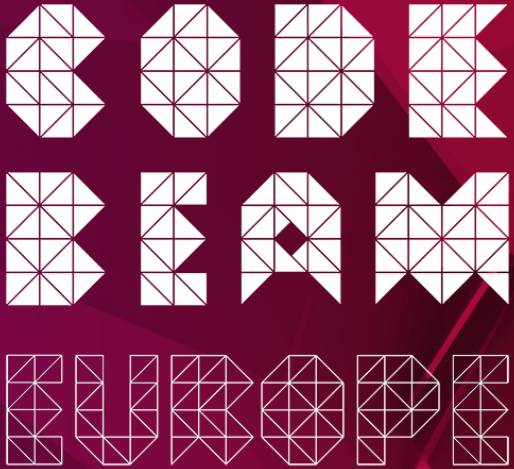

STOCKHOLM

HYBRID CONFERENCE

Improve your tests with Makina

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#CodeBEAM

The problem

files	blank	comment	code
4	760	383	4513

files	blank	comment	code
18	500	408	1692

Introduction to PBT

Writing unit-tests is hard and time-consuming:

```
reverse([]) == []
reverse([1]) == [1]
reverse([1 ,2]) == [2 ,1]
...
```

Property-Based Testing (PBT) philosophy:

Don't write tests, generate them.

A test execution in PBT consists of:

1. Data generation.
2. Property checking.
3. An shrinking strategy (if the property doesn't hold).

A property:

```
forall list <- list() do
  list == reverse(reverse(list))
end
```

In each test:

1. `list()` generates a random list:

   `[8 ,10 ,6] ...`

2. Checks the property:

   `[8, 10, 6] == reverse(reverse([8, 10, 6]))`

3. If the property doesn't hold returns a counter-example.

Testing *stateful* programs

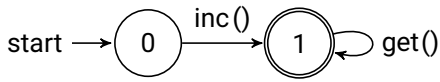
Imagine a simple counter:

Command	Returns
`start/1`	`:ok | :error`
`stop/0`	`:ok | :error`
`inc/0`	`:ok`
`get/0`	`integer()`

Unit test:

```
:ok = start(0)
:ok = inc()
1   = get()
:ok = stop()
```

This test can be represented:



To successfully test this program we need to:

- Generate sequences of commands.
- An internal state to track the changes in the program.
- A way to interact with the program under test.

PBT of *stateful* programs

Basic property of *stateful* programs:

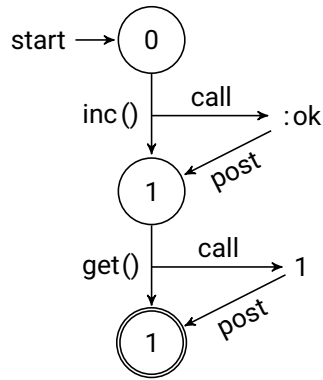
```
forall cmds <- commands(Counter) do
  :ok == run_commands(Counter, cmds)
end
```

where:

- `commands/1` generates sequences commands:

  ```
  [start(0), inc(), get(), stop()]
  ...
  ```

- `run_commands` executes the generated sequence.



PBT state machines

Introduced by `Erlang QuickCheck`.

Adopted by other PBT libraries such as `Proper`.

These libraries provide a DSL to model the system.

Proven effectiveness.

Very slow adoption.

Why?

Problems:

- Hard to write.
- Cryptic errors.
- Usually buggy.
- Code reuse is very hard.
- Hard to maintain.

Makina

`Makina` is a DSL to write PBT state machines.

- Fully compatible with `Erlang QuickCheck` and `PropEr`.
- Improved usability.
- Better error messages.
- Improved error detection in models.

A Makina model contains:

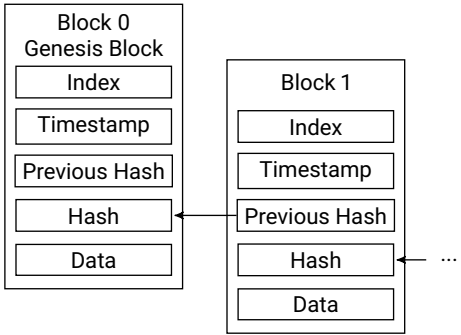
- `state`
- `command`
- `invariants`

Provides code reuse mechanisms:

- imports
- `extends`
- composition

Ethereum Blockchain

A blockchain is a distributed ledger that enables peer-to-peer transactions.



Ethereum is one of the largest blockchains.

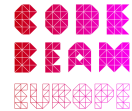
Introduced smart-contracts.

`etherex` a library to interact with Ethereum using Elixir.

The properties to test:

1. Mining blocks.
2. Account access.
3. Transfers between accounts.

Mining blocks



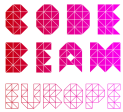
The API:

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

1. state?
2. invariants?
3. commands?

