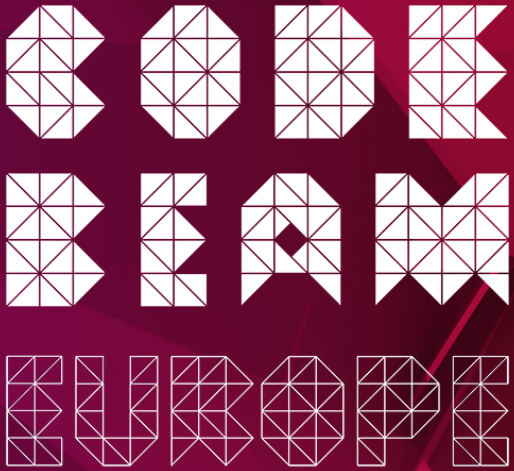


STOCKHOLM

HYBRID CONFERENCE

Improve your tests with Makina

Luis Eduardo Bueso de Barrio

May 20 | 2022

#CodeBEAM

files: 4

lines of code: 4513

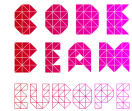
files: 4

lines of code: 4513

files: 18

lines of code: 1692

Property Based Testing



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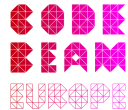

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Successful tools:

- Quviq QuickCheck
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PBT state-machines or models.

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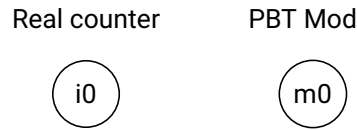

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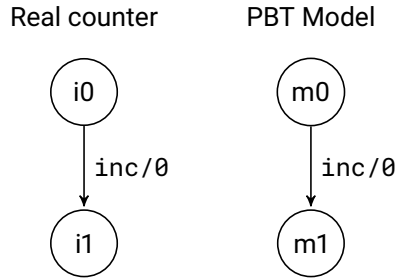

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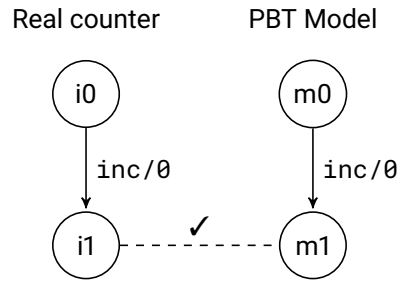

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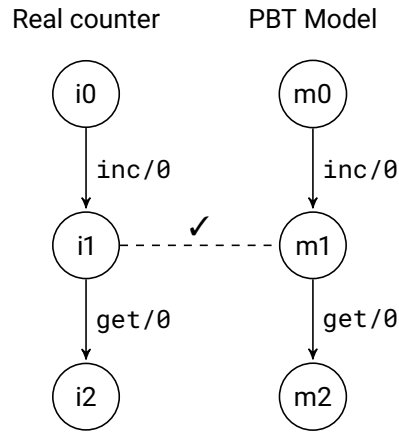

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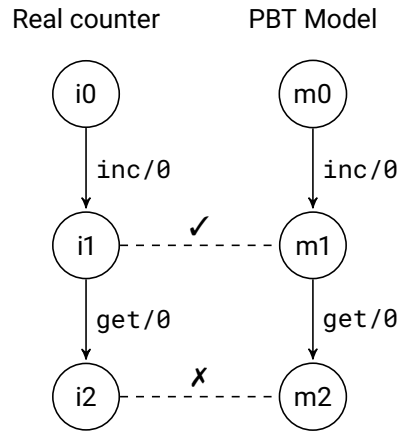
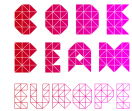


Problems with PBT models



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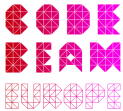
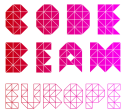


Despite their proven effectiveness:

- Very slow adoption

Problems with PBT models



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Why?

1. Models are hard to reuse.
2. Bugs in models are hard to detect.
3. Generate cryptic errors.

Problems with PBT models

Despite their proven effectiveness:

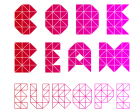
- Very slow adoption

Why?

1. Models are hard to reuse.
2. Bugs in models are hard to detect.
3. Generate cryptic errors.

All these problems made models hard to write and maintain.

Our solution: Makina



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Makina model

Proper/QuickCheck model

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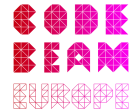
   - Automatic runtime-checks generation.

