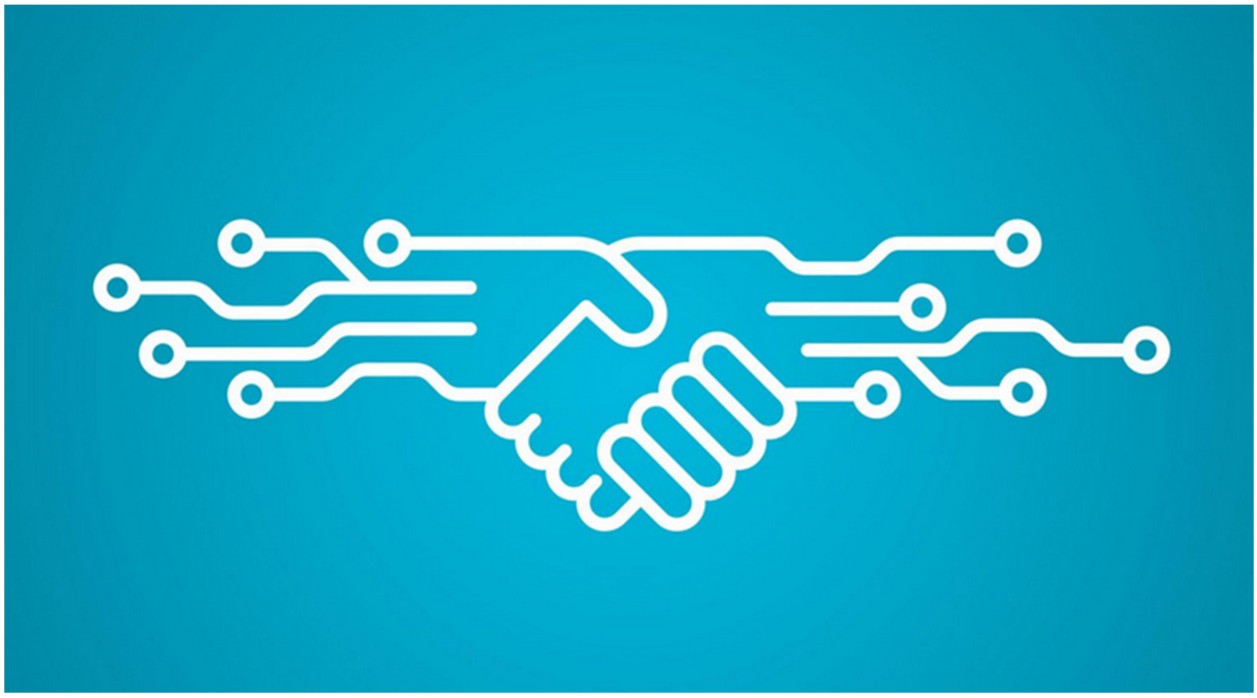
Plutus: Learning a smart-contract language



IOHK

Plutus: Learning a smart-contract language

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https://github.com/input-output-hk/plutus-pioneer-program

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Table of Contents

1 Plutus introduction 5

1.1 Installation of Haskell and Plutus 5

1.2 Running the Plutus playground 7

1.3 The EUTxO model 10

1.4 Plutus code 12

2 Simple validation scripts 13

2.1 Low-level untyped validation scripts 13

2.2 High Level typed validation scripts 17

2.3 Homework 20

3 Time, parameterized contracts and the cardano testnet 22

3.1 Time 23

3.2 Parameterized Contracts 29

3.3 The Cardano testnet 33

3.4 Homework 38

4 Monads, Traces & Contracts 43

4.1 Monads 43

4.2 The emulator trace monad 50

4.3 The contract monad 52

4.4 Homework 56

5 Native tokens 59

5.1 Simple Minting Policy 61

5.2 More Realistic Minting Policy 63

5.3 NFT-s 65

5.4 Homework 68

6 Deployment 73

6.1 The minting policy 73

6.2 Minting with the CLI 74

6.3 Deployment Scenarios 76
6.4 The Contracts 77
6.5 Minting with the PAB 83
7 State Machines 90
7.1 Commit schemes 90
7.2 Implementation without State Machines 91
7.3 State Machines 106
7.4 Homework 121
8 Testing 128
8.1 State Machine Example: Token Sale 128
8.2 Automatic testing using emulator traces 137
8.3 Test Coverage 140
8.4 Interlude optics 141
8.5 Property based testing with QuickCheck 143
8.6 Property based testing of Plutus contracts 145
8.7 Homework 155
9 Resources 160

1 Plutus introduction

Plutus is the native smart contract language for Cardano. It is a Turing-complete language written in Haskell, and Plutus smart contracts are effectively Haskell programs. By using Plutus, you can be confident in the correct execution of your smart contracts. It draws from modern language research to provide a safe, full-stack programming environment based on Haskell, the leading purely-functional programming language. [2]

So in order to understand this book and its code examples one has to understand the basics of the Haskell programming language. The Haskell project contains a list of learning resources as books and tutorials under its Documentation section, from which some are free and some commercial: https://www.haskell.org/documentation/.

1.1 Installation of Haskell and Plutus

The installation instructions are written for a Unix style OS (e.g. Mac OS or Linux). In order to install the Haskell toolchain, which is composed of GHC (Glasgow Haskell compiler), Cabal and some other tools, you can use GHCup: https://www.haskell.org/ghcup/. You will need curl installed on your OS, before you can use the GHCup installation.

After the installation is completed check from a terminal if you can run GHCi, the GHC Repl:

```
[user@fedora ~]$ ghci
GHCi, version 8.10.7: https://www.haskell.org/ghc/  :? for help
Prelude>
```

The GHCi version you will see can of course be different and should not matter as long as it is above or the same as the version shown in this example.

To run Plutus code examples from this book, you will need the following GIT repositories:

- https://github.com/input-output-hk/plutus-apps
- https://github.com/input-output-hk/plutus-pioneer-program

You will have to clone them with the git tool, that you will also need to install on your OS. Roughly speaking the plutus-apps repository contains the “off-chain” code for Plutus, that runs in a Wallet. It also references another repository called plutus, which contains the “on-chain” code for Plutus that runs on the Cardano blockchain.

To be able to build the code you will need to install the nix command line toolset. To install nix you can follow the instructions from their web-page: https://nixos.org/download.html.

Once nix is installed, you have to add the IOHK binary caches. You can do this by editing the /etc/nix/nix.conf, where you add the following lines:

```
substituters = https://hydra.iohk.io https://iohk.cachix.org https://cache.nixos.org/
trusted-public-keys    =    hydra.iohk.io:f/Ea+s+dFdN+3Y/G+FDgSq+a5NEWhJGzdjvKNGv0/EQ=
iohk.cachix.org-1:DpRUyj7h7V830dp/i6Nti+NEO2/nhblbov/8MW7Rqoo=        cache.nixos.org-
1:6NCHdD59X431o0gWypbMrAURkbJ16ZPMQFGspcDShjY=
```

If you don't have an /etc/nix/nix.conf or don't want to edit it, you may add the nix.conf lines to ~/.config/nix/nix.conf instead. You must be a trusted user to do this. If you are running NixOS you can, set the following NixOS options:

```
nix = {
  binaryCaches          = [ "https://hydra.iohk.io" "https://iohk.cachix.org" ];
  binaryCachePublicKeys                                                        =
[    "hydra.iohk.io:f/Ea+s+dFdN+3Y/G+FDgSq+a5NEWhJGzdjvKNGv0/EQ="    "iohk.cachix.org-
1:DpRUyj7h7V830dp/i6Nti+NEO2/nhblbov/8MW7Rqoo=" ];
};
```

The above nix configuration instructions are kept up-to-date in the plutus-apps repository [4].

A lot of dependencies are cached there and it will make the Plutus builds much faster.

The example code in this book comes directly from the plutus-pioneer-program git repository mentioned earlier. To build the code that is contained in the week folders follow these steps:

1. Open up a terminal and cd into a week folder of the plutus-pioneer-program repo, e.g. week01. You will need to figure out which commit of the plutus-apps repository this week uses. To do this open the cabal.project file, which contains various dependencies and scroll to the section *source-repository-package*:

```
source-repository-package
  type: git
  location: https://github.com/input-output-hk/plutus-apps.git
  tag: 41149926c108c71831cfe8d244c83b0ee4bf5c8a
```

2. Copy the commit under the tag section. cd into the plutus-apps repository and checkout the commit you just have copied:

```
[user@fedora ~/plutus-apps]$ git checkout 41149926c108c71831cfe8d244c83b0ee4bf5c8a
```

3. Now run the command nix-shell. When you do this for the first time it can take a while until everything has built. After the build your command prompt will change to the nix shell. In this shell cd back into the week01 folder and run the cabal build command:

```
[nix-shell: ~/plutus-apps]$ cabal build
```

4. This can also take some time if you build it the first time. When the build has finished you can start the GHC Repl with the *cabal repl* command:

```
[nix-shell: ~/plutus-pioneer-program/code/week01]$ cabal repl
Build profile: -w ghc-8.10.4.20210212 -O1
Preprocessing library for plutus-pioneer-program-week01-0.1.0.0..
GHCi, version 8.10.4.20210212: https://www.haskell.org/ghc/  :? for help
Ok, one module loaded.
Prelude Week01.EnglishAuction>
```

5. To leave the cabal repl simply type ":q".

Another useful thing to have is the documentation for various Plutus libraries. You can build the documentation yourself. From inside the nix-shell in the plutus-apps folder run:

```
[nix-shell:~/plutus-apps]$ build-and-serve-docs
Serving HTTP on 0.0.0.0 port 8002 (http://0.0.0.0:8002/) ...
```

You can open the displayed address and port in your web-browser and will see the high-level documentation for Plutus. A more useful thing is the Plutus library documentation which you will find at this location: http://0.0.0.0:8002/haddock. Because is not just a static file but and actual web-server you can search through it by pressing Ctrl+S.

1.2 Running the Plutus playground

The Plutus playground is an interactive environment where you can compile your Plutus code and simulate it. In the simulation you can specify:

- how many wallets with how many ADA (native currency of Cardano) you want to have
- which wallet actions also called a transactions, you want to perform at which timeslots
- what are the input parameters for your transactions if there are any input fields present

These transactions will then be executed on the playground and you can view them interactively. To set up the playground perform the following steps:

1. cd into the plutus-apps repository and start the nix-shell.
2. Then cd into the *plutus-playground-client/* and start the *plutus-playground-server*:

```
[nix-shell:~/plutus-apps/plutus-playground-client]$ plutus-playground-server
```

NOTE: The default server timeout is set to 80 seconds. If you want to increase the server timeout to e.g. 120 seconds you can pass a "-i 120s" argument to the command.

3. Open up another nix shell at the same location and start the playground client:

```
[nix-shell:~/plutus-apps/plutus-playground-client]$ npm start
...
Project is running at https://localhost:8009/
```

If you then go to your web-browser and open https://localhost:8009/ you will see the Plutus playground (Figure 1). In the middle you will see the editor window, where you can copy paste the code from the plutus-pioneer-program repository. You can delete the default example code. On the right side you see the compile and simulate buttons. With the compile button you compile the code and a status bar at the bottom of the editor will tell you if the compilation succeeded. If not it will throw an error pointing to the line that makes trouble.

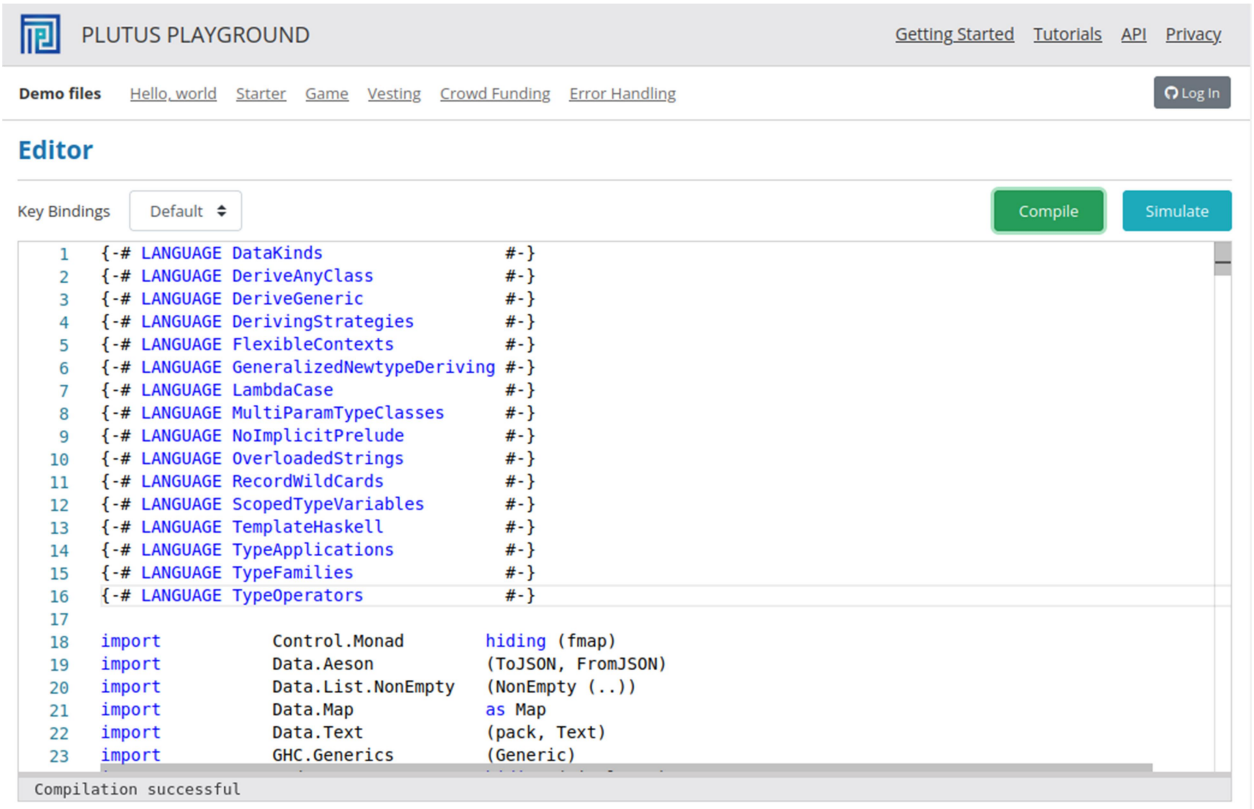

Figure 1 - Plutus playground editor

After the compilation successfully succeeded you can use the simulate button to open op the Simulate view (Figure 2). There you can add wallets, set amounts of Lovelace (= 0.000001 ADA) for initial funds of the wallets, trigger the available wallet functions and add wait actions. Once you are finished with defining your actions you can click on the Evaluate button. The transaction window will appear (Figure 3). There you will always see a genesis. If there were actions defined, there will also be other transactions and you can then click on different slots in the upper row and the transactions for these slots will appear.

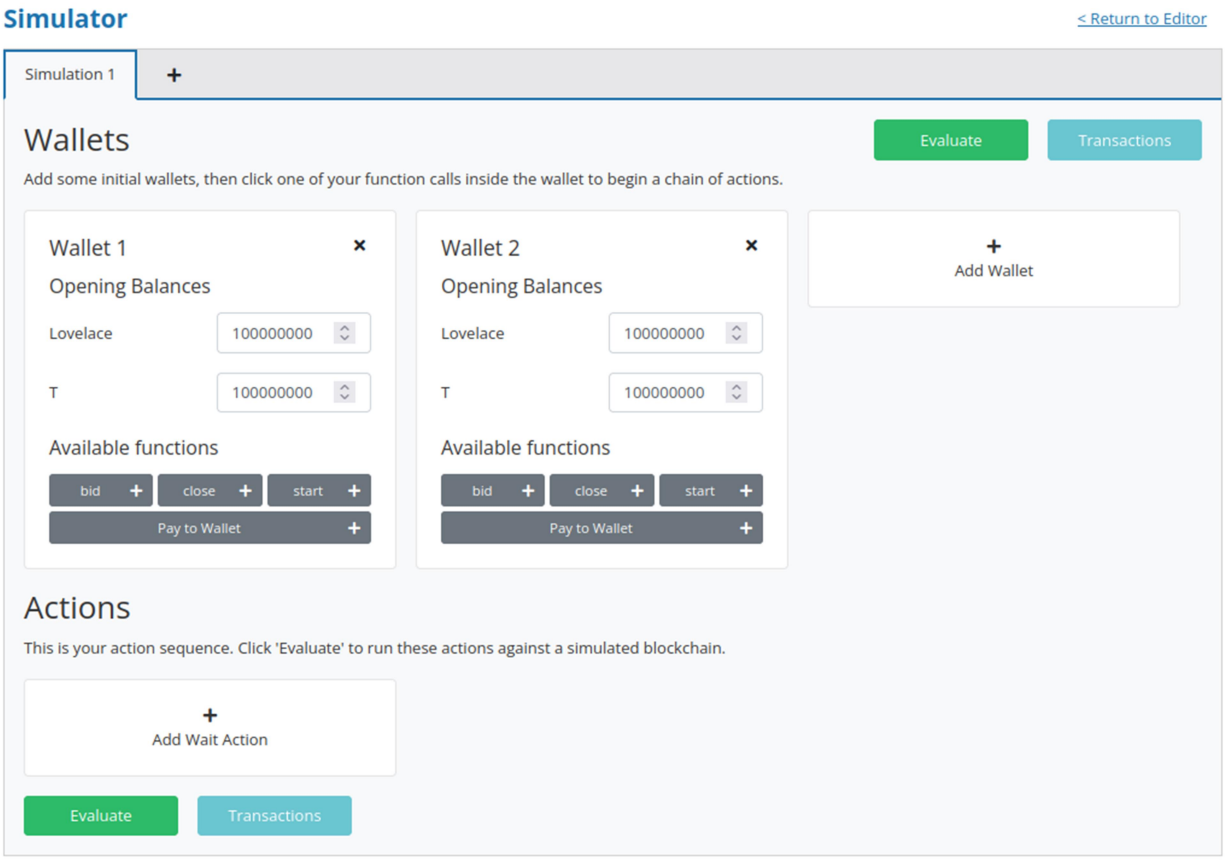

Figure 2 - Putus playground simulation

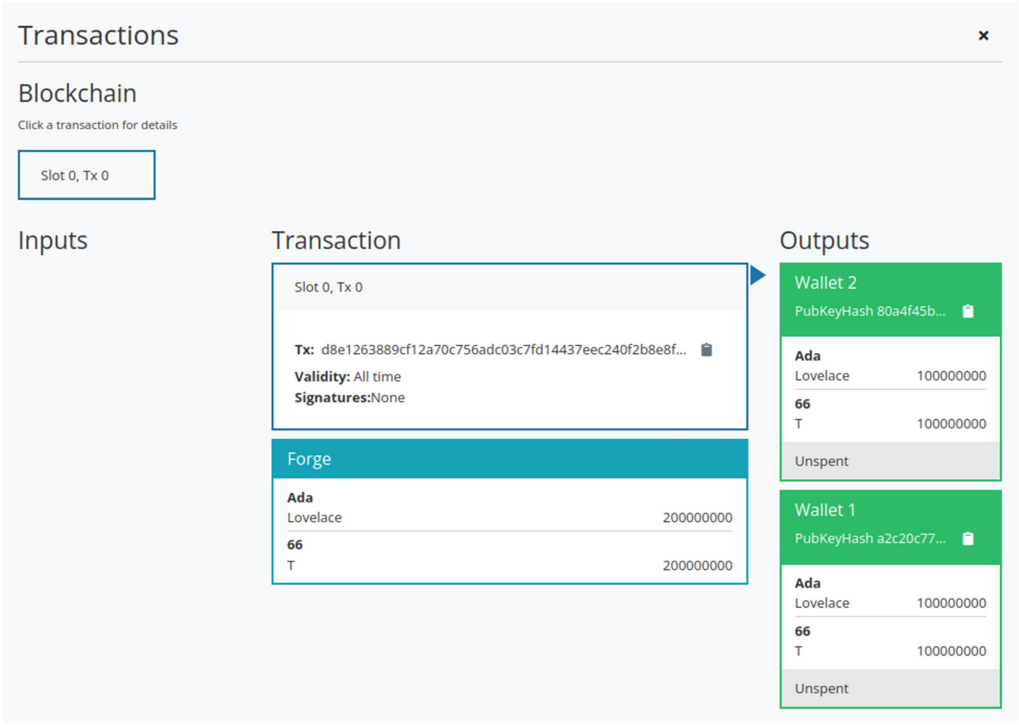

Figure 3 - Putus playground transactions

You can also use the online Plutus playground (https://playground.plutus.iohkdev.io) to compile your code. But it is not necessarily up-to-date with the code from the git repositories, so some Plutus code from the examples in this book may not compile.

The Auction example code in the folder week01 will not be covered here, since it is a to advanced example to start with. But you can look at the demonstration of this code in the videos “Auction Contract in the EUTxO-Model” and “Auction Contract on the Playground” that can both be found in the plutus-pioneer-program git repository under the Lecture #1 chapter.

1.3 The EUTxO model

The Cardano blockchain uses the Extenden UTXO model that is a variant of the Unspent Transaction Output (UTXO) model used by Bitcoin. Transactions consume unspent outputs (UTXOs) from previous transactions and produce new outputs which can be used as inputs to later transactions. Unspent outputs are the liquid funds on the blockchain. Users do not have individual accounts, but rather have a software wallet on a smartphone or PC which manages UTXOs on the blockchain and can initiate transactions involving UTXOs owned by the user. Every core node on the blockchain maintains a record of all of the currently unspent outputs, the UTXO set. When outputs are spent, they are removed from the UTXO set. [3]

There are other models than UTXO. Ethereum, for example, uses a so-called account-based model, which is what a normal bank uses, where everybody has an account and each account has a balance. If you transfer money from one account to another, then the balances get updated accordingly. But in the UTXO model, the input is always the entire balance of an UTXO and the outputs are newly created UTXOs from which one of them could be belonging to the user that provided his UTXO as input and would represent his change amount. For every transaction there is a fee to pay denominated in ADA for the Cardano blockchain.

As soon as an output is used as input in a transaction, it becomes spent and can never be used again. The output is specified by an address which is represented by a public key hash and a value which represents the ADA amount and any optional additional native tokens. We call them public key addresses. An output’s address determines which transactions are allowed to ‘unlock’ the output and use it as an input. A transaction must be signed by the owner of the private key corresponding to the address that defines the input UTXO. Think of an address as a ‘lock’ that can only be ‘unlocked’ by the right ‘key’ – the correct signature. [2]

The extended UTXO model introduces in addition to public key addresses also script addresses, that can contain some arbitrary logic, that defines under which conditions the UTXO can be

spent. The address is unlocked by and arbitrary piece of data called the redeemer, which in the conventional UTXO model would be a private key address. A UTXO also contains some arbitrary data called the datum, beside the amount of ADA sitting at the address. The datum together with the redeemer and the transaction context are the input information for a script that then chooses weather this transaction is valid and can be processed by a node on the network.

You can check the validity of a transaction in your wallet. If it is valid you can be sure it will be processed on the network, given the condition that all the UTXO inputs are still present at processing time. If they are not the transaction will simply fail and no fee will be charged to the user that sent the transaction. We call the script that validates a transaction the validator.

A transaction can be classified as a spending transaction that spends UTXOs or as a producing transaction that produces UTXOs. The truth is every transaction except the genesis transaction takes at least one UTXO as input and produces at least one UTXO as output. What we mean by the terms spending and producing is the context. Later in chapter 2 we will see code examples where we have a give function and a grab function. The give function gives some ADA to a script address and is for this reason a producing transaction. The grab function wants to collect ADA from a script address and is a spending transaction.

The producing transaction only has to include the hash of the script and the hash of the datum that both belong to the output UTXO. But optionally, it can include the datum and the script as well. If it does not, only a person that knows the datum by some other means not by looking at the blockchain would be able to ever spend such an output.

The spending transaction is responsible for providing the datum, the redeemer and the transaction context. It also provides the validator script. The script address is defined as a hash of the validator code written in Plutus core language, which also needs to be provided. The script addresses are publicly known.

As said the validator script takes the datum, the redeemer and the transaction context as input information. The input for the datum comes from each UTXO individually that are sitting at the script address. The datum can also be defined in the transaction context which is provided by the spending transaction. This makes it possible for the validator script to compare information from both datums and perform some arbitrary logic on them.

This limited view of the validator script that can see only inputs, outputs and the transaction that will be processed, has a security advantage compared to the Ethereum model, where the script can see the whole state of the blockchain. That enables Ethereum's scripts to be much more powerful but for this reason it's also very difficult to predict what a given script will do and that opens the door to all sorts of security issues. It can be mathematically proven that

every logic you can express in Ethereum you can also express in the extended UTxO model. And that makes it a much more safer and reliable transaction model compared to Ethereum.

1.4 Plutus code

The code for Plutus smart contracts is separated into two. First is the “on-chain” code, which consist of the validator function and some additional declarations and variables as the script address. This code gets compiled to Plutus Core language. It runs on the Cardano blockchain and once submitted it cannot be changed.

From the official documentation [2] we get the following description for Plutus Core:

Plutus Core is the scripting language used by Cardano to implement the EUTXO model. It is a simple, functional language similar to Haskell, and a large subset of Haskell can be used to write Plutus Core scripts. As a smart contract author, you don’t write any Plutus Core; rather, all Plutus Core scripts are generated by a Haskell compiler plugin called Plutus Tx.

The “off-chain” code is written in Haskell, just like the on-chain code, unlike Ethereum where the on-chain code is written in Solidity, but the off-chain code is written in JavaScript. That way, the business logic only needs to be written once. This logic can then be used in the validator script and in the code that builds the transactions that run the validator script. [2]

The off-chain code basically constructs the transaction and submits it to the blockchain. Since both the on-chain and off-chain code are written in Haskell they can reside in one Haskell file while testing your code, which allows them to share code between them.

2 Simple validation scripts

We said earlier that a script sitting on a UTXO address takes in 3 parameters: the datum, the redeemer and the transaction context, which is the submitted transaction with all the inputs and outputs. In the low-level implementation of Plutus these 3 parameters are represented with the same data type. In the high-level implementation you can use custom Haskell data types for datum and redeemer and a predefined type for the transaction context. You can use both of the implementations in your smart-contract code. The difference between them is code performance which is better for the low-level implementation data types.

The data type for the low-level implementation is called *BuiltinData*. It contains two conversion functions *builtinDataToData* and *dataToBuiltinData*, that can convert back and forth to the *Data* type. The Data type has its constructor exposed and has the following definition:

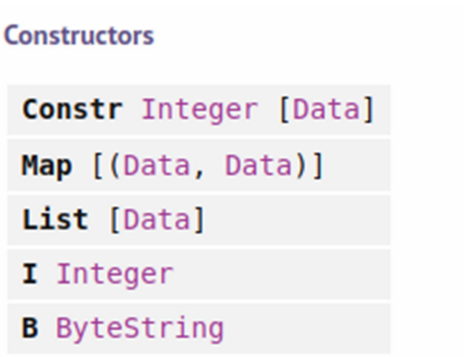

Figure 4 - Data constructor

Both data types are contained in the *PlutusTx* module. To be able to assign a string value to the B ByteString constructer you need to import the language extension *OverloadedStrings*.

2.1 Low-level untyped validation scripts

Lets look at the code from the *Gift.hs* file in the week02 folder.

```
1   {-# LANGUAGE DataKinds           #-}
2   {-# LANGUAGE FlexibleContexts    #-}
3   {-# LANGUAGE NoImplicitPrelude   #-}
4   {-# LANGUAGE ScopedTypeVariables #-}
5   {-# LANGUAGE TemplateHaskell     #-}
6   {-# LANGUAGE TypeApplications    #-}
7   {-# LANGUAGE TypeFamilies        #-}
8   {-# LANGUAGE TypeOperators       #-}
9
```

```
module Week02.Gift where

import           Control.Monad       hiding (fmap)
import           Data.Map            as Map
import           Data.Text           (Text)
import           Data.Void           (Void)
import           Plutus.Contract
import           PlutusTx            (Data (..))
import qualified PlutusTx
import qualified PlutusTx.Builtins   as Builtins
import           PlutusTx.Prelude    hiding (Semigroup(..), unless)
import           Ledger              hiding (singleton)
import           Ledger.Constraints  as Constraints
import qualified Ledger.Scripts      as Scripts
import           Ledger.Ada          as Ada
import           Playground.Contract (printJson, printSchemas,
                                      ensureKnownCurrencies, stage)
import           Playground.TH       (mkKnownCurrencies, mkSchemaDefinitions)
import           Playground.Types    (KnownCurrency (..))
import           Prelude             (IO, Semigroup (..), String)
import           Text.Printf         (printf)

{-# OPTIONS_GHC -fno-warn-unused-imports #-}

{-# INLINABLE mkValidator #-}
mkValidator :: BuiltinData -> BuiltinData -> BuiltinData -> ()
mkValidator _ _ _ = ()

validator :: Validator
validator = mkValidatorScript $$(PlutusTx.compile [|| mkValidator ||])

valHash :: Ledger.ValidatorHash
valHash = Scripts.validatorHash validator

scrAddress :: Ledger.Address
scrAddress = scriptAddress validator

type GiftSchema =
            Endpoint "give" Integer
        .\/ Endpoint "grab" ()

give :: AsContractError e => Integer -> Contract w s e ()
give amount = do
    let tx = mustPayToOtherScript valHash (Datum $ Builtins.mkI 0) $
             Ada.lovelaceValueOf amount
```

```
53      ledgerTx <- submitTx tx
54      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
55      logInfo @String $ printf "made a gift of %d lovelace" amount
56
57  grab :: forall w s e. AsContractError e => Contract w s e ()
58  grab = do
59      utxos <- utxosAt scrAddress
60      let orefs   = fst <$> Map.toList utxos
61          lookups = Constraints.unspentOutputs utxos      <>
62                    Constraints.otherScript validator
63          tx :: TxConstraints Void Void
64          tx      = mconcat [mustSpendScriptOutput oref $ Redeemer $
                      Builtins.mkI 17 | oref <- orefs]
65      ledgerTx <- submitTxConstraintsWith @Void lookups tx
66      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
67      logInfo @String $ "collected gifts"
68
69  endpoints :: Contract () GiftSchema Text ()
70  endpoints = awaitPromise (give' `select` grab') >> endpoints
71    where
72      give' = endpoint @"give" give
73      grab' = endpoint @"grab" $ const grab
74
75  mkSchemaDefinitions ''GiftSchema
76
77  mkKnownCurrencies []
```

There are various language pragmas added in the beginning. One that is worth of noticing is the *NoImplicitPrelude* extension which allows you to use a custom prelude. That being said some standard Haskell functions you are used to may not work since we are importing *Plutus.Prelude* in the import section. To check weather a function is included in the Plutus prelude simply start up the Repl and use the info command on it. To get a list of all functions of the custom prelude you can also search the Plutus library documentation that you have learned to build.

In our code we first define the validator function called *mkValidator*. It accepts the datum, the redeemer and the context. We chose to use the *BuiltinData* datatype. Because of that the output of the validator is the unit *( )*. We said earlier the validator only validates a given transaction and for that reason you would expect a Bool value as return type. This is the case if we use the high-level implementation. For the low-level we have instead the unit, which is returned if the transaction passed or the error type, that gets returned if it fails.

In our case the validation passes no matter the input arguments, which means that everyone can process this UTXO and take some ADA from it if it contains any. For this reason we call this

example gift. Next we want to define our *validator*. To get it we need to compile the validator to Plutus Core script. This is done in line 38.

To make use of the *mkValidatorScript* function we need to import *Ledger.Script*. The *compile* function from the *PlutusTx* module takes as input a syntax tree of a function which we can get if we put the oxford brackets *[|| mkValidator ||]* around our desired function. The compile function produces another syntax tree that is written in the Plutus core language. Then the $$ symbol called splice, takes a syntax tree and splices it back to Haskell source code, which is what we need for input to our *mkValidatorScrip* function. If you want to be able to call external helper functions from the validator function you need to add the *INLINABLE* pragma statement before the validator function (33).

Next we create the validator hash and the script address which contains the validator hash and staking information that is used when we stake to a stake pool. The *scriptAddress* function is contained in the module *Ledger.Address*. The definitions until now represent the on-chain code. Everything after that is the off-chain code.

First we define the endpoints that the user can use to interact with the blockchain from within his wallet. Our give endpoint takes an integer parameter, which will represent the amount of ADA we are willing to give and grab does not take any parameter because it just spends funds. Then we define the give and grab functions. For the give function we first define the transaction (52). The transaction says a certain amount of lovelace should be paid to the specified address and with this datum. Line 53 submits the transaction, line 54 awaits confirmation of the transaction and line 55 logs the provided information which can be seen on the playground.

For the grab function we first lookup all the UTXOs sitting at a given address (59). Then we get all the references of the UTXOs (60). Next we define lookups in order to tell the wallet how to construct the transaction (61). First we tell that we are looking for unspent outputs and second we provide the validator script. Then we define the transaction so that it consumes all the UTXOs (64). When we submit the transaction we provide the lookups in order to know how to find the UTXOs. Next we await for confirmation and after that we log a message.

In the endpoint function we give the user the choice of selecting between the 2 endpoints and then recourse to do the same again. In line 75 we generate the schema for that and in line 76 we call the *mkKnownCurrencies* function so that in the playground we have ADA available.

Let's look now at an example where the validator function fails. In order that we can use the *traceError* function we need also to import the *OverloadedStrings* language extension.

```
{-# LANGUAGE OverloadedStrings   #-}
mkValidator :: BuiltinData -> BuiltinData -> BuiltinData -> ()
mkValidator _ _ _ = traceError "BURNT!"
```

Now the validation will fail and the Grab transaction will not be processed. For our next example we will take into account the redeemer (example *FortyTwo.hs*).

```
mkValidator :: BuiltinData -> BuiltinData -> BuiltinData -> ()
mkValidator _ r _
    | r == Builtins.mkI 42 = ()
    | otherwise            = traceError "wrong redeemer!"
```

We will also need to modify the off-chain code. The grab function will take now an input parameter that will be of type Integer.

```
1   type GiftSchema =
2               Endpoint "give" Integer
3           .\/ Endpoint "grab" Integer
4
5   grab :: forall w s e. AsContractError e => Integer -> Contract w s e ()
6   grab n = do
7       utxos <- utxosAt scrAddress
8       let orefs   = fst <$> Map.toList utxos
9           lookups = Constraints.unspentOutputs utxos      <>
10                    Constraints.otherScript validator
11          tx :: TxConstraints Void Void
12          tx      = mconcat [mustSpendScriptOutput oref $ Redeemer $
13                             Builtins.mkI n | oref <- orefs]
14      ledgerTx <- submitTxConstraintsWith @Void lookups tx
15      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
16      logInfo @String $ "collected gifts"
17
18  endpoints :: Contract () GiftSchema Text ()
19  endpoints = awaitPromise (give' `select` grab') >> endpoints
20    where
21      give' = endpoint @"give" give
22      grab' = endpoint @"grab" grab
```

From the original code in *Gift.hs* what changes are lines 3, 5, 6, 12-13 and 22. These examples were for the low-level data types in the validator function.

2.2 High Level typed validation scripts

Now let's look at an example where we use the high-level data types. We call it a typed validation script. The code can be found in *Typed.hs*. Here we provide only the significant parts.

```
1   import qualified Ledger.Typed.Scripts as Scripts
2
```

```
3   mkValidator :: () -> Integer -> ScriptContext -> Bool
4   mkValidator _ r _ = traceIfFalse "wrong redeemer" $ r == 42
5
6   data Typed
7   instance Scripts.ValidatorTypes Typed where
8       type instance DatumType Typed = ()
9       type instance RedeemerType Typed = Integer
10
11  typedValidator :: Scripts.TypedValidator Typed
12  typedValidator = Scripts.mkTypedValidator @Typed
13      $$(PlutusTx.compile [|| mkValidator ||])
14      $$(PlutusTx.compile [|| wrap ||])
15    where
16      wrap = Scripts.wrapValidator @() @Integer
17
18  validator :: Validator
19  validator = Scripts.validatorScript typedValidator
20
21  give :: AsContractError e => Integer -> Contract w s e ()
22  give amount = do
23      let tx = mustPayToTheScript () $ Ada.lovelaceValueOf amount
24      ledgerTx <- submitTxConstraints typedValidator tx
25      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
26      logInfo @String $ printf "made a gift of %d lovelace" amount
```

First we need to import *Ledger.Typed.Scripts* instead of *Ledger.Scripts*. We mentioned we can use arbitrary data types for the datum and redeemer. Since we don't care for the datum we just use unit. But for the script we need to use the *ScriptContext* data type (3). And the result will now be of type Bool. To compile the validator function to Plutus core we need to introduce a new type that encodes the information of the datum and the redeemer (6-9). We can pick and arbitrary name for this type. It doesn't need any constructors we just need to make it an instance of *Scripts.ValidatorTypes*. Next we compile our validator function but because we need a translation from our custom types to the low-level types we need to add the wrap function (14-16). This gives us a typed validator and we turn it into an un-typed validator (18-19). In the off-chain code we redefine our give function. When constructing the transaction we use now the function *mustPayToTheScript* that is a typed version for the case that the transaction we are constructing only involves one script. We now only provide as input the datum and the amount of ADA in lovelace. Then we also need a to use the function *submitTxConstraints* to submit the transaction where we additionally provide as input our typed validator function. We also need the code for grab function introduced in the previous example and some code from the initial example, for the playground to work.

Now let's look at the functions that allow us to convert between the low-level and high-level data types. For this we need to look at the *PlutusTx.IsData.Class* module which contains the functions *toData* and *fromData*.

```
ghci> toData ()
Constr 0 []
ghci> fromData (Constr 0 []) :: Maybe ()
Just ()
ghci> fromData (Constr 1 []) :: Maybe ()
Nothing
ghci> toData (42 :: Integer)
I 42
ghci> fromData (I 42) :: Maybe Integer
Just 42
ghci> fromData (List []) :: Maybe Integer
Nothing
```

This works only for predefined instances of the ToData class, which you can get with the command *":i ToData"*. If you want another data type you need to make it an instance of this class. But Plutus provides a mechanism that automatically does that for you. We look at this in our next example (*IsData.hs*) where we use custom defined data types for our redeemer.

```
1   newtype MySillyRedeemer = MySillyRedeemer Integer
2
3   PlutusTx.unstableMakeIsData ''MySillyRedeemer
4
5   {-# INLINABLE mkValidator #-}
6   mkValidator :: () -> MySillyRedeemer -> ScriptContext -> Bool
7   mkValidator _ (MySillyRedeemer r) _ = traceIfFalse "wrong redeemer" $ r == 42
8
9   data Typed
10  instance Scripts.ValidatorTypes Typed where
11      type instance DatumType Typed = ()
12      type instance RedeemerType Typed = MySillyRedeemer
13
14  typedValidator :: Scripts.TypedValidator Typed
15  typedValidator = Scripts.mkTypedValidator @Typed
16      $$(PlutusTx.compile [|| mkValidator ||])
17      $$(PlutusTx.compile [|| wrap ||])
18    where
19      wrap = Scripts.wrapValidator @() @MySillyRedeemer
```

We first define out custom data type *MySillyRedeemer*. To make our data an instance of the *ToData* type class we can use a template Haskell function called *unstableMakeIsData* which does that for us. The syntax to provide a type is to use 2 double quotes in front of the type. If we manually try to convert it in the Repl we get the following result:

```
ghci> toData (MySillyRedeemer 42)
Constr 0 [I 42]
```

There is also a stable version of the template function which is more commonly used in production code. In our case we had only one data constructor but if there are many it's not clear how they will be ordered. The unstable version does not make any guarantees that between different Plutus version the constructer number corresponding to a given constructor will be preserved. Next the validator function now changes, where we pattern match the redeemer data type. Also the type instance and the wrapper function get updated. For the off-chain code only the transaction in the grab function has to be updated to:

```
tx = mconcat [mustSpendScriptOutput oref $ Redeemer $ PlutusTx.toBuiltinData
              (MySillyRedeemer r) | oref <- orefs]
```

2.3 Homework

Let's look now at an example where your custom data type is defined in record syntax. We will have to Booleans as input and the validator function should return True if both parameters are equal. You can find such an example in the *Solution2.hs* file from week02 examples.

```
1   {-# LANGUAGE DeriveAnyClass      #-}
2   {-# LANGUAGE DeriveGeneric       #-}
3
4   import           Data.Aeson           (FromJSON, ToJSON)
5   import           GHC.Generics         (Generic)
6   import           Playground.Contract  (printJson, printSchemas,
                                           ensureKnownCurrencies, stage, ToSchema)
7
8   data MyRedeemer = MyRedeemer
9       { flag1 :: Bool
10      , flag2 :: Bool
11      } deriving (Generic, FromJSON, ToJSON, ToSchema)
12
13  -- This should validate if the two Booleans in the redeemer are equal!
14  mkValidator :: () -> MyRedeemer -> ScriptContext -> Bool
15  mkValidator () (MyRedeemer b c) _ = traceIfFalse "wrong redeemer" $ b == c
16
17  grab :: forall w s e. AsContractError e => MyRedeemer -> Contract w s e ()
18  grab r = do
19      utxos <- utxosAt scrAddress
20      let orefs   = fst <$> Map.toList utxos
21          lookups = Constraints.unspentOutputs utxos      <>
22                    Constraints.otherScript validator
```

```
23          tx :: TxConstraints Void Void
24          tx      = mconcat [mustSpendScriptOutput oref $ Redeemer $
                               PlutusTx.toBuiltinData r | oref <- orefs]
25      ledgerTx <- submitTxConstraintsWith @Void lookups tx
26      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
27      logInfo @String $ "collected gifts"
```

Compared to our *Typed.hs* examples we need to add two new language extensions. After that we import 2 new libraries and from the *Playground.Contract* library we additionally import the *ToSchema* type class. Then we define our custom data type using record syntax where we derive the generic, JSON and schema type classes. Next we write our validator function where we can use pattern matching. And for the rest of the code the only thing that changes is the grab function. There we use now the *MyRedeemer* data type in the type signature and in the transaction definition (24) we provide the input parameter *r* that represents the data type *MyRedeemer*. In the Plutus playground if we define a grab action then we will see we have now two Boolean checkboxes with the above description of the record syntax functions (Figure 5). If booth fields are checked or unchecked the transaction should be valid. Otherwise it should fail.

