CODE BEAM EUROPE

STOCKHOLM

HYBRID CONFERENCE

Improve your tests with Makina

Luis Eduardo Bueso de Barrio

May 20 | 2022

#CodeBEAM

Before:

files	blank	comment	code
4	760	383	4513

After:

files	blank	comment	code
18	500	408	1692

PBT models

PBT models

Proprety-Based Testing (PBT) is a great testing methodology.

Successful tools widely used:

- Quviq QuickCheck
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PBT state-machines or models.

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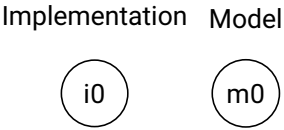

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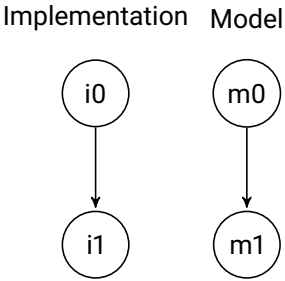

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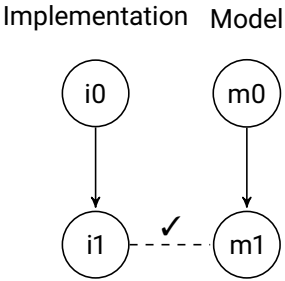

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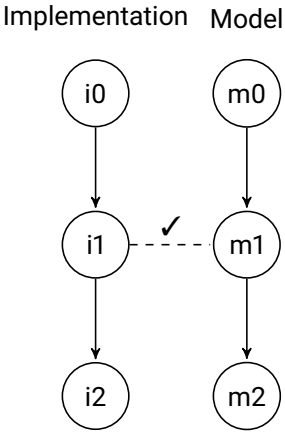

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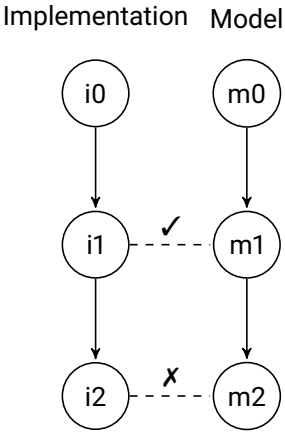

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Despite their proven effectiveness:

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Why?

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1. Models are hard to reuse.
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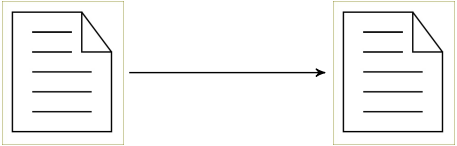
All these problems made models hard to write and maintain.

Our solution: Makina

Makina is a DSL for writing PBT models.



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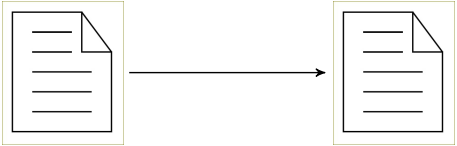

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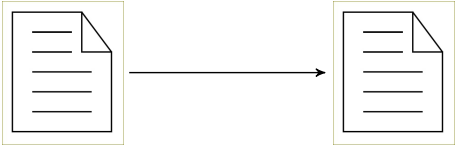

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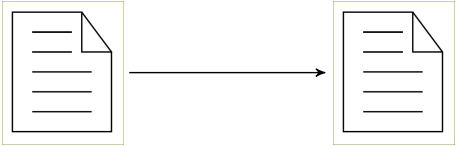

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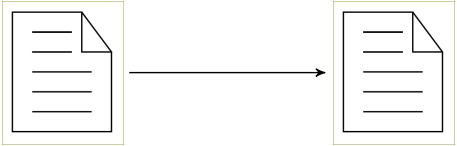

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3. Errors are hard to understand.
   - Automatic runtime-checks generation.

