Stateful Smart Contracts On Cardano

Part 1. Securing A Distributed State

Minting Unique Tokens With A Shared `PolicyId`

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Problem

Our needs, at the lowest level:

1. We want to distribute a smart contract's state over mutiple UTxOs, *and*...
2. ... We must ensure that it cannot be compromised by an attacker.

Otherwise, it would be pointless to use whatever abstractions we might come up with.

Problem

An informal statement of the problem might be the following.

> “ A smart contract's state, distributed over multiple of UTxOs, should be modified only by transactions validated by the smart contract itself. ”

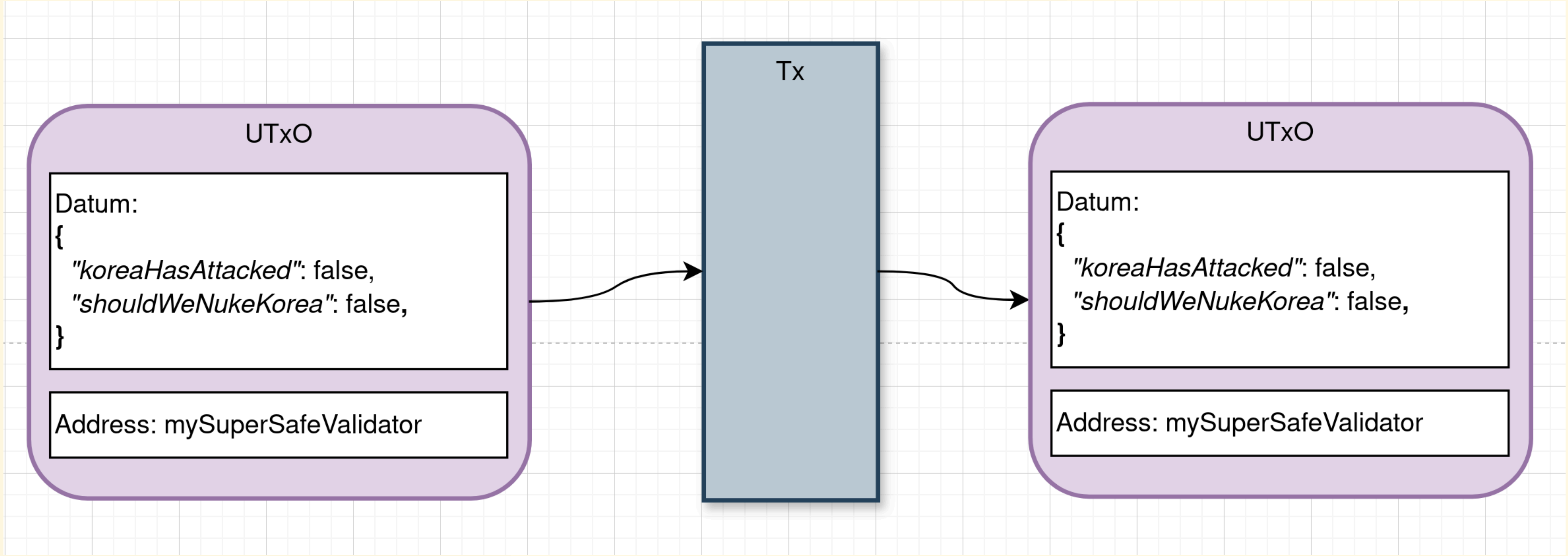
Problem

There are good news and bad news.

