:
  1. One input
  2. One output
     a. The amount and borrower should remain the same
     b. The lender should be different
  3. Signatures from all three parties

TRANSACTION



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Parameterizing Contract Execution

- To implement the **Transfer** command, we need to:
  1. Add a new **CommandData** subclass to **IOUContract**
  2. Fork the execution of **verify** based on the command type
  3. Add the new contract constraints

- We can fork **verify**’s execution using a **when** statement:

```
override fun verify(tx: LedgerTransaction) {
    val command = tx
        .commands
        .requireSingleCommand<IOUContract.Commands>()
    when (command.value) {
        is Commands.Issue -> requireThat { }
        is Commands.Transfer -> { }
    }
}
```

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Transfer Command - Implementation

Goal	Implement the `Transfer` command and contract constraints
Where?	• test/contract/IOUTransferTests.kt • contract/IOUContract.kt
Steps	1. Uncomment the tests in IOUTransferTests 2. Write the code to make the tests pass
Key Docs	N/A

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Transfer Command - Solution

Goal

Implement the `Transfer` command and contract constraints

Steps

- Define the `IOUContract.Transfer` class
- Define the corresponding constraints

Code

Add the Transfer command to the Commands interface:

```
interface Commands : CommandData {
    class Issue : TypeOnlyCommandData(), Commands
    class Transfer : TypeOnlyCommandData(), Commands
}
```

Add the `verify` function:

Over the page…

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Transfer Command - Solution

Code

```
val command = tx.commands.requireSingleCommand<IOUContract.Commands>()
when (command.value) {
    is Commands.Issue -> requireThat { /* … */ }
    is Commands.Transfer -> requireThat {
        "An IOU transfer transaction should only consume one input state."
            using (tx.inputs.size == 1)
        "An IOU transfer transaction should only create one output state."
            using (tx.outputs.size == 1)
        val input = tx.inputStates.single() as IOUState
        val output = tx.outputStates.single() as IOUState
        "Only the lender property may change."
            using (input == output.withNewLender(input.lender))
        "The lender property must change in a transfer."
            using (input.lender != output.lender)
        "The borrower, old lender and new lender only must sign an IOU
transfer transaction"
             using (command.signers.toSet() ==
        (input.participants.map { it.owningKey }.toSet() `union`
            output.participants.map { it.owningKey }.toSet()))
    }
```

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There are more (advanced) tests to complete!

Check out the tests in:

IOUSettleTests.kt

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- Further Constraints
- Tx-Level Constraints
- Value Constraints
- Signer Constraints
- **Another Command**

✓ Checkpoint

4. Flow

5. Network

6. API

Checkpoint – Progress So Far

Our progress so far

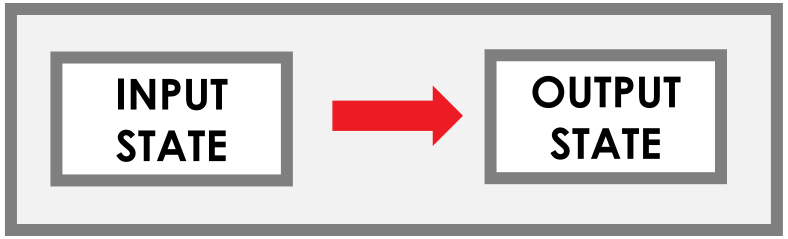
- We have defined a contract that allows IOU states on the ledger to only evolve in three specific ways:
  - Creation
  - Transfer
  - Settle

- We could further extend the behavior of IOU states by adding additional commands and contract code

- We now need to write the flow that will allow two nodes to speak to each other and agree the creation of IOUs

State grouping

- The simplest way to propose a transaction would be to have zero or one input states and zero or one output states
- This would be easy for the developer, but would prevent many important use cases



State grouping

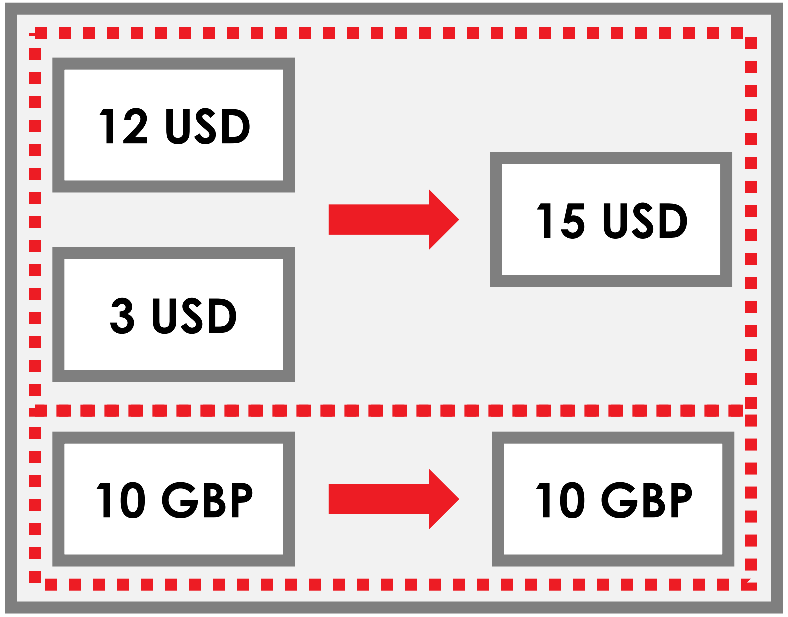
- Another way may be to **iterate over each input state and expect it to have an output state**
- This would make it possible move to two different cash states in different currencies simultaneously
- However, simultaneously dealing with inputs, exits, fungible states (that can split and merge) would make the API overly complex
- There must be another way…