Makina: The Language

Makina is implemented using Elixir macros.

```
defmodule Name do
  use Makina, [_option_]

  state [_attribute_]

  invariants [_invariants_]

  command _declaration_ do
    _command_body_
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*_option_*

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- `extends: [module()]`
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*_declaration_*

- `name(arg1, ... , argN)`
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*_command_body_*

- `pre boolean()`
- `args generator()`
- `call return_type`
- `next [updates()]`
- `post boolean()`

Ethereum Blockchain

Why Ethereum?

- It is a complex system.

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API

`accounts!/0`	`accounts/0`	`block_number!/0`
`call_transaction!/4`	`call_transaction!/5`	`call_transaction/4`
`client_version!/0`	`client_version/0`	`compile_solidity!/1`
`deploy!/3`	`deploy!/4`	`deploy/3`
`estimate_gas!/4`	`estimate_gas!/5`	`estimate_gas/4`
`estimate_gas_cost!/4`	`estimate_gas_cost!/5`	`estimate_gas_cost/4`
`gas_cost!/1`	`gas_cost/1`	`gas_price!/0`
...	...	...

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The properties to test:

1. Mining blocks.
2. Account access.
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How *`Makina`* handles this complexity?

Mining blocks

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The API:

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Command	Returns
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defmodule Blocks do
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```

1. create module.
2. import `Makina`.

Mining blocks

The API:

Command	Returns
`mine/0`	`:ok`
`block_number/0`	`integer()`

```elixir
defmodule Blocks do
  use Makina

  state height: 0
```

1. create module.
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3. define state.

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defmodule Blocks do
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    call Etherex.block_number
    next []
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    next height: height + 1
  end
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Running the test

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$ mix test
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Postcondition crashed:
** invariant "non_neg_height" check failed

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Last state: %{height: 0}
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  end

  command mine() do
    next height: height + 1
  end
end
```

Running the test

```
$ mix test
```

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defmodule Blocks do
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  command block_number() do
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  end

  command mine() do
    next height: height + 1
  end
end
```

Running the test

```
$ mix test

..................................................
..................................................

OK, passed 100 tests

51.5 mine/0
48.5 block_number/0
```

```ruby
defmodule Blocks do
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```

Adding type information

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```
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  state height: 0 :: integer()

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  command block_number() :: integer() do
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  end

  command mine() :: :ok do
    next height: height + 1
  end
end
```

Adding type information

```
$ mix gradient

$
```

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Something changes in `Etherex`...

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```

Adding type information

```
$ mix gradient

$
```

Something changes in `Etherex`...

```
$ mix gradient

The function call Etherex.block_number()
on line 8 is expected to have type integer()
but it has type
{:ok, quantity()} | {:error, error()}

$
```

```
1  defmodule Blocks do
2    use Makina, implemented_by: Etherex
3
4    state height: 0 :: integer()
5
6    invariants non_neg_height: height >= 0
7
8    command block_number() :: integer() do
9      post height == result
10   end
11
12   command mine() :: :ok do
13     next height: height + 1
14   end
15 end
```

Adding documentation

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```

Adding documentation

```elixir
defmodule Blocks do
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  @moduledoc """
  Checks blocks are mined correctly.
  """
  state height: 0 :: integer()

  invariants non_neg_height: height >= 0

  command block_number() :: integer() do
    @moduledoc "Gets the block number."
    post {:ok, height} == result
  end

  command mine() :: :ok do
    @moduledoc "Mines a new block."
    next height: height + 1
  end
end
```

Adding documentation

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iex> h Blocks
```

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Adding documentation

```
iex> h Blocks

Contains a Makina model called Blocks.

Checks blocks are mined correctly.

## Commands

- mine
- block_number

## State attributes

- height

## Invariants

- non_neg_height
```

```elixir
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  end

  command mine() :: :ok do
    @moduledoc "Mines a new block."
    next height: height + 1
  end
end
```

Adding documentation

```
iex> h Blocks.Command.Mine
```

```elixir
defmodule Blocks do
  use Makina, implemented_by: Etherex

  @moduledoc """
  Checks blocks are mined correctly.
  """
  state height: 0 :: integer()

  invariants non_neg_height: height >= 0

  command block_number() :: integer() do
    @moduledoc "Gets the block number."
    post height == result
  end

  command mine() :: :ok do
    @moduledoc "Mines a new block."
    next height: height + 1
  end
end
```