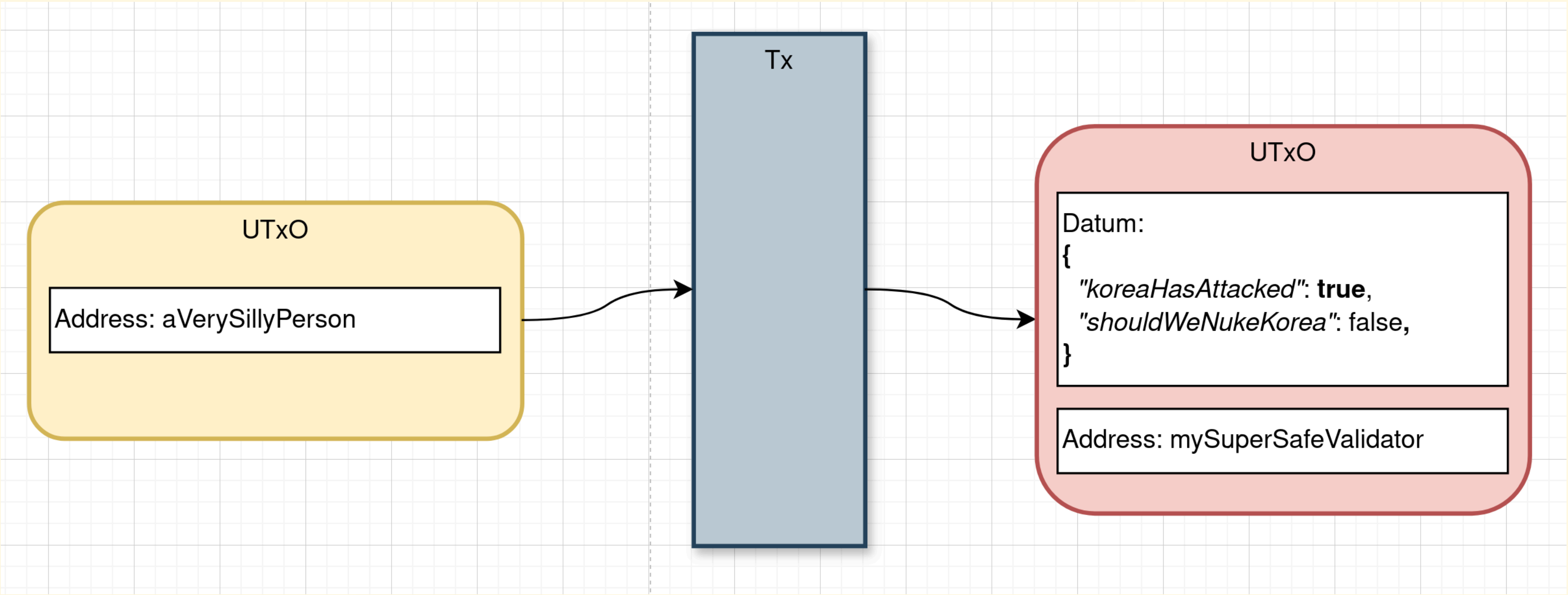
- **Good news**: Smart contracts (on-chain) can enforce the recipient(s) of the UTxOs being created, but...
- **Bad news**: ... They have **zero knowledge** about the sender of the UTxOs being spent.

Why is that a problem?