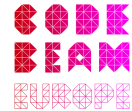
```
defmodule Blocks do
  use Makina, implemented_by: Etherex

  state height: 0

  invariants non_neg_height: height > 0

  command block_number() do
    post {:ok, height} == result
  end

  command mine() do
    call Etherex.Time.mine()
    next height: height + 1
  end
end
```

Consulting callback docs



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

# def post(state, arguments, result)

@spec post(dynamic_state(), arguments(), result()) :: boolean()

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

## Available variables

### State

- state contains the complete dynamic state of the model.
- height attribute defined in the state declaration.

### Arguments

- arguments contains all the generated arguments of the command.

### Result

- result variable that contains the result of the command execution.
```

Adding type information



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

  state height: 0 :: integer()

  invariants non_neg_height: height >= 0

  command block_number() :: {:ok, integer()} do
    post {:ok, height} == result
  end

  command mine() :: :ok do
    call Etherex.Time.mine()
    next height: height + 1
  end
end
```

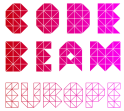
```
$ mix gradient

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

Adding documentation

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

  @moduledoc """
  Specifies the mining facilities of the blockchain.
  """

  state height: Etherex.block_number!() :: non_neg_integer()

  invariants non_genesis_block: height >= 0

  command block_number() :: {:ok, non_neg_integer()} do
    @moduledoc "Retrieves the block number from the blockchain."
    post {:ok, height} == result
  end

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

Consulting module docs

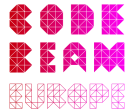
```
iex> h Blocks

# Blocks

Contains a Makina model called Blocks.

Specifies the mining facilities of the blockchain.

## Commands

- mine stored at Blocks.Command.Mine
- block_number stored at Blocks.Command.BlockNumber

Detailed information about each command can be accessed inside the interpreter:

iex> h Blocks.Command.NAME

## State attributes

- height

...
```



Running the test

```
$ mix test
Starting Quviq QuickCheck version 1.45.1

Failed! After 1 tests.
[
    Blocks.block_number/0,
    Blocks.mine/0,
]

================================================================================
Postcondition crashed:
** (Makina.Error) invariant "non_neg_height" check failed

Shrinking x.(1 times)
[
    Blocks.block_number/0
]

Last state: %{height: 0}

Finished in 0.1 seconds (0.00s async, 0.1s sync)
1 properties, 1 failure
```

Fixing the model



The error message:

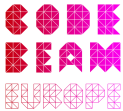
```
Postcondition crashed:
** invariant "non_neg_height" check failed

Shrinking x.(1 times)
[
    Blocks.block_number/0
]

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

What happened?

Invariant doesn't hold even on the initial state!

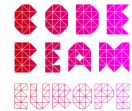
```
defmodule Blocks do
  use Makina, implemented_by: Etherex

  state height: 0

  invariants non_neg_height: height >= 0

  command block_number() do
    post {:ok, height} == result
  end

  command mine() do
    call Etherex.Time.mine()
    next height: height + 1
  end
end
```

Running the test



```
$ mix test
Starting Quviq QuickCheck version 1.45.1

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

51.5 Blocks.mine/0
48.5 Blocks.block_number/0

Finished in 8.6 seconds (0.00s async, 8.6s sync)
```

Account access



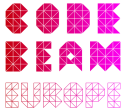
The API:

Command	Returns
`get_balance/1`	`:ok`

1. state?
2. invariants?
3. commands?

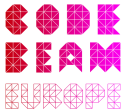
```
defmodule Accounts do
  use Makina, implemented_by: Etherex

  alias Etherex.Type

  state accounts: Etherex.accounts!() :: [Type.address()],
    balances: Etherex.balances!() :: %{Type.address() => integer()}

  command get_balance(account :: Type.address())
  :: {:ok, Type.quantity()} | {:error, Type.error()} do
    pre accounts != []
    post {:ok, balances[account]} == result
  end
end
```

Running the tests



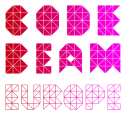
```
Starting Quviq QuickCheck version 1.45.1

1) property Accounts (ExamplesTest)
   ** (Makina.Error) argument ‘account‘ missing in command get_balance
   stacktrace:
   (makina 0.1.0) lib/makina/error.ex:9: Makina.Error.throw_error/1
   (examples 0.1.0) lib/accounts.ex:13: Accounts.Command.GetBalance.check_args/1
   (examples 0.1.0) lib/accounts.ex:1: Accounts.Behaviour.next_state/3
   Finished in 0.1 seconds (0.00s async, 0.1s sync)

   1 properties, 1 failure

   Randomized with seed 763550
```

Fixing the accounts model



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

  alias Etherex.Type

  state accounts: Etherex.accounts!() :: [Type.address()],
    balances: Etherex.balances!() :: %{Type.address() => integer()}

  command get_balance(account :: Type.address()) ::
  {:ok, Type.quantity()} | {:error, Type.error()} do
    pre accounts != []
    args account: oneof(accounts)
    valid_args account in accounts
    post {:ok, balances[account]} == result
  end
end
```

Running the test