Adding documentation

```
iex> h Blocks.Command.Mine

This module contains the functions necessary to
generate and execute the command mine.

Mines a new block.

## Definitions

- next
- call
- weight
- post
- args
- pre
```

```elixir
defmodule Blocks do
  use Makina, implemented_by: Etherex

  @moduledoc """
  Checks blocks are mined correctly.
  """
  state height: 0 :: integer()

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  command block_number() :: integer() do
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  end

  command mine() :: :ok do
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    next height: height + 1
  end
end
```

Adding documentation

```
iex> h Blocks.Command.Mine.post
```

```elixir
defmodule Blocks do
  use Makina, implemented_by: Etherex

  @moduledoc """
  Checks blocks are mined correctly.
  """
  state height: 0 :: integer()

  invariants non_neg_height: height >= 0

  command block_number() :: integer() do
    @moduledoc "Gets the block number."
    post height == result
  end

  command mine() :: :ok do
    @moduledoc "Mines a new block."
    next height: height + 1
  end
end
```

Adding documentation

```
iex> h Blocks.Command.Mine.post

This definition contains a predicate that should
be true after the execution of mine

## Available variables

### State

- state
- height

### Arguments

- arguments

### Result

- result
```

```elixir
defmodule Blocks do
  use Makina, implemented_by: Etherex

  @moduledoc """
  Checks blocks are mined correctly.
  """
  state height: 0 :: integer()

  invariants non_neg_height: height >= 0

  command block_number() :: integer() do
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  command mine() :: :ok do
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end
```

Account access

The API:

Command	Returns
`balance/1`	`integer()`

Account access

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Command	Returns
`balance/1`	`integer()`

1. create module.

```elixir
defmodule Accounts do

end
```

Account access

The API:

Command	Returns
`balance/1`	`integer()`

1. create module.
2. import *`Makina`*.

```elixir
defmodule Accounts do
  use Makina, implemented_by: Etherex

end
```

Account access

The API:

Command	Returns
`balance/1`	`integer()`

1. create module.
2. import *`Makina`*.
3. define state.

```elixir
defmodule Accounts do
  use Makina, implemented_by: Etherex

  @type balances() :: %{address() => integer()}

  state accounts: Etherex.accounts() :: [address()],
        balances: Etherex.balances() :: balances()

end
```

Account access

The API:

Command	Returns
`balance/1`	`integer()`

1. create module.
2. import *Makina*.
3. define state.
4. define commands.

```
defmodule Accounts do
  use Makina, implemented_by: Etherex

  @type balances() :: %{address() => integer()}

  state accounts: Etherex.accounts() :: [address()],
        balances: Etherex.balances() :: balances()

  command balance(account :: address()) :: integer() do
    pre accounts != []
    post balances[account] == result
  end
end
```

Running the test

```
$ mix test
```

```
defmodule Accounts do
  use Makina, implemented_by: Etherex

  @type balances() :: %{address() => integer()}

  state accounts: Etherex.accounts() :: [address()],
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    pre accounts != []
    post balances[account] == result
  end
end
```

Running the test

```
$ mix test

** (Makina.Error) argument
‘account‘ missing in command
get_balance
```

```elixir
defmodule Accounts do
  use Makina, implemented_by: Etherex

  @type balances() :: %{address() => integer()}

  state accounts: Etherex.accounts() :: [address()],
        balances: Etherex.balances() :: balances()

  command balance(account :: address()) :: integer() do
    pre accounts != []
    post balances[account] == result
  end
end
```

Running the test

```
$ mix test

** (Makina.Error) argument
‘account‘ missing in command
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This is a runtime-check added by *Makina*!