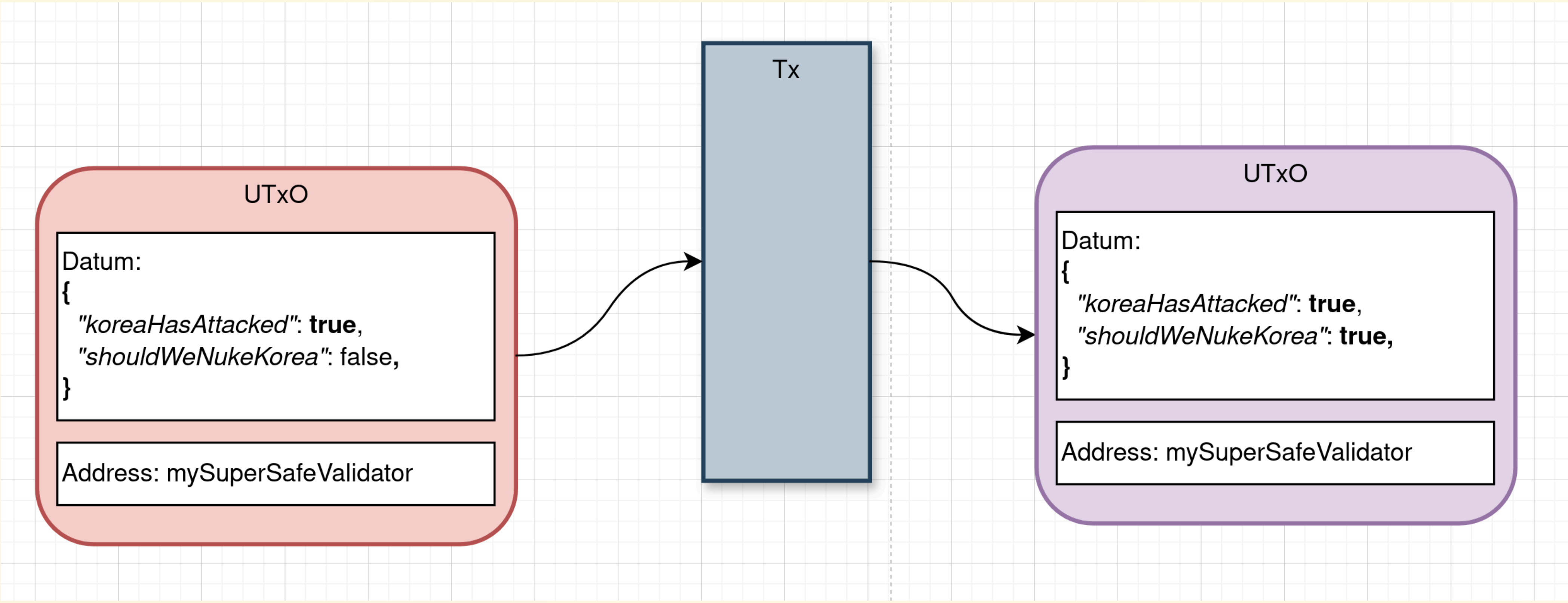
Example: Good State



Example: Attacker Setup



Example: (Very) Bad State



Problem

Compromised state could be the source of other, more serious issues.

What could be worse than WW3? Well, for example:

> “ *You* could be losing money!! ”

While total thermonuclear annihilation might be somewhat tolerable and even fun, losing money is not and we must avoid that at all costs.

Native Tokens

Native tokens, also called *assets*, are defined as:

- $\mathrm{AssetId} := \mathrm{PolicyId} \times \mathrm{AssetName}$
- $\mathrm{PolicyId} := (\mathbb{F}_{256})^{28}$ (hash of the minting validator script)
- $\mathrm{AssetName} := (\mathbb{F}_{256})^{32}$ (arbitrary string)

Where $\mathbb{F}_q := \{0, \ldots, q-1\}$.

Spending Validators

We call V the type of a Spending Validator:

$$V := (\text{Datum} \times \text{Redeemer} \times \text{ScriptContext}) \to \mathbb{B}$$

Minting Validators

We call M the type of a Minting Validator:

$$M := (\mathrm{Redeemer} \times \mathrm{ScriptContext}) \to \mathbb{B}$$

NB: Minting Validators do not take a Datum as inputs, because they do not spend UTxOs.

Minting The NFTs

Let $\mathrm{OutputReference}$ represent an on-chain reference to an UTxO.

We declare the following functions that produce smart contracts:

- $f_{start,mint} : \mathrm{OutputReference} \to M$
- $f_{add,mint} : M \to M$
- $f_{add,validate} : (M \times M) \to V$

Minting The NFTs

$newm$ takes an $\mathrm{OutputReference}$ `utxo` and returns a Minting Validator that produces a single token with $\mathrm{AssetName}$ `"Auth"`.

Such script is a **one-time** minting validator, because it ensures that `utxo` is consumed in the transaction (which can happen only once).