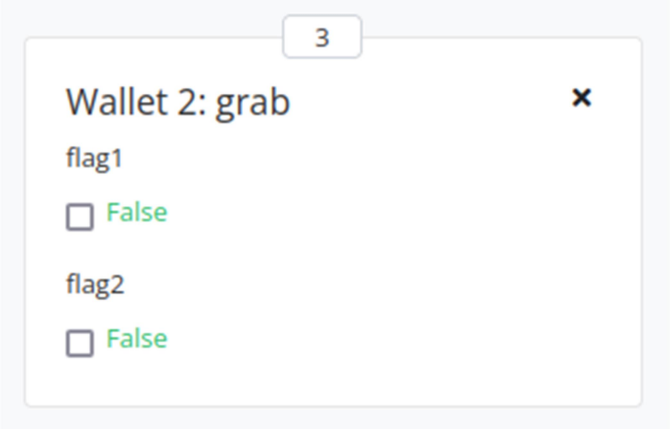

Figure 5 - Grab action

3 Time, parameterized contracts and the cardano testnet

In this chapter we will first time look at the script context. If we want to work with it we need to import the module *Ledger.Contexts* or just *Ledger* module which contains the data type *ScriptContext*. Script context defines two constructors that represent the transaction information and the script purpose (Figure 6). The script purpose constructor can be defined with four different parameters depending for what we use a script (Figure 8).

```
data ScriptContext
```

Constructors

```
ScriptContext
    scriptContextTxInfo :: TxInfo
    scriptContextPurpose :: ScriptPurpose
```

Figure 6 - Script context type

The transaction info data type is defined with various parameters that define properties of the transaction which are described in Figure 7. The *txInfoSignatories* parameter contains a list of public addresses which have signed this transaction. For producing transactions the *txInfoData* parameter is optional, whereas for spending transactions it is mandatory.

```
data TxInfo
```

A pending transaction. This is the view as seen by validator scripts, so some details are stripped out.

Constructors

```
TxInfo
```

`txInfoInputs :: [TxInInfo]`	Transaction inputs
`txInfoOutputs :: [TxOut]`	Transaction outputs
`txInfoFee :: Value`	The fee paid by this transaction.
`txInfoMint :: Value`	The `Value` minted by this transaction.
`txInfoDCert :: [DCert]`	Digests of certificates included in this transaction
`txInfoWdrl :: [(StakingCredential, Integer)]`	Withdrawals
`txInfoValidRange :: POSIXTimeRange`	The valid range for the transaction.
`txInfoSignatories :: [PubKeyHash]`	Signatures provided with the transaction, attested that they all signed the tx
`txInfoData :: [(DatumHash, Datum)]`	
`txInfoId :: TxId`	Hash of the pending transaction (excluding witnesses)

Figure 7 - Transaction info

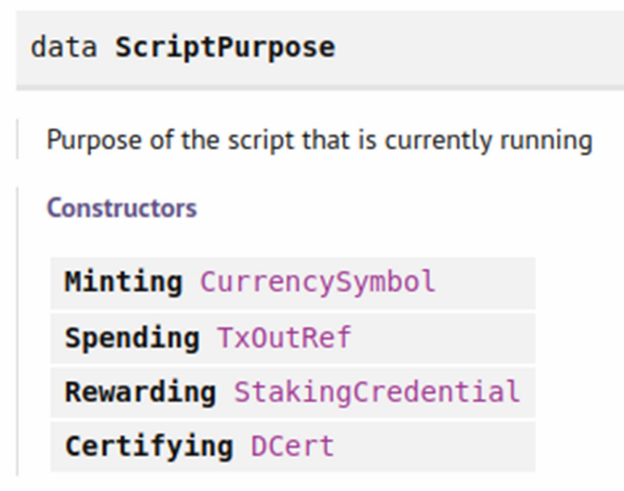

Figure 8 - Script purpose

3.1 Time

If we can validate transactions in the wallet we should have a mechanism that prevents a transaction being executed on a node if it does not fall in a certain time range. And for this we have the *txInfoValidRange* field that is part of the transaction info and specifies the time range in which a transaction is valid. This is part of the general check procedure that happens before a transaction is executed. Part of this procedure is also checking that all the inputs are present, that the balances add up and that the fees are included. If these pre-check succeeds we can be sure that the validation will succeed if it was also successfully validated in the wallet. By default all transactions use an infinite time range.

The consensus protocol of Cardano called Ouroboros uses slots instead of using POSIX time. Currently a slot equals to 1 second but this can change in the future. A hard fork which would change the slot interval is known around 36 hours in advance. For this reason slot intervals should not have an upper bound that is too further in the future as 36 hours. If we look at the *POSIXTimeRange* data type in depth we get the following information:

```
type POSIXTimeRange = Interval POSIXTime
--------------------------------------------------------------------------------
data Interval a
Constructors:
    ivFrom :: LowerBound a
    ivTo :: UpperBound a
--------------------------------------------------------------------------------
data LowerBound a
Constructors:
     (Extended a) Closure
--------------------------------------------------------------------------------
data UpperBound a
```

```
Constructors:
     (Extended a) Closure
-----------------------------------------------------------------------------------------
type Closure = Bool
-----------------------------------------------------------------------------------------
data Extended a
Constructors:
     NegInf
     Finite a
     PosInf
-----------------------------------------------------------------------------------------
newtype POSIXTime
Constructors:
     getPOSIXTime :: Integer
```

Closure specifies weather the boundary is included or not. POSIX time is measured as the number of milliseconds since 1970-01-01 00:00:00. There are also some functions available associated with the *Interval* data type:

- *member*: Checks whether a value is in an interval.
- *interval*: takes in two parameters and constructs an *Interval a* with boundaries included.
- *from*: gives an interval *a* that includes all values that are greater than or equal to a.
- *to*: gives an interval *a* that includes all values that are smaller than or equal to a.
- *always*: An interval *a* that covers every slot.
- *never*: An interval *a* that is empty.
- *singleton*: An interval *a* that only contains the one a.
- *hull*: 'hull a b' is the smallest interval containing a and b intervals.
- *intersection*: 'intersection a b' is the largest interval that is contained in a and in b intervals, if it exists.
- *overlap*: checks weather two intervals have a value in common and returns a Boolean
- *contains*: checks weather the second interval is contained in the first one
- *isEmpty*: checks weather an interval is empty
- *before*: checks weather a given time is before the given interval
- *after*: checks weather a given time is after the given interval

All of these functions and data types are included in the *Ledger.Interval* module. Let's look at some code examples that use these functions:

```
ghci> interval (10 :: Integer) 20
Interval {ivFrom = LowerBound (Finite 10) True, ivTo = UpperBound (Finite 20) True}
ghci> member 9 $ interval (10 :: Integer) 20
False
ghci> member 10 $ interval (10 :: Integer) 20
True
ghci> member 29 $ from (30 :: Integer)
```

```
False
ghci> member 30 $ from (30 :: Integer)
True
ghci> member 31 $ to (30 :: Integer)
False
ghci> member 30 $ to (30 :: Integer)
True
ghci> intersection (interval (10 :: Integer) 20) $ interval 18 30
Interval {ivFrom = LowerBound (Finite 18) True, ivTo = UpperBound (Finite 20) True}
ghci> contains (to (100 :: Integer)) $ interval 30 80
True
ghci> contains (to (100 :: Integer)) $ interval 30 101
False
ghci> overlaps (to (100 :: Integer)) $ interval 30 101
True
```

Next let's look at the *Vesting.hs* example found in week03 folder where we create a script address with some ADA that can be redeemed after a certain date has passed.

```
1   import           Ledger.Constraints   (TxConstraints)
2   import qualified Ledger.Constraints   as Constraints
3   import           Prelude              (IO, Semigroup (..), Show (..), String)
4
5   data VestingDatum = VestingDatum
6       { beneficiary :: PaymentPubKeyHash
7       , deadline    :: POSIXTime
8       } deriving Show
9
10  PlutusTx.unstableMakeIsData ''VestingDatum
11
12  {-# INLINABLE mkValidator #-}
13  mkValidator :: VestingDatum -> () -> ScriptContext -> Bool
14  mkValidator dat () ctx = traceIfFalse "beneficiary's signature missing"
                             signedByBeneficiary &&
15                           traceIfFalse "deadline not reached" deadlineReached
16    where
17      info :: TxInfo
18      info = scriptContextTxInfo ctx
19
20      signedByBeneficiary :: Bool
21      signedByBeneficiary = txSignedBy info $ unPaymentPubKeyHash $
                              beneficiary dat
22
23      deadlineReached :: Bool
24      deadlineReached = contains (from $ deadline dat) $ txInfoValidRange info
25
26  data Vesting
```

```
27  instance Scripts.ValidatorTypes Vesting where
28      type instance DatumType Vesting = VestingDatum
29      type instance RedeemerType Vesting = ()
30
31  typedValidator :: Scripts.TypedValidator Vesting
32  typedValidator = Scripts.mkTypedValidator @Vesting
33      $$(PlutusTx.compile [|| mkValidator ||])
34      $$(PlutusTx.compile [|| wrap ||])
35    where
36      wrap = Scripts.wrapValidator @VestingDatum @()
37
38  validator :: Validator
39  validator = Scripts.validatorScript typedValidator
40
41  valHash :: Ledger.ValidatorHash
42  valHash = Scripts.validatorHash typedValidator
43
44  scrAddress :: Ledger.Address
45  scrAddress = scriptAddress validator
46
47  data GiveParams = GiveParams
48      { gpBeneficiary :: !PaymentPubKeyHash
49      , gpDeadline    :: !POSIXTime
50      , gpAmount      :: !Integer
51      } deriving (Generic, ToJSON, FromJSON, ToSchema)
52
53  type VestingSchema =
54              Endpoint "give" GiveParams
55          .\/ Endpoint "grab" ()
56
57  give :: AsContractError e => GiveParams -> Contract w s e ()
58  give gp = do
59      let dat = VestingDatum
60                  { beneficiary = gpBeneficiary gp
61                  , deadline    = gpDeadline gp
62                  }
63          tx  = Constraints.mustPayToTheScript dat $ Ada.lovelaceValueOf $
                    gpAmount gp
64      ledgerTx <- submitTxConstraints typedValidator tx
65      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
66      logInfo @String $ printf "made a gift of %d lovelace to %s
                                 with deadline %s"
67          (gpAmount gp)
68          (show $ gpBeneficiary gp)
69          (show $ gpDeadline gp)
```

```
70
71  grab :: forall w s e. AsContractError e => Contract w s e ()
72  grab = do
73      now   <- currentTime
74      pkh   <- ownPaymentPubKeyHash
75      utxos <- Map.filter (isSuitable pkh now) <$> utxosAt scrAddress
76      if Map.null utxos
77          then logInfo @String $ "no gifts available"
78          else do
79              let orefs   = fst <$> Map.toList utxos
80                  lookups = Constraints.unspentOutputs utxos  <>
81                            Constraints.otherScript validator
82                  tx :: TxConstraints Void Void
83                  tx      = mconcat [Constraints.mustSpendScriptOutput oref
                                       unitRedeemer | oref <- orefs] <>
84                            Constraints.mustValidateIn (from now)
85              ledgerTx <- submitTxConstraintsWith @Void lookups tx
86              void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
87              logInfo @String $ "collected gifts"
88    where
89      isSuitable :: PaymentPubKeyHash -> POSIXTime -> ChainIndexTxOut -> Bool
90      isSuitable pkh now o = case _ciTxOutDatum o of
91          Left _          -> False
92          Right (Datum e) -> case PlutusTx.fromBuiltinData e of
93              Nothing -> False
94              Just d  -> beneficiary d == pkh && deadline d <= now
95
96  endpoints :: Contract () VestingSchema Text ()
97  endpoints = awaitPromise (give' `select` grab') >> endpoints
98    where
99      give' = endpoint @"give" give
100     grab' = endpoint @"grab" $ const grab
101
102 mkSchemaDefinitions ''VestingSchema
103
104 mkKnownCurrencies []
```

Compared to the last code example *Solution2.hs* from the week02 folder, we make a different import of *Ledger.Constraints* one qualified and one normal. And from the standard Prelude we also import the *Show* type class. Then we define the vesting datum, which contains the hash of the payment public key from the user that will retrieve the funds and the deadline after which the funds can be retrieved. We derive the Show type class so we can display our information in the console. Next we write our validator function, where we look at the datum and the context.

In the *where* clause we first define the transaction info. After that we implement our two conditions. For the first condition *signedByBenificiary* we use the *txSignedBy* function that takes a transaction info and a public key hash and returns True if the transaction was signed with this key. The function expects a *PubKeyHash* variable which we get with *unPaymentPubKeyHash*.

```
Prelude Ledger> :i PaymentPubKeyHash
type PaymentPubKeyHash :: *
newtype PaymentPubKeyHash
  = PaymentPubKeyHash {unPaymentPubKeyHash :: PubKeyHash}
      -- Defined in ‘Ledger.Address’
```

For the second condition *deadlineReached* we construct an interval that stretches from the deadline to infinity and if the validity interval *txInfoValidRange* from the transaction info object is contained in this interval the deadline is definitely reached. Next follows the code where we compile our validator and create the script address.

After that follows the off-chain code. First we define a data type called *GiveParams* that includes information necessary to construct the script address. We add an exclamation mark to the parameters so they get strictly evaluated. Then we write our give function where we first define the datum which we use in the next step when constructing the transaction.

For the grab function we can have more UTXOs sitting at the vesting address. First we get the current time and lookup our own payment public key hash. Then we get all suitable UTXOs, where we use the helper function *isSuitable*. It takes in our payment key, the current time and a UTXO and returns a Bool. Inside the body of the helper function we check the datum of the UTXO with the function *_ciTxOutDatum*. If it does not exist and only the hash exist we will get a Left type and can return false. If it exists we check the content of the datum. If there is a content present we can validate our two conditions. Else we also just return False.

After we filtered out the valid UTXOs we check if there are any. If there aren’t we log a message else we construct a transaction that collects all of them in one transaction. In the transaction we also use the function *mustValidateIn* that creates a validity interval for the transaction (84). In the real world there could be to many UTXOs to collect them in one transaction which can be only of a limited size. But in this example we forget about this case.

If you try this code out in the playground and have a scenario where wallet one makes a gift to wallet two and wallet three, you will need a slot in between the two gift actions because we defined the code in such a way that we wait for confirmation of the transaction before we finish with the give action. So it will be again available after the transaction is confirmed. You will also need to provide the payment public key hash in the give action of the wallet you want to give the funds. You can get this with the following commands inside the Repl:

```
Ghci> import Wallet.Emulator
Ghci> knownWallet 2
Wallet 7ce812d7a4770bbf58004067665c3a48f28ddd58
Ghci> mockWalletPaymentPubKey $ knownWallet 2
98c77c40ccc536e0d433874dae97d4a0787b10b3bca0dc2e1bdc7be0a544f0ac
```

The *Wallet* type represents real wallets like Daedalus and also mock wallets that are used in the playground. With the *mockWalletPaymentPubKey* function we get the public key hash of a specific wallet from the playground. Next you need to provide the deadline which needs to be in POSIX time. We can get this time with the following commands:

```
Ghci> import Ledger.Time
Ghci> import Ledger.TimeSlot
Ghci> import Data.Default
Ghci> slotToBeginPOSIXTime def 10
POSIXTime {getPOSIXTime = 1596059101000}
```

3.2 Parameterized Contracts

Let's look now at an example where our validation script takes an input parameter. The code for this can be found in the *Parameterized.hs* file in the week03 folder.

```
1   {-# LANGUAGE MultiParamTypeClasses #-}
2
3   data VestingParam = VestingParam
4       { beneficiary :: PaymentPubKeyHash
5       , deadline    :: POSIXTime
6       } deriving Show
7
8   PlutusTx.makeLift ''VestingParam
9
10  {-# INLINABLE mkValidator #-}
11  mkValidator :: VestingParam -> () -> () -> ScriptContext -> Bool
12  mkValidator p () () ctx = traceIfFalse "beneficiary's signature missing"
                              signedByBeneficiary &&
13                            traceIfFalse "deadline not reached" deadlineReached
14    where
15      info :: TxInfo
16      info = scriptContextTxInfo ctx
17
18      signedByBeneficiary :: Bool
19      signedByBeneficiary = txSignedBy info $ unPaymentPubKeyHash $
                              beneficiary p
20
21      deadlineReached :: Bool
```

```
22      deadlineReached = contains (from $ deadline p) $ txInfoValidRange info
23
24  data Vesting
25  instance Scripts.ValidatorTypes Vesting where
26      type instance DatumType Vesting = ()
27      type instance RedeemerType Vesting = ()
28
29  typedValidator :: VestingParam -> Scripts.TypedValidator Vesting
30  typedValidator p = Scripts.mkTypedValidator @Vesting
31      ($$(PlutusTx.compile [|| mkValidator ||])
       `PlutusTx.applyCode` PlutusTx.liftCode p)
32      $$(PlutusTx.compile [|| wrap ||])
33    where
34      wrap = Scripts.wrapValidator @() @()
35
36  validator :: VestingParam -> Validator
37  validator = Scripts.validatorScript . typedValidator
38
39  valHash :: VestingParam -> Ledger.ValidatorHash
40  valHash = Scripts.validatorHash . typedValidator
41
42  scrAddress :: VestingParam -> Ledger.Address
43  scrAddress = scriptAddress . validator
44
45  data GiveParams = GiveParams
46      { gpBeneficiary :: !PaymentPubKeyHash
47      , gpDeadline    :: !POSIXTime
48      , gpAmount      :: !Integer
49      } deriving (Generic, ToJSON, FromJSON, ToSchema)
50
51  type VestingSchema =
52              Endpoint "give" GiveParams
53          .\/ Endpoint "grab" POSIXTime
54
55  give :: AsContractError e => GiveParams -> Contract w s e ()
56  give gp = do
57      let p  = VestingParam
58                  { beneficiary = gpBeneficiary gp
59                  , deadline    = gpDeadline gp
60                  }
61          tx = Constraints.mustPayToTheScript () $ Ada.lovelaceValueOf $
                gpAmount gp
62      ledgerTx <- submitTxConstraints (typedValidator p) tx
63      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
```

```
64      logInfo @String $ printf "made a gift of %d lovelace to %s
                                 with deadline %s"
65          (gpAmount gp)
66          (show $ gpBeneficiary gp)
67          (show $ gpDeadline gp)
68
69  grab :: forall w s e. AsContractError e => POSIXTime -> Contract w s e ()
70  grab d = do
71      now   <- currentTime
72      pkh   <- ownPaymentPubKeyHash
73      if now < d
74          then logInfo @String $ "too early"
75          else do
76              let p = VestingParam
77                          { beneficiary = pkh
78                          , deadline    = d
79                          }
80              utxos <- utxosAt $ scrAddress p
81              if Map.null utxos
82                  then logInfo @String $ "no gifts available"
83                  else do
84                      let orefs   = fst <$> Map.toList utxos
85                          lookups = Constraints.unspentOutputs utxos      <>
86                                    Constraints.otherScript (validator p)
87                          tx :: TxConstraints Void Void
88                          tx      = mconcat [Constraints.mustSpendScriptOutput
                                    oref unitRedeemer | oref <- orefs] <>
89                                    Constraints.mustValidateIn (from now)
90                      ledgerTx <- submitTxConstraintsWith @Void lookups tx
91                      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
92                      logInfo @String $ "collected gifts"
93
94  endpoints :: Contract () VestingSchema Text ()
95  endpoints = awaitPromise (give' `select` grab') >> endpoints
96    where
97      give' = endpoint @"give" give
98      grab' = endpoint @"grab" grab
99
100 mkSchemaDefinitions ''VestingSchema
101
102 mkKnownCurrencies []
```

First we add an language extension called *MultiParamTypeClasses*. Other extensions and imports are the same as in the previous *Vesting.hs* example. Then we define the vesting parameter which has basically the same structure as in our vesting example.

Next we add our vesting parameter as an additional parameter to our validator function. The datum and the redeemer are set to unit ( ). Now during compilation all data should be known in advance but we can make an exception for the parameter if it is a static piece of data and not a function. We do this by calling the function *PlutusTx.liftCode* and then we combine it with the validator function that is now written in Plutus core with help of *PlutusTx.applyCode* function (31). Our type validator takes now as input the vesting parameter which can be seen in the type signature (29) and function definition (30). And additionally to that in the wrap function the datum changes now to unit (34).

To be able for this code to work we need a lift instance for our *VestingParam* parameter (8). And if there are multiple arguments in our parameter we need to add a the language pragma from line 1. Of course now in our validator function when we write our two conditions we read the data from the additional parameter instead of the datum. In line 26 the type of the datum changes to unit. When we define our validator, its hash and the script address instead of calling functions upon static piece of data we have now two functions that we need to combine with the dot notation (36 to 43).

When we define our endpoints we need an input parameter for grab which will be the POSIX time of the deadline. The payment public key hash we can get with the appropriate function. For the give parameter what changes compared to the previous code example is that we now input the vesting parameter variable together with the type validator when we submit the transaction and not as the datum contained in the transaction (62).

In the grab function we now add the POSIX time as an input parameter but the actual deadline is already set by the person who performs the give action. First we check if this parameter is larger than the current time (73) and if yes we log a »too early« message. If not we define our vesting parameter (76 to 78), then we get a list of all the UTXOs where we have to provide the vesting parameter as input to the script address (80). If there are any UTXOs then we construct the transaction and submit it same as in the vesting example, with the only difference that now in the lookups parameter we add the vesting variable to the validator (86). Compared to our last example where we filtered out the suitable UTXOs with the *isSuitable* function we now provide an input parameter to the script that automatically returns the UTXOs that match the public payment key hash and the exact deadline.

In the playground we have to provide the public key hash and the deadline for the give action. We also now specify the deadline we are looking for as an argument to grab. For this reason we cannot grab two gifts at once if they exist. We have to perform two grab actions and the posix time in the grab action has to exactly match the posix time in the give action, to be able to retrieve the funds. One thing to mention is an obvious failure of the playground.

If we try to make a gift wait until slot 10, then make a grab and wait for 2 more slots, the grab will succeed. But if the waiting time after the grab is 1 slot then the grab will fail no matter what the waiting time after the give action is. But since we used a posix time of 10 slots as input for the give and grab action this is in contradiction with counting the time.

3.3 The Cardano testnet

Here we will show how to use the Cardano command line interface to deploy some code to the cardano test net or main net. To do this you must run a cardano node which you can find here:

https://github.com/input-output-hk/cardano-node

On the right side under Releases section click on the latest cardano node (Figure 9).

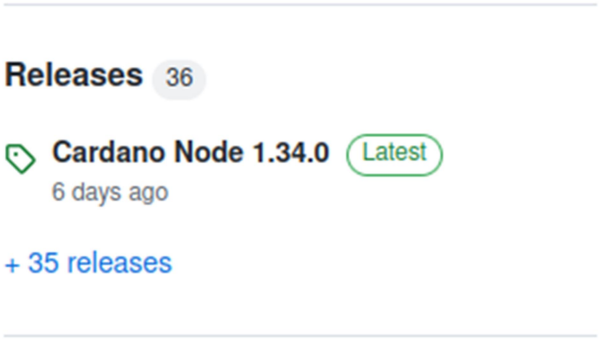

Figure 9 - Cardano node

Under the technical specifications chapter you have a downloads section where you can click on Hydra Binaries. A web-page opens where you can download your installer for a given OS. Once the cardano node is installed you can check your version with the command:

```
$ cardano-node --version
```

You will also need some configuration files which you can find again in the technical specifications chapter in the downloads section. Download the following test-net files:

- config
- byronGenesis
- shellyGenesis
- alonzoGenesis
- topology

Create a *testnet/* folder on your PC and put the files into that folder. Then put the file *start-node-testnet.sh* into that folder, which can be found in the week03 folder of the plutus-pioneer-program git repository. This bash script starts the cardano done.

When you start the node for the first time you will need to wait for a couple of hours for the test net to synchronize. Beside the cardano node also the Cardano command line interface (CLI) gets installed. You can look at the help page of the client with the command:

```
$ cardano-cli --help
```

You will get a list of top-level commands. If you want to search through a command use the same pattern and call the help page on this command to get available sub-commands:

```
$ caradno-cli address --help
```

You can repeat this procedure on a sub-command of the address command. To try out a Plutus contract we will need two keys. Use the following commands from within the *testnet* folder to create your two keys:

```
$ caradno-cli address key-gen --verification-key-file 01.vkey --signing-key-file 01.skey
$ caradno-cli address key-gen --verification-key-file 02.vkey --signing-key-file 02.skey
```

Next you will need to generate two payment addresses which will represent two wallets.

```
$ cardano-cli address build --payment-verification-key-file 01.vkey --testnet-magic
1097911063 –out-file 01.addr
$ cardano-cli address build --payment-verification-key-file 02.vkey --testnet-magic
1097911063 –out-file 02.addr
```

You can find the test-net magic number in the *testnet-shelley-genesis.json* configuration file. Now we need some test ADA to be able to make transactions on the test-net. For this we use something called the Faucet: https://testnets.cardano.org/en/testnets/cardano/tools/faucet/.

The faucet is a web-based service that provides test ADA to users of the test-net. On the above web-page you past in your address that you can find by viewing your 01.addr and 02.addr files and then complete the test that checks you not a robot. After that click on the Request funds button. If you want to see if the test ADA arrived you can query the blockchain:

```
$ export CARDANO_NODE_SOCKET_PATH=node.socket
$ cardano-cli query utxo --address $(cat 01.addr) --testnet-magic 1097911063
```

You should see on output of your the transaction hash and transaction index which together define an UTXO and information about how much ADA was sent. If you want to add funds to your second address and don't have an API key you will have to wait 24 hours to be able to send some test ADA again from the Faucet. An easier way is to send some ADA from you first address to your second address.

To send the ADA you can use the *send.sh* bash script which can be found in week03/testnet folder of the pioneer git repository. You will need to change the tx-in field with your transaction hash and the index specified after the # symbol. The transaction build command automatically calculates fees and creates change outputs in case your inputs are higher than the outputs.

There is a block on the Cardano test-net and main-net on average every twenty seconds so you will have to wait a bit before you check whether your transaction was processed. When it is you will have a new transaction has an UTXO that will contain the change ADA.

If we want now to use Plutus code in the cardano CLI we need to serialize and write to disk various Plutus types. We do this with the *Deploy.hs* code.

```
1   {-# LANGUAGE OverloadedStrings #-}
2   {-# LANGUAGE TypeApplications  #-}
3
4   module Week03.Deploy
5       ( writeJSON
6       , writeValidator
7       , writeUnit
8       , writeVestingValidator
9       ) where
10
11  import           Cardano.Api
12  import           Cardano.Api.Shelley   (PlutusScript (..))
13  import           Codec.Serialise       (serialise)
14  import           Data.Aeson            (encode)
15  import qualified Data.ByteString.Lazy  as LBS
16  import qualified Data.ByteString.Short as SBS
17  import           PlutusTx              (Data (..))
18  import qualified PlutusTx
19  import qualified Ledger
20
21  import           Week03.Parameterized
22
23  dataToScriptData :: Data -> ScriptData
24  dataToScriptData (Constr n xs) = ScriptDataConstructor n $
                                     dataToScriptData <$> xs
25  dataToScriptData (Map xs)      = ScriptDataMap [(dataToScriptData x,
                                     dataToScriptData y) | (x, y) <- xs]
26  dataToScriptData (List xs)     = ScriptDataList $ dataToScriptData <$> xs
27  dataToScriptData (I n)         = ScriptDataNumber n
28  dataToScriptData (B bs)        = ScriptDataBytes bs
29
```

```
30  writeJSON :: PlutusTx.ToData a => FilePath -> a -> IO ()
31  writeJSON file = LBS.writeFile file . encode . scriptDataToJson
                     ScriptDataJsonDetailedSchema . dataToScriptData .
                     PlutusTx.toData
32
33  writeValidator :: FilePath -> Ledger.Validator ->
                      IO (Either (FileError ()) ())
34  writeValidator file = writeFileTextEnvelope @(PlutusScript PlutusScriptV1)
                          file Nothing . PlutusScriptSerialised . SBS.toShort .
                          LBS.toStrict . serialise . Ledger.unValidatorScript
35
36  writeUnit :: IO ()
37  writeUnit = writeJSON "testnet/unit.json" ()
38
39  writeVestingValidator :: IO (Either (FileError ()) ())
40  writeVestingValidator = writeValidator "testnet/vesting.plutus" $
                            validator $ VestingParam
41                            { beneficiary = Ledger.PaymentPubKeyHash
                        "c2ff616e11299d9094ce0a7eb5b7284b705147a822f4ffbd471f971a"
42                            , deadline    = 1643235300000
43                            }
```

The *Cardano.Api* is the Haskell library which the cardano CLI uses. It has its own data type called *ScriptData*. With the *writeJSON* function we convert some Plutus data to script data and write it in a JSON format to a file (30-31). On lines 23 to 28 we define the conversion function *dataToScriptData*. Then we define the *writeUnit* function which basically writes a unit object to the specified file (36-37). We also need our Plutus validator script that we have to convert to a script and write it to a file. We do this with the *writeValidator* function (33-34). We want to apply this function to our parameterized contract. We do this with the *writeVestingValidator* IO action where we need to specify the beneficiary and the deadline. Note that we also use here our *validator* object which is available because we imported the *Week03.Parameterized* module, which is defined in the *Parameterized.hs* file.

We get the payment public key has of our second address with this command:

```
$ cardano-cli address key-hash --payment-verification-key-file 02.vkey –out-file 02.pkh
```

We copy the hash from the file 02.pkh and past it into the code for the IO action. We can get our deadline from epochconverter.com where we can specify the date and time and get back the POSIX time in milliseconds. We also need the actual address corresponding to the script. First we execute the command *writeVestingValidator* in the Repl. Then we execute:

```
$ cardano-cli address build-script --script-file vesting.plutus --testnet-magic
1097911063 --out-file vesting.addr
```

We can give now some ADA to the vesting address we just created. You can do this with the *give.sh* bash script also found in the testnet folder. In the *transaction build* command we use the *--tx-out-datum-hash-file* option that computes the hash of a datum written to a JSON file. After we run this script we can again check if the ADA arrived:

```
$ cardano-cli query utxo --address $(cat vesting.addr) --testnet-magic 1097911063
```

The second wallet wants now to grab that ADA and we can use the *grab.sh* bash script to do this. Since this is a spending transaction we need to provide also following things:

- The transaction hash and id which we provide in the *--tx-in* option.
- The actual script which we provide in the *--tx-in-script-file* option.
- The datum which we provide in the *--tx-in-datum-file* option. We get the unit datum if we load our *Deploy.hs* file in the Repl and execute the command *writeUnit*.
- The redeemer (same as the datum) which we provide in the *--tx-in-redeemer-file* option.
- In the *--tx-in-collateral* option you specify an UTXO that belongs to yourself and contains only ADA and no native tokens. It represents the collateral which must be large enough to cover the costs if validation would fail. This is a special case where you can circumvent the validation process and you would get a failed transaction. The nodes that process your transaction have to be reimbursed for that or the system would be open to denial of service attacks. We can use the 02.addr for collateral.
- In the *--required-signer-hash* field we specify the public key hash of our second address.
- The validity interval which we provide in the *--invalid-before* option. It has to be provided as slots. We get the current slot of the test-net with the command:

```
$ cardano-cli query tip --testnet-magic 1097911063
```

  The slot time we specify should be after our deadline.
- The protocol parameters which we provide in *--protocol-params-file* option. You get the content of the file with the command:

```
$ cardano-cli query protocol-parameters --testnet-magic 1097911063 --out-file
protocol.json
```

Once we configured everything the grab should work and if we would query the second address we should see that there are two UTXOs sitting at this address. For the main-net the procedure would be the same only that we would specify *--mainnet* option instead of *--testnet-magic*.

3.4 Homework

You can do the *Homework1.hs* and *Homework2.hs* examples by yourself. We will present here the solution and comment on it. For homework 1 we want to create a script address from which a beneficiary can retrieve his funds until a certain deadline. After the deadline we can retrieve the funds back to our own address. Here is the *Solution1.hs* code example.

```
1   import qualified Prelude as P
2
3   data VestingDatum = VestingDatum
4       { beneficiary1 :: PaymentPubKeyHash
5       , beneficiary2 :: PaymentPubKeyHash
6       , deadline     :: POSIXTime
7       } deriving P.Show
8
9   PlutusTx.unstableMakeIsData ''VestingDatum
10
11  {-# INLINABLE mkValidator #-}
12  mkValidator :: VestingDatum -> () -> ScriptContext -> Bool
13  mkValidator dat () ctx
14      | (unPaymentPubKeyHash (beneficiary1 dat) `elem` sigs) &&
          (to       (deadline dat) `contains` range) = True
15      | (unPaymentPubKeyHash (beneficiary2 dat) `elem` sigs) &&
          (from (1 + deadline dat) `contains` range) = True
16      | otherwise                                  = False
17    where
18      info :: TxInfo
19      info = scriptContextTxInfo ctx
20
21      sigs :: [PubKeyHash]
22      sigs = txInfoSignatories info
23
24      range :: POSIXTimeRange
25      range = txInfoValidRange info
26
27  grab :: forall w s e. AsContractError e => Contract w s e ()
28  grab = do
29      now    <- currentTime
30      pkh    <- ownPaymentPubKeyHash
31      utxos  <- utxosAt scrAddress
32      let utxos1 = Map.filter (isSuitable $ \dat -> beneficiary1 dat == pkh &&
                                 now <= deadline dat) utxos
33          utxos2 = Map.filter (isSuitable $ \dat -> beneficiary2 dat == pkh &&
                                 now >  deadline dat) utxos
```

```
34      logInfo @P.String $ printf "found %d gift(s) to grab"
                            (Map.size utxos1 P.+ Map.size utxos2)
35      unless (Map.null utxos1) $ do
36          let orefs   = fst <$> Map.toList utxos1
37              lookups = Constraints.unspentOutputs utxos1 P.<>
38                        Constraints.otherScript validator
39              tx :: TxConstraints Void Void
40              tx      = mconcat [Constraints.mustSpendScriptOutput oref
                                   unitRedeemer | oref <- orefs] P.<>
41                        Constraints.mustValidateIn (to now)
42          void $ submitTxConstraintsWith @Void lookups tx
43      unless (Map.null utxos2) $ do
44          let orefs   = fst <$> Map.toList utxos2
45              lookups = Constraints.unspentOutputs utxos2 P.<>
46                        Constraints.otherScript validator
47              tx :: TxConstraints Void Void
48              tx      = mconcat [Constraints.mustSpendScriptOutput oref $
                                   unitRedeemer | oref <- orefs] P.<>
49                        Constraints.mustValidateIn (from now)
50          void $ submitTxConstraintsWith @Void lookups tx
51    where
52      isSuitable :: (VestingDatum -> Bool) -> ChainIndexTxOut -> Bool
53      isSuitable p o = case _ciTxOutDatum o of
54          Left _          -> False
55          Right (Datum d) -> maybe False p $ PlutusTx.fromBuiltinData d
```

Compared to the *Vesting.hs* example our vesting datum changes were we add another beneficiary (3-7). Then our validator function changes were we cover 2 cases for which the transaction is valid (11-25). First the case the beneficiary retrieves the funds before the deadline. Second the case that the giver retrieves the funds after the deadline. The give function is practically the same as in the vesting example with the exception that the datum contains now 2 beneficiaries. The grab function however changes now. We construct 2 UTXO lists where for the first the current time should be before the deadline and for the second after (32-33). Then we define 2 cases where the first is that the first UTXO list is not empty and the second case is when the second UTXOs list is not empty. For each case we construct the transaction and submit it. The difference in the transactions is the validity interval (41 and 49). Some of the code is then the same as in the vesting example. The *isSuitable* function also changes. Now we take in a function and a transaction output and return a bool. We provide the functions in lines 32 and 33. In the body of the *isSuitable* function we use the *maybe* function which has following type signature:

```
maybe :: b -> (a -> b) -> Maybe a -> b
```

If the third parameter is a Nothing the first parameter is returned. Else we use the function a to b on the third parameter extracted from the Maybe to produce the result of type b. From the code in lines 52-55 and 32-33 we can see that the datum gets provided from an UTXO.