```elixir
defmodule Accounts do
  use Makina, implemented_by: Etherex

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        balances: Etherex.balances() :: balances()

  command balance(account :: address()) :: integer() do
    pre accounts != []
    post balances[account] == result
  end
end
```

Fixing the model

```
$ mix test

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```elixir
defmodule Accounts do
  use Makina, implemented_by: Etherex

  @type balances() :: %{address() => integer()}

  state accounts: Etherex.accounts() :: [address()],
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  command balance(account :: address()) :: integer() do
    args account: oneof(accounts)
    pre accounts != []
    post balances[account] == result
  end
end
```

Running the test

```
$ mix test
```

```elixir
defmodule Accounts do
  use Makina, implemented_by: Etherex
  @type balances() :: %{address() => integer()}

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  command balance(account :: address()) :: integer() do
    args account: oneof(accounts)
    pre accounts != []
    post balances[account] == result
  end
end
```

Running the test

```
$ mix test

.......................
.......................
.......................
.......................
OK, passed 100 tests

'100.0 get_balance/1
```

```elixir
defmodule Accounts do
  use Makina, implemented_by: Etherex
  @type balances() :: %{address() => integer()}

  state accounts: Etherex.accounts() :: [address()],
        balances: Etherex.balances() :: balances()

  command balance(account :: address()) :: integer() do
    args account: oneof(accounts)
    pre accounts != []
    post balances[account] == result
  end
end
```

Generating transactions

Generating transactions

The API to generate and check transactions:

Generating transactions

The API to generate and check transactions:

Command	Returns	Implemented
`mine/0`	`:ok`	✓
`block_number/0`	`integer()`	✓
`get_balance/1`	`integer()`	✓
`transfer/3`	`hash()`	

Generating transactions

The API to generate and check transactions:

Command	Returns	Implemented
`mine/0`	`:ok`	✓
`block_number/0`	`integer()`	✓
`get_balance/1`	`integer()`	✓
`transfer/3`	`hash()`	

We can compose *`Blocks`* and *`Accounts`*!

Generating transactions

The API to generate and check transactions:

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`transfer/3`	`hash()`	

We can compose *`Blocks`* and *`Accounts`*!

```
defmodule Transactions do
  use Makina,
    extends: [Blocks, Accounts],
    implemented_by: Etherex
end
```

Generating transactions

The API to generate and check transactions:

Command	Returns	Implemented
`mine/0`	`:ok`	✓
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We can compose `Blocks` and `Accounts`!

```
defmodule Transactions do
  use Makina,
    extends: [Blocks, Accounts],
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end
```

Generates a model `Transactions.Composed`.

Generating transactions

The API to generate and check transactions:

Command	Returns	Implemented
`mine/0`	`:ok`	✓
`block_number/0`	`integer()`	✓
`get_balance/1`	`integer()`	✓
`transfer/3`	`hash()`	

```
iex(1)> h Transactions.Composed
```

We can compose *Blocks* and *Accounts*!

```
defmodule Transactions do
  use Makina,
    extends: [Blocks, Accounts],
    implemented_by: Etherex
end
```

Generates a model *Transactions.Composed*.

Generating transactions

The API to generate and check transactions:

Command	Returns	Implemented
`mine/0`	`:ok`	✓
`block_number/0`	`integer()`	✓
`get_balance/1`	`integer()`	✓
`transfer/3`	`hash()`	

We can compose *Blocks* and *Accounts*!

```
defmodule Transactions do
  use Makina,
    extends: [Blocks, Accounts],
    implemented_by: Etherex
end
```

Generates a model *Transactions.Composed*.