Code: $f_{start,mint}$: $\mathrm{OutputReference} \rightarrow M$

```
validator(o: OutputReference) {
  fn run(_r: Redeemer, ctx: ScriptContext) -> Bool {
    // 0. The output reference is consumed by the transaction
    expect Some(_input) =
      ctx.transaction.inputs
        |> list.find(fn(input) { input.output_reference == o })
    // 1. The transaction's purpose is to mint a new token
    expect Mint(policy_id) = ctx.purpose
    // 2. There is a single NFT named "Auth" in the minted assets
    expect [(asset, amount)]: List<(AssetName, Int)> =
      ctx.transaction.mint
        |> value.from_minted_value()
        |> value.tokens(policy_id)
        |> dict.to_list()
    expect "Auth" == asset && 1 == amount
    // 3. There is a single output with the minted NFT
    expect [output] =
      ctx.transaction.outputs
        |> list.filter(
          fn(output: Output) {
            1 == quantity_of(output.value, policy_id, "Auth")
          },
        )
    expect [] =
      ctx.transaction.outputs
        |> list.filter(
          fn(output: Output) {
            1 != quantity_of(output.value, policy_id, "Auth")
          },
        )
    // 4. The minted NFT is in a UTxO with an empty list as Datum
    expect InlineDatum(datum) = output.datum
    expect []: List<AssetName> = datum
    True
  }
}
```

Code: $f_{add,validate} : (M \times M) \rightarrow V$

```
validator(newm_script: PolicyId, addm_script: PolicyId) {
  fn run(
    datum: (List<AssetName>, Hash<Blake2b_224, Script>),
    redeemer: AssetName,
    context: ScriptContext,
  ) -> Bool {
    // 0. The ScriptPurpose is to Spend an UTxO
    expect Spend(outref): ScriptPurpose = context.purpose
    // 1. The addm_script is involved in the transaction
    expect Some(mint_redeemer): Option<Redeemer> =
      context.transaction.redeemers |> dict.get(Mint(addm_script))
    // 2. The redeemer of the addm_script is the same as our redeemer
    expect address: AssetName = mint_redeemer
    expect address == redeemer
    // 3. The transaction pays a single UTxO to this script
    expect Some(input): Option<Input> =
      context.transaction.inputs |> list.at(outref.output_index)
    let self_address: Address = input.output.address
    expect [output] =
      context.transaction.outputs
        |> list.filter(fn(output: Output) { output.address == self_address })
    // 4. The output UTxO has the authorizing start NFT
    expect 1 == quantity_of(output.value, newm_script, "Auth")
    // 5. The datum of the output UTxO is the correct list of new_addm_assets
    expect InlineDatum(inline_output_datum) = output.datum
    expect output_datum: (List<AssetName>, Hash<Blake2b_224, Script>) =
      inline_output_datum
    let old_addm_assets: List<AssetName> = list.unique(datum.1st)
    let new_addm_assets: List<AssetName> = list.unique(output_datum.1st)
    expect 1 == list.length(new_addm_assets) - list.length(old_addm_assets)
    expect [redeemer] == list.difference(new_addm_assets, old_addm_assets)
    // 6. The address of the pay script is always the same
    expect datum.2nd == output_datum.2nd
    True
  }
}
```

Code: $f_{add,mint} : M \to M$

```
validator(s: PolicyId) {
  fn run(r: AssetName, ctx: ScriptContext) -> Bool {
    // 0. The transaction's purpose is to mint a new token
    expect Mint(policy_id) = ctx.purpose
    // 1. There is a single NFT named "Auth" in the minted assets
    expect [(asset, amount)]: List<(AssetName, Int)> =
      ctx.transaction.mint
        |> value.from_minted_value()
        |> value.tokens(policy_id)
        |> dict.to_list()
    expect r == asset && 1 == amount
    // 2. There is a single output with the minted NFT
    expect [_] =
      ctx.transaction.outputs
        |> list.filter(
             fn(output: Output) { 1 == quantity_of(output.value, policy_id, r) },
           )
    expect [] =
      ctx.transaction.outputs
        |> list.filter(
             fn(output: Output) { 1 != quantity_of(output.value, policy_id, r) },
           )
    // 3. There is a single output with the "Auth" NFT
    expect [_] =
      ctx.transaction.outputs
        |> list.filter(
             fn(output: Output) { 1 == quantity_of(output.value, s, "Auth") },
           )
    expect [] =
      ctx.transaction.outputs
        |> list.filter(
             fn(output: Output) { 1 != quantity_of(output.value, s, "Auth") },
           )
    // 4. There is a single input with the "Auth" NFT
    expect [_] =
      ctx.transaction.inputs
        |> list.filter(
             fn(input: Input) { 1 == quantity_of(input.output.value, s, "Auth") },
           )
    expect [] =
      ctx.transaction.inputs
        |> list.filter(
             fn(input: Input) { 1 != quantity_of(input.output.value, s, "Auth") },
           )
    True
  }
}
```