For homework 2 we want to modify the *Parameterized.hs* example in such a way that the input information is split between the additional parameter that will carry the payment public key hash and the datum that will carry the deadline. Here is the code.

```
1   import Prelude (IO, Semigroup (..), Show (..), String, undefined)
2
3   {-# INLINABLE mkValidator #-}
4   mkValidator :: PaymentPubKeyHash -> POSIXTime -> () -> ScriptContext -> Bool
5   mkValidator pkh s () ctx =
6       traceIfFalse "beneficiary's signature missing" checkSig      &&
7       traceIfFalse "deadline not reached"            checkDeadline
8     where
9       info :: TxInfo
10      info = scriptContextTxInfo ctx
11
12      checkSig :: Bool
13      checkSig = unPaymentPubKeyHash pkh `elem` txInfoSignatories info
14
15      checkDeadline :: Bool
16      checkDeadline = from s `contains` txInfoValidRange info
17
18  data Vesting
19  instance Scripts.ValidatorTypes Vesting where
20      type instance DatumType Vesting = POSIXTime
21      type instance RedeemerType Vesting = ()
22
23  typedValidator :: PaymentPubKeyHash -> Scripts.TypedValidator Vesting
24  typedValidator p = Scripts.mkTypedValidator @Vesting
25      ($$(PlutusTx.compile [|| mkValidator ||]) `PlutusTx.applyCode`
       PlutusTx.liftCode p)
26      $$(PlutusTx.compile [|| wrap ||])
27    where
28      wrap = Scripts.wrapValidator @POSIXTime @()
29
30  validator :: PaymentPubKeyHash -> Validator
31  validator = Scripts.validatorScript . typedValidator
32
33  scrAddress :: PaymentPubKeyHash -> Ledger.Address
```

```haskell
scrAddress = scriptAddress . validator

data GiveParams = GiveParams
    { gpBeneficiary :: !PaymentPubKeyHash
    , gpDeadline    :: !POSIXTime
    , gpAmount      :: !Integer
    } deriving (Generic, ToJSON, FromJSON, ToSchema)

type VestingSchema =
            Endpoint "give" GiveParams
        .\/ Endpoint "grab" ()

give :: AsContractError e => GiveParams -> Contract w s e ()
give gp = do
    let p  = gpBeneficiary gp
        d  = gpDeadline gp
        tx = Constraints.mustPayToTheScript d $ Ada.lovelaceValueOf $
             gpAmount gp
    ledgerTx <- submitTxConstraints (typedValidator p) tx
    void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
    logInfo @String $ printf "made a gift of %d lovelace
                             to %s with deadline %s"
        (gpAmount gp)
        (show $ gpBeneficiary gp)
        (show $ gpDeadline gp)

grab :: forall w s e. AsContractError e => Contract w s e ()
grab = do
    now   <- currentTime
    pkh   <- ownPaymentPubKeyHash
    utxos <- Map.filter (isSuitable now) <$> utxosAt (scrAddress pkh)
    if Map.null utxos
        then logInfo @String $ "no gifts available"
        else do
            let orefs   = fst <$> Map.toList utxos
                lookups = Constraints.unspentOutputs utxos        <>
                          Constraints.otherScript (validator pkh)
                tx :: TxConstraints Void Void
                tx      = mconcat [Constraints.mustSpendScriptOutput oref
                                   unitRedeemer | oref <- orefs] <>
                          Constraints.mustValidateIn (from now)
            ledgerTx <- submitTxConstraintsWith @Void lookups tx
            void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
            logInfo @String $ "collected gifts"
  where
```

```
76      isSuitable :: POSIXTime -> ChainIndexTxOut -> Bool
77      isSuitable now o = case _ciTxOutDatum o of
78          Left _          -> False
79          Right (Datum e) -> case PlutusTx.fromBuiltinData e of
80              Nothing -> False
81              Just d  -> d <= now
82
83  endpoints :: Contract () VestingSchema Text ()
84  endpoints = awaitPromise (give' `select` grab') >> endpoints
85    where
86      give' = endpoint @"give" give
87      grab' = endpoint @"grab" $ const grab
88
89  mkSchemaDefinitions ''VestingSchema
90
91  mkKnownCurrencies []
```

Compared to the parameterized example we import the undefined parameter with the standard Prelude. Next we create our validator function where the additional parameter carries the payment public key hash. There is now no need to create a vesting parameter type. The deadline is provided in the datum. For the helper functions there is a difference in the *checkSig* function (13) that now uses the *txInfoSignatories* function instead of the *txSignedBy* function. It basically gives you a list of all signatories. The instance for the vesting type also changes where the datum is now of type *POSIXTime* (20). And same holds true for the wrap function inside the type validator (28). The input parameter for the typed validator is now of type *PaymentPubKeyHash* (23) which is the same for the validator and script address. When constructing our endpoints the grab endpoint does not take in any parameter (44). For the give function the only difference is when we are constructing the transaction we specify the datum and input amount of lovelace (50). For the grab function we use rather the approach as in the *Vesting.hs* code example, where we filter out the UTXOs that have a suitable deadline (62). When we create the lookups we pass to the validator our own payment public key hash as input (68). When declaring the endpoints the grab endpoint has the *const* keyword prepended since it does not take any input parameters.

4 Monads, Traces & Contracts

In this chapter we will focus on the off-chain part of the Plutus contracts. The Plutus prelude contains functions that all have the INLINABLE pragma added which makes it possible to use these functions in the validation code that will then be compiled to Plutus core script. There are many Haskell libraries that weren't written taking into account the Plutus architecture so we can't use them for validation. For this reason the code for the validation script will be relatively simple and will not have many dependencies. The off-chain part however does not get compiled and is just Haskell code so we can use much more features in this code. The wallet code (off-chain code) is written in a special monad called the contract monad.

4.1 Monads

In this chapter we will briefly explain how monads in Haskell work. If you are familiar with this you can skip this chapter. Let's first look at input and output (IO). In Haskell we say to functions that work in the IO context actions. If you have a Haskell function that is not an action you can be sure it will always produce the same result given the same input parameters. This is called referential transparency. We also refer to the term "no side effects" which means that there is nothing from the outside world of a function that could be changing the state of the function. For example we can take a global variable that is used in a function and it could possibly change for setting a global state. For this reason also variables once they are declared in Haskell cannot be changed anymore except if we shadow it. An example of shadowing can be seen here:

```
foo = let x = 1
      in ((let x = 2 in x), x)
```

The final value of foo here is 2, which overwrote the value 1 set in the beginning. But such a case is rarely used in Haskell code. Haskell deals with side effects by using a IO type constructor that takes in one argument and is a member of the monad type class. This is then a IO action which is allowed to have side effects. An example of such an action is when we read some input from the terminal and compute a value from that input. The side effect here is that the input from the terminal can of course change. The monad type class implements 3 operators:

- the bind operator for which we use the >>= symbol
- the monad sequencing operator for which we use the >> symbol
- the return operator which for which se use the *return* keyword

Let's look at the type signatures of these three operators:

```
(>>=) :: m a -> (a -> m b) -> m b
```

```
(>>) :: m a -> m b -> m b
return :: a -> m a
```

First we explain the return operator. It simply take a value of type a and puts it into a context. So if we have for instance a String we can put it into a IO context with the following command:

```
ghci> a = return "Haskell" :: IO String
ghci> :t a
a :: IO String
```

Next let's explain the sequencing operator. From its type signature we would expect it takes as input two variables in a context and throws away the first one. Which is what it exactly does. This comes useful when you want to chain together function or action calls. For example let's look at code where we put together two *putStrLn* actions:

```
myText :: IO ()
myText = putStrLn "Learning" >> putStrLn "Haskell"

ghci> myText
Learning
Haskell
```

Now let's look at the final operator called bind which is the most useful one. It takes a type parameter in a context, then a function that converts the type specified in the first parameter but without the context to another type in a context which is then the result of this operator. So let's simply declare a variable that is of type *IO Int*, then a function that takes an *Int* and return and *IO Int* by adding 1 to it. And in the end we combine them with the bind operator.

```
monadExample1 :: IO Int
monadExample1 = do
  let a = return 1 :: IO Int
  let func var = return (var + 1) :: IO Int
  (a >>= func)
```

This function returns an *IO 2*. In case you are wondering what the *do* keyword does, it is a simplification or so called "syntactic sugar" for the following code:

```
monadExample :: IO Int
monadExample =
  (\a ->
    a >>=
      (\var ->
        return (var + 1) :: IO Int
      )
  ) (return 1 :: IO Int)
```

This code has the exact same meaning and also returns *IO 2*. So the *do* keyword allows us to more elegantly write an expression without having to use the lambda functions to connect our expressions. One more thing to mention is the use of the operator <- in the do notation. It allows us to take a parameter in a context and assign it to a variable without that context.

```
helloName :: IO ()
helloName = do
  putStrLn "What is your name?"
  name <- getLine
  putStrLn ("Hello " ++ name)

ghci> helloName
What is your name?
Luka
Hello Luka
```

The *getLine* function returns an *IO String*, but the name parameter is only of type *String*. You could rewrite this code without the do notation in the following form:

```
helloName :: IO ()
helloName =
  putStrLn "What is your name?" >>
  getLine >>=
  (\name -> return ("Hello " ++ name)) >>=
  putStrLn
```

What's important to note about the monad type class it supports other data constructors as well, not just IO. For instance also Maybe and Lists are also members of the monad type class. Let's have a look now at the Maybe type constructor. Here is the type signature:

```
data Maybe a = Nothing | Just a
```

It returns either a Nothing or a Just parameterized with the type a. Where can this type be used for example? For instance if we import the *readMaybe* function we can read a String and get a maybe value from it parameterized by a number type as integer.

```
ghci> import Text.Read (readMaybe)
ghci> readMaybe "42" :: Maybe Int
42
ghci> readMaybe "42 + text" :: Maybe Int
Nothing
```

Now we can show an example where we use the monad operators on a Maybe parameter. We want to write a function that takes 3 strings as input, then tries to convert them to integers and sums them together. The result will then be of type *Maybe Int*.

```haskell
import Text.Read (readMaybe)

foo :: String -> String -> String -> Maybe Int
foo x y z = case readMaybe x of
    Nothing -> Nothing
    Just k  -> case readMaybe y of
        Nothing -> Nothing
        Just l  -> case readMaybe z of
            Nothing -> Nothing
            Just m  -> Just (k + l + m)

bindMaybe :: Maybe a -> (a -> Maybe b) -> Maybe b
bindMaybe Nothing  _ = Nothing
bindMaybe (Just x) f = f x

foo' :: String -> String -> String -> Maybe Int
foo' x y z = readMaybe x `bindMaybe` \k ->
             readMaybe y `bindMaybe` \l ->
             readMaybe z `bindMaybe` \m ->
             Just (k + l + m)

foo'' :: String -> String -> String -> Maybe Int
foo'' x y z = threeInts (readMaybe x) (readMaybe y) (readMaybe z)

threeInts :: Monad m => m Int -> m Int -> m Int -> m Int
threeInts mx my mz =
    mx >>= \k ->
    my >>= \l ->
    mz >>= \m ->
    let s = k + l + m in return s

threeInts' :: Monad m => m Int -> m Int -> m Int -> m Int
threeInts' mx my mz = do
    k <- mx
    l <- my
    m <- mz
    let s = k + l + m
    return s
```

First we define our *foo* function with the use of nested case statements (3-10). Then we define a second version *foo'* which uses the helper function *bindMaybe* that basically works as the bind operator and is just defined for maybe values (12-14). With the help of this function and nested lambda expressions we create the *foo'* function (16-20). Now we define a third version called *foo''* that uses the helper function called *threeInts*. It takes as input three integers in a

monad context and with the help of the bind operator and nested lambda functions computes the sum and return the result again within the monad context (25-30). We could of course use the -> operator which is demonstrated in function *threeInts'* (32-38). Let's look now at another parameterized type called *Either*.

```
data Either a b = Left a | Right b
```

It is usually used in similar situations as Maybe but with a more descriptive option of returning another type instead of a Nothing if something goes wrong. The common way is to use the Left constructor to indicate the error and Right to return the result. We can now look at a similar code as before that uses the Either type instead of the Maybe type.

```
1   import Text.Read (readMaybe)
2
3   readEither :: Read a => String -> Either String a
4   readEither s = case readMaybe s of
5       Nothing -> Left $ "can't parse: " ++ s
6       Just a  -> Right a
7
8   foo :: String -> String -> String -> Either String Int
9   foo x y z = case readEither x of
10      Left err -> Left err
11      Right k  -> case readEither y of
12          Left err -> Left err
13          Right l  -> case readEither z of
14              Left err -> Left err
15              Right m  -> Right (k + l + m)
16
17  bindEither :: Either String a -> (a -> Either String b) -> Either String b
18  bindEither (Left err) _ = Left err
19  bindEither (Right x)  f = f x
20
21  foo' :: String -> String -> String -> Either String Int
22  foo' x y z = readEither x `bindEither` \k ->
23               readEither y `bindEither` \l ->
24               readEither z `bindEither` \m ->
25               Right (k + l + m)
26
27  foo'' :: String -> String -> String -> Either String Int
28  foo'' x y z = threeInts (readEither x) (readEither y) (readEither z)
```

With the *readEither* function we read a value from a string and return an error message if the string cannot be parsed to a value. The first version of the *foo* function uses again the nested case statements. Then we declare the *bindEither* function that has same structure as the

previous *bindMaybe* function. In our second version the *foo'* function we use *readEither*, *bindEither* and nested lambda functions similar to the maybe example. In the third version the *foo''* function has very little modifications compared to the maybe example. We replace only the read function with the either version but the *threeInts* function call stays the same. The reason for this is that it works purely with the monad type class and is not tied to a specific parameterized type as a maybe or a either type. Of course either is also a member of the monad type class which makes it possible for this function to work with either variables. Let's look now at the *Writer.hs* example where computations can produce also log outputs.

```
1   import Control.Monad
2
3   data Writer a = Writer a [String]
4       deriving Show
5
6   number :: Int -> Writer Int
7   number n = Writer n $ ["number: " ++ show n]
8
9   tell :: [String] -> Writer ()
10  tell xs = Writer () xs
11
12  foo :: Writer Int -> Writer Int -> Writer Int -> Writer Int
13  foo (Writer k xs) (Writer l ys) (Writer m zs) =
14    let
15      s = k + l + m
16      Writer _ us = tell ["sum: " ++ show s]
17    in
18      Writer s $ xs ++ ys ++ zs ++ us
19
20  bindWriter :: Writer a -> (a -> Writer b) -> Writer b
21  bindWriter (Writer a xs) f =
22    let
23      Writer b ys = f a
24    in
25      Writer b $ xs ++ ys
26
27  foo' :: Writer Int -> Writer Int -> Writer Int -> Writer Int
28  foo' x y z = x `bindWriter` \k ->
29               y `bindWriter` \l ->
30               z `bindWriter` \m ->
31               let s = k + l + m
32               in tell ["sum: " ++ show s] `bindWriter` \_ ->
33                  Writer s []
34
```

```
35  foo'' :: Writer Int -> Writer Int -> Writer Int -> Writer Int
36  foo'' x y z = do
37      s <- threeInts x y z
38      tell ["sum: " ++ show s]
39      return s
40
41  instance Functor Writer where
42      fmap = liftM
43
44  instance Applicative Writer where
45      pure = return
46      (<*>) = ap
47
48  instance Monad Writer where
49      return a = Writer a []
50      (>>=) = bindWriter
```

First we define our writer type and derive show. It contains the type variable and a list of strings that represents a log message. Second we define our *number* function which transforms an integer to a *Writer* type by adding a short description. Then we define the *tell* function that creates a writer from a string. For our *foo* function we take in three logging parameters of type *Writter Int* and produce a logging parameter of the same type. The function sums up the three parameters, concatenates the log messages and adds a "sum" log at the end. Next we write the *bindWriter* function that works as the bind operator for our *Writer* type. We can define our second version the *foo'* function with the bind function, four lambda function and the *tell* function. In the last example we use again our *threeInts* function but in order for this to work we need to make our writer type an instance of monad. Because the functor type class is a superclass of applicative and applicative is a superclass of monad we need to make also instances for those type classes. When defining the functor and applicative instances we use functions from the *Control.Monad* module that have basically same type signatures as functions that belong to the applicative and functor type classes. The code in lines 35 to 39 we could also rewrite without the do notation and it would look like this:

```
foo'' :: Writer Int -> Writer Int -> Writer Int -> Writer Int
foo'' x y z =
    threeInts x y z >>= \s ->
    tell ["sum: " ++ show s] >>
    return s
```

4.2 The emulator trace monad

The emulator trace monad enables you to run your code from the Repl instead of running the code on the Plutus playground. The word trace here defines actions that we would normally performe on the playground (e.g. defining initial conditions, performing give and grab actions). The *Emulator.Trace* type is defined in the *Plutus.Trace.Emulator* module. It is defined with the effect *Eff* monad. We run an emulator trace with the *runEmulatorTrace* function (Figure 10).

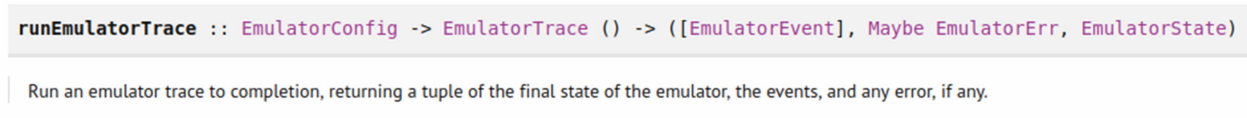

Figure 10 - Run emulator trace function

It takes in as input an *EmulatorConfig* and *EmulatorTrace* parameters. The emulator config (Figure 11) is an instance of the *Default* type class so if we import *Data.Default* we can make an default parameter. The command *def :: EmulatorConfig* will return an initial distribution of 10 wallets with each of them containing a 100 ADA with a default configuration for slots and fees.

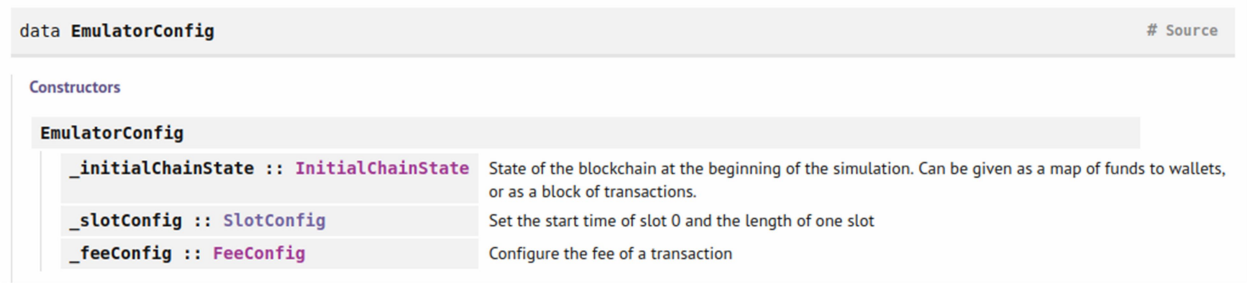

Figure 11 - Emulator config

There is also another function called *runEmulatorTracIO* that does not take in a config, it just uses the default configuration and it doesn't return the triple since it runs in IO. You can try to run it in the Repl with a unit emulator trace like this:

```
ghci> import Plutus.Trace.Emulator
ghci> import Data.Default
ghci> runEmulatorTracIO $ return ()
```

When running this function we get and output that first displays the genesis transaction that distributes the initial funds. Then we get a wait of 2 slots and after that we get the final balances. And because we didn't specify any transactions each of the 10 wallet has a 100 ADA. You usually specify an emulator config if you want to have more or less wallets or different initial funds. There is a variation of the IO function called *runEmulatorTracIO'*.

```
runEmulatorTraceIO' :: TraceConfig -> EmulatorConfig -> EmulatorTrace () -> IO ()
```

It takes in two additional parameters. The trace config has the following type signature.

```
TraceConfig
  :: (Wallet.Emulator.MultiAgent.EmulatorEvent' -> Maybe String)
     -> GHC.IO.Handle.Types.Handle -> TraceConfig
```

The first parameter is a function that basically filter out events that we are interested in and the second parameter is a handle with could represent the console standard output or error or it could be a file handle. We could use the file handle for displaying the output of the IO' function in a file. Now let's look at the *Trace.hs* file where we define a trace.

```
1   {-# LANGUAGE TypeApplications #-}
2   {-# LANGUAGE DataKinds        #-}
3
4   module Week04.Trace where
5
6   import Control.Monad.Freer.Extras as Extras
7   import Data.Default               (Default (..))
8   import Data.Functor               (void)
9   import Ledger.TimeSlot
10  import Plutus.Trace
11  import Wallet.Emulator.Wallet
12
13  import Week04.Vesting
14
15  -- EmulatorTrace a
16
17  test :: IO ()
18  test = runEmulatorTraceIO myTrace
19
20  myTrace :: EmulatorTrace ()
21  myTrace = do
22      h1 <- activateContractWallet (knownWallet 1) endpoints
23      h2 <- activateContractWallet (knownWallet 2) endpoints
24      callEndpoint @"give" h1 $ GiveParams
25          { gpBeneficiary = mockWalletPaymentPubKeyHash $ knownWallet 2
26          , gpDeadline    = slotToBeginPOSIXTime def 20
27          , gpAmount      = 10000000
28          }
29      void $ waitUntilSlot 20
30      callEndpoint @"grab" h2 ()
31      s <- waitNSlots 2
32      Extras.logInfo $ "reached " ++ show s
```

In addition to some standard Plutus modules we import also the *Vesting.hs* example (13). Then we define the emulator trace monad with a do block (21). Before we can call an endpoint we have to start the contract itself which we do in lines 22 and 23. As input parameter the function *activateContractWallet* takes the wallet on which to activate a contract and the contract itself. The result we get is a contract handle. The we call an endpoint with the *callEndpoint* function where we pass in a type level string which is defined with the @ symbol and works because we imported the language extension *TypeApplications*. We also pass in the handle and the input parameters (24-28). Then we wait until slot 20 where we use the *void* function that transforms a result to unit (29) and then call the grab endpoint from the wallet 2 (30). After that we wait another 2 slots and log a message.

4.3 The contract monad

The contract monad comes with four type parameters w, s, e and a. The a represents the result. The w allows the contract to write log messages. The purpose of this logging is to communicate between different contracts or pass information to the outside world. The s specifies what endpoints are available in the contract. The e specifies the type of error messages. Let's have a look now at some contract monad examples from the *Contract.hs* file.

```
1   {-# LANGUAGE OverloadedStrings #-}
2   {-# LANGUAGE TypeApplications  #-}
3   {-# LANGUAGE DataKinds         #-}
4   {-# LANGUAGE TypeOperators     #-}
5
6   module Week04.Contract where
7
8   import Control.Monad.Freer.Extras as Extras
9   import Data.Functor               (void)
10  import Data.Text                  (Text, unpack)
11  import Data.Void                  (Void)
12  import Plutus.Contract            as Contract
13  import Plutus.Trace.Emulator      as Emulator
14  import Wallet.Emulator.Wallet
15
16  -- Contract w s e a
17
18  myContract1 :: Contract () Empty Text ()
19  myContract1 = do
20      void $ Contract.throwError "BOOM!"
21      Contract.logInfo @String "hello from the contract"
22
```

```haskell
myTrace1 :: EmulatorTrace ()
myTrace1 = void $ activateContractWallet (knownWallet 1) myContract1

test1 :: IO ()
test1 = runEmulatorTraceIO myTrace1

myContract2 :: Contract () Empty Void ()
myContract2 = Contract.handleError
    (\err -> Contract.logError $ "caught: " ++ unpack err)
    myContract1

myTrace2 :: EmulatorTrace ()
myTrace2 = void $ activateContractWallet (knownWallet 1) myContract2

test2 :: IO ()
test2 = runEmulatorTraceIO myTrace2

type MySchema = Endpoint "foo" Int .\/ Endpoint "bar" String

myContract3 :: Contract () MySchema Text ()
myContract3 = do
    awaitPromise $ endpoint @"foo" Contract.logInfo
    awaitPromise $ endpoint @"bar" Contract.logInfo

myTrace3 :: EmulatorTrace ()
myTrace3 = do
    h <- activateContractWallet (knownWallet 1) myContract3
    callEndpoint @"foo" h 42
    callEndpoint @"bar" h "Haskell"

test3 :: IO ()
test3 = runEmulatorTraceIO myTrace3

myContract4 :: Contract [Int] Empty Text ()
myContract4 = do
    void $ Contract.waitNSlots 10
    tell [1]
    void $ Contract.waitNSlots 10
    tell [2]
    void $ Contract.waitNSlots 10

myTrace4 :: EmulatorTrace ()
myTrace4 = do
    h <- activateContractWallet (knownWallet 1) myContract4

```

```
68      void $ Emulator.waitNSlots 5
69      xs <- observableState h
70      Extras.logInfo $ show xs
71
72      void $ Emulator.waitNSlots 10
73      ys <- observableState h
74      Extras.logInfo $ show ys
75
76      void $ Emulator.waitNSlots 10
77      zs <- observableState h
78      Extras.logInfo $ show zs
79
80  test4 :: IO ()
81  test4 = runEmulatorTraceIO myTrace4
```

For the first example (18) we choose a contract where we do not want to write any log messages so we choose unit for w type parameter. We also do not need any endpoints so we choose the *Empty* type. For error messages we choose the type text. And we are also not interested in the result so we put a unit for type parameter a. First we throw and error message with the *throwError* function for which the input is of type Text (20). There are two possible *throwError* functions one from *Plutus.Trace.Emulator* module and the other from *Plutus.Contract* module. So we have to specify which one we are using. Then we log a message (21), which should not be confused with the w type variable which uses also a *logInfo* function from the *Control.Monad.Freer.Extras* module. This is just simple logging. The *logInfo* function is polymorphic which means it can take as input parameters various types so we specify the type of the string as @String. It could also be of type Text since we imported the *Data.Text* module and the *Overloaded* extension. We test the contract with *myTrace1* (23). There we activate the contract wallet and do not care about the result (24) and in the test statement we run the trace (26-27). For this example if we run it the log message from line 21 will not be shown because the contract will stop when the error on line 20 is thrown. So the execution of a contract is stopped at the point where an exception is raised.

In our next example we show how to catch and handle exceptions. We will run the contract1 but catch the exception. Contract 2 has the e variable of Void which means that it can't throw and error because void does not contain any variables in contrast to unit which contains one variable also called unit. The *handleError* function has the following type signature:

```
handleError :: (e -> Contract w s e' a) -> Contract w s e a -> Contract w s e' a
```

It takes a function and a contract as input parameters and if there is no error it returns the result of type a, if there is however an error the function is applied to the error type variable

and the contract produced by the function will be executed. When we call *handleError* we first provide the function (31) where the *err* variable is of type Text and the lambda function creates a contract where we only log the error which is now of type string. And then we add the first contract as input parameter. If we run now the test2 action we will catch the error, which means contract 1 will not be executed and instead the contract from the lambda function is executed. Let's look now at the third example where we take the s type parameter in account.

First we define a type synonym for the schema where endpoint types are declared (40). The "foo" and "bar" in this declarations are types not strings which is possible due to the *DataKinds* language extension. We use the type operator ".\/" that enables us to combine more endpoints and for that we need the *TypeOperators* language extension. Then we define contract 3 where we use the *endpoint* function.

```
endpoint :: (a -> Contract w s e b) -> Promise w s e b
```

This function takes in a function that changes the endpoint value a (in our case an *Int* or a *String*) to a contract and then returns a promise parameterized by the same types. A promise is a blocked contract waiting to be triggered by an outside stimulus, which would be in our case when a user tries to call the endpoint from his wallet and with an integer or a string as input. So when we call the *endpoint* function we first tell it which endpoint to invoke i.e. what will be the type of a (in our case an integer or a string) and then provide it with *logInfo* function which can take an integer or string and produce a contract that just logs that variable. With the *awaitPromise* function we turn a promise into a contract (44-45). In the trace action we now need the handle to be able to call an endpoint (49). The *callEndpoint* function takes in a contract handle and an endpoint value and then it invokes this endpoint. First we need to specify which endpoint to call and then we pass in our two parameters (50-51). If we look now at the off-chain code of the *Vesting.hs* contract we see how the give and grab contracts are called inside the endpoint contract. What we didn't describe in this example is the use of the *select* function that is used in the vesting endpoint contract. It takes in two contracts and returns the contract that makes progress first, discarding the other one.

In the final example 4 we look at the w type parameter that is responsible for communication between different contracts and the outside world. The w type cannot be of an arbitrary type but a type that is an instance of the type class monoid. We will use a list of integers which is an instance of monoid (56). In the body of our contract we first define a wait for 10 slots and throw away the result (58). Then we use the tell function that has following type signature:

```
tell :: w -> Contract w s e ()
```

So we provide a writer and the tell function creates a contract. We repeat this step two times (58-62). In the emulator trace we first activate the contract and then wait for 5 slots (66-68). We look up the state of a running contract with the *observableState* function. As argument it takes a handle of the running contract. Then we log the result we get (70). When we test this example we see that the first log returns just an empty list [], the second log returns [1] and the third log returns [1,2]. The state in the beginning is a *mempty* monoid and then each time you call the *tell* function the *mappend* function is used to update the state. On the real blockchain the user can interact with the contract by invoking endpoints and the contract can communicate back its state with the use of the *tell* function.

4.4 Homework

For this homework we want to write an emulator trace for a simple contract that pays some ADA to a give public key. The trace should take in 2 integer parameters that represent the amount of lovelace and it should call the pay contract twice. The recipient should be wallet two. Here is the code from the *Solution.hs* file.

```
1   {-# LANGUAGE DataKinds          #-}
2   {-# LANGUAGE DeriveAnyClass     #-}
3   {-# LANGUAGE DeriveGeneric      #-}
4   {-# LANGUAGE NumericUnderscores #-}
5   {-# LANGUAGE OverloadedStrings  #-}
6   {-# LANGUAGE TypeApplications   #-}
7   {-# LANGUAGE TypeOperators      #-}
8
9   module Week04.Solution where
10
11  import Data.Aeson             (FromJSON, ToJSON)
12  import Data.Functor           (void)
13  import Data.Text              (Text, unpack)
14  import GHC.Generics           (Generic)
15  import Ledger
16  import Ledger.Ada             as Ada
17  import Ledger.Constraints     as Constraints
18  import Plutus.Contract        as Contract
19  import Plutus.Trace.Emulator  as Emulator
20  import Wallet.Emulator.Wallet
21
22  data PayParams = PayParams
23      { ppRecipient :: PaymentPubKeyHash
24      , ppLovelace  :: Integer
25      } deriving (Show, Generic, FromJSON, ToJSON)
```

```
26
27  type PaySchema = Endpoint "pay" PayParams
28
29  payContract :: Contract () PaySchema Text ()
30  payContract = do
31      pp <- awaitPromise $ endpoint @"pay" return
32      let tx = mustPayToPubKey (ppRecipient pp) $ lovelaceValueOf $
                 ppLovelace pp
33      handleError (\err -> Contract.logInfo $ "caught error: " ++ unpack err) $
                    void $ submitTx tx
34      payContract
35
36  payTrace :: Integer -> Integer -> EmulatorTrace ()
37  payTrace x y = do
38      h <- activateContractWallet (knownWallet 1) payContract
39      let pkh = mockWalletPaymentPubKeyHash $ knownWallet 2
40      callEndpoint @"pay" h $ PayParams
41          { ppRecipient = pkh
42          , ppLovelace  = x
43          }
44      void $ Emulator.waitNSlots 1
45      callEndpoint @"pay" h $ PayParams
46          { ppRecipient = pkh
47          , ppLovelace  = y
48          }
49      void $ Emulator.waitNSlots 1
50
51  payTest1 :: IO ()
52  payTest1 = runEmulatorTraceIO $ payTrace 10_000_000 20_000_000
53
54  payTest2 :: IO ()
55  payTest2 = runEmulatorTraceIO $ payTrace 1000_000_000 20_000_000
```

First we create the type *PayParams* where we specify the recipient and the amount of lovelace we want to pay (22-25). Then we define the schema which has only the pay endpoint available. Next we define our pay contract that is parameterized by our schema and uses the Text type for the error message. In the first line of our contract we invoke the pay endpoint by immediately returning contract without any side effects (31). This means that we return the input parameters defined in the *PayParams* data type that are in a contract monad context. Next we create a transaction where we use the *mustPayToPubKey* function which takes in a public key hash (32). Then we handle the error when we submit the transaction. In our case the error will be triggered when we try to submit a transaction with a larger amount of lovelace than the wallet has available (33). Our trace will take in two parameters that represent the amount of

lovelace we want to pay. First we activate the contract and then we define the payment public key hash of wallet 2 (38-39).

Then we call our endpoints with the give parameters and wait for one slot after each endpoint call (40-49). In the end we create to IO actions that run our emulator traces with 2 different values. In the first run both payments should succeed but in the second run the first payment should produce an error because it tries to spend more funds as there are available. This error should be catched and the second payment should still be processed. Note that for the input values we are using numbers with underscores which is possible because we imported the *NumericUnderscores* language extension.

5 Native tokens

To be able to work with native tokens and ADA we need the modules *Plutus.V1.Ledger.Ada* and *Plutus.V1.Ledger.Value*. First we look at the value module where the type *Value* us defined.

Figure 12 - The Value type

Token name and currency symbol are just wrappers for the type *BuiltingByteString* that represents a byte string. These two byte strings define a native token or coin. The integer represents the amount of the currency. There is also another type called AssetClass (Figure 13).

Figure 13 - Asset class

It defines a assed class which is a native token or coin. A Value just says how many units of an asset class are contained in it. Now let's look at some examples from the Repl.

```
ghci> import Plutus.V1.Ledger.Value
ghci> import Plutus.V1.Ledger.Ada
ghci> :set –XoverloadedStrings
ghci> :t adaSymbol
adaSymbol :: CurrencySymbol
ghci> adaSymbol

ghci> :t adaToken
adaToken :: TokenName
ghci> adaToken
""
ghci> :t lovelaceValueOf
lovelaceValueOf :: Integer -> Value
ghci> lovelaceValueOf 123
Value (Map [(,Map [("",123)])])
```

We import the two modules and activate the language extension so we can enter byte strings as literal strings. Because both currency symbol and token name implement the *IsString* class we can enter both of them as literal strings. We see that the ADA currency symbol and token

name are just an empty byte string. We can create a value of 123 lovelace with the function *lovelaceValueOf*. Next we combine values and also create values that includes tokens.

```
ghci> lovelaceValueOf 123 <> lovelaceValueOf 10
Value (Map [(,Map [("",133)])])
ghci> :t singleton
singleton :: CurrencySymbol -> TokenName -> Integer -> Value
ghci> singleton "a8ff" "ABC" 7
Value (Map [(a8ff,Map [("ABC",7)])])
ghci> singleton "a8ff" "ABC" 7 <> lovelaceValueOf 42 <> singleton "a8ff" "XYZ" 100
Value (Map [(,Map [("",42)]),(a8ff,Map [("ABC",7),("XYZ",100)])])
ghci> let v = it
ghci> :t valueOf
valueOf :: Value -> CurrencySymbol -> TokenName -> Integer
ghci> valueOf v "a8ff" "XYZ"
100
ghci> valueOf v "a8ff" "abc"
0
ghci> :t flattenValue
flattenValue :: Value -> [(CurrencySymbol, TokenName, Integer)]
ghci> flattenValue v
[(,"",42),(a8ff,"XYZ",100),(a8ff,"ABC",7)]
```

Since Value is an instance of monoid and semigroup is a superclass of monoid we can use the <> operator for combining values. With the *singleton* function we can construct a value of just one asset class. For the currency symbol we can't use an arbitrary string. Instead we must use a hexadecimal value. We can also combine values that contain different native tokes and ADA. With the *it* keyword we get the previous result. The *valueOf* function extracts the given amount of lovelace or a token. The *flattenValue* function takes a value and returns a list of triples that contain information from the value parameter.

In general a transaction can't delete or create tokens. The inputs equal the outputs if we also take in account fees that need to be paid. Fees depend on the size of a transaction in bytes and on the scripts that need to be run to validate a transaction. The script takes more fees if it consumes more memory. The minting policies are responsible for managing tokens. The hexadecimal value that is the currency symbol represents the hash of the minting policy script. If we want to create or burn tokens the minting script has to be contained in the transaction which is then executed together with the validation script. The purpose of the minting script is to decide whether the given transaction is allowed to mint or burn tokens. And for ADA which has an empty string for the script hash, that means that there is no script which would allow minting or burning of ADA. All the ADA that exists comes from the genesis block and from monetary expansion. After each epoch rewards are paid and parts of these rewards come from monetary expansion where certain percentage of remaining reserves gets paid as rewards. The total amount of ADA in the system is fixed, it can never change.

5.1 Simple Minting Policy

So far when we looked at the *ScriptPurpose* type variable of the *ScriptContext* data type we were only concerned with the *Spending* constructor that takes as input a transaction reference. In the transaction information *TxInfo* data type we can specify a *Value* data type for the *txInfoMint* variable. Minting policies are triggered if this field contains a non-zero value. For each currency symbol defined in this field the corresponding minting policy is triggered. A minting policy has only two inputs, the redeemer and the context. The script purpose is then set to *Minting*. All of the minting policies contained in a transaction have to pass in order that the transaction passes, otherwise it fails. Let's look at a simple example now.

```
1   import           GHC.Generics           (Generic)
2   import           Plutus.Contract        as Contract
3   import           Plutus.Trace.Emulator  as Emulator
4   import qualified PlutusTx
5   import           PlutusTx.Prelude       hiding (Semigroup(..), unless)
6   import           Ledger                 hiding (mint, singleton)
7   import           Ledger.Constraints     as Constraints
8   import qualified Ledger.Typed.Scripts   as Scripts
9   import           Ledger.Value           as Value
10  import           Playground.Contract    (printJson, printSchemas, stage,
                                             ensureKnownCurrencies, ToSchema)
11  import           Playground.TH          (mkKnownCurrencies,
                                             mkSchemaDefinitions)
12  import           Playground.Types       (KnownCurrency (..))
13  import           Prelude                (IO, Show (..), String)
14  import           Text.Printf            (printf)
15  import           Wallet.Emulator.Wallet
16
17  {-# INLINABLE mkPolicy #-}
18  mkPolicy :: () -> ScriptContext -> Bool
19  mkPolicy () _ = True
20
21  policy :: Scripts.MintingPolicy
22  policy = mkMintingPolicyScript $$(PlutusTx.compile
                                      [|| Scripts.wrapMintingPolicy mkPolicy ||])
23
24  curSymbol :: CurrencySymbol
25  curSymbol = scriptCurrencySymbol policy
26
27  data MintParams = MintParams
28      { mpTokenName :: !TokenName
29      , mpAmount    :: !Integer
30      } deriving (Generic, ToJSON, FromJSON, ToSchema)
```

```
31
32  type FreeSchema = Endpoint "mint" MintParams
33
34  mint :: MintParams -> Contract w FreeSchema Text ()
35  mint mp = do
36      let val     = Value.singleton curSymbol (mpTokenName mp) (mpAmount mp)
37          lookups = Constraints.mintingPolicy policy
38          tx      = Constraints.mustMintValue val
39      ledgerTx <- submitTxConstraintsWith @Void lookups tx
40      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
41      Contract.logInfo @String $ printf "forged %s" (show val)
42
43  endpoints :: Contract () FreeSchema Text ()
44  endpoints = mint' >> endpoints
45    where
46      mint' = awaitPromise $ endpoint @"mint" mint
47
48  mkSchemaDefinitions ''FreeSchema
49
50  mkKnownCurrencies []
51
52  test :: IO ()
53  test = runEmulatorTraceIO $ do
54      let tn = "ABC"
55      h1 <- activateContractWallet (knownWallet 1) endpoints
56      h2 <- activateContractWallet (knownWallet 2) endpoints
57      callEndpoint @"mint" h1 $ MintParams
58          { mpTokenName = tn
59          , mpAmount    = 555
60          }
61      callEndpoint @"mint" h2 $ MintParams
62          { mpTokenName = tn
63          , mpAmount    = 444
64          }
65      void $ Emulator.waitNSlots 1
66      callEndpoint @"mint" h1 $ MintParams
67          { mpTokenName = tn
68          , mpAmount    = -222
69          }
70      void $ Emulator.waitNSlots 1
```

First we create the *mkPolicy* function that represents the policy and will also be compiled to Plutus Core (35-37). We use unit for the redeemer and return a bool, which is used in the typed version. Our minting policy will always return *True* no matter the context.

Then we compile the minting policy (39-40). We use the *mkMintingPolicyScript* function to create the minting policy script and with the *wrapMintingPolicy* function we convert our typed version to an un-typed version before we compile it. Because we use this function we also need to add the *INLINABLE* pragma before the *mkPolicy* function. Next we can get the currency symbol with the function *scriptCurrencySymbol* where we need to provide as input the compiled minting policy. The output is the hash of the script. Similar to how we parameterized validators we could also do this with minting policies. This completes the on-chain part.
For the off-chain part we first declare our minting parameters where we specify the token name and the amount (45-48). If the amount is a positive number we mint tokens and if it is a negative number we burn tokens. Then we define the schema with only one endpoint called mint (50). The mint contract takes minting parameters as input. In the body of the contract we first compute the Value that we want to forge (54). As lookups we specify the minting policy. The only constrain we put on our transaction is *mustMintValue* function that takes as input the previously defined Value. We can skip the redeemer since it has the value of unit. When we submit the transaction it will automatically transfer the minted value to the wallet if it is positive. If it is negative it will try to find sufficiently many tokens in the users wallet that will then be burned. After that we wait for confirmation and then log a message. The endpoint contract then follows the same pattern as in previous examples. In the end we define a emulator trace where we mint and burn some tokens in wallet 1 and 2 (70-88). One thing to notice is that when we try this out on the playground the UTXO that gets assigned the tokens will also get 2 ADA assigned which is the minimum UTXO value of ADA. For the actual Cardano blockchain this value can be different.