Makina: The Language



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

  state [_attribute_]

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  command _declaration_ do
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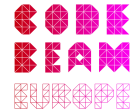

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- extends: module()
- extends: [module()]
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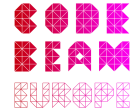

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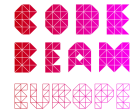

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declaration

- name(arg1, ... , argN)

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*_option_*

- `extends: module()`
- `extends: [module()]`
- `implemented_by: module()`

*_attribute_*

- `name: expr`

*_declaration_*

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

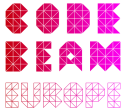
*_command_body_*

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

Ethereum Blockchain

Why Ethereum?

- It is a complex system.



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Why Ethereum?

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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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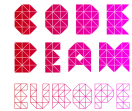
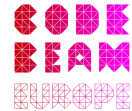
How *Makina* handles this complexity?

Mining blocks

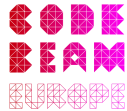


Mining blocks



The API:

Mining blocks



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Command	Returns
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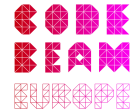
Mining blocks



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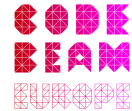

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defmodule Blocks do
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```

1. create module.
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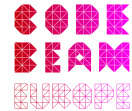
Mining blocks



The API:

Command	Returns
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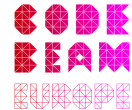
```elixir
defmodule Blocks do
  use Makina

  state height: 0
```

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

Mining blocks



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```elixir
defmodule Blocks do
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  invariants non_neg_height: height > 0
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  command block_number() do
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    args []
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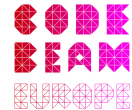
Mining blocks



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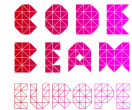
  invariants non_neg_height: height > 0

  command block_number() do
    pre true
    args []
    call Etherex.block_number
```

Mining blocks



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  command block_number() do
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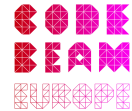
    call Etherex.block_number
    next []
```

Mining blocks



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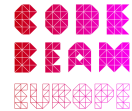
    next []
    post height == result
```

Mining blocks



The API:

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

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

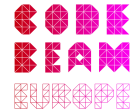
```
defmodule Blocks do
  use Makina

  state height: 0

  invariants non_neg_height: height > 0

  command block_number() do
    pre true
    args []
    call Etherex.block_number
    next []
    post height == result
  end
```

Mining blocks



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`mine/0`	`:ok`
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defmodule Blocks do
  use Makina, implemented_by: Etherex

  state height: 0

  invariants non_neg_height: height > 0

  command block_number() do
    post height == result
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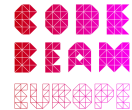
Mining blocks



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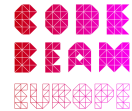
```

Running the test



```
$ mix test
```

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

  state height: 0

  invariants non_neg_height: height > 0

  command block_number() do
    post height == result
  end

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

Running the test

```
$ mix test

Failed! After 1 tests.

Postcondition crashed:
** invariant "non_neg_height" check failed

block_number/0

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

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

  state height: 0

  invariants non_neg_height: height > 0

  command block_number() do
    post height == result
  end

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

Running the test

```
$ mix test

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Postcondition crashed:
** invariant "non_neg_height" check failed

block_number/0

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

This is a runtime check added by *Makina*!

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

  state height: 0

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  command block_number() do
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end
```
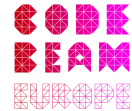

Fixing the model



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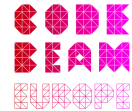
Fixing the model



```
$ mix test

Failed! After 1 tests.

Postcondition crashed:
** invariant "non_neg_height" check failed

block_number/0

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

This is a runtime check added by *Makina*!

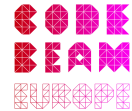
```
defmodule Blocks do
  use Makina, implemented_by: Etherex

  state height: 0

  invariants non_neg_height: height >= 0

  command block_number() do
    post height == result
  end

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

Running the test

```
$ mix test
```

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

  state height: 0

  invariants non_neg_height: height >= 0

  command block_number() do
    post height == result
  end

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

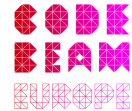
Running the test



```
$ mix test

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

OK, passed 100 tests

51.5 mine/0
48.5 block_number/0
```

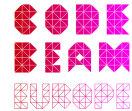
```
defmodule Blocks do
  use Makina, implemented_by: Etherex

  state height: 0

  invariants non_neg_height: height >= 0

  command block_number() do
    post height == result
  end

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

Adding type information



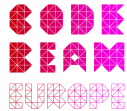
```
1  defmodule Blocks do
2    use Makina, implemented_by: Etherex
3
4    state height: 0
5
6    invariants non_neg_height: height >= 0
7
8    command block_number() do
9      post height == result
10   end
11
12   command mine() do
13     next height: height + 1
14   end
15 end
```