State grouping

- Consider the following simplified currency trade transaction:
  - Input: $12 owned by Alice
  - Input: $3 owned by Alice
  - Input: £10 owned by Bob
  - Output: £10 owned by Alice
  - Output: $15 owned by Bob

State grouping

To verify this transaction, we want to verify two groups of states (the USD states and the GBP states) in isolation:



State grouping

`TransactionForContract`

has a method which can help:

```
fun <T : ContractState, K : Any>
groupStates(
    ofType: Class<T>,
    selector: (T) -> K
): List<InOutGroup<T, K>>
```

Where `InOutGroup` is defined as follows:

```
data class InOutGroup
<out T : ContractState, out K : Any>(
    val inputs: List<T>,
    val outputs: List<T>,
    val groupingKey: K)
```

State grouping

- Any states for which the selector returns the same value will be placed in the same **InOutGroup**

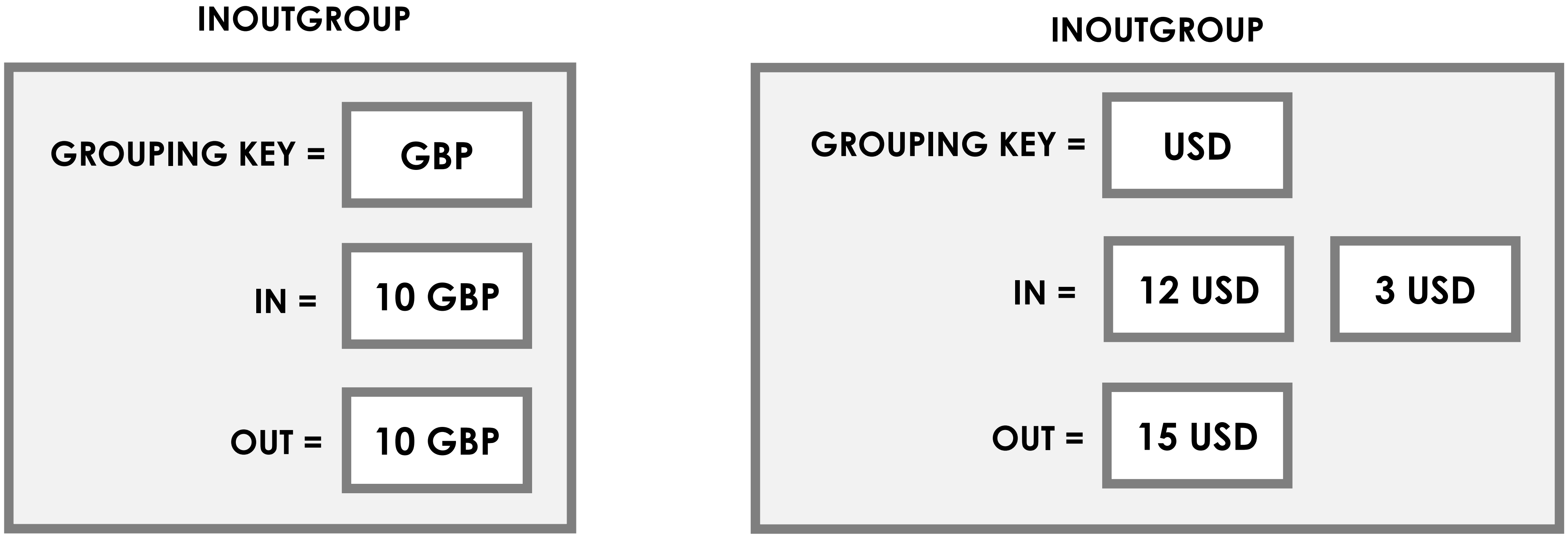
- In our case, we can use the following grouping function

```
val groups = tx.groupStates(Cash.State::class.java) {
    it -> it.amount.token
}
```

- Where **`amount.token`** is the currency of each cash state

State grouping

`groupStates()` produces the following `InOutGroup`s:



INOUTGROUP

GROUPING KEY = GBP

IN = 10 GBP

OUT = 10 GBP

INOUTGROUP

GROUPING KEY = USD

IN = 12 USD 3 USD

OUT = 15 USD

State grouping

- You can now apply different verification logic to each group:

```
for ((in, out, key) in groups) {
    when (key) {
        is GBP -> { // GBP verification logic. }
        is USD -> { // USD verification logic. }
        else -> throw IllegalArgumentException(
            "Unrecognised currency: $key”
        )
    }
}
```