5.2 More Realistic Minting Policy

Now we will look at a minting policy that is parameterized by a payment public key hash. The minting or burning of the tokens will only be allowed if the owner of that key has signed the transaction. Here is the code from the *Signed.hs* example.

```
1   {-# INLINABLE mkPolicy #-}
2   mkPolicy :: PaymentPubKeyHash -> () -> ScriptContext -> Bool
3   mkPolicy pkh () ctx = txSignedBy (scriptContextTxInfo ctx) $
                          unPaymentPubKeyHash pkh
4
5   policy :: PaymentPubKeyHash -> Scripts.MintingPolicy
6   policy pkh = mkMintingPolicyScript $
7       $$(PlutusTx.compile [|| Scripts.wrapMintingPolicy . mkPolicy ||])
8       `PlutusTx.applyCode`
9       PlutusTx.liftCode pkh
```

```
10
11  curSymbol :: PaymentPubKeyHash -> CurrencySymbol
12  curSymbol = scriptCurrencySymbol . policy
13
14  data MintParams = MintParams
15      { mpTokenName :: !TokenName
16      , mpAmount    :: !Integer
17      } deriving (Generic, ToJSON, FromJSON, ToSchema)
18
19  type FreeSchema = Endpoint "mint" MintParams
20
21  mint :: MintParams -> Contract w FreeSchema Text ()
22  mint mp = do
23      pkh <- Contract.ownPaymentPubKeyHash
24      let val     = Value.singleton (curSymbol pkh) (mpTokenName mp)
                                      (mpAmount mp)
25          lookups = Constraints.mintingPolicy $ policy pkh
26          tx      = Constraints.mustMintValue val
27      ledgerTx <- submitTxConstraintsWith @Void lookups tx
28      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
29      Contract.logInfo @String $ printf "forged %s" (show val)
```

We add only the functions and parameters that changed compared to the previous *Free.hs* example. First we create our policy function that takes now the payment public key hash as an additional parameter (1-3). We use the *txSignedBy* function to check whether the transaction was signed with the given public key. Here is its type signature.

```
txSignedBy :: TxInfo -> PubKeyHash -> Bool
```

Next we compile the policy function where we use now the same pattern as in our *Parameterized.hs* code (5-9). Then we create the currency symbol which now takes in the public key as a parameter (11-12). For the off-chain code we declare the minting parameters and the schema the same way as in the *Free.hs* code. And for the mint function what changes is that we first look up our own payment public key hash for which we use the function from the *Contract* module to avoid collision for the same function from another module. Then we also change the value and the lookups declaration. When defining the value we add to the currency symbol our public payment key hash as input parameter and for the lookups we do the same for the policy parameter (24-25).

When writing Plutus code try to compile it as often as possible to avoid multiple errors at the end when running it in tha playground.

If we run now the test trace we notice something interesting. When checking the balances of the wallets we see that the currency symbol for the token that wallet one and two got, is different. That was not the case with our first example. The token name is still the same. The reason for this is that the minting script is now longer a constant but is a function so the same is true for the hash of the script which represents the currency symbol. And because the input parameter is the wallet public payment key hash which is different for wallet 1 and wallet 2 also the currency symbol for those two wallets gets computed differently. So the wallets contain now two different tokens or asset classes.

5.3 NFT-s

Non fungible tokens can exist only once, which means there is only one token in existence. This means we have to put a constraint on our transaction and say that only one token is allowed to be minted and that the transaction that triggers the mint can be executed only once. In order to do that we need something on the Cardano blockchain that we can refer to in our minting policy and is unique i.e. it exists only in one transaction. And the trick is we use a UTXO, since it can exist only once and when consumed in a transaction it is never again available. If there is another UTXO sitting at the same address with the same value and datum it still has another ID. We identify an UTXO with the transaction ID that produced it and the index it got assigned, since a transaction can produce more than one UTXO. And transactions are unique, there can never be the same transaction again. They are unique because they spend fees which come from UTXOs and they themselves are unique. Which brings us to an induction. So the idea is that we name a specific UTXO as parameter to our minting policy and then we check that the transaction that does the minting consumes this UTXO. Let's look at the *NFT.hs* code.

```
1   -- import Playground.Contract (printJson, printSchemas,
                                  ensureKnownCurrencies, stage, ToSchema)
2   -- import Playground.TH       (mkKnownCurrencies, mkSchemaDefinitions)
3   -- import Playground.Types    (KnownCurrency (..))
4   import qualified Data.Map as Map
5   import           Prelude  (IO, Semigroup (..), Show (..), String)
6
7   {-# INLINABLE mkPolicy #-}
8   mkPolicy :: TxOutRef -> TokenName -> () -> ScriptContext -> Bool
9   mkPolicy oref tn () ctx = traceIfFalse
                              "UTxO not consumed" hasUTxO &&
10                            traceIfFalse "wrong amount minted"
                              checkMintedAmount
11    where
12      info :: TxInfo
```

```
13      info = scriptContextTxInfo ctx
14
15      hasUTxO :: Bool
16      hasUTxO = any (\i -> txInInfoOutRef i == oref) $ txInfoInputs info
17
18      checkMintedAmount :: Bool
19      checkMintedAmount = case flattenValue (txInfoMint info) of
20          [(_, tn', amt)] -> tn' == tn && amt == 1
21          _               -> False
22
23  policy :: TxOutRef -> TokenName -> Scripts.MintingPolicy
24  policy oref tn = mkMintingPolicyScript $
25      $$(PlutusTx.compile [|| \oref' tn' -> Scripts.wrapMintingPolicy $
           mkPolicy oref' tn' ||])
26          `PlutusTx.applyCode`
27          PlutusTx.liftCode oref
28          `PlutusTx.applyCode`
29          PlutusTx.liftCode tn
30
31  curSymbol :: TxOutRef -> TokenName -> CurrencySymbol
32  curSymbol oref tn = scriptCurrencySymbol $ policy oref tn
33
34  data NFTParams = NFTParams
35      { npToken   :: !TokenName
36      , npAddress :: !Address
37      } deriving (Generic, FromJSON, ToJSON, Show)
38
39  type NFTSchema = Endpoint "mint" NFTParams
40
41  mint :: NFTParams -> Contract w NFTSchema Text ()
42  mint np = do
43      utxos <- utxosAt $ npAddress np
44      case Map.keys utxos of
45          []       -> Contract.logError @String "no utxo found"
46          oref : _ -> do
47              let tn      = npToken np
48              let val     = Value.singleton (curSymbol oref tn) tn 1
49                  lookups = Constraints.mintingPolicy (policy oref tn) <>
                              Constraints.unspentOutputs utxos
50                  tx      = Constraints.mustMintValue val <>
                              Constraints.mustSpendPubKeyOutput oref
51              ledgerTx <- submitTxConstraintsWith @Void lookups tx
52              void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
53              Contract.logInfo @String $ printf "forged %s" (show val)
54
```

```
55  endpoints :: Contract () NFTSchema Text ()
56  endpoints = mint' >> endpoints
57    where
58      mint' = awaitPromise $ endpoint @"mint" mint
59
60  test :: IO ()
61  test = runEmulatorTraceIO $ do
62      let tn = "ABC"
63          w1 = knownWallet 1
64          w2 = knownWallet 2
65      h1 <- activateContractWallet w1 endpoints
66      h2 <- activateContractWallet w2 endpoints
67      callEndpoint @"mint" h1 $ NFTParams
68          { npToken   = tn
69          , npAddress = mockWalletAddress w1
70          }
71      callEndpoint @"mint" h2 $ NFTParams
72          { npToken   = tn
73          , npAddress = mockWalletAddress w2
74          }
75      void $ Emulator.waitNSlots 1
```

Compared to our previous code example we do not use the Playground modules and we add the Map module and add Semigroup to the Prelude module. In the *mkPolicy* function we have now 2 additional parameters, the transaction output reference and the token name (8). In the body of this function we check that the UTXO is consumed and that we mint only 1 token. For the helper functions we first get the script context info. Then for the *hasUTxO* parameter we use the *txInfoInputs* helper function of the *TxInfo* type that gives us a list of transaction inputs that are of type *TxInInfo* (15-16). This type has the following structure (Figure 14).

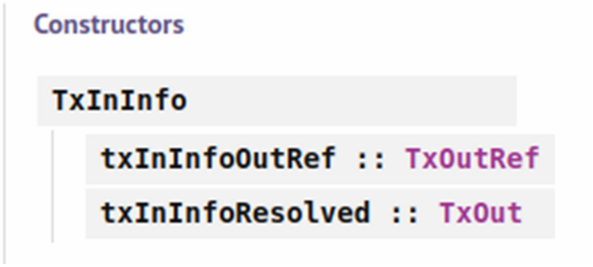

Figure 14 - Transaction input info

For the *checkMintedAmount* parameter we check that that the list we get from the minted info field contains only one triple and that the name and quantity match (18-21). Next we define our policy that has now the transaction output reference and token name as input parameters and same holds true for the currency symbol (23-32).

For the off-chain code we create our NFT parameters type variable where we define the token name and the contract address (34-37). In the schema we define only one endpoint called mint (39). In the body of the mint contract we first lookup all the UTXOs sitting at the given address (43). In the map that we get the keys that represent the *txOutRefs*. If there are none we log an error message and if there is at least one we take the 1st one (it could be any one). After that we get the token name and define the value, lookups and transaction. For the currency symbol and policy we have to provide our input parameters. For the lookups in the *unspentOutputs* function we could specify only the one UTXO that we need but we can also give a Map of UTXOs and the one we need just has to be contained in the Map (49). For the transaction we put a constrain that the given value must be minted and the transaction we are constructing spends the given output reference for our UTXO (50). This line of code ensures that the transaction can be performed only one, since we are referencing in a transaction a UTXO that will be unavailable after this transaction completes. After that we submit the transaction, wait for confirmation and log a message. Our endpoints definition follows the same pattern as before (55-58). In our emulator trace we define a token name and start the contract for wallet one and wallet two. Then we call the mint endpoint for the first and second wallet and wait for one slot that the transactions can be processed. The *mockWalletAddress* functions takes as input a wallet and produces an address. This works only for playground wallets. And again when we run the code we end up with two different currency symbols which means the NTFs that wallet 1 and 2 contain are unique.

5.4 Homework

For the first homework we want to implement a Marry era style monetary policy. What you are allowed to do is that you can specify signatures that have to be present in the minting transaction and specify the deadline that says minting can only happen before a certain deadline. So we want to create a minting policy that has 2 parameters, a public key hash and POSIX time. And the transaction should only succeed if it is signed by the corresponding signature and if the deadline has not passed. Let's look at the code *Solution1.hs*.

```
1   import Data.Default    (Default (..))
2   import Ledger.TimeSlot
3   import Prelude         (IO, Semigroup (..), Show (..), String)
4
5   {-# INLINABLE mkPolicy #-}
6   -- This policy should only allow minting (or burning) of tokens if the owner
    -- of the specified PaymentPubKeyHash has signed the transaction and if the
7   -- specified deadline has not passed.
8   mkPolicy :: PaymentPubKeyHash -> POSIXTime -> () -> ScriptContext -> Bool
```

```
9   mkPolicy pkh deadline () ctx =
10      traceIfFalse "signature missing" (txSignedBy info $
                                          unPaymentPubKeyHash pkh) &&
11      traceIfFalse "deadline missed"   (to deadline `contains`
                                          txInfoValidRange info)
12    where
13      info = scriptContextTxInfo ctx
14
15  policy :: PaymentPubKeyHash -> POSIXTime -> Scripts.MintingPolicy
16  policy pkh deadline = mkMintingPolicyScript $
17      $$(PlutusTx.compile [|| \pkh' deadline' -> Scripts.wrapMintingPolicy $
                                                   mkPolicy pkh' deadline' ||])
18      `PlutusTx.applyCode`
19      PlutusTx.liftCode pkh
20      `PlutusTx.applyCode`
21      PlutusTx.liftCode deadline
22
23  curSymbol :: PaymentPubKeyHash -> POSIXTime -> CurrencySymbol
24  curSymbol pkh deadline = scriptCurrencySymbol $ policy pkh deadline
25
26  data MintParams = MintParams
27      { mpTokenName :: !TokenName
28      , mpDeadline  :: !POSIXTime
29      , mpAmount    :: !Integer
30      } deriving (Generic, ToJSON, FromJSON, ToSchema)
31
32  type SignedSchema = Endpoint "mint" MintParams
33
34  mint :: MintParams -> Contract w SignedSchema Text ()
35  mint mp = do
36      pkh <- Contract.ownPaymentPubKeyHash
37      now <- Contract.currentTime
38      let deadline = mpDeadline mp
39      if now > deadline
40          then Contract.logError @String "deadline passed"
41          else do
42              let val     = Value.singleton (curSymbol pkh deadline)
                                              (mpTokenName mp) (mpAmount mp)
43                  lookups = Constraints.mintingPolicy $ policy pkh deadline
44                  tx      = Constraints.mustMintValue val <>
                              Constraints.mustValidateIn (to $ now + 60000)
45              ledgerTx <- submitTxConstraintsWith @Void lookups tx
46              void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
47              Contract.logInfo @String $ printf "forged %s" (show val)
48
```

```
49  endpoints :: Contract () SignedSchema Text ()
50  endpoints = mint' >> endpoints
51    where
52      mint' = awaitPromise $ endpoint @"mint" mint
53
54  mkSchemaDefinitions ''SignedSchema
55
56  mkKnownCurrencies []
57
58  test :: IO ()
59  test = runEmulatorTraceIO $ do
60      let tn       = "ABC"
61          deadline = slotToBeginPOSIXTime def 100
62      h <- activateContractWallet (knownWallet 1) endpoints
63      callEndpoint @"mint" h $ MintParams
64          { mpTokenName = tn
65          , mpDeadline  = deadline
66          , mpAmount    = 555
67          }
68      void $ Emulator.waitNSlots 110
69      callEndpoint @"mint" h $ MintParams
70          { mpTokenName = tn
71          , mpDeadline  = deadline
72          , mpAmount    = 555
73          }
74      void $ Emulator.waitNSlots 1
```

Compared to the *Signed.hs* code example we make two new imports and add the Semigroup type class to the Prelude import. Then we define our policy function where we take 2 input parameters: the payment public key hash and the deadline (8). Next we check that the correct signature is present and that the validity interval is before now (9-13). After that we compile the policy function and define the currency symbol (15-24). For the off-chain code we first define our minting parameters that include the token name, deadline and amount (26-30). For the schema we have only the mint endpoint. In the mint contract we get our own public key hash and the current POSIX time. If the current time is before the deadline we proceed with actions if not we just log a message. First we define the value where the currency symbol takes in our two parameters (42). Same is true for policy parameter in the lookups variable (43). When we construct the transaction we say which value should be minted and define the validity interval for the transaction (44). Then we submit the transaction, wait for confirmation and log a message. We define our endpoints contract as usual and create a schema definition and some currencies for the playground. In the emulator trace we define our token name and

deadline. Then we activate the contract for wallet one and call our first endpoint. After that we wait for 110 slots and then call again the endpoint. This second call should fail since the deadline will already pass and we should not be able to mint any tokens. For our second homework we want to create a similar minting policy as in the *NFT.hs* example where we fix the token name to an empty byte string. Let's look at the code example from *Solution2.hs*.

```
{-# INLINABLE tn #-}
tn :: TokenName
tn = TokenName emptyByteString

{-# INLINABLE mkPolicy #-}
-- Minting policy for an NFT, where the minting transaction must consume the
-- given UTxO as input and where the TokenName will be the empty ByteString.
mkPolicy :: TxOutRef -> () -> ScriptContext -> Bool
mkPolicy oref () ctx = traceIfFalse "UTxO notconsumed"    hasUTxO &&
                       traceIfFalse "wrong amount minted" checkMintedAmount
  where
    info :: TxInfo
    info = scriptContextTxInfo ctx

    hasUTxO :: Bool
    hasUTxO = any (\i -> txInInfoOutRef i == oref) $ txInfoInputs info

    checkMintedAmount :: Bool
    checkMintedAmount = case flattenValue (txInfoMint info) of
        [(cs, tn', amt)] -> cs  == ownCurrencySymbol ctx &&
                            tn' == tn && amt == 1
        _                -> False

policy :: TxOutRef -> Scripts.MintingPolicy
policy oref = mkMintingPolicyScript $
    $$(PlutusTx.compile [|| Scripts.wrapMintingPolicy . mkPolicy ||])
    `PlutusTx.applyCode`
    PlutusTx.liftCode oref

curSymbol :: TxOutRef -> CurrencySymbol
curSymbol = scriptCurrencySymbol . policy

type NFTSchema = Endpoint "mint" Address

mint :: Address -> Contract w NFTSchema Text ()
mint addr = do
    utxos <- utxosAt addr
    case Map.keys utxos of
```

```
38          []       -> Contract.logError @String "no utxo found"
39          oref : _ -> do
40              let val     = Value.singleton (curSymbol oref) tn 1
41                  lookups = Constraints.mintingPolicy (policy oref) <>
                              Constraints.unspentOutputs utxos
42                  tx      = Constraints.mustMintValue val <>
                              Constraints.mustSpendPubKeyOutput oref
43              ledgerTx <- submitTxConstraintsWith @Void lookups tx
44              void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
45              Contract.logInfo @String $ printf "forged %s" (show val)
46
47  endpoints :: Contract () NFTSchema Text ()
48  endpoints = mint' >> endpoints
49    where
50      mint' = awaitPromise $ endpoint @"mint" mint
51
52  test :: IO ()
53  test = runEmulatorTraceIO $ do
54      let w1 = knownWallet 1
55          w2 = knownWallet 2
56      h1 <- activateContractWallet w1 endpoints
57      h2 <- activateContractWallet w2 endpoints
58      callEndpoint @"mint" h1 $ mockWalletAddress w1
59      callEndpoint @"mint" h2 $ mockWalletAddress w2
60      void $ Emulator.waitNSlots 1
```

First we define our token name which is an empty byte string. Then we define our policy function that takes now as input only the transaction output reference (8). The first helper function that checks the transaction output reference is the same as in the NFT example. The second helper function however changes. There we can now compare the currency symbol, the token name and the amount (18-20). The token name is now a fixed variable rather than an input parameter. We compile our policy where we have now only one parameter and define the currency symbol (23-30). Next comes the off-chain code. When defining the schema we take as input only the address which is also the input for the mint contract. The mint contract compared to the NFT example is very similar. What changes is the definition of the value and lookups variables where we provide for the currency symbol and the policy only one parameter (40-41). In the emulator trace we now do not need to define a token name but only pass in the address as input when calling the endpoint.

6 Deployment

In this lecture we will get to know the PAB - Plutus application backend. The PAB provides the components and an environment to help developers create and test DApps (decentralized applications), before deploying them to a live production environment. The PAB is a single Haskell library that makes it easier to write the off-chain infrastructure and the on-chain scripts [5]. We will see how to use the PAB to interact with contracts on the Cardano testnet and show an example how to mint native tokens on the testnet using the Cardano CLI and PAB.

6.1 The minting policy

In this chapter we will present the on-chain code found in the file week06/Token/OnChain.hs. The code is similar to the NFT example. Let's look at the code.

```
1   {-# LANGUAGE DataKinds           #-}
2   {-# LANGUAGE DeriveAnyClass      #-}
3   {-# LANGUAGE DeriveGeneric       #-}
4   {-# LANGUAGE FlexibleContexts    #-}
5   {-# LANGUAGE NoImplicitPrelude   #-}
6   {-# LANGUAGE NumericUnderscores  #-}
7   {-# LANGUAGE OverloadedStrings   #-}
8   {-# LANGUAGE ScopedTypeVariables #-}
9   {-# LANGUAGE TemplateHaskell     #-}
10  {-# LANGUAGE TypeApplications    #-}
11  {-# LANGUAGE TypeFamilies        #-}
12  {-# LANGUAGE TypeOperators       #-}
13
14  module Week06.Token.OnChain
15      ( tokenPolicy
16      , tokenCurSymbol
17      ) where
18
19  import qualified PlutusTx
20  import           PlutusTx.Prelude           hiding (Semigroup(..), unless)
21  import           Ledger                     hiding (mint, singleton)
22  import qualified Ledger.Typed.Scripts       as Scripts
23  import           Ledger.Value               as Value
24
25  {-# INLINABLE mkTokenPolicy #-}
26  mkTokenPolicy :: TxOutRef -> TokenName -> Integer ->
                     () -> ScriptContext -> Bool
27  mkTokenPolicy oref tn amt () ctx = traceIfFalse "UTxO not consumed" hasUTxO
28                      && traceIfFalse "wrong amount minted" checkMintedAmount
```

```
29    where
30      info :: TxInfo
31      info = scriptContextTxInfo ctx
32
33      hasUTxO :: Bool
34      hasUTxO = any (\i -> txInInfoOutRef i == oref) $ txInfoInputs info
35
36      checkMintedAmount :: Bool
37      checkMintedAmount = case flattenValue (txInfoMint info) of
38          [(_, tn', amt')] -> tn' == tn && amt' == amt
39          _                -> False
40
41  tokenPolicy :: TxOutRef -> TokenName -> Integer -> Scripts.MintingPolicy
42  tokenPolicy oref tn amt = mkMintingPolicyScript $
43      $$(PlutusTx.compile [|| \oref' tn' amt' -> Scripts.wrapMintingPolicy $
                               mkTokenPolicy oref' tn' amt' ||])
44      `PlutusTx.applyCode`
45      PlutusTx.liftCode oref
46      `PlutusTx.applyCode`
47      PlutusTx.liftCode tn
48      `PlutusTx.applyCode`
49      PlutusTx.liftCode amt
50
51  tokenCurSymbol :: TxOutRef -> TokenName -> Integer -> CurrencySymbol
52  tokenCurSymbol oref tn = scriptCurrencySymbol . tokenPolicy oref tn
```

First we define our token policy that takes in three additional parameters: the transaction output reference, token name and the amount of tokens we want to create. In the NFT example the amount was not necessary since we wanted to create only one token. In the body of the function we check that the referenced UTXO is consumed and that the token name and quantity match (27-39). Then we compile our token policy function and create the currency symbol. All together this code represents the on-chain part.

6.2 Minting with the CLI

We will use now the command line interface to mint tokens. If we recall chapter 3 where we already used the CLI we remember that we needed the serialized script that will now be computed from our minting policy instead of a validator. If we check in the documentation for the type *MintingPolicy* we see it's just a wrapper around the *Script* type (Figure 15). Also the type *Validator* is a wrapper around the script type. We define various helper functions in the *Utils.hs* file. There we have the *writeMintingPolicy* function that will create our serialized script.

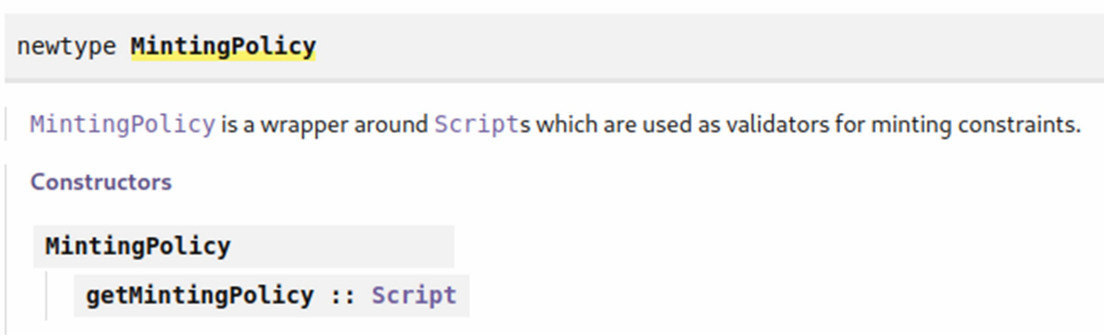

Figure 15 - Minting policy

Let's have look now at the transaction output reference type (Figure 16). The picture shows us that a UTXO is specified by a reference to the transaction that created it which is represented by the *TxId* type and an index which gets assigned to each of the UTXOs a transaction has produced. The *TxId* type is just a newtype wrapper around the *BuiltinByteString* type.

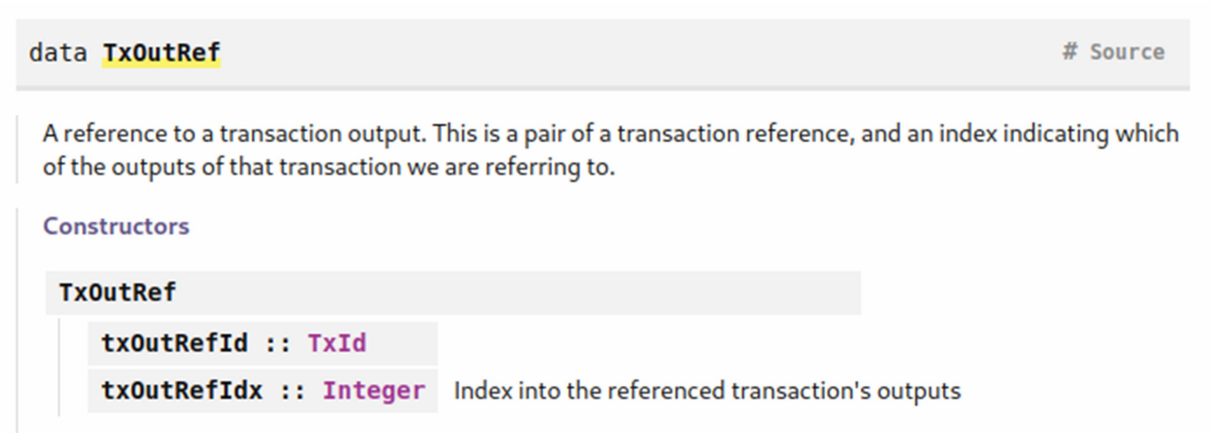

Figure 16 - Transaction output reference

The *TxId* type is also an instance of the *IsString* type class that implements the function *fromString* which you can use to convert between string and another type. Now we focus on the CLI where you can again create a testnet folder, download all necessary configuration files, create key address pairs and startup the cardano node. You can also use the week06/testnet folder where the configuration files are already included. The bash scripts we will use in this example you can find directly in the week06 folder. The script *env.sh* sets all important environment variables that we will use. Once run you can use other bash scripts. With the *query-key1.sh* script we can get the list of UTXOs sitting at our address together with the amounts of test ADA. As we said a UTXO is defined with the transaction hash followed by the # symbol and then the transaction index. We can use this string and convert it to a transaction output reference with the helper function *unsafeReadTxOutRef* that is in the Utils module. And with the code from the file *app/token-policy.hs* we can serialize the correct minting policy. This module is added to the cabal file so we can run in with the following command:

```
$ cabal exec token-policy -- policy.plutus <TxHash#TxIx> 123456 PPP
```

You will need to provide the transaction hash and index that you got from the query command in the filed <TxHash#TxIx>. We create an amount of 123456 tokens with name PPP. Now we can actually mint the token and we will use the *mint-token-cli.sh* script for that. It takes in 5 parameters: the transaction output reference, amount, token name, address file and the signing key file. Next it gets the protocol parameters for which we use the protocol-parameters command from the Cardano CLI. After that it creates the token policy file. Then we compute the policy id called pid and the token name in hexadecimal format which is a requirement from the Cardano CLI. The function that can convert a token name to the hexadecimal format is called *unsafeTokenNameToHex* and can be found in the Utils module. The parameter *v* represent the value we want to mint and the CLI uses the convention that we first specify the amount and then the pid and hex token name separated by a dot.

Next comes the actual transaction command. With the transaction build command we construct our transaction where we input various data as in the example we showed in chapter 3. The difference is that we now specify 3 mint parameters: the value, the script file and the redeemer file. For the tx-out parameter we specify some ADA which should be greater than the minimal amount of ADA required for a UTXO. What's important to notice here is that the minimal amount is not a constant but is rather calculated from size of the output in bytes. In the end we specify where to write the unsigned transaction to. Then we use the CLI commands to sign and submit the transaction. We mint the token with the following command.

```
$ ./mint-token-cli.sh <TxHash#TxIx> 123456 PPP testnet/01.addr testnet/01.skey
```

After we run the command we can wait for a few seconds and then run again the query-key1.sh script to check if the token got minted. We can also go to explorer.cardano-testnet.iohkdev.io which is a cardano blockchain explorer for the cardano testnet. There we have to input our transaction ID and we will see transaction information such as how many ADA was sent from which to which address and what tokens were minted. We could do the same procedure on the main net where we would replace the Magic ID with --mainnet.

6.3 Deployment Scenarios

Let's look at the deployment models for the Plutus application backend - PAB. There are two deployment models envisioned for the PAB: Hosted and in-browser. We will use the hosted model. It works by running a cardano node on a server, a cardano wallet backend which for example is used by the Daedalus wallet, a chain index and the PAB itself.

The chain index handles saving of the blockchain information in an SQL database. It can be used for instance to lookup a datum belonging to a datum hash, which the cardano node can't do. Our PAB should have access to our wallet so an external user of our dApp would then interact with our PAB through a user interface that has endpoints available (Figure 17).

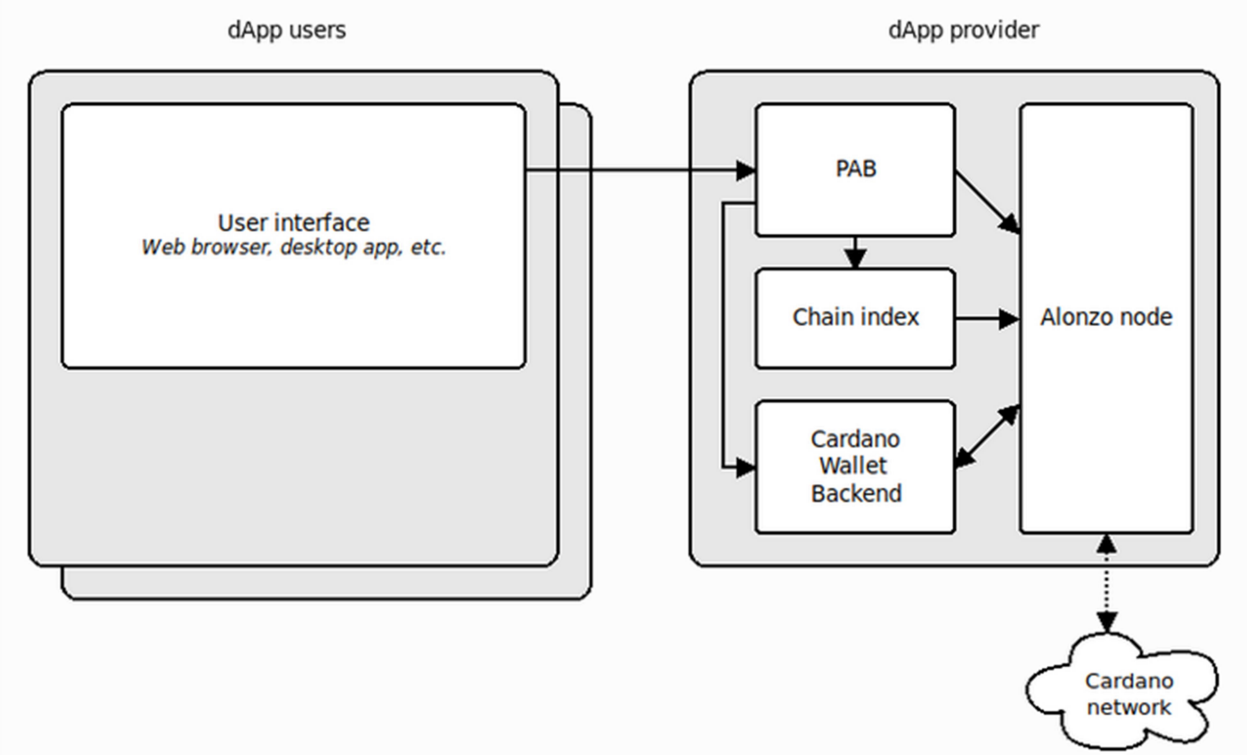

Figure 17 - dApp schema

6.4 The Contracts

We will now define some off-chain code written in a contract monad that the PAB can execute. First we look at the *getCredentials* helper function defined in the Utils module.

```
data Address
```

Address with two kinds of credentials, normal and staking.

Constructors

```
Address
    addressCredential :: Credential
    addressStakingCredential :: Maybe StakingCredential
```

Figure 18 - Address type

It takes in a Plutus Address type (Figure 18). We can look at *Credential* type in Figure 19. It holds a public key hash and a validator hash.

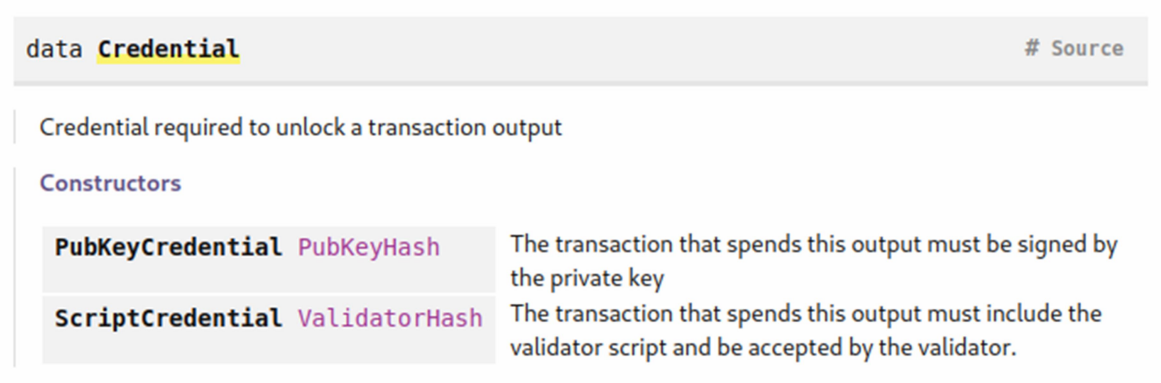

Figure 19 - Credential type

Then we can look up the *StakingCredential* type (Figure 20). It holds again a *Credential* type and a staking pointer that is represented by three integers.

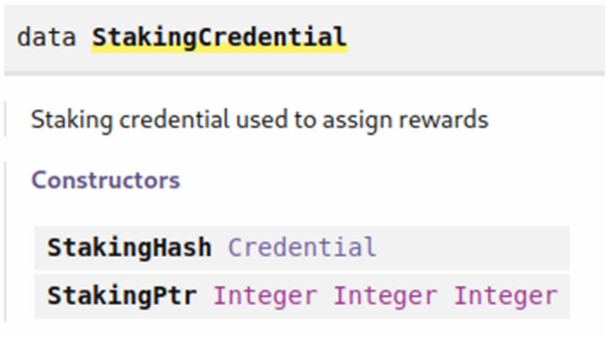

Figure 20 - Staking credential

So the *getCredentials* function returns a Nothing if it the input is a script address and a Just value if it is a public key address that contains a payment public key hash and maybe a stake public key hash. Let's look now at the off-chain code contained in the *OffChain.hs* file.

```
1   {-# LANGUAGE DataKinds           #-}
2   {-# LANGUAGE DeriveAnyClass      #-}
3   {-# LANGUAGE DeriveGeneric       #-}
4   {-# LANGUAGE FlexibleContexts    #-}
5   {-# LANGUAGE NoImplicitPrelude   #-}
6   {-# LANGUAGE OverloadedStrings   #-}
7   {-# LANGUAGE ScopedTypeVariables #-}
8   {-# LANGUAGE TypeApplications    #-}
9   {-# LANGUAGE TypeFamilies        #-}
10
11  module Week06.Token.OffChain
12      ( TokenParams (..)
```

```
13      , adjustAndSubmit, adjustAndSubmitWith
14      , mintToken
15      ) where
16
17  import           Control.Monad               hiding (fmap)
18  import           Data.Aeson                  (FromJSON, ToJSON)
19  import qualified Data.Map                    as Map
20  import           Data.Maybe                  (fromJust)
21  import           Data.OpenApi.Schema         (ToSchema)
22  import           Data.Text                   (Text, pack)
23  import           Data.Void                   (Void)
24  import           GHC.Generics                (Generic)
25  import           Plutus.Contract             as Contract
26  import           Plutus.Contract.Wallet      (getUnspentOutput)
27  import qualified PlutusTx
28  import           PlutusTx.Prelude            hiding (Semigroup(..), unless)
29  import           Ledger                      hiding (mint, singleton)
30  import           Ledger.Constraints          as Constraints
31  import qualified Ledger.Typed.Scripts        as Scripts
32  import           Ledger.Value                as Value
33  import           Prelude                     (Semigroup (..), Show (..),
                                                  String)
34  import qualified Prelude
35  import           Text.Printf                 (printf)
36
37  import           Week06.Token.OnChain
38  import           Week06.Utils                (getCredentials)
39
40  data TokenParams = TokenParams
41      { tpToken   :: !TokenName
42      , tpAmount  :: !Integer
43      , tpAddress :: !Address
44      } deriving (Prelude.Eq, Prelude.Ord, Generic, FromJSON, ToJSON,
                    ToSchema, Show)
45
46  adjustAndSubmitWith :: ( PlutusTx.FromData (Scripts.DatumType a)
47                         , PlutusTx.ToData (Scripts.RedeemerType a)
48                         , PlutusTx.ToData (Scripts.DatumType a)
49                         , AsContractError e
50                         )
51                      => ScriptLookups a
52                      -> TxConstraints (Scripts.RedeemerType a)
                                         (Scripts.DatumType a)
53                      -> Contract w s e CardanoTx
54  adjustAndSubmitWith lookups constraints = do
```

```
55      unbalanced <- adjustUnbalancedTx <$> mkTxConstraints lookups constraints
56      Contract.logDebug @String $ printf "unbalanced: %s" $ show unbalanced
57      unsigned <- balanceTx unbalanced
58      Contract.logDebug @String $ printf "balanced: %s" $ show unsigned
59      signed <- submitBalancedTx unsigned
60      Contract.logDebug @String $ printf "signed: %s" $ show signed
61      return signed
62
63  adjustAndSubmit :: ( PlutusTx.FromData (Scripts.DatumType a)
64                     , PlutusTx.ToData (Scripts.RedeemerType a)
65                     , PlutusTx.ToData (Scripts.DatumType a)
66                     , AsContractError e
67                     )
68                  => Scripts.TypedValidator a
69                  -> TxConstraints (Scripts.RedeemerType a)
                                     (Scripts.DatumType a)
70                  -> Contract w s e CardanoTx
71  adjustAndSubmit inst = adjustAndSubmitWith $
                           Constraints.typedValidatorLookups inst
72
73  mintToken :: TokenParams -> Contract w s Text CurrencySymbol
74  mintToken tp = do
75      Contract.logDebug @String $ printf "started minting: %s" $ show tp
76      let addr = tpAddress tp
77      case getCredentials addr of
78          Nothing      -> Contract.throwError $ pack $ printf
                            "expected pubkey address, but got %s" $ show addr
79          Just (x, my) -> do
80              oref <- getUnspentOutput
81              o    <- fromJust <$> Contract.txOutFromRef oref
82              Contract.logDebug @String $ printf "picked UTxO at %s with value
                                  %s" (show oref) (show $ _ciTxOutValue o)
83
84              let tn          = tpToken tp
85                  amt         = tpAmount tp
86                  cs          = tokenCurSymbol oref tn amt
87                  val         = Value.singleton cs tn amt
88                  c           = case my of
89                      Nothing -> Constraints.mustPayToPubKey x val
90                      Just y  -> Constraints.mustPayToPubKeyAddress x y val
91                  lookups     = Constraints.mintingPolicy
                                      (tokenPolicy oref tn amt) <>
92                                Constraints.unspentOutputs
                                      (Map.singleton oref o)
93                  constraints = Constraints.mustMintValue val          <>
```

```
94                                  Constraints.mustSpendPubKeyOutput oref <> c
95
96              void $ adjustAndSubmitWith @Void lookups constraints
97              Contract.logInfo @String $ printf "minted %s" (show val)
98              return cs
```

First we define our token parameter type that holds the token name, the amount and the address. This is not the change address but the address where the tokens should be sent after the minting. The change address will then be picked by the wallet.