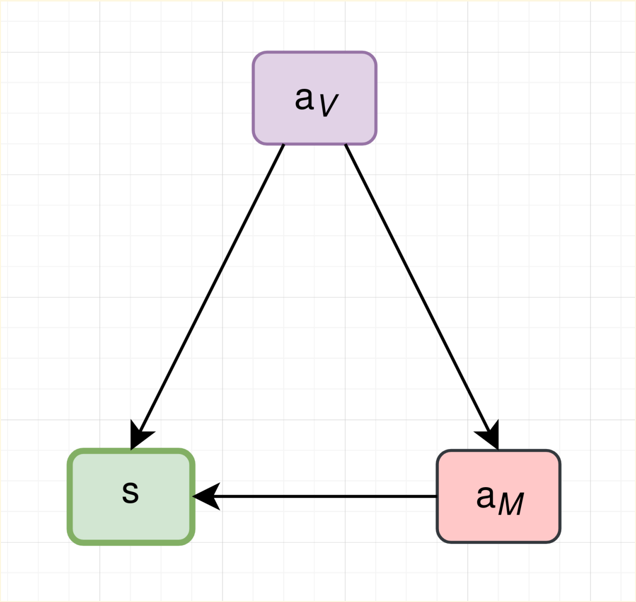
Minting The NFTs

In particular, let $o : \mathrm{OutputReference}$.

We build the following three contracts that will take part in the generation of our NFTs:

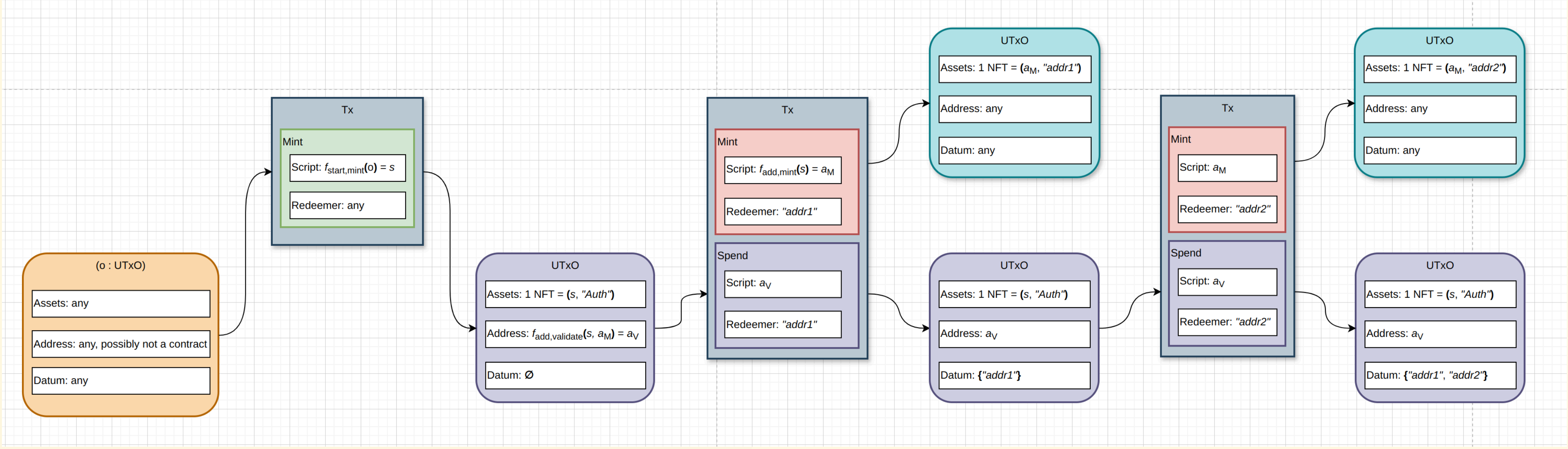
- $(s : M) = f_{start,mint}(o)$
- $(a_M : M) = f_{add,mint}(s)$
- $(a_V : V) = f_{add,validate}(s, a_M)$