Adding type information



```
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 type information



```
$ mix gradient

$
```

```
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 type information

```
$ mix gradient

$
```

Something changes in `Etherex`...

```
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
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12   command mine() :: :ok do
13     next height: height + 1
14   end
15 end
```

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
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8    command block_number() :: integer() do
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```
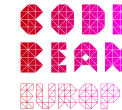
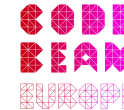

Adding documentation



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

  state height: 0 :: integer()

  invariants non_neg_height: height >= 0

  command block_number() :: integer() do

    post {:ok, height} == result
  end

  command mine() :: :ok do

    next height: height + 1
  end
end
```

Adding documentation



```
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 {:ok, height} == result
  end

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

Adding documentation

```
iex> h Blocks
```

```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 {:ok, height} == result
  end

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

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
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 {:ok, 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
```

```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()

  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
```

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

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    @moduledoc "Mines a new block."
    next height: height + 1
  end
end
```
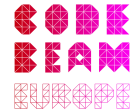
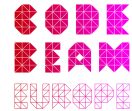

Account access



The API:

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

Account access



The API:

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

1. create module.

```
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.

```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
```

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

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

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

Running the test

```
$ mix test

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

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

  state accounts: Etherex.accounts() :: [address()],
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Running the test

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This is a runtime-check added by *Makina*!

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defmodule Accounts do
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Fixing the model

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$ mix test

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‘account‘ missing in command
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This is a runtime-check added by *Makina*!

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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
```

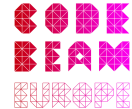
```elixir
defmodule Accounts do
  use Makina, implemented_by: Etherex
  @type balances() :: %{address() => integer()}

  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
```

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
```

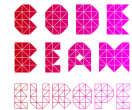
Generating transactions



Generating transactions

The API to generate and check transactions:

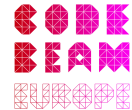
Generating transactions



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:

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
```

Generating transactions

The API to generate and check transactions:

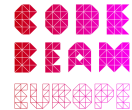
Command	Returns	Implemented
`mine/0`	`:ok`	✓
`block_number/0`	`integer()`	✓
`get_balance/1`	`integer()`	✓
`transfer/3`	`hash()`	

We can compose *Blocks* and *Accounts*!

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

Generates a model *Transactions.Composed*.

Generating transactions



The API to generate and check transactions:

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

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  use Makina,
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end
```

Generates a model *Transactions.Composed*.

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

# Transactions.Composed

## Commands

- mine stored
- get_balance
- block_number

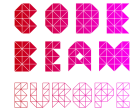
## State attributes

- height
- balances
- accounts

## Invariants

- non_neg_height
```

Generating transactions



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Transactions extends: Transactions.Composed.
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defmodule Transactions do
  use Makina,
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end
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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

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$ mix test
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```

Running the test

```
$ mix test

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

Postcondition failed.

block_number() -> 1

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

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

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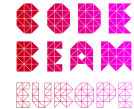
         to: oneof(accounts),
         value: pos_integer()
    next height: height + 1,
         balances: update(balances, from, to, value)
  end
end
```

Running the test



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  end
end
```

Running the test

```
$ mix test

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

Postcondition failed.

get_balance("0x90f8bf6a479f320") -> 979000

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

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Fixing the model

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

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Model execution is performed in two phases:

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

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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.

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    pre transactions == []
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Fixing the model

Makina makes the difference between symbolic and dynamic explicit.

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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.

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1. Add symbolic attributes to the state.

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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),
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1. Add symbolic attributes to the state.
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    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
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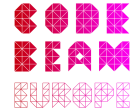
Fixing the model

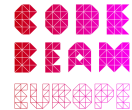


```elixir
defmodule Transactions.GasCost do
  use Makina, extends: Transactions
```

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

```elixir
  end
end
```

Fixing the model



```elixir
defmodule Transactions.GasCost do
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We import `Transactions` model using `:extends`.

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

```elixir
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Fixing the model

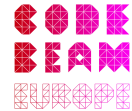
We import *Transactions* model using `:extends`.

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
```

Running the test



```
$ mix test
```

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defmodule Transactions.GasCost do
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  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
```

```elixir
defmodule Transactions.GasCost do
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    args hash: oneof(transactions)
    next transactions: List.delete(transactions, hash),
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  end
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```
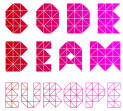

Results



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.

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

Links

Makina library:

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

Makina examples:

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

Etherex library:

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