If we look at the *mintToken* function we see it takes in the token parameters and returns a contract parameterized with the currency symbol. We won't really need this since this was used in an oracle example from a previous lecture of the plutus pioneer program. First we log that we are starting the mint (75) and then we define the address. Then we use the *getCredentials* helper function (77). If it returns Nothings which means we got a script address we raise an error. If it's not nothing we extract the payment public key hash and optionally the staking key hash. Next we use the helper function *getUnspentOutput* that looks for an unspent UTXO and returns its output reference (80). With the function *txOutFromRef* we get the actual output for which we can be sure at this moment that it exists (81). Then we log some information about the output and its value. After that come several definitions. First we define the token name and the amount we want to mint. Then we compute the currency symbol (86) and the value (87) we want to mint. Depending on whether we do have staking involved we compute two different constrains (88-90). For the lookups we specify the minting policy which we can get because we imported the module from the *OnChain.hs* file and the unspent outputs. Because there is only one output we can use the *Map.singleton* function. The last definitions are our constraints where we constrain the minting value, to which address it should be paid and of course which UTXO we want to spend. This makes sure there can be only one minting transaction for the given currency symbol. Now we want to submit the transaction. For that we use the helper function *adjustAndSubmitWith*. The reason for this is that we want some more extensive logging and that we want to take care of the minimal ADA requirement. In the end we log some minimal information and return the currency symbol.

There is also an emulator trace where this contract can be tested. It can be found in the *Trace.hs* file. In there we activate the contract for wallet 1 with some input parameters. And if we run it we get the newly minted token with the specified amount. The *mintToken* contract does not return any information to the user and it does not have any endpoints. Let's look now at a second contract from the *week06/Monitor.hs* example. It's a long running contract that monitors an address that is in contrast to the previous example where the mint immediately returns the result. Let's have a look at the code.

```
{-# LANGUAGE DataKinds           #-}
{-# LANGUAGE FlexibleContexts    #-}
{-# LANGUAGE OverloadedStrings   #-}
{-# LANGUAGE ScopedTypeVariables #-}
{-# LANGUAGE TypeApplications    #-}
{-# LANGUAGE TypeFamilies        #-}

module Week06.Monitor
    ( monitor
    ) where

import           Data.Functor    (void)
import qualified Data.Map        as Map
import           Data.Monoid     (Last (..))
import           Data.Text       (Text)
import           Plutus.Contract as Contract
import           Ledger
import           Text.Printf     (printf)

monitor :: Address -> Contract (Last Value) Empty Text a
monitor addr = do
    Contract.logInfo @String $ printf "started monitoring address %s" $
                        show addr
    go
  where
    go = do
        utxos <- utxosAt addr
        let v = Map.foldl' (\w o -> w <> _ciTxOutValue o) mempty utxos
        tell $ Last $ Just v
        void $ waitNSlots 1
        go
```

It takes an address as its only argument and then it queries the blockchain and reports the value sitting at that address. We report this value with the use of the w parameter. For it we choose the *Last Value* type that is an instance of monoid type class.

```
Prelude> import Data.Monoid
Prelude Data.Monoid> :i Last
type Last :: * -> *
newtype Last a = Last {getLast :: Maybe a}
```

We see that Last is just a newtype wrapper around a Maybe. It changes the monoid instance of Maybe a and it always keeps the last Just.

```
Prelude Data.Monoid> mempty :: Last Char
```

```
Last {getLast = Nothing}
Prelude Data.Monoid> Last (Just 'a') <> Last (Just 'b')
Last {getLast = Just 'b'}
Prelude Data.Monoid> Last (Just 'a') <> Last (Just 'b') <> Last Nothing
Last {getLast = Just 'b'}
```

What we want to do in this code example is to write the last Value found at the given address in regular intervals. The go function calls itself recursively so it goes on forever (25-30). In each iteration we first find all UTXOs at the given address. We want to find the value contained at this address so we fold over the UTXOs to add the values from them to a single parameter. We use the accumulator w in the lambda function and add to it the value from a single UTXO (27). Then we tell the value and wait for one slot before repeating the process. So every slot this will update the observable slot contained in the w parameter value.

6.5 Minting with the PAB

We will use now the code from the *week06/PAB.hs* file to hook up our minting and monitor contracts to the PAB. Let's look at the code.

```
1   {-# LANGUAGE DeriveAnyClass    #-}
2   {-# LANGUAGE DeriveGeneric     #-}
3   {-# LANGUAGE OverloadedStrings #-}
4   {-# LANGUAGE TypeApplications  #-}
5
6   module Week06.PAB
7       ( Address
8       , TokenContracts (..)
9       ) where
10
11  import           Data.Aeson                           (FromJSON, ToJSON)
12  import           Data.OpenApi.Schema                  (ToSchema)
13  import           GHC.Generics                         (Generic)
14  import           Ledger                               (Address)
15  import           Plutus.PAB.Effects.Contract.Builtin (Empty, HasDefinitions
                                 (..), SomeBuiltin (..), endpointsToSchemas)
16  import           Prettyprinter                        (Pretty (..), viaShow)
17  import           Wallet.Emulator.Wallet               (knownWallet,
                                                          mockWalletAddress)
18
19  import qualified Week06.Monitor                       as Monitor
20  import qualified Week06.Token.OffChain                as Token
21
22  data TokenContracts = Mint Token.TokenParams | Monitor Address
23      deriving (Eq, Ord, Show, Generic, FromJSON, ToJSON, ToSchema)
```

```
24
25  instance Pretty TokenContracts where
26      pretty = viaShow
27
28  instance HasDefinitions TokenContracts where
29
30      getDefinitions        = [Mint exampleTP, Monitor exampleAddr]
31
32      getContract (Mint tp)      = SomeBuiltin $ Token.mintToken @() @Empty tp
33      getContract (Monitor addr) = SomeBuiltin $ Monitor.monitor addr
34
35      getSchema = const $ endpointsToSchemas @Empty
36
37  exampleAddr :: Address
38  exampleAddr = mockWalletAddress $ knownWallet 1
39
40  exampleTP :: Token.TokenParams
41  exampleTP = Token.TokenParams
42      { Token.tpAddress = exampleAddr
43      , Token.tpAmount  = 123456
44      , Token.tpToken   = "PPP"
45      }
```

First we import our monitor and minting examples (19-20). In the beginning we define a data type called *TokenContracts* that represents everything a PAB can do which means it will define which contracts the PAB will expose (22). From it we derive a bunch of type classes (23). We need to define the *Pretty* instance for our token contracts and use the *viaShow* function. Then we need to write an instance for the class *HasDefinitions* that has 3 methods. One is called *getDefinitions* that is a list of values of the token contract type. For the list we use some sample values that we define at the end of our code (37-45). The *getContract* method tells us which contract should run given a value of the token contracts type (32-33). We have to wrap our contract in the *SomeBuiltin* constructor. Finally we provide the empty schema for both contracts where we use the Empty type (35). Now we can write an application that starts the PAB with our contracts. The code can be found in *app/token-pab.hs*.

```
1   {-# LANGUAGE DataKinds          #-}
2   {-# LANGUAGE DerivingStrategies #-}
3   {-# LANGUAGE FlexibleContexts   #-}
4   {-# LANGUAGE OverloadedStrings  #-}
5   {-# LANGUAGE RankNTypes         #-}
6   {-# LANGUAGE TypeApplications   #-}
7   {-# LANGUAGE TypeFamilies       #-}
8
```

```haskell
module Main
    ( main
    ) where

import qualified Plutus.PAB.Effects.Contract.Builtin as Builtin
import           Plutus.PAB.Run                     (runWith)

import           Week06.PAB                         (TokenContracts)

main :: IO ()
main = do
    runWith (Builtin.handleBuiltin @TokenContracts)
```

It's quite simple. All it does it calls the *runWith* function that takes in the token contracts parameter. This code represents the executable that will start the PAB and it will be specialized to the provided contracts. But for this to work we have to start some other applications as well. That are the applications shown in the dApp schema (Figure 17). We already know how to set up a cardano node. What we also need is a wallet and the chain index. In order to set that up we can follow the instructions for the PAB in the plutus-apps git repository: https://github.com/input-output-hk/plutus-apps/blob/main/plutus-pab/test-node/README.md

We will look now at these instructions step by step. Our node should already be running. The next step is the wallet. When we are in the nix shell cardano-wallet is available as a command. We can use the bash script *start-testnet-wallet.sh* to start the wallet backend from the nix shell. The next step is to create a wallet. For that we can use the *create-wallet.sh* bash script. The script takes following input parameters: the name of the wallet, the passphrase and the file name where to write it. A file gets generated with the recovery phrase. We can now use the recovery phrase to import our wallet into the Daedalus wallet. After that we need to fund that wallet by either sending funds from an existing wallet to the new one or we use the testnet Faucet. Now we also have to inform the wallet backend about our new wallet. We can do this with the bash script *load-wallet.sh*. The request body in the curl command is the json file we just created. When we run this script we get a json object as response that contains the wallet ID which we will later need in the PAB, so we save it to the *env.sh* file. Next we can start the chain index with the script *start-testnet-chain-index.sh*. The chain index takes a long time to synchronize; it could be longer than the node itself. We can start the PAB with the bash script *start-testnet-pab.sh*. There we have to use the passphrase that we choose when we created the wallet. Before we do this we need to do some more configurations. In the *pab-config.yml* configuration file we provide in the command *developmentOptions* a parameter that allows us to specify from which block we want to start synchronizing the PAB, which can speed up the synchronization process. We can get the block id from the node where it's logged after the

“new tip:” keyword every time a block gets created and the slot after the “at slot” keyword. So we can take just the last entry. Because we make a fresh start there is no database yet and we need to migrate it before we start the PAB. We do this with the bash script *migrate-pab.sh*. We run this script and then we can run the *start-testnet-pab.*sh script. From the output we will see that the PAB is available at port 9080 on the localhost. To get a nice interface we can go to localhost:9080/swagger/swagger-ui. There we have various HTTP endpoints available that we can execute and look at the results directly in this UI. With the /api/contract/activate endpoint we can start the contract on the PAB to do the minting or the monitoring. The cool thing about the UI is when we run an endpoint we also get the associated curl command displayed which we can copy into a bash script and run it with our parameters. You can find the minting command in the bash script *mint-token-curl.sh*. For this script we need the address of our wallet, which we can get if we use Yoroi or Daedalus wallet where we go to the receive tab and look at our receiving address. Or we can use the wallet backend directly which is demonstrated in the script *get-address.sh*. The script generates many wallet addresses from which we can pick one and write it to our *env.hs* file. But we need to provide our addresses in Plutus format which separates the payment public key hash and the staking public key hash. We get the pkh and skh with use of the helper functions *payment-key-hash* and *stake-key-hash* specified at the beginning of the bash file. If we run now the *mint-token-curl.sh* script we can look at our wallet under Assets and our PPP token should appear. There is also the option to mint the token directly from a Haskell script. We can look at the *app/mint-token.hs* file.

```
{-# LANGUAGE OverloadedStrings  #-}

module Main
    ( main
    ) where

import Control.Exception          (throwIO)
import Data.String                (IsString (..))
import Network.HTTP.Req
import System.Environment         (getArgs)
import Text.Printf                (printf)
import Wallet.Emulator.Wallet     (WalletId (..))
import Wallet.Types               (ContractInstanceId (..))
import Week06.PAB                 (TokenContracts (..))
import Week06.Token.OffChain      (TokenParams (..))
import Week06.Utils               (contractActivationArgs, unsafeReadAddress,
                                   unsafeReadWalletId)

main :: IO ()
main = do
```

```
20      [amt', tn', wid', addr'] <- getArgs
21      let wid = unsafeReadWalletId wid'
22          tp  = TokenParams
23                  { tpToken   = fromString tn'
24                  , tpAmount  = read amt'
25                  , tpAddress = unsafeReadAddress addr'
26                  }
27      printf "minting token for wallet id %s with parameters %s\n"
               (show wid) $ show tp
28      cid <- mintToken wid tp
29      printf "minted tokens, contract instance id: %s\n" $ show cid
30
31  mintToken :: WalletId -> TokenParams -> IO ContractInstanceId
32  mintToken wid tp = do
33      v <- runReq defaultHttpConfig $ req
34          POST
35          (http "127.0.0.1" /: "api"  /: "contract" /: "activate")
36          (ReqBodyJson $ contractActivationArgs wid $ Mint tp)
37          jsonResponse
38          (port 9080)
39      let c = responseStatusCode v
40      if c == 200
41          then return $ responseBody v
42          else throwIO $ userError $ printf "ERROR: %d\n" c
```

We recall that there were quite few steps before we got to the JSON body of our curl command in the *mint-token-curl.sh* script. In Haskell that's much easier. Our program takes in 4 parameters: the amount, the token name, the wallet ID and the address (20). Then we pass them into appropriate types (21-26). From the Utils module we can use the function *unsafeReadWalletId* that converts a string into a real wallet ID and similar *unsafeReadAddress* converts a string into a real address. Then we call the *mintToken* function (28) which takes a wallet ID and token parameters as input and makes a HTTP request. If the response code is 200 we return the response body which will be of type *ContractIntsanceID*. Else we log an error. With the bash script *mint-token-haskell.sh* we can now mint the token by using our Haskell file. As command line parameters it takes in the amount and token name. Now we can also look at the Haskell code for monitoring found in *app/monitor.hs*.

```
1   {-# LANGUAGE NumericUnderscores #-}
2   {-# LANGUAGE OverloadedStrings  #-}
3
4   module Main
5       ( main
6       ) where
```

```
7
8   import Control.Concurrent                          (threadDelay)
9   import Control.Exception                           (throwIO)
10  import Control.Monad                               (when)
11  import Data.Aeson                                  (FromJSON (..))
12  import Data.Aeson.Types                            (parseMaybe)
13  import Data.Maybe                                  (fromMaybe)
14  import Data.Monoid                                 (Last (..))
15  import Data.Text                                   (pack)
16  import Network.HTTP.Req
17  import Plutus.PAB.Events.ContractInstanceState     (PartiallyDecodedResponse
                                                        (..))
18  import Plutus.PAB.Webserver.Types                  (ContractInstanceClientState
                                                        (..))
19  import Plutus.V1.Ledger.Value                      (Value, flattenValue)
20  import System.Environment                          (getArgs)
21  import Text.Printf                                 (printf)
22  import Wallet.Emulator.Wallet                      (WalletId (..))
23  import Week06.PAB                                  (Address, TokenContracts (..))
24  import Wallet.Types                                (ContractInstanceId (..))
25  import Week06.Utils                                (cidToString,
                                                        contractActivationArgs,
                                                        unsafeReadAddress,
                                                        unsafeReadWalletId)
26
27  main :: IO ()
28  main = do
29      [wid', addr'] <- getArgs
30      let wid  = unsafeReadWalletId wid'
31          addr = unsafeReadAddress addr'
32      printf "monitoring address %s on wallet %s\n" (show addr) $ show wid
33      cid <- startMonitor wid addr
34      printf "started monitor-process with contract id %s\n\n" $
              cidToString cid
35      go cid mempty
36    where
37      go :: ContractInstanceId -> Value -> IO a
38      go cid v = do
39          cic <- getMonitorState cid
40          let v' = fromMaybe v $ observedValue cic
41          when (v' /= v) $
42              printf "%s\n\n" $ show $ flattenValue v'
43          threadDelay 1_000_000
44          go cid v'
45
```

```
46  startMonitor :: WalletId -> Address -> IO ContractInstanceId
47  startMonitor wid addr = do
48      v <- runReq defaultHttpConfig $ req
49          POST
50          (http "127.0.0.1" /: "api"  /: "contract" /: "activate")
51          (ReqBodyJson $ contractActivationArgs wid $ Monitor addr)
52          jsonResponse
53          (port 9080)
54      let c = responseStatusCode v
55      when (c /= 200) $
56          throwIO $ userError $ printf "ERROR: %d\n" c
57      return $ responseBody v
58
59  getMonitorState :: ContractInstanceId ->
                       IO (ContractInstanceClientState TokenContracts)
60  getMonitorState cid = do
61      v <- runReq defaultHttpConfig $ req
62          GET
63          (http "127.0.0.1" /: "api"  /: "contract" /: "instance" /:
            pack (cidToString cid) /: "status")
64          NoReqBody
65          jsonResponse
66          (port 9080)
67      let c = responseStatusCode v
68      when (c /= 200) $
69          throwIO $ userError $ printf "ERROR: %d\n" c
70      return $ responseBody v
71
72  observedValue :: ContractInstanceClientState TokenContracts -> Maybe Value
73  observedValue cic = do
74      Last mv <- parseMaybe parseJSON $ observableState $ cicCurrentState cic
75      mv
```

The body of the main function is similar to how we did the minting. From it we call now two helper functions the *startMonitor* function that starts the monitoring and the *getMonitorState* function that gets the state of the monitor contract and some other information as the tokens we have in our wallet. We can use the *monitor.sh* script to start our code. There we input the environment variables wallet id and address.

Altogether we presented now 3 different ways how to mint our tokens: using the client, using the PAB and using Haskell functions directly. We have to note that these operations are quite resource hungry. If you have around 12GB of RAM it can still happen you will need to increase the size of your SWAP partition to 50GB to get the chain index to actually sync.

7 State Machines

In this chapter we will look at state machines (SM). They can be useful to write shorter and more concise code for both the on-chain and off-chain part. There is support for state machines in the Plutus libraries that is higher level and builds on top of the lover level mechanisms we have seen so far. But what we do have to mention is that at the current time of writing there is a certain overhead using state machines. If you write a contract with state machines it will require more resources to run as if you wrote the same contract without state machines. Because of that SM have not seen much use in practice yet. However the Plutus team is permanently working on improving performance and optimizing the compiler and interpreter so we can expect state machines to be really useful in the near future.

7.1 Commit schemes

Let's imagine a game played between Alice and Bob. It's similar to rock-paper-scissors but with only two options. Instead we have one gesture for 0 and one gesture for 1. If they both raise the same gesture then Alice wins and if they raise a different gesture then Bob wins. Let's say that Alice and Bob can't meet in person but rather play the game via email. Now we come to the problem how to make sure when Alice sends her choice to Bob that Bob does not read the email before making his choice to get an unfair advantage. There is a trick that is used in cryptographic protocols and it's about commit schemes. The idea is that Alice does not reveal her choice to Bob but rather commits to it so she later cannot change her mind. One way to make that work is using hash functions. Hashes are one way functions because given a hash it's impossible to construct the original text or byte string from which the hash was computed. The problem we have now is that Bob will soon figure out which hash belongs to which number since there are only two choices. So what Alice can do is that she first concatenates her choice number with some arbitrary byte string (that we call a nonce) before hashing it and then sends the hash to Bob. And when they check their choices Alice has to send to Bob her choice and the nonce in plain text so Bob can compute the hash on his own and make sure Alice did not cheat. We will try to implement such an example in Plutus together with the code we have seen so far. The idea is Alice and Bob put down a certain amount of money that then gets processed accordingly to their choices. We also implement the possibility when Alice opens the game by posting her hash and if Bob does not reply, she can retrieve her funds after a certain amount of time. Or if Bob replies and Alice sees she has lost and does not reply, Bob can retrieve his funds after a certain amount of time has passed.

7.2 Implementation without State Machines

We will first look at the example how to implement the game in Plutus from the previous chapter without using state machines. Let's first look at the *EvenOdd.hs* file.

```
{-# LANGUAGE DataKinds             #-}
{-# LANGUAGE DeriveAnyClass        #-}
{-# LANGUAGE DeriveGeneric         #-}
{-# LANGUAGE FlexibleContexts      #-}
{-# LANGUAGE MultiParamTypeClasses #-}
{-# LANGUAGE NoImplicitPrelude     #-}
{-# LANGUAGE OverloadedStrings     #-}
{-# LANGUAGE ScopedTypeVariables   #-}
{-# LANGUAGE TemplateHaskell       #-}
{-# LANGUAGE TypeApplications      #-}
{-# LANGUAGE TypeFamilies          #-}
{-# LANGUAGE TypeOperators         #-}

module Week07.EvenOdd
    ( Game (..)
    , GameChoice (..)
    , FirstParams (..)
    , SecondParams (..)
    , GameSchema
    , endpoints
    ) where

import           Control.Monad        hiding (fmap)
import           Data.Aeson           (FromJSON, ToJSON)
import qualified Data.Map             as Map
import           Data.Text            (Text)
import           GHC.Generics         (Generic)
import           Ledger               hiding (singleton)
import           Ledger.Constraints   as Constraints
import qualified Ledger.Typed.Scripts as Scripts
import           Ledger.Ada           as Ada
import           Ledger.Value
import           Playground.Contract  (ToSchema)
import           Plutus.Contract      as Contract
import qualified PlutusTx
import           PlutusTx.Prelude     hiding (Semigroup(..), unless)
import           Prelude              (Semigroup (..), Show (..), String)
import qualified Prelude

data Game = Game
```

```
41      { gFirst          :: !PaymentPubKeyHash
42      , gSecond         :: !PaymentPubKeyHash
43      , gStake          :: !Integer
44      , gPlayDeadline   :: !POSIXTime
45      , gRevealDeadline :: !POSIXTime
46      , gToken          :: !AssetClass
47      } deriving (Show, Generic, FromJSON, ToJSON, Prelude.Eq, Prelude.Ord)
48
49  PlutusTx.makeLift ''Game
50
51  data GameChoice = Zero | One
52      deriving (Show, Generic, FromJSON, ToJSON, ToSchema, Prelude.Eq,
                  Prelude.Ord)
53
54  instance Eq GameChoice where
55      {-# INLINABLE (==) #-}
56      Zero == Zero = True
57      One  == One  = True
58      _    == _    = False
59
60  PlutusTx.unstableMakeIsData ''GameChoice
61
62  data GameDatum = GameDatum BuiltinByteString (Maybe GameChoice)
63      deriving Show
64
65  instance Eq GameDatum where
66      {-# INLINABLE (==) #-}
67      GameDatum bs mc == GameDatum bs' mc' = (bs == bs') && (mc == mc')
68
69  PlutusTx.unstableMakeIsData ''GameDatum
70
71  data GameRedeemer = Play GameChoice | Reveal BuiltinByteString |
                        ClaimFirst | ClaimSecond
72      deriving Show
73
74  PlutusTx.unstableMakeIsData ''GameRedeemer
75
76  {-# INLINABLE lovelaces #-}
77  lovelaces :: Value -> Integer
78  lovelaces = Ada.getLovelace . Ada.fromValue
79
80  {-# INLINABLE gameDatum #-}
81  gameDatum :: Maybe Datum -> Maybe GameDatum
82  gameDatum md = do
83      Datum d <- md
```

```
84      PlutusTx.fromBuiltinData d
85
86  {-# INLINABLE mkGameValidator #-}
87  mkGameValidator :: Game -> BuiltinByteString -> BuiltinByteString ->
                       GameDatum -> GameRedeemer -> ScriptContext -> Bool
88  mkGameValidator game bsZero' bsOne' dat red ctx =
89      traceIfFalse "token missing from input" (assetClassValueOf
                    (txOutValue ownInput) (gToken game) == 1) &&
90      case (dat, red) of
91          (GameDatum bs Nothing, Play c) ->
92              traceIfFalse "not signed by second player"
                (txSignedBy info (unPaymentPubKeyHash $ gSecond game)) &&
93              traceIfFalse "first player's stake missing"  (lovelaces
                (txOutValue ownInput) == gStake game) &&
94              traceIfFalse "second player's stake missing" (lovelaces
                (txOutValue ownOutput) == (2 * gStake game)) &&
95              traceIfFalse "wrong output datum"
                (outputDatum == GameDatum bs (Just c)) &&
96              traceIfFalse "missed deadline"
                (to (gPlayDeadline game) `contains` txInfoValidRange info) &&
97              traceIfFalse "token missing from output"
                (assetClassValueOf (txOutValue ownOutput) (gToken game) == 1)
98
99          (GameDatum bs (Just c), Reveal nonce) ->
100             traceIfFalse "not signed by first player"
                (txSignedBy info (unPaymentPubKeyHash $ gFirst game)) &&
101             traceIfFalse "commit mismatch"
                (checkNonce bs nonce c) &&
102             traceIfFalse "missed deadline"
                (to (gRevealDeadline game) `contains` txInfoValidRange info) &&
103             traceIfFalse "wrong stake"
                (lovelaces (txOutValue ownInput) == (2 * gStake game)) &&
104             traceIfFalse "NFT must go to first player" nftToFirst
105
106         (GameDatum _ Nothing, ClaimFirst) ->
107             traceIfFalse "not signed by first player"
                (txSignedBy info (unPaymentPubKeyHash $ gFirst game)) &&
108             traceIfFalse "too early"
                (from (1 + gPlayDeadline game) `contains` txInfoValidRange info)
                &&
109             traceIfFalse "first player's stake missing"
                (lovelaces (txOutValue ownInput) == gStake game) &&
110             traceIfFalse "NFT must go to first player" nftToFirst
111
112         (GameDatum _ (Just _), ClaimSecond) ->
```

```
113             traceIfFalse "not signed by second player"
                (txSignedBy info (unPaymentPubKeyHash $ gSecond game)) &&
114             traceIfFalse "too early"
                (from (1 + gRevealDeadline game) `contains`
                 txInfoValidRange info) &&
115             traceIfFalse "wrong stake"
                (lovelaces (txOutValue ownInput) == (2 * gStake game)) &&
116             traceIfFalse "NFT must go to first player"   nftToFirst
117
118         _ -> False
119   where
120     info :: TxInfo
121     info = scriptContextTxInfo ctx
122
123     ownInput :: TxOut
124     ownInput = case findOwnInput ctx of
125         Nothing -> traceError "game input missing"
126         Just i  -> txInInfoResolved i
127
128     ownOutput :: TxOut
129     ownOutput = case getContinuingOutputs ctx of
130         [o] -> o
131         _   -> traceError "expected exactly one game output"
132
133     outputDatum :: GameDatum
134     outputDatum = case gameDatum $ txOutDatumHash ownOutput >>=
                      flip findDatum info of
135         Nothing -> traceError "game output datum not found"
136         Just d  -> d
137
138     checkNonce :: BuiltinByteString -> BuiltinByteString ->
                      GameChoice -> Bool
139     checkNonce bs nonce cSecond = sha2_256
                                    (nonce `appendByteString` cFirst) == bs
140       where
141         cFirst :: BuiltinByteString
142         cFirst = case cSecond of
143             Zero -> bsZero'
144             One  -> bsOne'
145
146     nftToFirst :: Bool
147     nftToFirst = assetClassValueOf (valuePaidTo info $ unPaymentPubKeyHash $
                                      gFirst game) (gToken game) == 1
148
149 data Gaming
```

```
150 instance Scripts.ValidatorTypes Gaming where
151     type instance DatumType Gaming = GameDatum
152     type instance RedeemerType Gaming = GameRedeemer
153
154 bsZero, bsOne :: BuiltinByteString
155 bsZero = "0"
156 bsOne  = "1"
157
158 typedGameValidator :: Game -> Scripts.TypedValidator Gaming
159 typedGameValidator game = Scripts.mkTypedValidator @Gaming
160     ($$(PlutusTx.compile [|| mkGameValidator ||])
161         `PlutusTx.applyCode` PlutusTx.liftCode game
162         `PlutusTx.applyCode` PlutusTx.liftCode bsZero
163         `PlutusTx.applyCode` PlutusTx.liftCode bsOne)
164     $$(PlutusTx.compile [|| wrap ||])
165   where
166     wrap = Scripts.wrapValidator @GameDatum @GameRedeemer
167
168 gameValidator :: Game -> Validator
169 gameValidator = Scripts.validatorScript . typedGameValidator
170
171 gameAddress :: Game -> Ledger.Address
172 gameAddress = scriptAddress . gameValidator
173
174 findGameOutput :: Game -> Contract w s Text (Maybe (TxOutRef,
                           ChainIndexTxOut, GameDatum))
175 findGameOutput game = do
176     utxos <- utxosAt $ gameAddress game
177     return $ do
178         (oref, o) <- find f $ Map.toList utxos
179         dat       <- gameDatum $ either (const Nothing) Just $
                         _ciTxOutDatum o
180         return (oref, o, dat)
181   where
182     f :: (TxOutRef, ChainIndexTxOut) -> Bool
183     f (_, o) = assetClassValueOf (_ciTxOutValue o) (gToken game) == 1
184
185 waitUntilTimeHasPassed :: AsContractError e => POSIXTime ->
                           Contract w s e ()
186 waitUntilTimeHasPassed t = do
187     s1 <- currentSlot
188     logInfo @String $ "current slot: " ++ show s1 ++
                        ", waiting until " ++ show t
189     void $ awaitTime t >> waitNSlots 1
190     s2 <- currentSlot
```

```haskell
    logInfo @String $ "waited until: " ++ show s2

data FirstParams = FirstParams
    { fpSecond         :: !PaymentPubKeyHash
    , fpStake          :: !Integer
    , fpPlayDeadline   :: !POSIXTime
    , fpRevealDeadline :: !POSIXTime
    , fpNonce          :: !BuiltinByteString
    , fpCurrency       :: !CurrencySymbol
    , fpTokenName      :: !TokenName
    , fpChoice         :: !GameChoice
    } deriving (Show, Generic, FromJSON, ToJSON, ToSchema)

firstGame :: forall w s. FirstParams -> Contract w s Text ()
firstGame fp = do
    pkh <- Contract.ownPaymentPubKeyHash
    let game = Game
            { gFirst          = pkh
            , gSecond         = fpSecond fp
            , gStake          = fpStake fp
            , gPlayDeadline   = fpPlayDeadline fp
            , gRevealDeadline = fpRevealDeadline fp
            , gToken          = AssetClass (fpCurrency fp, fpTokenName fp)
            }
        v  = lovelaceValueOf (fpStake fp) <> assetClassValue (gToken game) 1
        c    = fpChoice fp
        bs   = sha2_256 $ fpNonce fp `appendByteString` if c == Zero then
               bsZero else bsOne
        tx   = Constraints.mustPayToTheScript (GameDatum bs Nothing) v
    ledgerTx <- submitTxConstraints (typedGameValidator game) tx
    void $ awaitTxConfirmed $ getCardanoTxId ledgerTx
    logInfo @String $ "made first move: " ++ show (fpChoice fp)

    waitUntilTimeHasPassed $ fpPlayDeadline fp

    m   <- findGameOutput game
    now <- currentTime
    case m of
        Nothing             -> throwError "game output not found"
        Just (oref, o, dat) -> case dat of
            GameDatum _ Nothing -> do
                logInfo @String "second player did not play"
                let lookups = Constraints.unspentOutputs
                              (Map.singleton oref o) <>
                              Constraints.otherScript (gameValidator game)
```

```
234                     tx'     = Constraints.mustSpendScriptOutput oref
                                  (Redeemer $ PlutusTx.toBuiltinData ClaimFirst)
235                               <> Constraints.mustValidateIn (from now)
236                 ledgerTx' <- submitTxConstraintsWith @Gaming lookups tx'
237                 void $ awaitTxConfirmed $ getCardanoTxId ledgerTx'
238                 logInfo @String "reclaimed stake"
239
240             GameDatum _ (Just c') | c' == c -> do
241
242                 logInfo @String "second player played and lost"
243                 let lookups = Constraints.unspentOutputs
                                  (Map.singleton oref o) <>
244                               Constraints.otherScript (gameValidator game)
245                     tx'     = Constraints.mustSpendScriptOutput oref
                                  (Redeemer $ PlutusTx.toBuiltinData $ Reveal $
                                  fpNonce fp) <>
246                               Constraints.mustValidateIn (to $ now + 1000)
247                 ledgerTx' <- submitTxConstraintsWith @Gaming lookups tx'
248                 void $ awaitTxConfirmed $ getCardanoTxId ledgerTx'
249                 logInfo @String "victory"
250
251             _ -> logInfo @String "second player played and won"
252
253 data SecondParams = SecondParams
254     { spFirst          :: !PaymentPubKeyHash
255     , spStake          :: !Integer
256     , spPlayDeadline   :: !POSIXTime
257     , spRevealDeadline :: !POSIXTime
258     , spCurrency       :: !CurrencySymbol
259     , spTokenName      :: !TokenName
260     , spChoice         :: !GameChoice
261     } deriving (Show, Generic, FromJSON, ToJSON, ToSchema)
262
263 secondGame :: forall w s. SecondParams -> Contract w s Text ()
264 secondGame sp = do
265     pkh <- Contract.ownPaymentPubKeyHash
266     let game = Game
267             { gFirst          = spFirst sp
268             , gSecond         = pkh
269             , gStake          = spStake sp
270             , gPlayDeadline   = spPlayDeadline sp
271             , gRevealDeadline = spRevealDeadline sp
272             , gToken          = AssetClass (spCurrency sp, spTokenName sp)
273             }
274     m <- findGameOutput game
```

```
275      case m of
276          Just (oref, o, GameDatum bs Nothing) -> do
277              logInfo @String "running game found"
278              now <- currentTime
279              let token   = assetClassValue (gToken game) 1
280              let v       = let x = lovelaceValueOf (spStake sp) in x <> x
                                 <> token
281                  c       = spChoice sp
282                  lookups = Constraints.unspentOutputs
                                 (Map.singleton oref o) <>
283                            Constraints.otherScript (gameValidator game) <>
284                            Constraints.typedValidatorLookups
                                 (typedGameValidator game)
285                  tx      = Constraints.mustSpendScriptOutput oref (Redeemer $
                                 PlutusTx.toBuiltinData $ Play c) <>
286                            Constraints.mustPayToTheScript
                                 (GameDatum bs $ Just c) v <>
287                            Constraints.mustValidateIn (to now)
288              ledgerTx <- submitTxConstraintsWith @Gaming lookups tx
289              let tid = getCardanoTxId ledgerTx
290              void $ awaitTxConfirmed tid
291              logInfo @String $ "made second move: " ++ show (spChoice sp)
292
293              waitUntilTimeHasPassed $ spRevealDeadline sp
294
295              m'   <- findGameOutput game
296              now' <- currentTime
297              case m' of
298                  Nothing             -> logInfo @String "first player won"
299                  Just (oref', o', _) -> do
300                      logInfo @String "first player didn't reveal"
301                      let lookups' = Constraints.unspentOutputs
                                         (Map.singleton oref' o') <>
302                                     Constraints.otherScript
                                         (gameValidator game)
303                          tx'      = Constraints.mustSpendScriptOutput oref'
                                         (Redeemer $ PlutusTx.toBuiltinData
                                          ClaimSecond) <>
304                                     Constraints.mustValidateIn (from now') <>
305                                     Constraints.mustPayToPubKey (spFirst sp)
                                         (token <> adaValueOf
                                          (getAda minAdaTxOut))
306                      ledgerTx' <- submitTxConstraintsWith @Gaming
                                     lookups' tx'
307                      void $ awaitTxConfirmed $ getCardanoTxId ledgerTx'
```

```
308                     logInfo @String "second player won"
309
310         _ -> logInfo @String "no running game found"
311
312 type GameSchema = Endpoint "first" FirstParams .\/
                    Endpoint "second" SecondParams
313
314 endpoints :: Contract () GameSchema Text ()
315 endpoints = awaitPromise (first `select` second) >> endpoints
316   where
317     first  = endpoint @"first"  firstGame
318     second = endpoint @"second" secondGame
```

We call this code EvenOdd because if the sum of the choices is even the first player wins and if it is odd the second player wins. First we create the data type game that will be used as a parameter for the contract (40-47). There we define the first and second player with their public key hashes. Then we also define their stake, the playing deadline and the revealing deadline. And in the end we define a NFT token. Since the game contains some state that is changing and UTXOs together with their datums are immutable we need to create a new UTXO every time the state of the game is changing. And to be able to connect the old UTXO with the new one we can use an NFT that exists only once and gets assigned to the new UTXO every time the state changes. We then call this token a stake token. Another reason we need this NFT is that somebody could create a UTXO at the same address with the same datum and would try to disturb the game. So in order to uniquely be able to identify our UTXO with which we start the game we need an NFT that exists only once. The type game choice defines the two moves the players can make (51-52). Then we derive the Plutus equality for the game choice type (54-58). For this to work with template Haskell we need to add the inalienable pragma. We will use the game datum as state information for the contract (62-63). The byte string there is the hash that the first player submits and maybe game choice is the move of the second player. It's a maybe because in the beginning the second player has not yet moved. We implement also the Plutus equality for the game datum (65-67). Next we implement the game redeemer with the options that corresponds to our player actions (71-72). Play means when the second player moves and makes a game choice, reveal is for the case that first player reveals his nonce which is the byte string argument, claim first is the case when the second player does not move and the first player claims back his stake and claim second is for the case if the first player does not reveal his nonce and the deadline passes for the second player to collect his earnings. Then we define two helper functions. The function *lovelaces* when given a value extracts the amount of lovelaces (76-78). And the function *gameDatum* given a maybe datum tries to deserialize that if it's a Just to a maybe game datum (80-84).

Now we write our game validator function. The first parameter is the game parameter that we defined in the beginning. The second and third parameters are the byte strings with the digit zero and the digit one that represents the choice. Then we take in the datum, redeemer and context. Let's look first at the helper function before we come to the main body. For the *ownInput* function we use the function *findOwnInput* (Figure 21) (123-126).

Figure 21 - findOwnInput function

It takes in a script context and produces a maybe transaction input info. If a script would be used for minting this function would return Nothing.

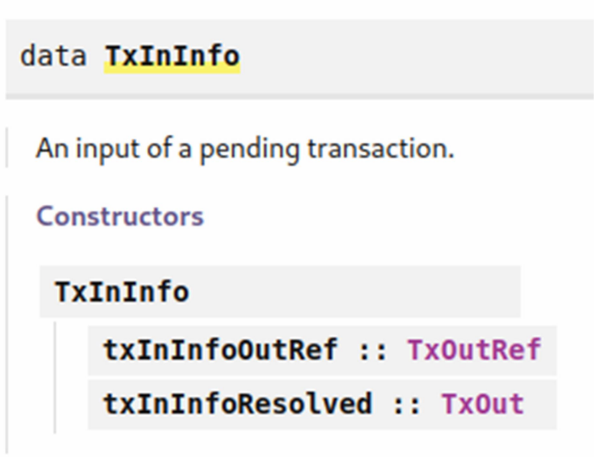

Figure 22 - Transaction input infor

What we are interested in inside the *TxInInfo* type is the transaction output. The idea of our game is that with each state change we consume an UTXO and produce another one at the same address. For the *ownOutput* function we use the *getContinuingOutputs* function.

```
getContinuingOutputs :: ScriptContext -> [TxOut]
```

It takes a script context and returns a list of transaction outputs. And in our case we expect there is exactly one output sitting at our address (128-131). The output datum function should give us a game datum of our own output (133-136). We use the function *findDatum* that takes in a datum hash and a transaction info and then returns a maybe datum (Figure 23). A maybe datum because we said that the producing transaction can optionally include the datum in the output. It is required only to include the hash of the datum.