```
iex(1)> h Transactions.Composed

# Transactions.Composed

## Commands

- mine stored
- get_balance
- block_number

## State attributes

- height
- balances
- accounts

## Invariants

- non_neg_height
```

Generating transactions

```
Transactions extends: Transactions.Composed.
```

```elixir
defmodule Transactions do
  use Makina,
    implemented_by: Etherex,
    extends: [Accounts, Blocks]

end
```

Generating transactions

```
Transactions extends: Transactions.Composed.
```

Command	Returns
`transfer/3`	`hash()`

```
defmodule Transactions do
  use Makina,
    implemented_by: Etherex,
    extends: [Accounts, Blocks]

  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next balances: update(balances, from, to, value)
  end
end
```

Running the test

```
$ mix test
```

```elixir
defmodule Transactions do
  use Makina,
    implemented_by: Etherex,
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  command transfer(from, to, value) :: hash() do
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    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next balances: update(balances, from, to, value)
  end
end
```

Running the test

```
$ mix test

transfer("0xffcf8fdee72ac11",
         "0x90f8bf6a479f320",
         1)
block_number()

Postcondition failed.

block_number() -> {:ok, 1}

Last state: %{height: 0, ...}
```

```elixir
defmodule Transactions do
  use Makina,
    implemented_by: Etherex,
    extends: [Accounts, Blocks]

  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next balances: update(balances, from, to, value)
  end
end
```

Fixing the model

```
$ mix test

transfer("0xffcf8fdee72ac11",
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defmodule Transactions do
  use Makina,
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  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next height: height + 1,
         balances: update(balances, from, to, value)
  end
end
```

Running the test

```
$ mix test
```

```elixir
defmodule Transactions do
  use Makina,
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  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next height: height + 1,
         balances: update(balances, from, to, value)
  end
end
```

Running the test

```
$ mix test

transfer("0x90f8bf6a479f320",
         "0xffcf8fdee72ac11",
         1),
get_balance("0x90f8bf6a479f320")

Postcondition failed.

get_balance("0x90f8bf6a479f320")
-> {:ok, 979000}

Last state: %{
    balances: %{
        "0x90f8bf6a479f320" => 1000000
        .. }
    .. }
```

```
defmodule Transactions do
  use Makina,
    implemented_by: Etherex,
    extends: [Accounts, Blocks]

  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next height: height + 1,
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end
```

Fixing the model

To fix this error we need to extract the gas cost after producing a transaction.

```
defmodule Transactions do
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  command transfer(from, to, value) :: hash() do
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To fix this error we need to extract the gas cost after producing a transaction.

Model execution is performed in two phases:

1. Generation of the command sequence.
2. Real execution of the test.

```
defmodule Transactions do
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         to: oneof(accounts),
         value: pos_integer()
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         balances: update(balances, from, to, value)
  end
end
```

Fixing the model

To fix this error we need to extract the gas cost after producing a transaction.

Model execution is performed in two phases:

1. Generation of the command sequence.
2. Real execution of the test.

PBT libraries solve this documenting:

- symbolic state: state of the model during phase 1.
- dynamic state: state of the model during phase 2.

```
defmodule Transactions do
  use Makina,
    implemented_by: Etherex,
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  command transfer(from, to, value) :: hash() do
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    args from: oneof(accounts),
         to: oneof(accounts),
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    next height: height + 1,
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end
```

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         balances: update(balances, from, to, value)

  end

  command get_balance() do
    pre transactions == []
  end
end
```

Fixing the model

Makina makes the difference between symbolic and dynamic explicit.

```
defmodule Transactions do
  use Makina,
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Fixing the model

Makina makes the difference between symbolic and dynamic explicit.

Provides two mechanisms to add information about symbolic state:

- `symbolic(t)` type.
- `symbolic(expr)` macro.

```
defmodule Transactions do
  use Makina,
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    pre accounts != []
    args from: oneof(accounts),
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         value: pos_integer()
    next height: height + 1,

         balances: update(balances, from, to, value)

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Rules on symbolic state:

- An attribute with a symbolic type cannot be inspected in `next`.
- If we need to update a symbolic attribute we should use symbolic macro.

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defmodule Transactions do
  use Makina,
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  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next height: height + 1,

         balances: update(balances, from, to, value)

  end

  command get_balance() do
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To fix our model we need

1. Add symbolic attributes to the state.