Dependencies



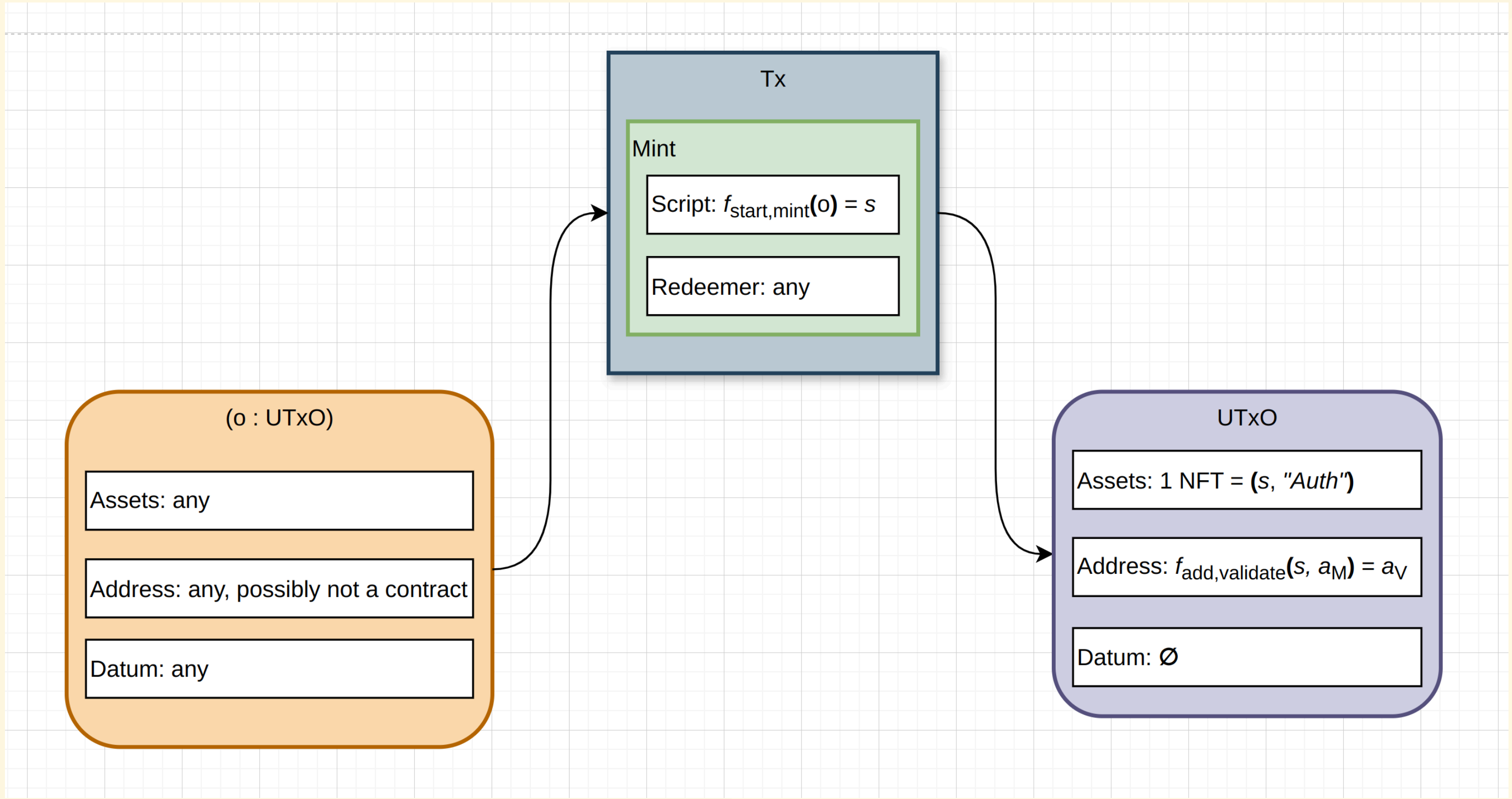
NB: "$\rightarrow$" means "depends on".