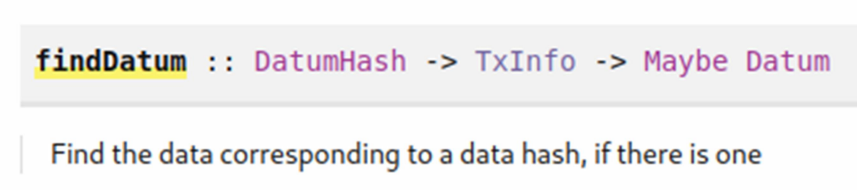

Figure 23 - Find datum function

The check nonce function is for the case that the first player has won and wants to prove it by revealing his nonce and proving that the hash submitted at the beginning of the game fits this nonce (138-144). The first argument is the hash he submitted, the second is the nonce and the third is the move that the second player made. To compute the hash we take the nonce concatenate it with the byte string and apply the SHA 256 hash function. At the end we define the *nftToFirst* function (146-147). The idea is after the game finishes the 1st player gets back his NFT no matter who won the game.

One thing to notice about our code at this point is we haven't spent much consideration about the staking address. In general a user could use an address where the payment part goes to the winner but the staking part goes to the looser, since these 2 addresses could be different. So one has to be careful when specifying the input data and take this consideration into account. Let's now look at the conditions in the body of the validator function. There is one condition that applies to all cases simultaneously. That is the input we are validating has to contain the state token (89). Then the rules after that depend on the situation. The first situation is when the 1st player has moved and 2nd player is moving now and chooses the move *c* (91-97). First we check that the second player actually signs the transaction. Then we check that the first player has put down his stake. In the third condition we check that the second player added in this transaction his own stake. After that we check the datum from the transaction context. Then we check that the move has to happen before the first deadline. And in the end we check that the NFT is passed to the transaction output UTXO. The second situation is both players have moved and the 1st player has won (99-104). And to prove it and collect his winnings he has to reveal his nonce. So first we check that the transaction is signed by the first player. Then the nonce must agree with the hash we submitted earlier. He must do this before the reveal deadline. The input must contain the stakes of both players. And finally the NFT must go back to the first player. The third situation is that the 2nd player does not move and the 1st player wants his stake back (106-110). So the transaction must be signed by the first player has to have a validity interval after the deadline has passed. The first player has provided his stake and he must get back his NFT token. The last situation is both players have moved but the 1st player has lost and did not reveal his nonce (112-116). So the transaction must be signed by the 2nd player. The reveal deadline should pass. The input must contain the stakes of both players. And the token has to go back to the first player. In all other cases we fail validation.

Let's look at the rest of the on-chain code. First we define the helper that bundles information what the datum and the redeemer types are (149-152). Then we define the byte strings that we use for choice 1 and choice 2. Then we define our typed validator and compile the code with our parameters (158-166). After that we define the game validator and game address.

For the off-chain code we first define two helper functions. The *findGameOutput* function takes as input a game type parameter and then in the contract monad tries to find the UTXO (174-180). And because it could fail we are returning a maybe type. We return the transaction output reference, the transaction output chain index and the game datum. We use the find function that has following type signature:

```
Prelude> import Data.List
Prelude Data.List> :i find
find :: Foldable t => (a -> Bool) -> t a -> Maybe a
Prelude Data.List> find even [1 :: Int, 3, 4, 5, 6]
Just 4
```

It works like this: if it finds an element in the container that satisfies the initial condition then it returns a Just of that element. Our helper function *f* checks weather the output contains the token. With the second function *waitUntilTimeHasPassed* we take in a posix time and wait until that time has passed and then we wait for 1 more slot (185-191). Then come the two contracts for the two players with the corresponding input parameters for each contract. In the first contract we first get our public key. Then we define several parameters (207-218). First the value of the game type, second the amount of lovelace we put in as our stake plus the NFT we put in, then *c* is our choice, next we compute the hash of our nonce with the appended choice and in the end we define our transactions. Then we submit, wait for the transaction to process and log a message. Now the second player has a chance to move but it must happen before the play deadline so as first player we wait until the deadline has passed (223). And then there are several cases. First we check if we find the UTXO containing the NFT and if yes we check the datum. One case is that it is Nothing so the 2nd player did not moved (230). In that case as constraints we say we must spend this UTXO we found with this redeemer and as lookups we need to provide the UTXO and the validator. Then the second case is that the second player did move and he chooses the same move as we did so we won (240). So we have to reveal our nonce. We use the Reveal nonce game redeemer. And we need to submit this transaction before the deadline for revealing has passed. The third case is the second player won and in that case we don't do anything.

Now for the second contract for player 2 the input parameters are very similar (253-261). We do not need to provide the second players public key hash because we look up our own public key hash. Then we define the game value (266-273). Next we try to find the UTXO that contains

the NFT. If we find it we continue by defining several parameters (280-287). We define the token, *v* represents the output which is twice the stake and the NFT and *c* is our choice. For the transaction we put the constraints that we must spend the existing UTXO with the redeemer Play that holds our choice. Then we create a new UTXO with the updated datum and we must do this before the deadline passes. For the lookups we provide the UTXO. Because we are consuming the script output we need the validator and because we are also producing we need the script instance. After we defined our parameters we submit the transaction, wait for confirmation and log a message. Then we wait until the reveal deadline has passed so the first player can make his move. Next we try again to find the UTXO which could be now a different one. If we do not find it the first player made his reveal and had won, so we do nothing. If we do find it we must spend the UTXO that we have found, we must do this after the deadline has passed and return the NFT to the first player. Because every UTXO has to contain some ADA we must add some ADA when returning the NFT. Then we submit the transaction and log that the 2nd player has won. In the end we define the schema and define the endpoints contract. We can test this now with the emulator trace defined in the *TestEvenOdd.hs* file.

```
1   {-# LANGUAGE DataKinds             #-}
2   {-# LANGUAGE FlexibleContexts      #-}
3   {-# LANGUAGE MultiParamTypeClasses #-}
4   {-# LANGUAGE NoImplicitPrelude     #-}
5   {-# LANGUAGE NumericUnderscores    #-}
6   {-# LANGUAGE OverloadedStrings     #-}
7   {-# LANGUAGE ScopedTypeVariables   #-}
8   {-# LANGUAGE TypeApplications      #-}
9   {-# LANGUAGE TypeFamilies          #-}
10
11  module Week07.TestEvenOdd
12      ( test
13      , test'
14      , GameChoice (..)
15      ) where
16
17  import           Control.Monad              hiding (fmap)
18  import           Control.Monad.Freer.Extras as Extras
19  import           Data.Default               (Default (..))
20  import qualified Data.Map                   as Map
21  import           Ledger
22  import           Ledger.TimeSlot
23  import           Ledger.Value
24  import           Ledger.Ada                 as Ada
25  import           Plutus.Trace.Emulator      as Emulator
26  import           PlutusTx.Prelude
```

```
27  import           Prelude                    (IO, Show (..))
28  import           Wallet.Emulator.Wallet
29
30  import           Week07.EvenOdd
31
32  test :: IO ()
33  test = do
34      test' Zero Zero
35      test' Zero One
36      test' One Zero
37      test' One One
38
39  w1, w2 :: Wallet
40  w1 = knownWallet 1
41  w2 = knownWallet 2
42
43  test' :: GameChoice -> GameChoice -> IO ()
44  test' c1 c2 = runEmulatorTraceIO' def emCfg $ myTrace c1 c2
45    where
46      emCfg :: EmulatorConfig
47      emCfg = def { _initialChainState = Left $ Map.fromList
48                      [ (w1, v <> assetClassValue (AssetClass
                          (gameTokenCurrency, gameTokenName)) 1)
49                      , (w2, v)
50                      ]
51                  }
52
53      v :: Value
54      v = Ada.lovelaceValueOf 1_000_000_000
55
56  gameTokenCurrency :: CurrencySymbol
57  gameTokenCurrency = "ff"
58
59  gameTokenName :: TokenName
60  gameTokenName = "STATE TOKEN"
61
62  myTrace :: GameChoice -> GameChoice -> EmulatorTrace ()
63  myTrace c1 c2 = do
64      Extras.logInfo $ "first move: " ++ show c1 ++ ", second move: " ++ show
    c2
65
66      h1 <- activateContractWallet w1 endpoints
67      h2 <- activateContractWallet w2 endpoints
68
69      let pkh1      = mockWalletPaymentPubKeyHash w1
```

```
70          pkh2      = mockWalletPaymentPubKeyHash w2
71          stake     = 100_000_000
72          deadline1 = slotToBeginPOSIXTime def 5
73          deadline2 = slotToBeginPOSIXTime def 10
74
75          fp = FirstParams
76                  { fpSecond         = pkh2
77                  , fpStake          = stake
78                  , fpPlayDeadline   = deadline1
79                  , fpRevealDeadline = deadline2
80                  , fpNonce          = "SECRETNONCE"
81                  , fpCurrency       = gameTokenCurrency
82                  , fpTokenName      = gameTokenName
83                  , fpChoice         = c1
84                  }
85          sp = SecondParams
86                  { spFirst          = pkh1
87                  , spStake          = stake
88                  , spPlayDeadline   = deadline1
89                  , spRevealDeadline = deadline2
90                  , spCurrency       = gameTokenCurrency
91                  , spTokenName      = gameTokenName
92                  , spChoice         = c2
93                  }
94
95      callEndpoint @"first" h1 fp
96
97      void $ Emulator.waitNSlots 3
98
99      callEndpoint @"second" h2 sp
100
101     void $ Emulator.waitNSlots 10
```

The idea is that you can test our code for all possible choices. So we define our *test* IO action such that all possible game choices are covered (32-37). We define the two wallets (39-41). The *test'* function takes in 2 choices and runs the emulator trace where it assigns 1000 ADA to both wallets and the token to wallet 1 (43-54). Then we define our trace that also takes as input our two choices. We start the contract for both wallets and save the returned handle (66-67). We look up the payment public key hashes and use the stake of 100 ADA. Then we define the deadlines which are a bit short in our case but for the example it will be fine (72-73). Next we define the parameters for the first and second player. Now we can call the endpoint for the first player, wait for 3 slots, call the endpoint for the second player and wait for 10 slots.

7.3 State Machines

A state machine (SM) is a system that starts in one state and normally there are available transitions to other states. And there can be also final states from which there are no transitions left. For our game we can also draw a state diagram where all the nodes represent a state and all the arrows represent transitions (Figure 24).

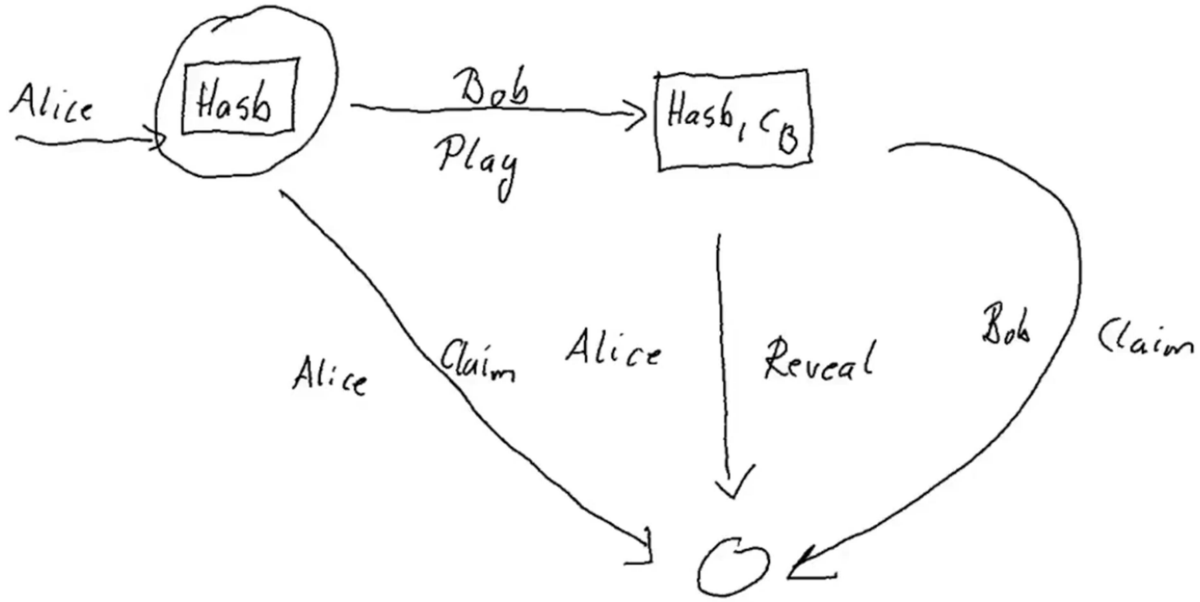

Figure 24 - Game state diagram

In the blockchain the states will be represented by UTXO sitting at the state machine script address. The state of the state machine will be the datum of the UTXO and a transition is represented by a transaction. There is special support in the Plutus libraries to implement such state machines which makes our code shorter compared to the case without using SM. The module *Plutus.Contract.StateMachine* contains all the code for using SM. Let's first look at the definition of a *StateMachine* type (Figure 25). It takes two parameters that are state and input which correspond to datum and redeemer. It is a record type with four fields. The *smTransition* function defines from which state using which transition you can define another state. The *State* type is defined with the state data and a state value of type *Value*. If the transition is not allowed we return a Nothing in the function, else we return a tuple from which the second component is the new state. And the *TxConstraints* define additional constraints that the transaction that does the transition must have. The *smFinal* function tells us weather we are transitioning to a final state. If yes then we do not produce a new UTXO and there is no value attached to the transition. The *smCheck* function takes in the datum, redeemer and context and basically makes an additional check that can't be expressed with the transaction constrains.

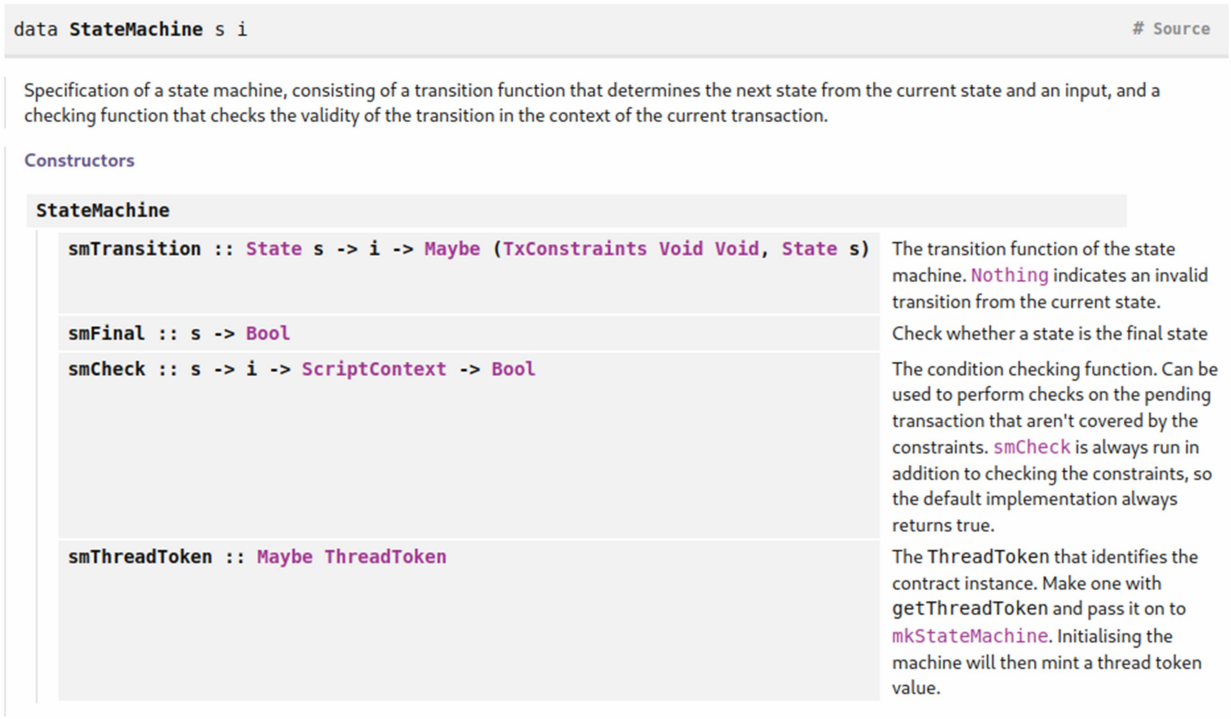

Figure 25 - State machine type

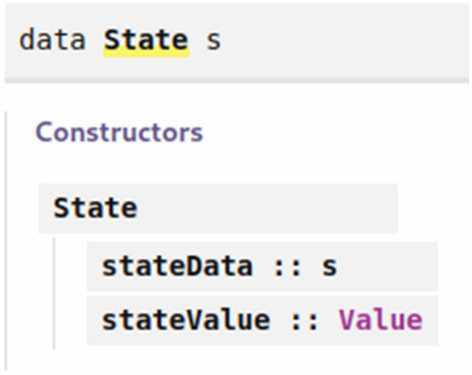

Figure 26 - State type

The *smThreadToken* serves the same purpose as the NFT we were using in the previous chapter to identify our UTXO for the game (Figure 27).

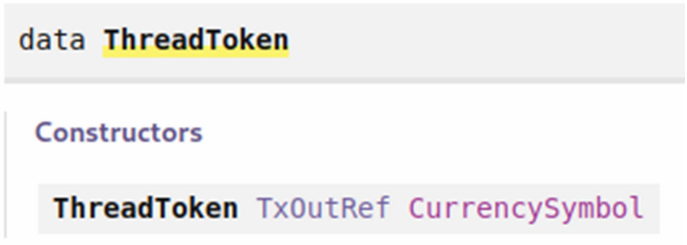

Figure 27 - Thread token

If we look at the thread token it's a reference to a UTXO and a currency symbol. And the UTXO in our case will be the one that uniquely identifies the minting transaction of the NFT. So we don't have to worry about the NFT, it will automatically be taken care of. So let's look now at the code in *StateMachine.hs* that uses now state machines.

```
{-# LANGUAGE DataKinds              #-}
{-# LANGUAGE DeriveAnyClass         #-}
{-# LANGUAGE DeriveGeneric          #-}
{-# LANGUAGE FlexibleContexts       #-}
{-# LANGUAGE MultiParamTypeClasses  #-}
{-# LANGUAGE NoImplicitPrelude      #-}
{-# LANGUAGE OverloadedStrings      #-}
{-# LANGUAGE ScopedTypeVariables    #-}
{-# LANGUAGE TemplateHaskell        #-}
{-# LANGUAGE TypeApplications       #-}
{-# LANGUAGE TypeFamilies           #-}
{-# LANGUAGE TypeOperators          #-}

module Week07.StateMachine
    ( Game (..)
    , GameChoice (..)
    , FirstParams (..)
    , SecondParams (..)
    , GameSchema
    , Last (..)
    , ThreadToken
    , Text
    , endpoints
    ) where

import           Control.Monad                hiding (fmap)
import           Data.Aeson                   (FromJSON, ToJSON)
import           Data.Monoid                  (Last (..))
import           Data.Text                    (Text, pack)
import           GHC.Generics                 (Generic)
import           Ledger                       hiding (singleton)
import           Ledger.Ada                   as Ada
import           Ledger.Constraints           as Constraints
import           Ledger.Typed.Tx
import qualified Ledger.Typed.Scripts         as Scripts
import           Plutus.Contract              as Contract
import           Plutus.Contract.StateMachine
import qualified PlutusTx
import           PlutusTx.Prelude             hiding (Semigroup(..), check,
                                               unless)
```

```
40  import           Playground.Contract          (ToSchema)
41  import           Prelude                      (Semigroup (..), Show (..),
                                                  String)
42  import qualified Prelude
43
44  data Game = Game
45      { gFirst          :: !PaymentPubKeyHash
46      , gSecond         :: !PaymentPubKeyHash
47      , gStake          :: !Integer
48      , gPlayDeadline   :: !POSIXTime
49      , gRevealDeadline :: !POSIXTime
50      , gToken          :: !ThreadToken
51      } deriving (Show, Generic, FromJSON, ToJSON, Prelude.Eq)
52
53  PlutusTx.makeLift ''Game
54
55  data GameChoice = Zero | One
56      deriving (Show, Generic, FromJSON, ToJSON, ToSchema, Prelude.Eq,
                  Prelude.Ord)
57
58  instance Eq GameChoice where
59      {-# INLINABLE (==) #-}
60      Zero == Zero = True
61      One  == One  = True
62      _    == _    = False
63
64  PlutusTx.unstableMakeIsData ''GameChoice
65
66  data GameDatum = GameDatum BuiltinByteString (Maybe GameChoice) | Finished
67      deriving Show
68
69  instance Eq GameDatum where
70      {-# INLINABLE (==) #-}
71      GameDatum bs mc == GameDatum bs' mc' = (bs == bs') && (mc == mc')
72      Finished        == Finished          = True
73      _               == _                 = False
74
75  PlutusTx.unstableMakeIsData ''GameDatum
76
77  data GameRedeemer = Play GameChoice | Reveal BuiltinByteString |
                        ClaimFirst | ClaimSecond
78      deriving Show
79
80  PlutusTx.unstableMakeIsData ''GameRedeemer
81
```

```haskell
{-# INLINABLE lovelaces #-}
lovelaces :: Value -> Integer
lovelaces = Ada.getLovelace . Ada.fromValue

{-# INLINABLE gameDatum #-}
gameDatum :: TxOut -> (DatumHash -> Maybe Datum) -> Maybe GameDatum
gameDatum o f = do
    dh      <- txOutDatum o
    Datum d <- f dh
    PlutusTx.fromBuiltinData d

{-# INLINABLE transition #-}
transition :: Game -> State GameDatum -> GameRedeemer -> Maybe
              (TxConstraints Void Void, State GameDatum)
transition game s r = case (stateValue s, stateData s, r) of
    (v, GameDatum bs Nothing, Play c)
        | lovelaces v == gStake game         ->
          Just ( Constraints.mustBeSignedBy (gSecond game) <>
                 Constraints.mustValidateIn (to $ gPlayDeadline game)
               , State (GameDatum bs $ Just c) (lovelaceValueOf $
                                                  2 * gStake game) )

    (v, GameDatum _ (Just _), Reveal _)
        | lovelaces v == (2 * gStake game)   ->
          Just ( Constraints.mustBeSignedBy (gFirst game) <>
                 Constraints.mustValidateIn (to $ gRevealDeadline game)
               , State Finished mempty )

    (v, GameDatum _ Nothing, ClaimFirst)
        | lovelaces v == gStake game         ->
          Just ( Constraints.mustBeSignedBy (gFirst game) <>
                 Constraints.mustValidateIn (from $ 1 + gPlayDeadline game)
               , State Finished mempty )

    (v, GameDatum _ (Just _), ClaimSecond)
        | lovelaces v == (2 * gStake game)   ->
          Just ( Constraints.mustBeSignedBy (gSecond game) <>
                 Constraints.mustValidateIn (from $ 1 +
                                             gRevealDeadline game)
               , State Finished mempty )

    _                                        -> Nothing

{-# INLINABLE final #-}
final :: GameDatum -> Bool
```

```
120 final Finished = True
121 final _        = False
122
123 {-# INLINABLE check #-}
124 check :: BuiltinByteString -> BuiltinByteString -> GameDatum ->
             GameRedeemer -> ScriptContext -> Bool
125 check bsZero' bsOne' (GameDatum bs (Just c)) (Reveal nonce) _ =
126     sha2_256 (nonce `appendByteString` if c == Zero then bsZero' else
                  bsOne') == bs
127 check _       _      _                       _              _ = True
128
129 {-# INLINABLE gameStateMachine #-}
130 gameStateMachine :: Game -> BuiltinByteString -> BuiltinByteString ->
                        StateMachine GameDatum GameRedeemer
131 gameStateMachine game bsZero' bsOne' = StateMachine
132     { smTransition  = transition game
133     , smFinal       = final
134     , smCheck       = check bsZero' bsOne'
135     , smThreadToken = Just $ gToken game
136     }
137
138 {-# INLINABLE mkGameValidator #-}
139 mkGameValidator :: Game -> BuiltinByteString -> BuiltinByteString ->
                       GameDatum -> GameRedeemer -> ScriptContext -> Bool
140 mkGameValidator game bsZero' bsOne' = mkValidator $ gameStateMachine
                                                       game bsZero' bsOne'
141
142 type Gaming = StateMachine GameDatum GameRedeemer
143
144 bsZero, bsOne :: BuiltinByteString
145 bsZero = "0"
146 bsOne  = "1"
147
148 gameStateMachine' :: Game -> StateMachine GameDatum GameRedeemer
149 gameStateMachine' game = gameStateMachine game bsZero bsOne
150
151 typedGameValidator :: Game -> Scripts.TypedValidator Gaming
152 typedGameValidator game = Scripts.mkTypedValidator @Gaming
153     ($$(PlutusTx.compile [|| mkGameValidator ||])
154         `PlutusTx.applyCode` PlutusTx.liftCode game
155         `PlutusTx.applyCode` PlutusTx.liftCode bsZero
156         `PlutusTx.applyCode` PlutusTx.liftCode bsOne)
157     $$(PlutusTx.compile [|| wrap ||])
158   where
159     wrap = Scripts.wrapValidator @GameDatum @GameRedeemer
```

```
160
161 gameValidator :: Game -> Validator
162 gameValidator = Scripts.validatorScript . typedGameValidator
163
164 gameAddress :: Game -> Ledger.Address
165 gameAddress = scriptAddress . gameValidator
166
167 gameClient :: Game -> StateMachineClient GameDatum GameRedeemer
168 gameClient game = mkStateMachineClient $ StateMachineInstance
                      (gameStateMachine' game) (typedGameValidator game)
169
170 data FirstParams = FirstParams
171     { fpSecond         :: !PaymentPubKeyHash
172     , fpStake          :: !Integer
173     , fpPlayDeadline   :: !POSIXTime
174     , fpRevealDeadline :: !POSIXTime
175     , fpNonce          :: !BuiltinByteString
176     , fpChoice         :: !GameChoice
177     } deriving (Show, Generic, FromJSON, ToJSON, ToSchema)
178
179 mapError' :: Contract w s SMContractError a -> Contract w s Text a
180 mapError' = mapError $ pack . show
181
182 waitUntilTimeHasPassed :: AsContractError e => POSIXTime ->
                                                  Contract w s e ()
183 waitUntilTimeHasPassed t = void $ awaitTime t >> waitNSlots 1
184
185 firstGame :: forall s. FirstParams -> Contract (Last ThreadToken) s Text ()
186 firstGame fp = do
187     pkh <- Contract.ownPaymentPubKeyHash
188     tt  <- mapError' getThreadToken
189     let game   = Game
190             { gFirst          = pkh
191             , gSecond         = fpSecond fp
192             , gStake          = fpStake fp
193             , gPlayDeadline   = fpPlayDeadline fp
194             , gRevealDeadline = fpRevealDeadline fp
195             , gToken          = tt
196             }
197         client = gameClient game
198         v      = lovelaceValueOf (fpStake fp)
199         c      = fpChoice fp
200         bs     = sha2_256 $ fpNonce fp `appendByteString` if c == Zero then
                    bsZero else bsOne
201     void $ mapError' $ runInitialise client (GameDatum bs Nothing) v
```

```
202     logInfo @String $ "made first move: " ++ show (fpChoice fp)
203     tell $ Last $ Just tt
204
205     waitUntilTimeHasPassed $ fpPlayDeadline fp
206
207     m <- mapError' $ getOnChainState client
208     case m of
209         Nothing     -> throwError "game output not found"
210         Just (o, _) -> case tyTxOutData $ ocsTxOut o of
211
212             GameDatum _ Nothing -> do
213                 logInfo @String "second player did not play"
214                 void $ mapError' $ runStep client ClaimFirst
215                 logInfo @String "first player reclaimed stake"
216
217             GameDatum _ (Just c') | c' == c -> do
218                 logInfo @String "second player played and lost"
219                 void $ mapError' $ runStep client $ Reveal $ fpNonce fp
220                 logInfo @String "first player revealed and won"
221
222             _ -> logInfo @String "second player played and won"
223
224 data SecondParams = SecondParams
225     { spFirst          :: !PaymentPubKeyHash
226     , spStake          :: !Integer
227     , spPlayDeadline   :: !POSIXTime
228     , spRevealDeadline :: !POSIXTime
229     , spChoice         :: !GameChoice
230     , spToken          :: !ThreadToken
231     } deriving (Show, Generic, FromJSON, ToJSON)
232
233 secondGame :: forall w s. SecondParams -> Contract w s Text ()
234 secondGame sp = do
235     pkh <- Contract.ownPaymentPubKeyHash
236     let game   = Game
237             { gFirst          = spFirst sp
238             , gSecond         = pkh
239             , gStake          = spStake sp
240             , gPlayDeadline   = spPlayDeadline sp
241             , gRevealDeadline = spRevealDeadline sp
242             , gToken          = spToken sp
243             }
244         client = gameClient game
245     m <- mapError' $ getOnChainState client
246     case m of
```

```
247          Nothing          -> logInfo @String "no running game found"
248          Just (o, _) -> case tyTxOutData $ ocsTxOut o of
249              GameDatum _ Nothing -> do
250                  logInfo @String "running game found"
251                  void $ mapError' $ runStep client $ Play $ spChoice sp
252                  logInfo @String $ "made second move: " ++ show (spChoice sp)
253
254                  waitUntilTimeHasPassed $ spRevealDeadline sp
255
256                  m' <- mapError' $ getOnChainState client
257                  case m' of
258                      Nothing -> logInfo @String "first player won"
259                      Just _  -> do
260                          logInfo @String "first player didn't reveal"
261                          void $ mapError' $ runStep client ClaimSecond
262                          logInfo @String "second player won"
263
264              _ -> throwError "unexpected datum"
265
266  type GameSchema = Endpoint "first" FirstParams .\/
                      Endpoint "second" SecondParams
267
268  endpoints :: Contract (Last ThreadToken) GameSchema Text ()
269  endpoints = awaitPromise (first `select` second) >> endpoints
270    where
271      first  = endpoint @"first"  firstGame
272      second = endpoint @"second" secondGame
```

In the beginning we again define our game type (44-51). The difference to the previous example is that the token was of type asset class and now it's of type thread token. The game choice stays the same. What changes is the game datum where we add the second constructer called *Finished* that we did not need before (66-67). We need it for state machine mechanism to work. And when we make the Eq instance for the game datum we take this second constructor in account. The redeemer and the two helper functions are the same as before (77-91). Then we write the transition function for the state machine. It takes the game parameter and then the state datum and redeemer. And then we return a Nothing if the transition is not allowed or just a pair of new state and constraints on the transaction. First we again have the case where the 1st player has already moved and the 2nd player wants to make his move with choice *c*. The parameter *s* holds the combination of datum and value. The *stateValue* parameter gives us the value of the UTXO we are consuming and *stateData* gives us the datum. So first we check that the value is the stake of the game (97). If the check passes we return a Just where we put the constraints on the transaction for the signature and validity interval and include the new state.

Compared to our previous code where we did not use SM all conditions from the first case are also satisfied in our first SM case. The second case is when the 2nd player has moved and the 1st player realizes he has won and wants to reveal his nonce. Compared to our previous code the condition for revealing the nonce is missing here because we cannot formulate it as a constraint and we will take care of it later. We also do not return the token because it gets burned when we reached our final state. The third case is where the 2nd player does not move so the 1st player wants to reclaim his stake. Again if we compare the conditions we see we satisfy all as in the non SM example. The last case is that the 2nd player has moved and the 1st player does not reveal his nonce. Again all the all conditions are satisfied as in the non SM example. In the end we say for all other combinations we return nothing. All together the code gets shorter because we do not need any helper functions and do not need to take care of the NFT. What we have to add for the SM is the final state which basically says finished (118-121). Because we left out the nonce check in the transition function we define it now (123-127).

Next we can define our state machine that takes in the game parameter and two byte strings (129-136). In the body we just provide the four fields we have just defined. Our old function *mkGameValidator* can now be replaced with the state machine and we use the *mkValidator* function to transform it (138-140). We define the *gameStateMachine'* where we fix the two additional parameters and we can use then this function in the off-chain code (148-149). The compilation process, computation of the validator and the address is same as in the previous example. What we additionally define is the state machine client and we need this to be able to interact with the SM from our wallet (167-168) (Figure 28).

Figure 28 - State machine client

If we look at the definition we see it has 2 fields. The state machine instance field is defined by two new fields that are the state machine and the validator code for this SM (Figure 29).

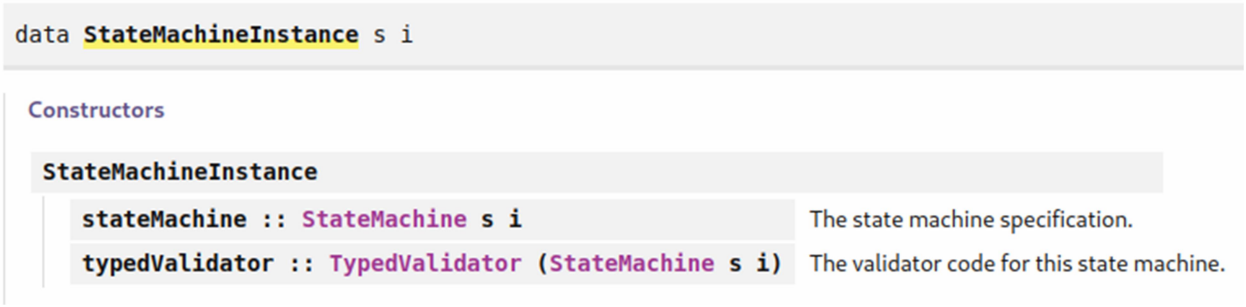

Figure 29 - State machine instance

The chooser field handles the case if we do not use the thread token mechanism and have several UTXOs sitting at our address. With it we can pick the right one. Now we come to the off-chain code. The *FirstParams* type is defined same way as in the previous example. The state machine contracts have a specific constraint on the Error type called *SMContractError*. But we want to use text for the error type so we define a function that handles the conversion (179-180). The helper function *waitUntilTimeHasPassed* is the same as in the previous code. In the *firstGame* contract we again first look up our own key and then we get our thread token (188). Then we define the game parameter (189-196) and after it we define the game client. Next three variables the stake, choice and hash are same as before. In line 201 the *runInitialise* function first mints the NFT corresponding to the thread token, then it creates the UTXO at the state machine address and we give the datum and value as input arguments. After that we log that we have made the first move and then we use the *tell* function to communicate the thread token. This is for the second player to be able to find the game. Then we wait for the 2nd player to move. In the previous example after the wait we needed to use the helper function *findGameOutput* which we can now replace with the *getOnChainState* function (Figure 30).

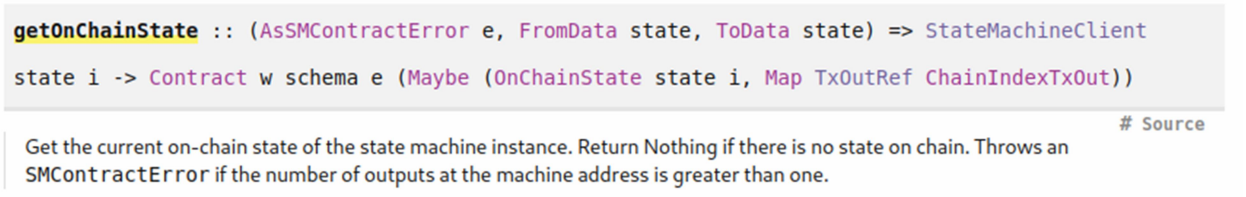

Figure 30 - Get onchain state

It takes in a state machine client and returns a maybe of on chains state and a map with transaction output references as keys and chain indexes as values. The on-chain state has 3 fields available but we use only the first two (Figure 31). The first two fields are further displayed in Figure 32 and Figure 33. The typed script transaction output contains the transaction output and datum that is already deserialized which in our case means it would be of type *GameDatum*. And the typed script transaction output reference contains the transaction output reference and another typed script transaction output.

```
data OnChainState s i
```

Typed representation of the on-chain state of a state machine instance

Constructors

OnChainState	
`ocsTxOut :: TypedScriptTxOut (StateMachine s i)`	Typed transaction output
`ocsTxOutRef :: TypedScriptTxOutRef (StateMachine s i)`	Typed UTXO
`ocsTx :: ChainIndexTx`	Transaction that produced the output

Figure 31 - Onchain state

```
data TypedScriptTxOut a
```

A `TxOut` tagged by a phantom type: and the connection type of the output.

Constructors

```
(FromData (DatumType a), ToData (DatumType a)) => TypedScriptTxOut
  tyTxOutTxOut :: TxOut
  tyTxOutData :: DatumType a
```

Figure 32 - Typed script transaction output

```
data TypedScriptTxOutRef a
```

A `TxOutRef` tagged by a phantom type: and the connection type of the output.

Constructors

```
TypedScriptTxOutRef
  tyTxOutRefRef :: TxOutRef
  tyTxOutRefOut :: TypedScriptTxOut a
```

Figure 33 - Typed script transaction output reference

Once we have our on-chain state we can use the *tyTxOutData* function to directly access the datum. And after that we have the two cases that the second player has not moved or that he has moved and we see that we won. For the first case we do the reclaim (214). And for the second case we reveal our nonce (219). In both cases we use the *runStep* function that takes in a state machine client and the redeemer and returns a contract (Figure 34). It actually creates a transaction, submits it and transitions the state machine.