```
$ mix test
Starting Quviq QuickCheck version 1.45.1

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

'100.0 Accounts.get_balance/1

Finished in 4.6 seconds (0.00s async, 4.6s sync)
1 properties, 0 failures
```

Generating transactions

The API to generate and check transactions:

Command	Returns
`mine/0`	`:ok`
`block_number/0`	`{:ok, integer()}`
`get_balance/1`	`{:ok, integer()}`
`transfer/3`	`{:ok, hash()}`

We can compose `Blocks` and `Accounts`!

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

Generates a model `Transactions.Composed`.

State is the union:

- `:height`
- `:accounts`
- `:balances`

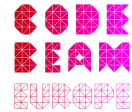
Invariants are the union:

- `:non_genesis_block`

Commands are the union:

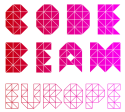
- `mine/0`
- `block_number/0`
- `get_balance/1`

Generating transactions



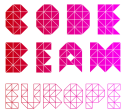
```
defmodule Transactions do
  use Makina, implemented_by: Etherex, extends: [Accounts, Blocks]
  alias Etherex.Type

  command transfer(
            from :: Type.address(),
            to :: Type.address(),
            value :: Type.quantity()
          ) :: {:ok, Type.hash()} do
    pre accounts != []
    args from: oneof(accounts), to: oneof(accounts), value: pos_integer()
    valid_args from in accounts and to in accounts

    next balances: update_balances(balances, from, to, value)
  end

  def update_balances(balances, from, to, value) do
    balances |> Map.update!(from, &(&1 - value)) |> Map.update!(to, &(&1 + value))
  end
end
```

Running the test



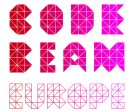
```
$ mix test
Starting Quviq QuickCheck version 1.45.1

Failed! After 1 tests.
[
    Transactions.transfer("0xffcf8fdee72ac11b5c542428b35eef5769c409f0",
                          "0x90f8bf6a479f320ead074411a4b0e7944ea8c9c1",
                          423319221061516289),
    Transactions.get_balance("0x90f8bf6a479f320ead074411a4b0e7944ea8c9c1"),
    Transactions.mine(),
    Transactions.mine(),
    Transactions.block_number()
]

================================================================================
Postcondition failed.

...

Shrinking xxx.xx.x.x.x(4 times)
```

Running the test



```
[
    Transaction.transfer("0xffcf8fdee72ac11b5c542428b35eef5769c409f0",
                         "0x90f8bf6a479f320ead074411a4b0e7944ea8c9c1",
                         1),
    Transactions.block_number()
]

================================================================================
Postcondition failed.

...

Transactions.block_number() -> {:ok, 1}


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

Finished in 0.8 seconds (0.00s async, 0.8s sync)
1 properties, 1 failure
```

Fixing the transactions model

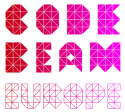


```elixir
defmodule Transactions do
  use Makina, implemented_by: Etherex, extends: [Accounts, Blocks]
  alias Etherex.Type

  command transfer(
    from :: Type.address(),
    to :: Type.address(),
    value :: Type.quantity()
  ) :: {:ok, Type.hash()} do
    pre accounts != []
    args from: oneof(accounts), to: oneof(accounts), value: pos_integer()
    valid_args from in accounts and to in accounts

    next balances: update_balances(balances, from, to, value),
         height: height + 1
  end

  def update_balances(balances, from, to, value) do
    balances |> Map.update!(from, &(&1 - value)) |> Map.update!(to, &(&1 + value))
  end
end
```

Running the test

```
$ mix test --only transactions
Starting Quviq QuickCheck version 1.45.1

..Failed! After 2 tests.
[
    ...
]

================================================================================
Postcondition failed.

...

Shrinking xxxx.x.x.x.x.xx.x(6 times)
[
    Transactions.transfer("0x90f8bf6a479f320ead074411a4b0e7944ea8c9c1",
                          "0x90f8bf6a479f320ead074411a4b0e7944ea8c9c1",
                          1),
    Transactions.get_balance("0x90f8bf6a479f320ead074411a4b0e7944ea8c9c1")
]

================================================================================
Postcondition failed.
```

Running the tests



```
Commands:

...

Transactions.get_balance("0x90f8bf6a479f320ead074411a4b0e7944ea8c9c1")
  -> {:ok, 999999999999999999999999979000}

Last state:
%{
  balances: %{
    "0x90f8bf6a479f320ead074411a4b0e7944ea8c9c1" => 1000000000000000000000000000000,
    ...
  },
  ...
}
Finished in 1.1 seconds (0.00s async, 1.1s sync)
3 properties, 1 failure
```