Example: Full Example

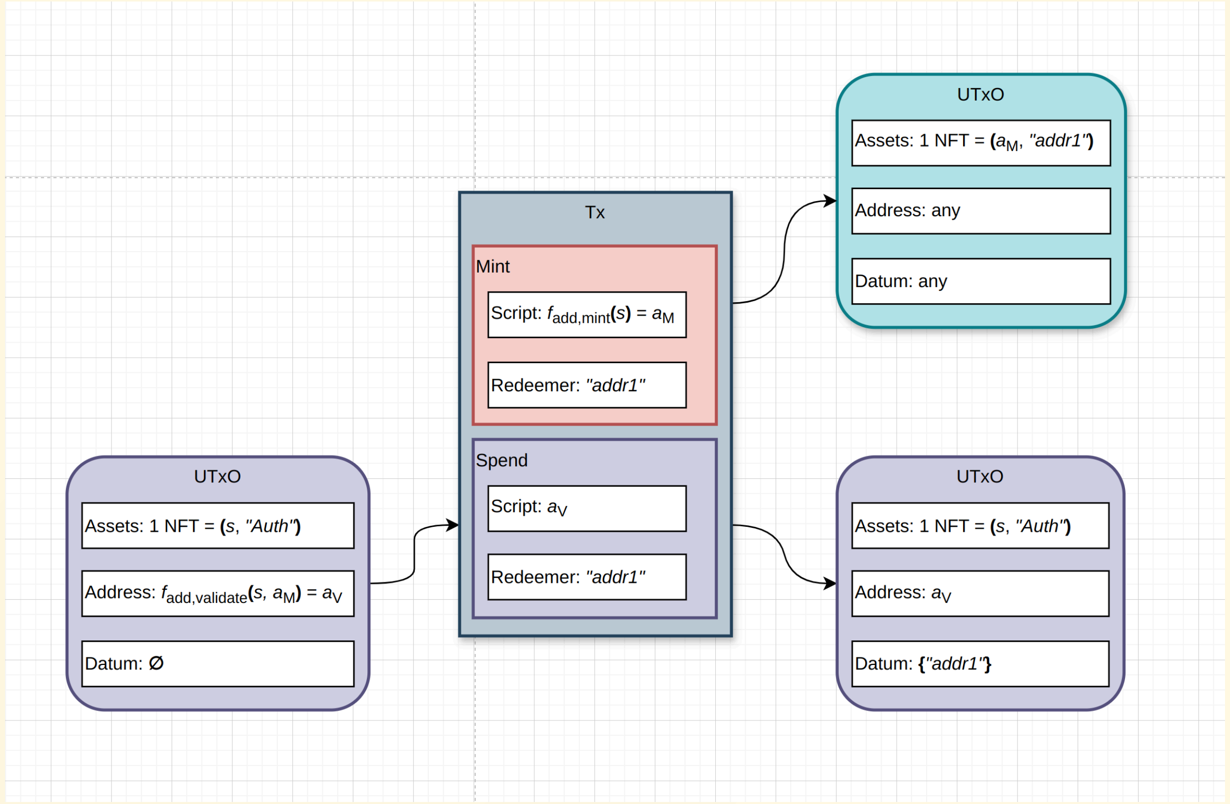


NB Cyan UTxOs contain the minted NFTs that we will use to authenticate our smart contract's state.

Example: Start The Minting Process



Example: Minting The 1st NFT



Example: Minting The 2nd NFT