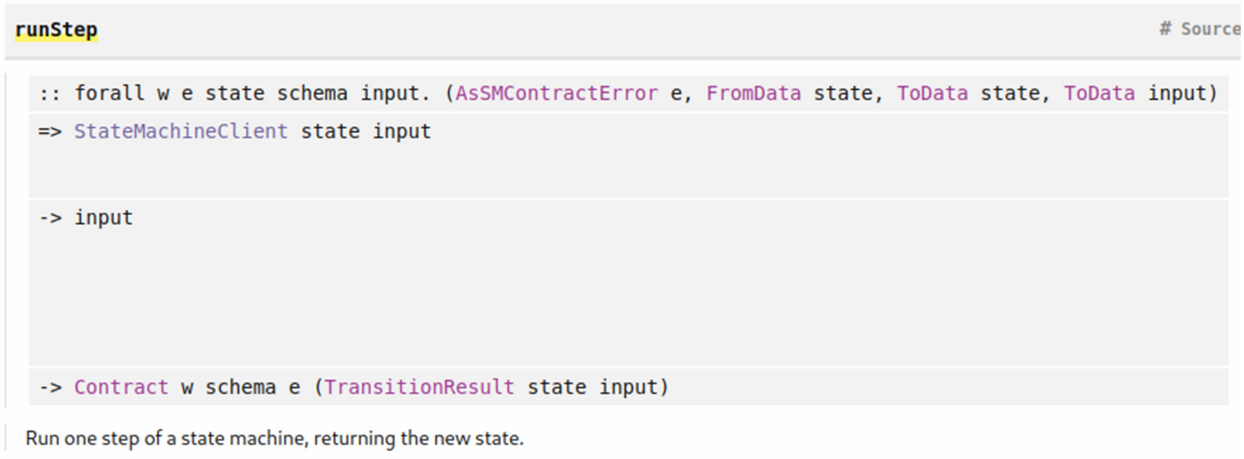

Figure 34 - Run step

The *TransitionResult* type encodes weather the transition failed or succeeded. All the constraints are available to the state machine mechanism and that allows it to automatically compose the transaction that is needed. So we do not need any lookups or helper functions. The second game contract is similar to the first. We first look up our key hash and then define the game parameters and the client. With the *getOnChainState* function we again get the UTXO that represents the state machine. If we don't find the game we just log a message but if we do find it we look up the output and the game datum. And then again we use *runStep* to play our move. After it we wait until the reveal deadline has passed (254). We then again check the new state and if there is a Nothing the first player has won and we don't do anything. Else we claim our win (261). In order to test this we use the code from the *TestStateMachine.hs* example.

```
1   {-# LANGUAGE DataKinds             #-}
2   {-# LANGUAGE FlexibleContexts      #-}
3   {-# LANGUAGE MultiParamTypeClasses #-}
4   {-# LANGUAGE NoImplicitPrelude     #-}
5   {-# LANGUAGE NumericUnderscores    #-}
6   {-# LANGUAGE OverloadedStrings     #-}
7   {-# LANGUAGE ScopedTypeVariables   #-}
8   {-# LANGUAGE TypeApplications      #-}
9   {-# LANGUAGE TypeFamilies          #-}
10
```

```haskell
module Week07.TestStateMachine
    ( test
    , test'
    , GameChoice (..)
    ) where

import           Control.Monad              hiding (fmap)
import           Control.Monad.Freer.Extras as Extras
import           Data.Default               (Default (..))
import           Ledger.TimeSlot
import           Plutus.Trace.Emulator      as Emulator
import           PlutusTx.Prelude
import           Prelude                    (IO, Show (..))
import           Wallet.Emulator.Wallet

import           Week07.StateMachine

test :: IO ()
test = do
    test' Zero Zero
    test' Zero One
    test' One Zero
    test' One One

test' :: GameChoice -> GameChoice -> IO ()
test' c1 c2 = runEmulatorTraceIO $ myTrace c1 c2

myTrace :: GameChoice -> GameChoice -> EmulatorTrace ()
myTrace c1 c2 = do
    Extras.logInfo $ "first move: " ++ show c1 ++ ", second move: " ++ show
c2


    let w1 = knownWallet 1
    let w2 = knownWallet 2

    h1 <- activateContractWallet w1 endpoints
    h2 <- activateContractWallet w2 endpoints

    let pkh1      = mockWalletPaymentPubKeyHash w1
        pkh2      = mockWalletPaymentPubKeyHash w2
        stake     = 5_000_000
        deadline1 = slotToEndPOSIXTime def 5
        deadline2 = slotToEndPOSIXTime def 10

        fp = FirstParams
```

```
55                  { fpSecond          = pkh2
56                  , fpStake           = stake
57                  , fpPlayDeadline    = deadline1
58                  , fpRevealDeadline  = deadline2
59                  , fpNonce           = "SECRETNONCE"
60                  , fpChoice          = c1
61                  }
62
63      callEndpoint @"first" h1 fp
64
65      tt <- getTT h1
66
67      let sp = SecondParams
68                  { spFirst           = pkh1
69                  , spStake           = stake
70                  , spPlayDeadline    = deadline1
71                  , spRevealDeadline  = deadline2
72                  , spChoice          = c2
73                  , spToken           = tt
74                  }
75
76      void $ Emulator.waitNSlots 3
77
78      callEndpoint @"second" h2 sp
79
80      void $ Emulator.waitNSlots 10
81    where
82      getTT :: ContractHandle (Last ThreadToken) GameSchema Text ->
                 EmulatorTrace ThreadToken
83      getTT h = do
84          void $ Emulator.waitNSlots 1
85          Last m <- observableState h
86          case m of
87              Nothing -> getTT h
88              Just tt -> Extras.logInfo ("read thread token " ++ show tt) >>
                           return tt
```

It is very similar to the even odd test code. It is simples because we do not have to specify an initial state. We define our *test'* function that takes in our choices and runs the emulator trace (35-36). The default initial state for the SM is 10 wallets with 100 ADA each. Because of that we decrease the stake from 100 to 5 ADA. What is different in this trace is that we use the *slotToEndPOSIXTime* function. We use this function to fix the issue that off-chain part should construct a transaction that has a correct time interval but the conversion between slots and

posix time does not always work when using state machines because of unfaithfulness. So we see that the state machine approach automatically guarantees that the on-chain and off-chain code fit together. The produced transactions from it are correctly validated.

7.4 Homework

For homework we will modify the state machine code to implement the rock-paper-scissors game. Let's look at the code *RockPaperScissors.hs*.

```
1    data Game = Game
2        { gFirst          :: !PaymentPubKeyHash
3        , gSecond         :: !PaymentPubKeyHash
4        , gStake          :: !Integer
5        , gPlayDeadline   :: !POSIXTime
6        , gRevealDeadline :: !POSIXTime
7        , gToken          :: !ThreadToken
8        } deriving (Show, Generic, FromJSON, ToJSON, Prelude.Eq)
9
10   PlutusTx.makeLift ''Game
11
12   data GameChoice = Rock | Paper | Scissors
13       deriving (Show, Generic, FromJSON, ToJSON, Prelude.Eq, Prelude.Ord)
14
15   instance Eq GameChoice where
16       {-# INLINABLE (==) #-}
17       Rock     == Rock     = True
18       Paper    == Paper    = True
19       Scissors == Scissors = True
20       _        == _        = False
21
22   PlutusTx.unstableMakeIsData ''GameChoice
23
24   {-# INLINABLE beats #-}
25   beats :: GameChoice -> GameChoice -> Bool
26   beats Rock     Scissors = True
27   beats Paper    Rock     = True
28   beats Scissors Paper    = True
29   beats _        _        = False
30
31   data GameDatum = GameDatum BuiltinByteString (Maybe GameChoice) | Finished
32       deriving Show
33
34   instance Eq GameDatum where
35       {-# INLINABLE (==) #-}
```

```
36      GameDatum bs mc == GameDatum bs' mc' = (bs == bs') && (mc == mc')
37      Finished        == Finished          = True
38      _               == _                 = False
39
40  PlutusTx.unstableMakeIsData ''GameDatum
41
42  data GameRedeemer = Play GameChoice | Reveal BuiltinByteString GameChoice |
                        ClaimFirst | ClaimSecond
43      deriving Show
44
45  PlutusTx.unstableMakeIsData ''GameRedeemer
46
47  {-# INLINABLE lovelaces #-}
48  lovelaces :: Value -> Integer
49  lovelaces = Ada.getLovelace . Ada.fromValue
50
51  {-# INLINABLE transition #-}
52  transition :: Game -> State GameDatum -> GameRedeemer -> Maybe
                  (TxConstraints Void Void, State GameDatum)
53  transition game s r = case (stateValue s, stateData s, r) of
54      (v, GameDatum bs Nothing, Play c)
55          | lovelaces v == gStake game             ->
            Just ( Constraints.mustBeSignedBy (gSecond game) <>
56                 Constraints.mustValidateIn (to $ gPlayDeadline game)
57               , State (GameDatum bs $ Just c) (lovelaceValueOf $ 2 *
                                                  gStake game) )
58
59      (v, GameDatum _ (Just c), Reveal _ c')
60          | (lovelaces v == (2 * gStake game)) &&
61            (c' `beats` c)                         ->
            Just ( Constraints.mustBeSignedBy (gFirst game) <>
62                 Constraints.mustValidateIn (to $ gRevealDeadline game)
63               , State Finished mempty )
64
65
66          | (lovelaces v == (2 * gStake game)) &&
67            (c' == c)                              ->
            Just ( Constraints.mustBeSignedBy (gFirst game) <>
68                 Constraints.mustValidateIn (to $ gRevealDeadline game) <>
69                 Constraints.mustPayToPubKey (gSecond game)
70                                             (lovelaceValueOf $ gStake game)
71               , State Finished mempty )
72
73      (v, GameDatum _ Nothing, ClaimFirst)
74          | lovelaces v == gStake game             ->
```

```
              Just ( Constraints.mustBeSignedBy (gFirst game) <>
                     Constraints.mustValidateIn (from $ 1 + gPlayDeadline game)
                   , State Finished mempty )

      (v, GameDatum _ (Just _), ClaimSecond)
          | lovelaces v == (2 * gStake game)       ->
              Just ( Constraints.mustBeSignedBy (gSecond game) <>
                     Constraints.mustValidateIn (from $ 1 + gRevealDeadline
                                                 game)
          , State Finished mempty )

      _                                            -> Nothing

  {-# INLINABLE final #-}
  final :: GameDatum -> Bool
  final Finished = True
  final _        = False

  {-# INLINABLE check #-}
  check :: BuiltinByteString -> BuiltinByteString -> BuiltinByteString ->
           GameDatum -> GameRedeemer -> ScriptContext -> Bool
  check bsRock' bsPaper' bsScissors' (GameDatum bs (Just _))
        (Reveal nonce c) _ =
      sha2_256 (nonce `appendByteString` toBS c) == bs
    where
      toBS :: GameChoice -> BuiltinByteString
      toBS Rock     = bsRock'
      toBS Paper    = bsPaper'
      toBS Scissors = bsScissors'
  check _ _ _ _ _ _ = True

  {-# INLINABLE gameStateMachine #-}
  gameStateMachine :: Game -> BuiltinByteString -> BuiltinByteString ->
                      BuiltinByteString -> StateMachine GameDatum GameRedeemer
  gameStateMachine game bsRock' bsPaper' bsScissors' = StateMachine
      { smTransition  = transition game
      , smFinal       = final
      , smCheck       = check bsRock' bsPaper' bsScissors'
      , smThreadToken = Just $ gToken game
      }

  {-# INLINABLE mkGameValidator #-}
  mkGameValidator :: Game -> BuiltinByteString -> BuiltinByteString ->
                     BuiltinByteString -> GameDatum -> GameRedeemer ->
                     ScriptContext -> Bool
```

```
112 mkGameValidator game bsRock' bsPaper' bsScissors' = mkValidator $
      gameStateMachine game bsRock' bsPaper' bsScissors'
113
114 type Gaming = StateMachine GameDatum GameRedeemer
115
116 bsRock, bsPaper, bsScissors :: BuiltinByteString
117 bsRock     = "R"
118 bsPaper    = "P"
119 bsScissors = "S"
120
121 gameStateMachine' :: Game -> StateMachine GameDatum GameRedeemer
122 gameStateMachine' game = gameStateMachine game bsRock bsPaper bsScissors
123
124 typedGameValidator :: Game -> Scripts.TypedValidator Gaming
125 typedGameValidator game = Scripts.mkTypedValidator @Gaming
126     ($$(PlutusTx.compile [|| mkGameValidator ||])
127         `PlutusTx.applyCode` PlutusTx.liftCode game
128         `PlutusTx.applyCode` PlutusTx.liftCode bsRock
129         `PlutusTx.applyCode` PlutusTx.liftCode bsPaper
130         `PlutusTx.applyCode` PlutusTx.liftCode bsScissors)
131     $$(PlutusTx.compile [|| wrap ||])
132   where
133     wrap = Scripts.wrapValidator @GameDatum @GameRedeemer
134
135 gameValidator :: Game -> Validator
136 gameValidator = Scripts.validatorScript . typedGameValidator
137
138 gameAddress :: Game -> Ledger.Address
139 gameAddress = scriptAddress . gameValidator
140
141 gameClient :: Game -> StateMachineClient GameDatum GameRedeemer
142 gameClient game = mkStateMachineClient $ StateMachineInstance
                    (gameStateMachine' game) (typedGameValidator game)
143
144 data FirstParams = FirstParams
145     { fpSecond         :: !PaymentPubKeyHash
146     , fpStake          :: !Integer
147     , fpPlayDeadline   :: !POSIXTime
148     , fpRevealDeadline :: !POSIXTime
149     , fpNonce          :: !BuiltinByteString
150     , fpChoice         :: !GameChoice
151     } deriving (Show, Generic, FromJSON, ToJSON)
152
153 mapError' :: Contract w s SMContractError a -> Contract w s Text a
154 mapError' = mapError $ pack . show
```

```
155
156 waitUntilTimeHasPassed :: AsContractError e => POSIXTime ->
                                                 Contract w s e ()
157 waitUntilTimeHasPassed t = void $ awaitTime t >> waitNSlots 1
158
159 firstGame :: forall s. FirstParams -> Contract (Last ThreadToken) s Text ()
160 firstGame fp = do
161     pkh <- Contract.ownPaymentPubKeyHash
162     tt  <- mapError' getThreadToken
163     let game   = Game
164             { gFirst          = pkh
165             , gSecond         = fpSecond fp
166             , gStake          = fpStake fp
167             , gPlayDeadline   = fpPlayDeadline fp
168             , gRevealDeadline = fpRevealDeadline fp
169             , gToken          = tt
170             }
171         client = gameClient game
172         v      = lovelaceValueOf (fpStake fp)
173         c      = fpChoice fp
174         x      = case c of
175                      Rock     -> bsRock
176                      Paper    -> bsPaper
177                      Scissors -> bsScissors
178         bs     = sha2_256 $ fpNonce fp `appendByteString` x
179     void $ mapError' $ runInitialise client (GameDatum bs Nothing) v
180     logInfo @String $ "made first move: " ++ show (fpChoice fp)
181     tell $ Last $ Just tt
182
183     waitUntilTimeHasPassed $ fpPlayDeadline fp
184
185     m <- mapError' $ getOnChainState client
186     case m of
187         Nothing     -> throwError "game output not found"
188         Just (o, _) -> case tyTxOutData $ ocsTxOut o of
189
190             GameDatum _ Nothing -> do
191                 logInfo @String "second player did not play"
192                 void $ mapError' $ runStep client ClaimFirst
193                 logInfo @String "first player reclaimed stake"
194
195             GameDatum _ (Just c') | c `beats` c' || c' == c -> do
196                 logInfo @String "second player played and lost or drew"
197                 void $ mapError' $ runStep client $ Reveal (fpNonce fp) c
198                 logInfo @String "first player revealed and won or drew"
```

```
199
200             _ -> logInfo @String "second player played and won"
201
202 data SecondParams = SecondParams
203     { spFirst          :: !PaymentPubKeyHash
204     , spStake          :: !Integer
205     , spPlayDeadline   :: !POSIXTime
206     , spRevealDeadline :: !POSIXTime
207     , spChoice         :: !GameChoice
208     , spToken          :: !ThreadToken
209     } deriving (Show, Generic, FromJSON, ToJSON)
210
211 secondGame :: forall w s. SecondParams -> Contract w s Text ()
212 secondGame sp = do
213     pkh <- Contract.ownPaymentPubKeyHash
214     let game   = Game
215             { gFirst          = spFirst sp
216             , gSecond         = pkh
217             , gStake          = spStake sp
218             , gPlayDeadline   = spPlayDeadline sp
219             , gRevealDeadline = spRevealDeadline sp
220             , gToken          = spToken sp
221             }
222         client = gameClient game
223     m <- mapError' $ getOnChainState client
224     case m of
225         Nothing     -> logInfo @String "no running game found"
226         Just (o, _) -> case tyTxOutData $ ocsTxOut o of
227             GameDatum _ Nothing -> do
228                 logInfo @String "running game found"
229                 void $ mapError' $ runStep client $ Play $ spChoice sp
230                 logInfo @String $ "made second move: " ++ show (spChoice sp)
231
232                 waitUntilTimeHasPassed $ spRevealDeadline sp
233
234                 m' <- mapError' $ getOnChainState client
235                 case m' of
236                     Nothing -> logInfo @String "first player won or drew"
237                     Just _  -> do
238                         logInfo @String "first player didn't reveal"
239                         void $ mapError' $ runStep client ClaimSecond
240                         logInfo @String "second player won"
241
242             _ -> throwError "unexpected datum"
243
```

```
244  type GameSchema = Endpoint "first" FirstParams .\/
                       Endpoint "second" SecondParams
245
246  endpoints :: Contract (Last ThreadToken) GameSchema Text ()
247  endpoints = awaitPromise (first `select` second) >> endpoints
248    where
249      first  = endpoint @"first"  firstGame
250      second = endpoint @"second" secondGame
```

The imports and language pragmas are the same as in the SM example. Also the game type stays the same (1-8). What changes is the game choice parameter and the Eq instance of it. Then we define the *beats* function that takes in two game choices and returns a Bool (15-20). Next we define the game datum and its Eq instance same way as before. For the game redeemer there is a difference in the reveal option where we have to specify now also the game choice since there are 2 possibilities (42-43). One is that the game is a draw and the other one is that we have won. This will also have effect on our transition function where we will have now 5 possible cases. The difference compared to the previous code is in the second case where the 1st player chooses to reveal his choice and we consider again 2 possibilities. The first is that the 1st player has won and the second is that there is a draw in which case we put a constraint that the 2nd player gets his stake back. Now we proceed to the *check* function that takes in three byte strings for our three choices and checks weather the checksum is valid (90-99). The *gameStateMachine* function gets also updated accordingly to our three choices (101-108). Same is true for the game validator and the compiled code. The rest of the on-chain code is the same as in our previous example. In the first game contract when defining parameters what changes is that we define an additional parameter x that gives us the byte string for our choice (174-177) and we use it when computing the hash of the nonce (178). And another change is in the second case after the play deadline when the 2nd player reveals his choice and has lost or drew (195-198). Then for the second game everything stays the same except the log message on line 236 changes were we say »first player won or drew«.

8 Testing

In this chapter we will look at another example for state machines and then look at how Haskells property testing is implemented for Plutus smart contracts.

8.1 State Machine Example: Token Sale

Here we will look at an example where a person wants to make a token sale. The idea is we lock tokens in a contract an allow users to buy them for a fixed price. Figure 35 shows a simple example of the token sale and the code follows below.

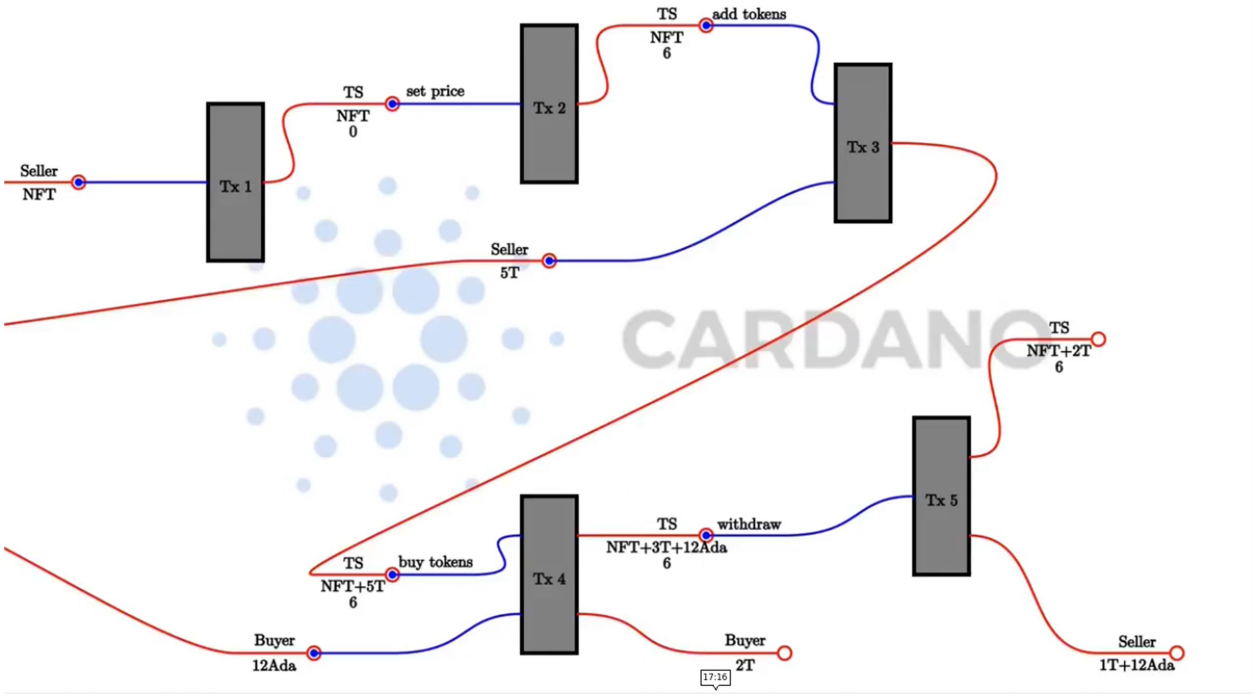

Figure 35 - Token sale

```
1    {-# LANGUAGE DataKinds             #-}
2    {-# LANGUAGE DeriveAnyClass        #-}
3    {-# LANGUAGE DeriveGeneric         #-}
4    {-# LANGUAGE FlexibleContexts      #-}
5    {-# LANGUAGE MultiParamTypeClasses #-}
6    {-# LANGUAGE NoImplicitPrelude     #-}
7    {-# LANGUAGE OverloadedStrings     #-}
8    {-# LANGUAGE ScopedTypeVariables   #-}
9    {-# LANGUAGE TemplateHaskell       #-}
10   {-# LANGUAGE TypeApplications      #-}
11   {-# LANGUAGE TypeFamilies          #-}
12   {-# LANGUAGE TypeOperators         #-}
```

```
13
14  {-# OPTIONS_GHC -g -fplugin-opt PlutusTx.Plugin:coverage-all #-}
15
16  module Week08.TokenSale
17      ( TokenSale (..)
18      , TSRedeemer (..)
19      , tsCovIdx
20      , TSStartSchema
21      , TSUseSchema
22      , startEndpoint
23      , useEndpoints
24      , useEndpoints'
25      ) where
26
27  import           Control.Monad                hiding (fmap)
28  import           Data.Aeson                   (FromJSON, ToJSON)
29  import           Data.Monoid                  (Last (..))
30  import           Data.Text                    (Text, pack)
31  import           GHC.Generics                 (Generic)
32  import           Plutus.Contract              as Contract
33  import           Plutus.Contract.StateMachine
34  import qualified PlutusTx
35  import           PlutusTx.Code                (getCovIdx)
36  import           PlutusTx.Coverage            (CoverageIndex)
37  import           PlutusTx.Prelude             hiding (Semigroup(..), check,
                                                  unless)
38  import           Ledger                       hiding (singleton)
39  import           Ledger.Ada                   as Ada
40  import           Ledger.Constraints           as Constraints
41  import qualified Ledger.Typed.Scripts         as Scripts
42  import           Ledger.Value
43  import           Prelude                      (Semigroup (..), Show (..),
                                                   uncurry)
44  import qualified Prelude
45
46  data TokenSale = TokenSale
47      { tsSeller :: !PaymentPubKeyHash
48      , tsToken  :: !AssetClass
49      , tsTT     :: !ThreadToken
50      } deriving (Show, Generic, FromJSON, ToJSON, Prelude.Eq)
51
52  PlutusTx.makeLift ''TokenSale
53
54  data TSRedeemer =
55        SetPrice Integer
```

```
56        | AddTokens Integer
57        | BuyTokens Integer
58        | Withdraw Integer Integer
59        deriving (Show, Prelude.Eq)
60
61    PlutusTx.unstableMakeIsData ''TSRedeemer
62
63    {-# INLINABLE lovelaces #-}
64    lovelaces :: Value -> Integer
65    lovelaces = Ada.getLovelace . Ada.fromValue
66
67    {-# INLINABLE transition #-}
68    transition :: TokenSale -> State Integer -> TSRedeemer -> Maybe
                    (TxConstraints Void Void, State Integer)
69    transition ts s r = case (stateValue s, stateData s, r) of
70        (v, _, SetPrice p)   | p >= 0           ->
                               Just ( Constraints.mustBeSignedBy (tsSeller ts)
71                                   , State p v )
72
73        (v, p, AddTokens n)  | n > 0            ->
                               Just ( mempty
74                                   , State p $ v
75                                     <>
76                                     assetClassValue (tsToken ts) n )
77
78        (v, p, BuyTokens n)  | n > 0            ->
                               Just ( mempty
79                                   , State p $ v
80                                     <>
81                                     assetClassValue (tsToken ts) (negate n)
82                                     <> lovelaceValueOf (n * p) )
83
84        (v, p, Withdraw n l) | n >= 0 && l >= 0 ->
                               Just ( Constraints.mustBeSignedBy (tsSeller ts)
85                                   , State p $ v
86                                     <>
87                                     assetClassValue (tsToken ts) (negate n)
88                                     <> lovelaceValueOf (negate l) )
89
90        _                                       -> Nothing
91
92    {-# INLINABLE tsStateMachine #-}
93    tsStateMachine :: TokenSale -> StateMachine Integer TSRedeemer
94    tsStateMachine ts = mkStateMachine (Just $ tsTT ts) (transition ts)
                          (const False)
```

```haskell

{-# INLINABLE mkTSValidator #-}
mkTSValidator :: TokenSale -> Integer -> TSRedeemer -> ScriptContext -> Bool
mkTSValidator = mkValidator . tsStateMachine

type TS = StateMachine Integer TSRedeemer

tsTypedValidator :: TokenSale -> Scripts.TypedValidator TS
tsTypedValidator ts = Scripts.mkTypedValidator @TS
    ($$(PlutusTx.compile [|| mkTSValidator ||])
     `PlutusTx.applyCode` PlutusTx.liftCode ts)
    $$(PlutusTx.compile [|| wrap ||])
  where
    wrap = Scripts.wrapValidator @Integer @TSRedeemer

tsValidator :: TokenSale -> Validator
tsValidator = Scripts.validatorScript . tsTypedValidator

tsAddress :: TokenSale -> Ledger.Address
tsAddress = scriptAddress . tsValidator

tsClient :: TokenSale -> StateMachineClient Integer TSRedeemer
tsClient ts = mkStateMachineClient $ StateMachineInstance
              (tsStateMachine ts) (tsTypedValidator ts)

tsCovIdx :: CoverageIndex
tsCovIdx = getCovIdx $$(PlutusTx.compile [|| mkTSValidator ||])

mapErrorSM :: Contract w s SMContractError a -> Contract w s Text a
mapErrorSM = mapError $ pack . show

startTS :: AssetClass -> Contract (Last TokenSale) s Text ()
startTS token = do
    pkh <- Contract.ownPaymentPubKeyHash
    tt  <- mapErrorSM getThreadToken
    let ts = TokenSale
            { tsSeller = pkh
            , tsToken  = token
            , tsTT     = tt
            }
        client = tsClient ts
    void $ mapErrorSM $ runInitialise client 0 mempty
    tell $ Last $ Just ts
    logInfo $ "started token sale " ++ show ts

```

```
setPrice :: TokenSale -> Integer -> Contract w s Text ()
setPrice ts p = void $ mapErrorSM $ runStep (tsClient ts) $ SetPrice p

addTokens :: TokenSale -> Integer -> Contract w s Text ()
addTokens ts n = void $ mapErrorSM $ runStep (tsClient ts) $ AddTokens n

buyTokens :: TokenSale -> Integer -> Contract w s Text ()
buyTokens ts n = void $ mapErrorSM $ runStep (tsClient ts) $ BuyTokens n

withdraw :: TokenSale -> Integer -> Integer -> Contract w s Text ()
withdraw ts n l = void $ mapErrorSM $ runStep (tsClient ts) $ Withdraw n l

type TSStartSchema =
        Endpoint "start"      (CurrencySymbol, TokenName)
type TSUseSchema =
        Endpoint "set price"  Integer
    .\/ Endpoint "add tokens" Integer
    .\/ Endpoint "buy tokens" Integer
    .\/ Endpoint "withdraw"   (Integer, Integer)

startEndpoint :: Contract (Last TokenSale) TSStartSchema Text ()
startEndpoint = forever
              $ handleError logError
              $ awaitPromise
              $ endpoint @"start" $ startTS . AssetClass

useEndpoints' :: ( HasEndpoint "set price" Integer s
                 , HasEndpoint "add tokens" Integer s
                 , HasEndpoint "buy tokens" Integer s
                 , HasEndpoint "withdraw" (Integer, Integer) s
                 )
              => TokenSale
              -> Contract () s Text ()
useEndpoints' ts = forever
                 $ handleError logError
                 $ awaitPromise
                 $ setPrice' `select` addTokens' `select` buyTokens'
                   `select` withdraw'
  where
    setPrice'  = endpoint @"set price"  $ setPrice ts
    addTokens' = endpoint @"add tokens" $ addTokens ts
    buyTokens' = endpoint @"buy tokens" $ buyTokens ts
    withdraw'  = endpoint @"withdraw"   $ Prelude.uncurry $ withdraw ts

useEndpoints :: TokenSale -> Contract () TSUseSchema Text ()
```

```
182  useEndpoints = useEndpoints'
```

First we define the TokenSale that will be used for parameterizing our transition function (46-50). It contains the sellers address, the tokens we will sell and the thread token for identifying the UTXO for the token sale. For the redeemer type we provide the operations tha we saw in Figure 35 (54-59). The integers represent price in lovelace and amount of tokens. Then we define a helper function to extract lovelace amount from a value type (63-65). In the transition function we first put in our parameter, then the state that defines the price of the token and the remaining two parameters follow the same patter as in the previous SM example (68). In the case statement we split the state to the value and the datum (69). Next follow the four transitions. In the first case the seller wants to set the price to the new value *p* (70-71). We only allow that if the price is non-negative. The only constraints we put is that the seller has to sign the transaction and for the state we set now *p* as the new datum and *v* as value stays the same. In the second case we add tokens and demand that the amount is positive (73-76). We put no constraints to this action so anybody can add tokens to the contract. For the new state the price does not change but the value changes that are now the old value plus the amount of tokens that are added. Third case is we define buying tokens (78-82). Also here we put no constraints so anybody can buy tokens. The price again does not change but the value is reduced for the amount of tokens that a person bought and the corresponding price in ADA is added. In the last case we define the withdrawal of tokens and lovelace (84-88). Here we insist that the seller has to sign the transaction. And the value decreases for the amount of tokens and lovelace that the seller wants to withdraw. In the end we also define the case that all other transitions are illegal. Now that we have the transition function we define the state machine where we use the smart constructer called *mkStateMachine* (92-94). It takes in 3 arguments. The first is maybe the thread token, then the transition function and the function that determines if states are final or not. And in our case we do not have a final state so we can always return False. After that we can turn our state machine into a validator function (96-98) and compile it (102-107). Then we define the state machine client that is used to interact with the SM in the off-chain code (115-116). What is new is that we define the coverage index (118-119). That is related to getting coverage information for tests. Next we define our helper function that transforms the type of the error from the SM type to text (121-122). This was now the on-chain code.

For the off-chain code we first define the contract function *startTS*. It takes in one parameter and uses the writer functionality. First we look up our own payment public key hash and get the thread token. Then we define the token sale and client parameters (128-133). Next we initialize the client with the initial state 0 and mempty. After that we tell the token sell value so that

other contracts are able to lookup that value an participate in the token sale (135). And in the end we log a message. Then come simple functions corresponding to actions we can take and they are guaranteed to sync with the on-chain code i.e. they create transactions that are valid and will pass validation (138-148). We now have to define 2 schemas. One to start the token sale that will have only one endpoint (150-151) and one to use the token sale that has four endpoints (152-156). For the withdraw action we first put in how many tokens we want to withdraw and then how many lovelace. The start endpoint and use endpoint bundle up the actions we have defined (158-179). The *uncurry* function takes two separate input parameters for a function call and converts them into a pair of integers in a tuple for a function call.

```
uncurry :: (a -> b -> c) -> (a, b) -> c
Prelude> :t uncurry (+)
uncurry (+) :: Num c => (c, c) -> c
```

To try now out this code we can use the emulator trace defined in the test/Spec/Trace.hs file.

```
1    {-# LANGUAGE DataKinds             #-}
2    {-# LANGUAGE FlexibleContexts      #-}
3    {-# LANGUAGE MultiParamTypeClasses #-}
4    {-# LANGUAGE NumericUnderscores    #-}
5    {-# LANGUAGE OverloadedStrings     #-}
6    {-# LANGUAGE ScopedTypeVariables   #-}
7    {-# LANGUAGE TypeApplications      #-}
8    {-# LANGUAGE TypeFamilies          #-}
9
10   module Spec.Trace
11       ( tests
12       , testCoverage
13       , runMyTrace
14       ) where
15
16   import           Control.Exception                          (try)
17   import           Control.Lens
18   import           Control.Monad                              hiding (fmap)
19   import           Control.Monad.Freer.Extras                 as Extras
20   import           Data.Default                               (Default (..))
21   import           Data.IORef
22   import qualified Data.Map                                   as Map
23   import           Data.Monoid                                (Last (..))
24   import           Ledger
25   import           Ledger.Value
26   import           Ledger.Ada                                 as Ada
27   import           Plutus.Contract.Test
28   import           Plutus.Contract.Test.Coverage
```

```
29  import           Plutus.Trace.Emulator                          as Emulator
30  import qualified PlutusTx.Prelude                                as Plutus
31  import           System.Exit                                   (ExitCode (..))
32  import           Test.Tasty
33  import qualified Test.Tasty.HUnit                               as HUnit
34
35  import           Plutus.Contract.Test.Coverage.ReportCoverage
                     (writeCoverageReport)
36  import           Week08.TokenSale
37
38  tests :: TestTree
39  tests = checkPredicateOptions
40      myOptions
41      "token sale trace"
42      myPredicate
43      myTrace
44
45  testCoverage :: IO ()
46  testCoverage = do
47      cref <- newCoverageRef
48      e <- try $ defaultMain $ checkPredicateOptionsCoverage
49          myOptions
50          "token sale trace"
51          cref
52          myPredicate
53          myTrace
54      case e of
55          Left (c :: ExitCode) -> do
56              putStrLn $ "Tasty exited with: " ++ show c
57              report <- readCoverageRef cref
58              writeCoverageReport "TokenSaleTrace" tsCovIdx report
59          Right () -> putStrLn $ "unexpected tasty result"
60
61  myOptions :: CheckOptions
62  myOptions = defaultCheckOptions & emulatorConfig .~ emCfg
63
64  myPredicate :: TracePredicate
65  myPredicate =
66      walletFundsChange w1 (Ada.lovelaceValueOf   10_000_000  <>
                              assetClassValue token (-60) <>
                              Plutus.negate (toValue minAdaTxOut)) .&&.
67      walletFundsChange w2 (Ada.lovelaceValueOf (-20_000_000) <>
                              assetClassValue token   20) .&&.
68      walletFundsChange w3 (Ada.lovelaceValueOf (- 5_000_000) <>
                              assetClassValue token    5)
```

```
69
70  runMyTrace :: IO ()
71  runMyTrace = runEmulatorTraceIO' def emCfg myTrace
72
73  emCfg :: EmulatorConfig
74  emCfg = EmulatorConfig (Left $ Map.fromList [(knownWallet w, v) |
                           w <- [1 .. 3]]) def def
75    where
76      v :: Value
77      v = Ada.lovelaceValueOf 1_000_000_000 <> assetClassValue token 1000
78
79  currency :: CurrencySymbol
80  currency = "aa"
81
82  name :: TokenName
83  name = "A"
84
85  token :: AssetClass
86  token = AssetClass (currency, name)
87
88  myTrace :: EmulatorTrace ()
89  myTrace = do
90      h <- activateContractWallet w1 startEndpoint
91      callEndpoint @"start" h (currency, name)
92      void $ Emulator.waitNSlots 5
93      Last m <- observableState h
94      case m of
95          Nothing -> Extras.logError @String "error starting token sale"
96          Just ts -> do
97              Extras.logInfo $ "started token sale " ++ show ts
98
99              h1 <- activateContractWallet w1 $ useEndpoints ts
100             h2 <- activateContractWallet w2 $ useEndpoints ts
101             h3 <- activateContractWallet w3 $ useEndpoints ts
102
103             callEndpoint @"set price" h1 1_000_000
104             void $ Emulator.waitNSlots 5
105
106             callEndpoint @"add tokens" h1 100
107             void $ Emulator.waitNSlots 5
108
109             callEndpoint @"buy tokens" h2 20
110             void $ Emulator.waitNSlots 5
111
112             callEndpoint @"buy tokens" h3 5
```

```
113             void $ Emulator.waitNSlots 5
114
115             callEndpoint @"withdraw" h1 (40, 10_000_000)
116             void $ Emulator.waitNSlots 5
117
118 checkPredicateOptionsCoverage :: CheckOptions
119                               -> String
120                               -> CoverageRef
121                               -> TracePredicate
122                               -> EmulatorTrace ()
123                               -> TestTree
124 checkPredicateOptionsCoverage options nm (CoverageRef ioref)
      predicate action =
125   HUnit.testCaseSteps nm $ \step -> do
126       checkPredicateInner options predicate action step
            (HUnit.assertBool nm) (\rep -> modifyIORef ioref (rep<>))
```

We run the trace with a custom emulator configuration *emCfg* (73-77). It gives an initial distribution of ADA and native tokens with the token name “A” and currency symbol “aa”. Now for the trace first we activate the start endpoint for wallet one (90). Then we call the start endpoint and wait for 5 slots (91-92). Then we check the observable state and in the case that it’s nothing we log an error message. Else we start the use endpoints that are parameterized by the *ts* value. Then we call various endpoints. First the wallet one sets the price of the token (103). Then wallet one adds 100 tokens (106). Next wallet two buys 20 tokens (109) and wallet three buys 5 tokens (112). In the end wallet one makes a withdraw of 40 tokens and 10 ADA.

If you want to test this code that resides in the Spec/ folder you need to use the command:

```
$ cabal repl plutus-pioneer-program-week08:test:plutus-pioneer-program-week08-tests
```

8.2 Automatic testing using emulator traces

Plutus uses the Tasty test framework. You can find the tasty package with a description and example on hackage.haskell.org. Tests are of type *TestTree*. There is special support for tests in Plutus in the module *Plutus.Contract.Test*. There are various types of tests that are supported but we will look at two of those types: one that works with emulator traces and one that uses property based testing. By using the *checkPredicate* function we produce something that the tasty framework can understand (Figure 36). There is also a variation of that function called *checkPredicateOptions* that takes in an additional parameter of type *CheckOptions* (Figure 37). It has no constructors exposed but we can use various functions with it (Figure 38).

checkPredicate

```
:: String                  Descriptive name of the test
-> TracePredicate          The predicate to check
-> EmulatorTrace ()
-> TestTree
```

Check if the emulator trace meets the condition

Figure 36 - Check predicate function

checkPredicateOptions

```
:: CheckOptions            Options to use
-> String                  Descriptive name of the test
-> TracePredicate          The predicate to check
-> EmulatorTrace ()
-> TestTree
```

A version of `checkPredicate` with configurable `CheckOptions`

Figure 37 - Check predicate options

```
data CheckOptions
```

Options for running the

```
defaultCheckOptions :: CheckOptions
```

```
minLogLevel :: Lens' CheckOptions LogLevel
```

```
emulatorConfig :: Lens' CheckOptions EmulatorConfig
```

```
changeInitialWalletValue :: Wallet -> (Value -> Value) -> CheckOptions -> CheckOptions
```

Modify the value assigned to the given wallet in the initial distribution.

Figure 38 - Check options type

The *Lens'* type is related to Optics in Haskell. We can use it to set an emulator config. To modify the *CheckOptions* without using lens we can use the *changeInitialWalletValue* function. Given a wallet and a function that updates the initial value it modifies the check options where the given wallet has the function applied to it. Going back to the checkPredicate function let's look at the *TracePredicate* type (Figure 39). It is a condition on a trace that represents the actual test. We see that there are also logical combinators so given a trace we can negate it or make a logical »and« or »or«.

```
type TracePredicate = FoldM (Eff '[Reader InitialDistribution, Error EmulatorFoldErr,
Writer (Doc Void)]) EmulatorEvent Bool                                    # Source
```

Figure 39 - Trace predicate

There is a wide variety of available predicates in the Assertion chapter of the *Plutus.Contract.Test* module. We will use the *walletFundsChange* predicate (Figure 40).

```
walletFundsChange :: Wallet -> Value -> TracePredicate
```

Check that the funds in the wallet have changed by the given amount, exluding fees.

Figure 40 - Wallet funds change

It checks for a given wallet after the trace is completed. The wallet funds will change by the given value excluding fees so we can look at the value change without fees. There is also a variation of this function called *walletFundsExactChange* where this fee is not automatically taken care of. If we now look again at the *test/Spec/Trace.hs* file from the previous chapter in the *tests* parameter we are using the *checkPredicateOptions* function (38-43) where we input my options that contains the emulator config (61-62). We start with the default option and add the emulator config. The operator ".~" is part of Haskell optics and says that we set the *emulatorConfig* part to the given value. When defining *myPredicate* we use the logical "and" to combine three predicates and we use the *walletFundsChange* function (64-68). The fees are taken care of automatically when we use this function but not the minimal ADA deposit that we have to take care of. If we want to run the test we have to first get into our test repl as shown at the end of the previous sub-chapter. Then we execute the command:

```
ghci> :l test/Spec/Trace.hs
Ok, one module loaded.
ghci> import Test.Tasty
ghci> defaultMain tests
All 1 tests passed (0.34s)
```

If the test does not pass we would get a longer log message with an error output.