```
defmodule Transactions do
  use Makina,
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  command transfer(from, to, value) :: hash() do
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    args from: oneof(accounts),
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To fix our model we need

1. Add symbolic attributes to the state.

```
defmodule Transactions do
  use Makina,
    implemented_by: Etherex,
    extends: [Accounts, Blocks]

  state transactions: [] :: [symbolic(hash())]
        balances: super() :: symbolic(balances)

  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next height: height + 1,

         balances: update(balances, from, to, value)

  end

  command get_balance() do
    pre transactions == []
  end
end
```

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- If we need to update a symbolic attribute we should use symbolic macro.

To fix our model we need

1. Add symbolic attributes to the state.
2. Store and update symbolic attributes.

```
defmodule Transactions do
  use Makina,
    implemented_by: Etherex,
    extends: [Accounts, Blocks]

  state transactions: [] :: [symbolic(hash())]
        balances: super() :: symbolic(balances)

  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next height: height + 1,

         balances: update(balances, from, to, value)

  end

  command get_balance() do
    pre transactions == []
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end
```

Fixing the model

Makina makes the difference between symbolic and dynamic explicit.

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```
defmodule Transactions do
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  state transactions: [] :: [symbolic(hash())]
        balances: super() :: symbolic(balances)

  command transfer(from, to, value) :: hash() do
    pre accounts != []
    args from: oneof(accounts),
         to: oneof(accounts),
         value: pos_integer()
    next height: height + 1,
         transactions: [result | transactions],
         balances: update(balances, from, to, value)
                        |> symbolic()
  end

  command get_balance() do
    pre transactions == []
  end
end
```

Fixing the model

```
defmodule Transactions.GasCost do
  use Makina, extends: Transactions

  end
end
```

We import `Transactions` model using `:extends`.

Fixing the model

We import `Transactions` model using `:extends`.

We add a command that gets the cost of a transaction.

```
defmodule Transactions.GasCost do
  use Makina, extends: Transactions

  end
end
```

Fixing the model

We import `Transactions` model using `:extends`.

We add a command that gets the cost of a transaction.

```
defmodule Transactions.GasCost do
  use Makina, extends: Transactions

  command gas_cost(hash :: hash())
      :: {address(), quantity()} do
    pre transactions != []
    args hash: oneof(transactions)
    next transactions: List.delete(transactions, hash),
         balances: update_gas(balances, result)
                   |> symbolic()
    end
  end
end
```

Running the test

```
$ mix test
```

```
defmodule Transactions.GasCost do
  use Makina, extends: Transactions

  command gas_cost(hash :: hash())
      :: {address(), quantity()} do
    pre transactions != []
    args hash: oneof(transactions)
    next transactions: List.delete(transactions, hash),
         balances: update_gas(balances, result)
                   |> symbolic()
    end
  end
end
```

Running the test

```
$ mix test

.........................
.........................
.........................
.........................

OK, passed 100 tests

'25.5 mine/0
'24.9 block_number/0
'23.6 transfer/3
'14.3 gas_cost/1
'11.8 get_balance/1
```

```
defmodule Transactions.GasCost do
  use Makina, extends: Transactions

  command gas_cost(hash :: hash())
      :: {address(), quantity()} do
    pre transactions != []
    args hash: oneof(transactions)
    next transactions: List.delete(transactions, hash),
         balances: update_gas(balances, result)
                   |> symbolic()
    end
  end
end
```

Results

Results

Problem on PBT models	`Makina` solution
Hard to reuse.	Modular and composable models.
Bugs are hard to detect.	Type and specs generation.
Generate cryptic errors.	Automatic runtime-checks.

Results

Problem on PBT models	`Makina` solution
Hard to reuse.	Modular and composable models.
Bugs are hard to detect.	Type and specs generation.
Generate cryptic errors.	Automatic runtime-checks.

Before `Makina`	After `Makina`
4 files 4513 lines	18 files 1692 lines

Links

Makina library:

- `https://gitlab.com/babel-upm/makina/makina/`

Etherex library:

- `https://gitlab.com/babel-upm/blockchain/etherex`

Slides and code examples:

- `https://github.com/lbueso/code_beam_2022`