8.3 Test Coverage

Plutus makes use of code coverage that enables the user to see how much code is covered by your tests. The *checkPredicateCoverage* function uses the *CoverageRef* variable (Figure 41).

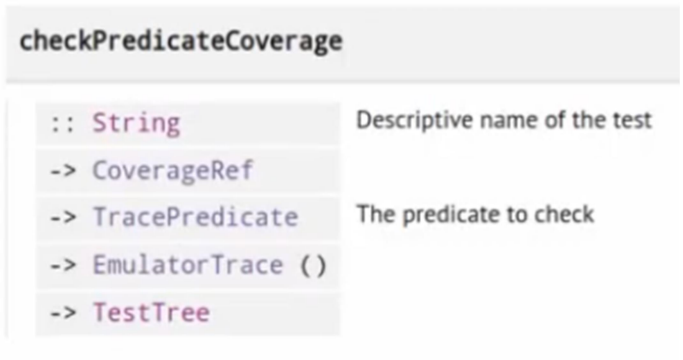

Figure 41 - Check predicate coverage

If we look again at the code in *test/Spec/Trace.hs* we have the *checkPredicateOptionsCoverage* function that combines the functions *checkPredicateOptions* and *checkPredicateCoverage* (118-126). The *CoverageRef* type is just a newtype wrapper around a *IORef* for *CoverageReport* (Figure 42). And we can get a coverage reference with the *newCoverageRef* function.

Figure 42 - Coverage reference

So using that we define the *testCoverage* IO action (45-59). First we get the coverage reference, then we use the *checkPredicateOptionsCoverage* function but because we are in IO we need the *defaultMain* function for this to work which always throws a default code exception at the end even if all test pass. With the *try* statement we are catching this exception. Then we provide the parameters as previously but with the new reference. In the body of the case

statement we should always get the Left constructor and if the test succeeds it should be a zero return code and if they don't it should be a non-zero code. But in either case we read the report and write it to the TokenSaleTrace HTML file by using the coverage index. If we open it in a web-browser the lines highlighted green represent conditions that passed for all tests and the dark highlighted lines represent conditions that were never met.

8.4 Interlude optics

The most used Haskell library for optics is called Lens. Optics are used to reach deeply into hierarchical data types to manipulate parts of them. Let's look at the example code from *Week08/Lens.hs* where we will look at a problem and show how to solve it with lens.

```
1   {-# LANGUAGE TemplateHaskell #-}
2
3   module Week08.Lens where
4
5   import Control.Lens
6
7   newtype Company = Company {_staff :: [Person]} deriving Show
8
9
10  data Person  = Person
11      { _name    :: String
12      , _address :: Address
13      } deriving Show
14
15  newtype Address = Address {_city :: String} deriving Show
16
17  alejandro, lars :: Person
18  alejandro = Person
19    {  _name    = "Alejandro"
20    ,  _address = Address {_city = "Zacateca"}
21    }
22  lars = Person
23    {  _name    = "Lars"
24    ,  _address = Address {_city = "Regensburg"}
25    }
26
27  iohk :: Company
28  iohk = Company { _staff = [alejandro, lars] }
29
30  goTo :: String -> Company -> Company
31  goTo there c = c {_staff = map movePerson (_staff c)}
```

```
32    where
33      movePerson p = p {_address = (_address p) {_city = there}}
34
35  makeLenses ''Company
36  makeLenses ''Person
37  makeLenses ''Address
38
39  goTo' :: String -> Company -> Company
40  goTo' there c = c & staff . each . address . city .~ there
```

The company data type is just a newtype wrapper around a list of persons with the accessor called staff (7). Person is a record type with fields name and address (10-13). Address is a newtype wrapper around a string with the accessor called city (15). As an example we define two persons (17-25) and a company where the staff consist of these two persons (27-28). The function *goTo* takes in a city name as a string and a company and changes for all the staff memebers the address field (30-33). For this example we use the record update syntax. Dealing with nested record types can become quite messy because you always have to keep the old fields in place and update the new ones. And this is what optics is trying to solve by providing first class field accessors. You could say that optics provide a programmable dot, which is similar to other languages as Java where you can access an attribute with the dot notation. The lenses library provides some template Haskell features but it expects some underscore conventions which we used in our accessor names. You need to provide the types for which you want to have lenses (35-37). And the name of the lenses will be the names of the original fields without the underscore. There is a way to inspect what code the template Haskell writes at compile time. You can activate the flag »:set –ddump-splices«. If you reload your Lens module in the Repl you will get an extended output for the template Haskell definitions. Here is a short demonstration of how to use lenses in the Repl.

```
ghci> :l src/Week08/Lens.hs
ghci> import Control.Lens
ghci> lars ^. name
"Lars"
ghci> lars ^. address
Address {_city = "Regensburg"}
ghci> lars ^. address . city
"Regensburg"
ghci> lars & name .~ "LARS"
Person {_name = "LARS", _address = Address {_city = "Regensburg"}}
ghci> lars & address . city .~ "Munich"
Person {_name = "Lars", _address = Address {_city = "Munich"}}
```

The combination of lenses is done with the dot notation. The ampersand notation is used to set a record type field. There is also a different type of optics called traversals which does not only

zoom into one field but into many simultaneously. If you would have a list it would zoom into all elements. Here is an example using the *each* traversable.

```
ghci> [1 :: Int, 3, 4] & each .~ 42
[42, 42, 42]
```

Various types of lenses can be combined with the dot operator. We can see such an example in our code with the *goTo'* function (39-40).

8.5 Property based testing with QuickCheck

QuickCheck is a Haskell library for property based testing. In contrast to Unit testing where the cases of test are hardcoded we only specify a property function which defines a property of our code. It takes in a given variable and returns True if our code upholds the property for the given variable. Then variables are randomly picked by the QuickCheck library and the test passes if for all variables the property function returns True. Let's look at the code in *QuickCheck.hs*.

```haskell
module Week08.QuickCheck where

prop_simple :: Bool
prop_simple = 2 + 2 == (4 :: Int)

-- Insertion sort code:

-- | Sort a list of integers in ascending order.
--
-- >>> sort [5,1,9]
-- [1,5,9]
--
sort :: [Int] -> [Int] -- not correct
sort []     =  []
sort (x:xs) =  insert x xs

-- | Insert an integer at the right position into an /ascendingly sorted/
-- list of integers.
--
-- >>> insert 5 [1,9]
-- [1,5,9]
--
insert :: Int -> [Int] -> [Int] -- not correct
insert x []                     =  [x]
insert x (y:ys)  | x <= y       =  x : ys
                 | otherwise    =  y : insert x ys
```

```
27
28  isSorted :: [Int] -> Bool
29  isSorted []           = True
30  isSorted [_]          = True
31  isSorted (x : y : ys) = x <= y && isSorted (y : ys)
32
33  prop_sort_sorts :: [Int] -> Bool
34  prop_sort_sorts xs = isSorted $ sort xs
35
36  prop_sort_preserves_length :: [Int] -> Bool
37  prop_sort_preserves_length xs = length (sort xs) == length xs
```

First we define the *sort* and the helper *insert* functions that sort a list (13-26). Next we define the *isSorted* function that checks weather a list of integers is sorted (28-31). With the function *prop_sort_sorts* we test the sorting property of the *sort* function (33-34) and with the function *prop_sort_preserves_length* we test that the sort function preserves the length of the list (36-37). We can run our example code with the following command:

```
ghci> quickCheck prop_sort_sorts
*** Failed! Falsified (after 8 tests and 4 shrinks):
[0,0,-1]
ghci> sort [0,0,-1]
[0,-1]
```

What the message means quick check tried out 8 examples of a list and after it found one it tried 4 times to further simplify it and returned it as an example in the Repl. And after we tried the example manually we really see that the list does not get sorted.

When QuickCheck checks a property it starts with simple random arguments and then makes them more and more complex over time.

By default quick check tries 100 arguments to test our property. For our sort function we could implement a fix as specify line 15 as follows:

```
sort (x:xs) =  insert x $ sort xs
```

If we run this code and test it we see that a 100 test pass, but if we manually try the previous list it does get sorted but a zero value disappears from the list.

```
ghci> sort [0,0,-1]
```

```
[-1,0]
```

So it means our test is only good enough as good the *prop_sort_sorts* function is. But we can detect this with another property called *prop_sort_preserves_length* (36-37). And for this function we do get a counter example where the test now fails. And the bug is on line 25 that we can change to the following code where both test will pass:

```
insert x (y:ys)  | x <= y       =  x : y : ys
```

8.6 Property based testing of Plutus contracts

The problem we encounter when writing property based tests for Plutus contracts is how do you test code that has effect on the real world as for example our blockchain. We can explain this on the example of testing file operation with QuickCheck. The idea is you start with a model which is an idealized system. There must be some sort of relation between the real system and the model. And then what quick check does it generates a random sequence of actions so for the file system it would generate for example opening, reading and writing sequences.

You can apply an action to your model and apply it to the real world. So both progress to a new state and after that you compare the two and check whether they are still in sync (Figure 43).

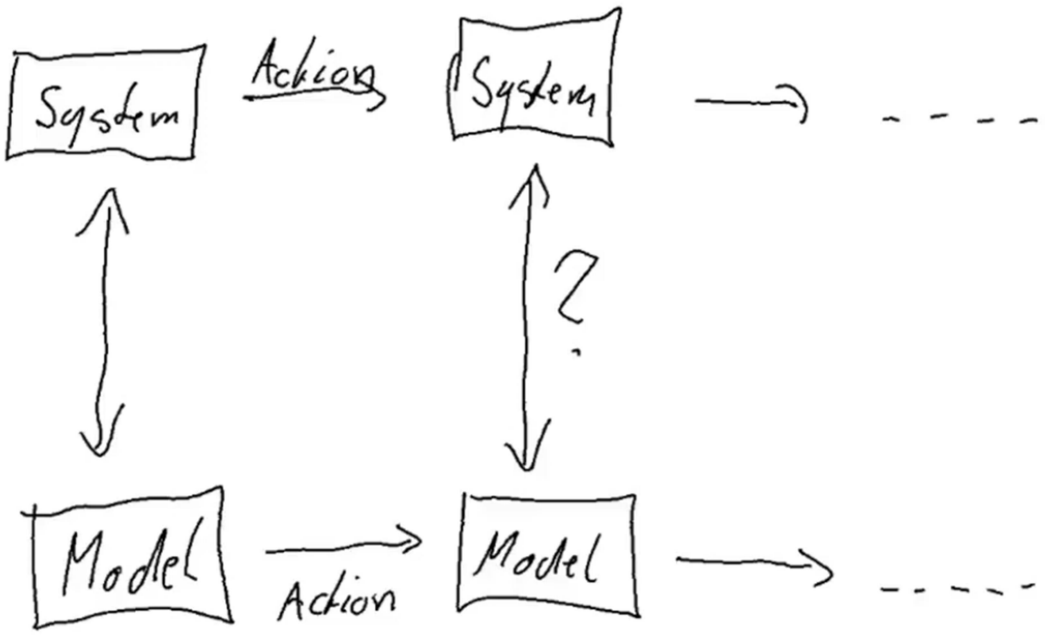

Figure 43 - Testing schema

And shrinking in this case would be if you have a list of actions you could skip some and try if the test still fails. This is how property testing also works in Plutus. We will look at the example of our token sale contract. The code for this is in *test/Spec/Model.hs*.

```
{-# LANGUAGE DataKinds             #-}
{-# LANGUAGE DeriveAnyClass        #-}
{-# LANGUAGE DeriveGeneric         #-}
{-# LANGUAGE FlexibleContexts      #-}
{-# LANGUAGE FlexibleInstances     #-}
{-# LANGUAGE GADTs                 #-}
{-# LANGUAGE InstanceSigs          #-}
{-# LANGUAGE MultiParamTypeClasses #-}
{-# LANGUAGE NumericUnderscores    #-}
{-# LANGUAGE OverloadedStrings     #-}
{-# LANGUAGE RankNTypes            #-}
{-# LANGUAGE ScopedTypeVariables   #-}
{-# LANGUAGE StandaloneDeriving    #-}
{-# LANGUAGE TemplateHaskell       #-}
{-# LANGUAGE TypeApplications      #-}
{-# LANGUAGE TypeFamilies          #-}
{-# LANGUAGE TypeOperators         #-}

module Spec.Model
    ( tests
    , test
    , TSModel (..)
    )  where

import           Control.Lens                                    hiding
                                                                 (elements)
import           Control.Monad                                   (forM_, void,
                                                                  when)
import           Data.Map                                        (Map)
import qualified Data.Map                                        as Map
import           Data.Maybe                                      (isJust,
                                                                  isNothing)
import           Data.Monoid                                     (Last (..))
import           Data.String                                     (IsString
                                                                  (..))
import           Data.Text                                       (Text)
import           Plutus.Contract
import           Plutus.Contract.Test
import           Plutus.Contract.Test.ContractModel              as Test
import           Plutus.Contract.Test.ContractModel.Symbolics
import           Plutus.Trace.Emulator                           as Trace
```

```
38  import           Ledger                                          hiding
                                                                     (singleton)
39  import           Ledger.Ada                                      as Ada
40  import           Ledger.Value
41  import           Test.QuickCheck
42  import           Test.Tasty
43  import           Test.Tasty.QuickCheck
44
45  import           Week08.TokenSaleFixed                           (TokenSale
                (..), TSStartSchema, TSUseSchema, startEndpoint, useEndpoints')
46
47  type TSUseSchema' = TSUseSchema .\/ Endpoint "init" TokenSale
48
49  useEndpoints'' :: Contract () TSUseSchema' Text ()
50  useEndpoints'' = awaitPromise $ endpoint @"init" useEndpoints'
51
52  data TSState = TSState
53      { _tssPrice    :: !Integer
54      , _tssLovelace :: !Integer
55      , _tssToken    :: !Integer
56      } deriving Show
57
58  makeLenses ''TSState
59
60  newtype TSModel = TSModel {_tsModel :: Map Wallet TSState}
61      deriving Show
62
63  makeLenses ''TSModel
64
65  tests :: TestTree
66  tests = testProperty "token sale model" prop_TS
67
68  instance ContractModel TSModel where
69
70      data Action TSModel =
71                Start Wallet
72              | SetPrice Wallet Wallet Integer
73              | AddTokens Wallet Wallet Integer
74              | Withdraw Wallet Wallet Integer Integer
75              | BuyTokens Wallet Wallet Integer
76          deriving (Show, Eq)
77
78      data ContractInstanceKey TSModel w s e p where
79          StartKey :: Wallet -> ContractInstanceKey TSModel
                                  (Last TokenSale) TSStartSchema Text ()
```

```
80          UseKey   :: Wallet -> Wallet -> ContractInstanceKey
                                            TSModel () TSUseSchema' Text ()
81
82      instanceWallet :: ContractInstanceKey TSModel w s e p -> Wallet
83      instanceWallet (StartKey w) = w
84      instanceWallet (UseKey _ w) = w
85
86      instanceTag :: SchemaConstraints w s e => ContractInstanceKey
                                                  TSModel w s e p ->
                                                  ContractInstanceTag
87      instanceTag key = fromString $ "instance tag for: " ++ show key
88
89      arbitraryAction :: ModelState TSModel -> Gen (Action TSModel)
90      arbitraryAction _ = oneof
91          [ Start     <$> genWallet
92          , SetPrice  <$> genWallet <*> genWallet <*> genNonNeg
93          , AddTokens <$> genWallet <*> genWallet <*> genNonNeg
94          , BuyTokens <$> genWallet <*> genWallet <*> genNonNeg
95          , Withdraw  <$> genWallet <*> genWallet <*> genNonNeg <*> genNonNeg
96          ]
97
98      initialState :: TSModel
99      initialState = TSModel Map.empty
100
101     initialInstances :: [StartContract TSModel]
102     initialInstances =    [StartContract (StartKey v) () | v <- wallets]
103                        ++ [StartContract (UseKey v w) () | v <- wallets,
                                                               w <- wallets]
104
105     precondition :: ModelState TSModel -> Action TSModel -> Bool
106     precondition s (Start w)          = isNothing $ getTSState' s w
107     precondition s (SetPrice v _ _)   = isJust    $ getTSState' s v
108     precondition s (AddTokens v _ _)  = isJust    $ getTSState' s v
109     precondition s (BuyTokens v _ _)  = isJust    $ getTSState' s v
110     precondition s (Withdraw v _ _ _) = isJust    $ getTSState' s v
111
112     nextState :: Action TSModel -> Spec TSModel ()
113     nextState (Start w) = do
114         wait 3
115         (tsModel . at w) $= Just (TSState 0 0 0)
116         withdraw w $ Ada.toValue minAdaTxOut
117     nextState (SetPrice v w p) = do
118         wait 3
119         when (v == w) $
120             (tsModel . ix v . tssPrice) $= p
```

```
121     nextState (AddTokens v w n) = do
122         wait 3
123         started <- hasStarted v
            -- has the token sale started?
124         when (n > 0 && started) $ do
125             bc <- actualValPart <$> askModelState (view $ balanceChange w)
126             let token = tokens Map.! v
127             when (tokenAmt + assetClassValueOf bc token >= n) $ do
                -- does the wallet have the tokens to give?
128                 withdraw w $ assetClassValue token n
129                 (tsModel . ix v . tssToken) $~ (+ n)
130     nextState (BuyTokens v w n) = do
131         wait 3
132         when (n > 0) $ do
133             m <- getTSState v
134             case m of
135                 Just t
136                     | t ^. tssToken >= n -> do
137                         let p = t ^. tssPrice
138                             l = p * n
139                         withdraw w $ lovelaceValueOf l
140                         deposit w $ assetClassValue (tokens Map.! v) n
141                         (tsModel . ix v . tssLovelace) $~ (+ l)
142                         (tsModel . ix v . tssToken)    $~ (+ (- n))
143                 _ -> return ()
144     nextState (Withdraw v w n l) = do
145         wait 3
146         when (v == w) $ do
147             m <- getTSState v
148             case m of
149                 Just t
150                     | t ^. tssToken >= n && t ^. tssLovelace >= l -> do
151                         deposit w $ lovelaceValueOf l <>
                            assetClassValue (tokens Map.! w) n
152                         (tsModel . ix v . tssLovelace) $~ (+ (- l))
153                         (tsModel . ix v . tssToken) $~ (+ (- n))
154                 _ -> return ()
155
156     startInstances :: ModelState TSModel -> Action TSModel ->
                          [StartContract TSModel]
157     startInstances _ _ = []
158
159     instanceContract :: (SymToken -> AssetClass) -> ContractInstanceKey
                            TSModel w s e p -> p -> Contract w s e ()
160     instanceContract _ (StartKey _) () = startEndpoint
```

```
161     instanceContract _ (UseKey _ _) () = useEndpoints''
162
163     perform :: HandleFun TSModel -> (SymToken -> AssetClass) -> ModelState
                   TSModel -> Action TSModel -> SpecificationEmulatorTrace ()
164     perform h _ m (Start v)         = do
165         let handle = h $ StartKey v
166         withWait m $ callEndpoint @"start" handle
                         (tokenCurrencies Map.! v, tokenNames Map.! v)
167         Last mts <- observableState handle
168         case mts of
169             Nothing -> Trace.throwError $ GenericError $
                           "starting token sale for wallet " ++ show v ++ " failed"
170             Just ts -> forM_ wallets $ \w ->
171                 callEndpoint @"init" (h $ UseKey v w) ts
172     perform h _ m (SetPrice v w p)   = withWait m $ callEndpoint
                                           @"set price"  (h $ UseKey v w) p
173     perform h _ m (AddTokens v w n)  = withWait m $ callEndpoint
                                           @"add tokens" (h $ UseKey v w) n
174     perform h _ m (BuyTokens v w n)  = withWait m $ callEndpoint
                                           @"buy tokens" (h $ UseKey v w) n
175     perform h _ m (Withdraw v w n l) = withWait m $ callEndpoint
                                           @"withdraw"   (h $ UseKey v w) (n, l)
176
177 withWait :: ModelState TSModel -> SpecificationEmulatorTrace () ->
                SpecificationEmulatorTrace ()
178 withWait m c = void $ c >> waitUntilSlot ((m ^. Test.currentSlot) + 3)
179
180 deriving instance Eq (ContractInstanceKey TSModel w s e p)
181 deriving instance Show (ContractInstanceKey TSModel w s e p)
182
183 getTSState' :: ModelState TSModel -> Wallet -> Maybe TSState
184 getTSState' s v = s ^. contractState . tsModel . at v
185
186 getTSState :: Wallet -> Spec TSModel (Maybe TSState)
187 getTSState v = do
188     s <- getModelState
189     return $ getTSState' s v
190
191 hasStarted :: Wallet -> Spec TSModel Bool
192 hasStarted v = isJust <$> getTSState v
193
194 wallets :: [Wallet]
195 wallets = [w1, w2]
196
197 tokenCurrencies :: Map Wallet CurrencySymbol
```

```
198  tokenCurrencies = Map.fromList $ zip wallets ["aa", "bb"]
199
200  tokenNames :: Map Wallet TokenName
201  tokenNames = Map.fromList $ zip wallets ["A", "B"]
202
203  tokens :: Map Wallet AssetClass
204  tokens = Map.fromList [(w, AssetClass (tokenCurrencies Map.! w,
           tokenNames Map.! w)) | w <- wallets]
205
206  genWallet :: Gen Wallet
207  genWallet = elements wallets
208
209  genNonNeg :: Gen Integer
210  genNonNeg = getNonNegative <$> arbitrary
211
212  tokenAmt :: Integer
213  tokenAmt = 1_000
214
215  prop_TS :: Actions TSModel -> Property
216  prop_TS = withMaxSuccess 100 . propRunActionsWithOptions
217      (defaultCheckOptions & emulatorConfig . initialChainState .~ Left d)
218      defaultCoverageOptions
219      (const $ pure True)
220    where
221
222      d :: InitialDistribution
223      d = Map.fromList $ [ ( w
224                           , lovelaceValueOf 1_000_000_000 <>
225                             mconcat [assetClassValue t tokenAmt |
                               t <- Map.elems tokens])
226                         | w <- wallets
227                         ]
228
229  test :: IO ()
230  test = quickCheck prop_TS
```

In the import section we import the *Plutus.Contract.Test, Test.QuickCheck, Test.Tasty* and *Test.Tasty.QuickCheck* modules. The last one provides a link between the quick check and tasty libraries. We define the *TSUseSchema'* schema which adds a new endpoint to our previous schema that takes the argument of type *TokenSale* (47). The idea is that once we start our token sale we somehow must be able to cummunicate the TokenSale parameter to the use contract. The init endpoint simply calls the *useEndpoints'* function with the value provided in the endpoint (49-50). Then we define the token sale state data type (52-56).

It has three fields: the current price, the current supply of lovelace and current supply of tokens in the contract UTXO. Now we define our model that we presented in Figure 43 (60-61). That is just a Map from wallet to token sale state. The idea is we will have two wallets and each of the wallet will run their token sale and the wallets will trade different tokens. We implement lenses for that (58, 63). All the logic is now in the instance of the type class contract model for the *TSModel* type. Here we provide how our model should behave and is linked to the actual contract. First we have a so called associated data type (70-76). It is an associated action type which represents the actions that quick check will generate. We have one constructor for each of the endpoints and have different arguments to keep track of the wallets that are in play. Then we define another associated data type called instance key (78-80). The idea is for each instance of the contract that we are running we want a key that identifies this instance. Here instead of just providing the constructors we write the in the form of just providing the type signatures. This is called generalized algebraic data type (GADT). GADT allow us to have different type parameters and we need this because our contracts can have different type parameters. For the *UseKey* type the first wallet is the one running the token sale and the second wallet is the one interacting with it. There are two signatures because we had a start and a use contract. The next function *instanceWallet* tells the system how to extract the wallet that a given contract is running on by its constraint instance key (82-84). Then we implement the *instanceTag* method that takes one of these keys and turns it into a contract instance tag which implements the *isString* type class (86-87). And we use this type class when we switch on the overloaded string extension. For the contract instance key we are also deriving Show (181). We will have one start instance for each wallet and then one use instance for each pair of wallets. The *arbitraryAction* function is supposed to generate an arbitrary action (89-96). »oneof« is one of the combinators provided by quick check and given a list of arbitrary actions it picks one of those. The *genWallet* function generates a random wallet from wallet 1 or wallet 2. We combine the *genWallet* then through the fmap operator with several wallet actions. The *genNonNeg* function generates a non negative integer. Next comes *initialState* which is the initial state of our model that contains just an empty map which means no token sale has started yet (98-99). The *initialInstances* function gives the initial contract instances that have to run (101-103). In the body of the function we have contracts that are supposed to run in the beginning. With them we want to start the token sale for each wallet and then the use contract for each pair of wallets. The precondition function allows us to say that some actions may not be legal in a given model state (105-110). So for example we can say that we can only start a token sale if it hasn't already started. The precondition on the start should be it hasn't started yet and for other actions it should be that it has started. As input we use the model state type that has no constructors exposed (Figure 44).

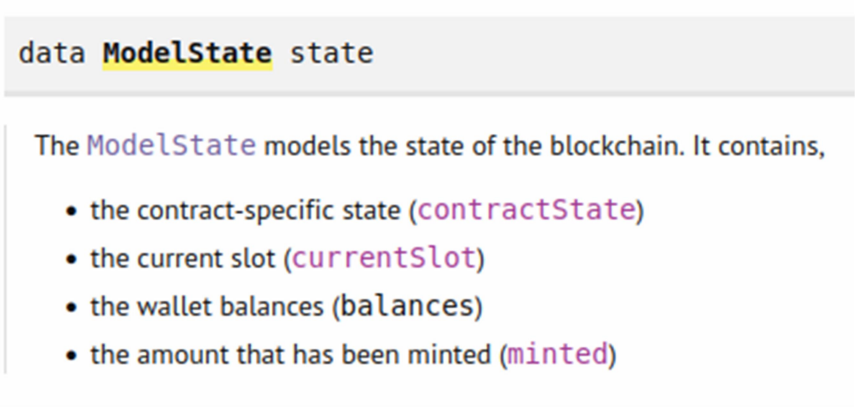

Figure 44 - Model state

But it contains a couple of functions that operate on the model state. The most important one is the *contractState* function which is a lens from model state to state (Figure 45).

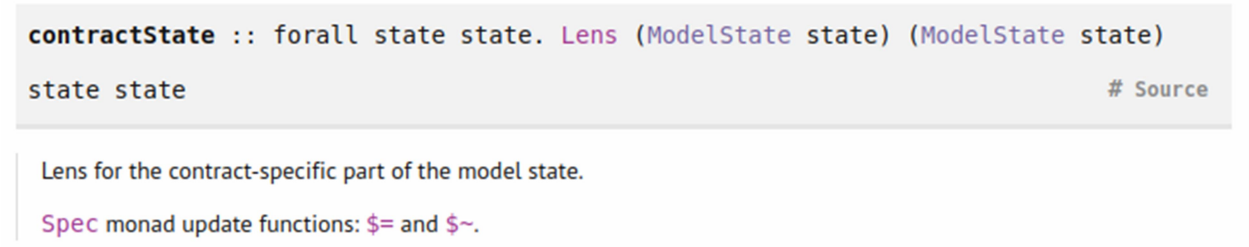

Figure 45 - Contract state function

There is also a current slot optic that is a getter which means we can only look at it but cannot set it. The *getTSState'* function given a model state and a wallet it tries to extract the token sale that this wallet is running (183-184). When we explained our testing principle in the beginning we said for each action we must know what effect that action will have on our model. And that's what the *nextState* function is for (112-154). It takes an action and results in a Spec monad that has the purpose of describing effects on our TS model. In this model there is a concept of how much every wallet owns. And in the Spec monad you can that a given wallet earns some funds or sends them elsewhere. And you can say that time passes in between. The model and the actual simulator must keep in sync as far as slots are concerned. The first do block says when we do the start for the token sale then in the model for key w there now will be a *tss* state and the value of this *TSState* will be 0 0 0. And the last statement is the effect of the funds on the wallet. We say the wallet w in question loses funds. That's because when we start the token sale we need to put down the minimal ADA for the token sale UTXO. Similar we define other states where we deal with setting the price, adding tokens, buying tokens and make a withdrawal. Then we have the *startInstances* function (156-157). There is the possibility to start our contract instances later so given a model statement action you can give a list of contracts that are supposed to be started. But because we start them all in the beginning we

put here an empty list. Now we start providing the link between our model and the actual emulator and the first part of this is done by the *instanceContract* function (159-161). It takes in a function that we don't use a key and a parameter value which in our case is always unit. And then we have to say which contract corresponds to that. If the key is a start key it's the start endpoint contract and if the key is a use key it's the use endpoint contract. And finally the *perform* function tells us how an action is actually expressed in an actual action in the emulator on the blockchain (163-175). In the end we get the specification emulator trace monad that you can think of as an emulator trace. In the cases following after the first one we use the *withWait* function that should ensure that something takes exactly three slots (177-178). And then we call various endpoints with the key parameters that correspond to actions. This provides the links between the model and the actions with actual operations that are supposed to happen on the blockchain or in the emulator. The start action is a bit trickier because of the mechanism that when we start a token sale we have to call the init endpoint which is now happening in this do block. The start contract actually writes the token sale into this observable state (167). To tie everything together we can run now the *propRunActionsWithOptions* function (Figure 46).

propRunActionsWithOptions

```
:: ContractModel state
=> CheckOptions                              Emulator options
-> CoverageOptions                           Coverage options
-> (ModelState state -> TracePredicate)      Predicate to check at the end
-> Actions state                             The actions to run
-> Property
```

Figure 46 - Properties run action with options

It takes check options which allow us for example to specify a fund distribution in our wallets. Then it takes coverage options but we will not use this in our example. Then it takes an additional predicate to check at the end. With the final model state you can provide a trace predicate and then that will also be tested but we won't use this either. Then it returns something of action state to property. We use this function in the *prop_TS* function (215-227). We are composing it with the *withMaxSuccess* function that comes from quick check and we can specify how many test cases to run. We start with the default check option and add our emulator config and initial chain state and then set it to an initial distribution where every wallet should get a thousand ADA and a thousand tokens. Wallet 1 will be selling token »A« and

wallet two will be selling token »B«. The *prop_TS* function returns a property check you can think of as a Bool used by quick check. Because we saw before we can randomly generate action sequences quick check can handle our property TS function since it takes in the *Actions* type. And the property that is actually checked is that what we say in the next state function what happens to our model that that is actually reflected when we perform the actions on the blockchain in our emulator traces. So this will check that what we say should happen in the model actually does happen on the blockchain. And in the Repl we can then run our test function that calls our property test function (229-230). When we run this in the Repl we also get some statistics. We see which actions were actually tried and how many of them were rejected due to preconditions. Let's look now how we can grab all of this into a test suite.

```
1   module Main
2       ( main
3       ) where
4
5   import qualified Spec.Model
6   import qualified Spec.Trace
7   import           Test.Tasty
8
9   main :: IO ()
10  main = defaultMain tests
11
12  tests :: TestTree
13  tests = testGroup "token sale"
14      [ Spec.Trace.tests
15      , Spec.Model.tests
16      ]
```

This represents now the main program of our test suite. *tests* is our test tree where we just put these two tests that we wrote. And we can run the tests with the »cabal test« command. What we have to note is that when testing with quick check we provide the off-chain code but a user could write their own off-chain code that for example would try to steal the funds. And such scenarios are then not covered by our testing procedures.

8.7 Homework

For homework we will modify the token sale contract such that it accepts an additional transition called close that can be called only by the seller to close the UTXO and collect all the remaining tokens, lovelace and the NFT. Let's look at the *Week08/TokenSaleWithClose.hs* code.

```
1    data TokenSale = TokenSale
```

```
2       { tsSeller :: !PaymentPubKeyHash
3       , tsToken  :: !AssetClass
4       , tsTT     :: !ThreadToken
5       } deriving (Show, Generic, FromJSON, ToJSON, Prelude.Eq)
6
7   PlutusTx.makeLift ''TokenSale
8
9   data TSRedeemer =
10        SetPrice Integer
11      | AddTokens Integer
12      | BuyTokens Integer
13      | Withdraw Integer Integer
14      | Close
15      deriving (Show, Prelude.Eq)
16
17  PlutusTx.unstableMakeIsData ''TSRedeemer
18
19  {-# INLINABLE lovelaces #-}
20  lovelaces :: Value -> Integer
21  lovelaces = Ada.getLovelace . Ada.fromValue
22
23  {-# INLINABLE transition #-}
24  transition :: TokenSale -> State (Maybe Integer) -> TSRedeemer -> Maybe
                  (TxConstraints Void Void, State (Maybe Integer))
25  transition ts s r = case (stateValue s, stateData s, r) of
26      (v, Just _, SetPrice p)   | p >= 0                              ->
      Just ( Constraints.mustBeSignedBy (tsSeller ts)
27         , State (Just p) v )
28
29      (v, Just p, AddTokens n)  | n > 0                               ->
      Just ( mempty
30         , State (Just p) $
31           v <>
32           assetClassValue (tsToken ts) n )
33
34      (v, Just p, BuyTokens n)  | n > 0                               ->
      Just ( mempty
35         , State (Just p) $
36           v <>
37           assetClassValue (tsToken ts) (negate n) <>
38           lovelaceValueOf (n * p) )
39
40      (v, Just p, Withdraw n l) | n >= 0 && l >= 0 &&
41       v `geq` (w <> toValue minAdaTxOut) ->
         Just ( Constraints.mustBeSignedBy (tsSeller ts)
```

```
42        , State (Just p) $
43          v <>
44          negate w )
45
46            where
47              w = assetClassValue (tsToken ts) n <>
48                lovelaceValueOf 1
49      (_, Just _, Close)                                              ->
          Just ( Constraints.mustBeSignedBy (tsSeller ts)
50      , State Nothing mempty )
51
52      _ -> Nothing
53
54  {-# INLINABLE tsStateMachine #-}
55  tsStateMachine :: TokenSale -> StateMachine (Maybe Integer) TSRedeemer
56  tsStateMachine ts = mkStateMachine (Just $ tsTT ts)
                                       (transition ts) isNothing
57
58  {-# INLINABLE mkTSValidator #-}
59  mkTSValidator :: TokenSale -> Maybe Integer -> TSRedeemer ->
                     ScriptContext -> Bool
60  mkTSValidator = mkValidator . tsStateMachine
61
62  type TS = StateMachine (Maybe Integer) TSRedeemer
63
64  tsTypedValidator :: TokenSale -> Scripts.TypedValidator TS
65  tsTypedValidator ts = Scripts.mkTypedValidator @TS
66      ($$(PlutusTx.compile [|| mkTSValidator ||])
         `PlutusTx.applyCode` PlutusTx.liftCode ts)
67      $$(PlutusTx.compile [|| wrap ||])
68    where
69      wrap = Scripts.wrapValidator @(Maybe Integer) @TSRedeemer
70
71  tsValidator :: TokenSale -> Validator
72  tsValidator = Scripts.validatorScript . tsTypedValidator
73
74  tsAddress :: TokenSale -> Ledger.Address
75  tsAddress = scriptAddress . tsValidator
76
77  tsClient :: TokenSale -> StateMachineClient (Maybe Integer) TSRedeemer
78  tsClient ts = mkStateMachineClient $ StateMachineInstance
                  (tsStateMachine ts) (tsTypedValidator ts)
79
80  mapErrorSM :: Contract w s SMContractError a -> Contract w s Text a
81  mapErrorSM = mapError $ pack . show
```

```
82
83  startTS :: AssetClass -> Contract (Last TokenSale) s Text ()
84  startTS token = do
85      pkh <- Contract.ownPaymentPubKeyHash
86      tt  <- mapErrorSM getThreadToken
87      let ts = TokenSale
88              { tsSeller = pkh
89              , tsToken  = token
90              , tsTT     = tt
91              }
92          client = tsClient ts
93      void $ mapErrorSM $ runInitialise client (Just 0) mempty
94      tell $ Last $ Just ts
95      logInfo $ "started token sale " ++ show ts
96
97  setPrice :: TokenSale -> Integer -> Contract w s Text ()
98  setPrice ts p = void $ mapErrorSM $ runStep (tsClient ts) $ SetPrice p
99
100 addTokens :: TokenSale -> Integer -> Contract w s Text ()
101 addTokens ts n = void (mapErrorSM $ runStep (tsClient ts) $ AddTokens n)
102
103 buyTokens :: TokenSale -> Integer -> Contract w s Text ()
104 buyTokens ts n = void $ mapErrorSM $ runStep (tsClient ts) $ BuyTokens n
105
106 withdraw :: TokenSale -> Integer -> Integer -> Contract w s Text ()
107 withdraw ts n l = void $ mapErrorSM $ runStep (tsClient ts) $ Withdraw n l
108
109 close :: TokenSale -> Contract w s Text ()
110 close ts = void $ mapErrorSM $ runStep (tsClient ts) Close
111
112 type TSStartSchema =
113         Endpoint "start"      (CurrencySymbol, TokenName)
114 type TSUseSchema =
115         Endpoint "set price"  Integer
116     .\/ Endpoint "add tokens" Integer
117     .\/ Endpoint "buy tokens" Integer
118     .\/ Endpoint "withdraw"   (Integer, Integer)
119     .\/ Endpoint "close"      ()
120
121 startEndpoint :: Contract (Last TokenSale) TSStartSchema Text ()
122 startEndpoint = forever
123               $ handleError logError
124               $ awaitPromise
125               $ endpoint @"start" $ startTS . AssetClass
126
```

```
127  useEndpoints' :: ( HasEndpoint "set price" Integer s
128                   , HasEndpoint "add tokens" Integer s
129                   , HasEndpoint "buy tokens" Integer s
130                   , HasEndpoint "withdraw" (Integer, Integer) s
131                   , HasEndpoint "close" () s
132                   )
133                => TokenSale
134                -> Promise () s Text ()
135  useEndpoints' ts = setPrice' `select` addTokens' `select` buyTokens'
                        `select` withdraw' `select` close'
136    where
137      setPrice'  = endpoint @"set price"  $ \p      ->
                     handleError logError (setPrice ts p)
138      addTokens' = endpoint @"add tokens" $ \n      ->
                     handleError logError (addTokens ts n)
139      buyTokens' = endpoint @"buy tokens" $ \n      ->
                     handleError logError (buyTokens ts n)
140      withdraw'  = endpoint @"withdraw"   $ \(n, l) ->
                     handleError logError (withdraw ts n l)
141      close'     = endpoint @"close"      $ \()     ->
                     handleError logError (close ts)
142
143  useEndpoints :: TokenSale -> Contract () TSUseSchema Text ()
144  useEndpoints = forever . awaitPromise . useEndpoints'
```

In the *TSRedeemer* data type we define our Close action (9-15). Then in the transition function our state parameter takes in a Maybe integer. And at the end of the body we add the case of close which closes the token sale (49-50). The type signatures for state machine, validator, TS type and ts client get updated accordingly. Also the wrap helper function takes in the maybe integer type. When we call the *runInitialise* function in the startTS contract we have to provide now a Just 0 value. In lines 109-110 we define our close contract. And in the *TSUseSchema* we add the close endpoint. Similar we do in the type signature of the *useEndpoints'* function and in its body we add the close endpoint call.

9 Resources

[1] The Plutus Pioneer Programm git repository

https://github.com/input-output-hk/plutus-pioneer-program

[2] The Cardano documentation

https://docs.cardano.org/plutus/learn-about-plutus

https://docs.cardano.org/plutus/eutxo-explainer

[3] The Extended UTXO Ledger Model paper

https://hydra.iohk.io/build/12982960/download/1/extended-utxo-specification.pdf

[4] The Plutus apps repository

https://github.com/input-output-hk/plutus-apps

[5] Plutus application backend blog post

https://iohk.io/en/blog/posts/2021/10/28/plutus-application-backend-pab-supporting-dapp-development-on-cardano/