Mica

Automated Differential Testing for OCaml Modules

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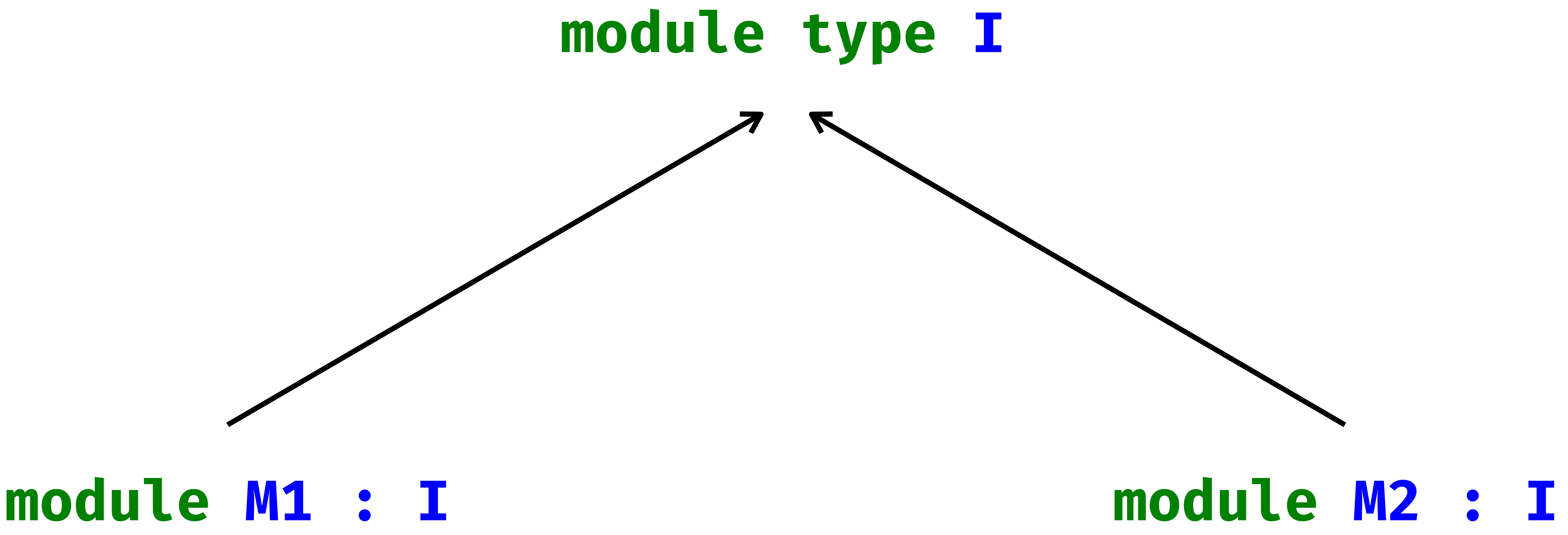
Representation Independence



```
module type I
```

interface / signature

```
module M1 : I
```

```
module M2 : I
```

implementations

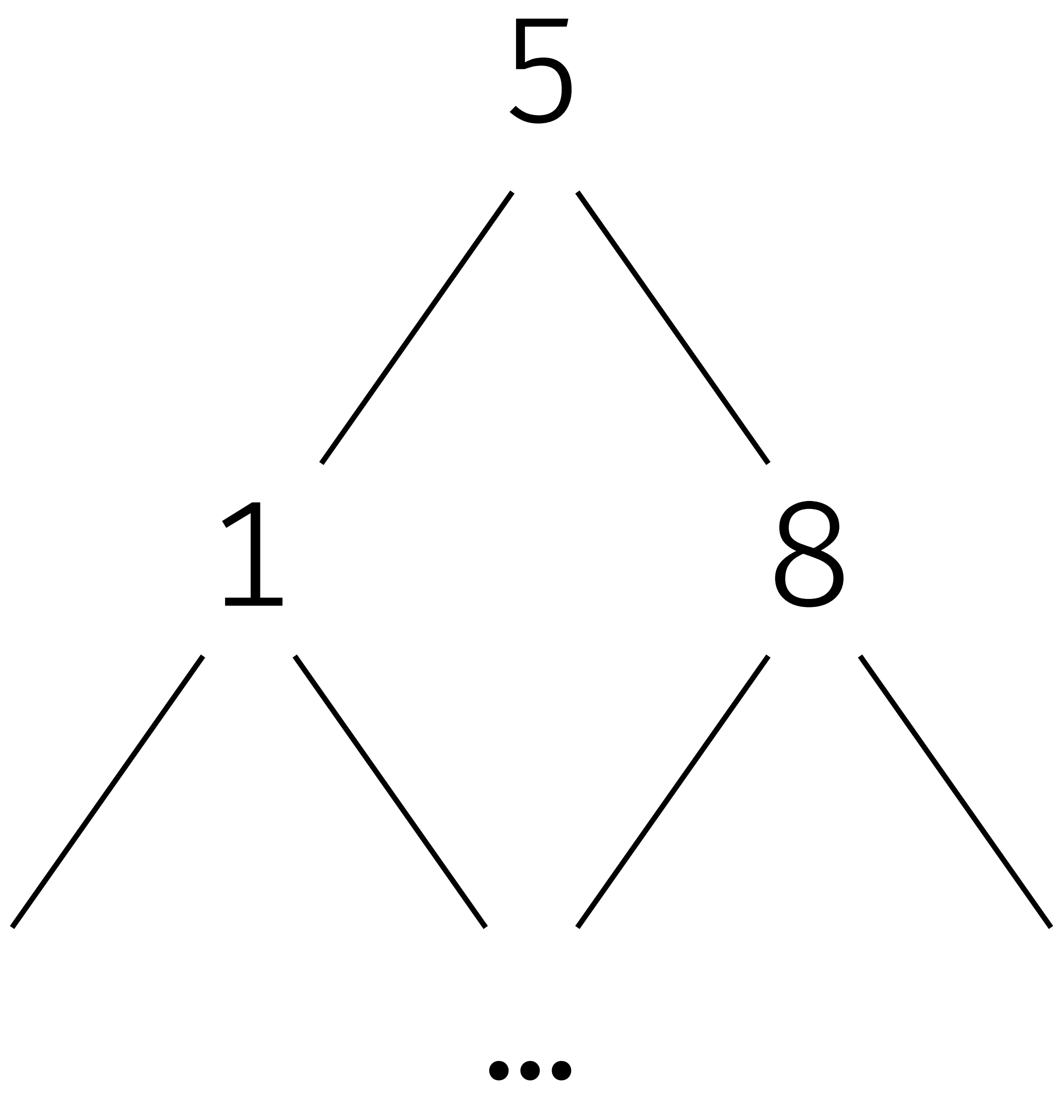
Example: **Finite Sets**

```
module type Set = sig
  type 'a t
  val empty : 'a t
  val add   : 'a → 'a t → 'a t
  val union : 'a t → 'a t → 'a t
  …
end
```

{1, 5, 8, …} ⇝ [1; 5; 8; …]

```
module ListSet : SetIntf = struct
  type 'a t = 'a list
  (* Invariant : no duplicates in list *)
  …
end
```

{1, 5, 8, …} ⇝



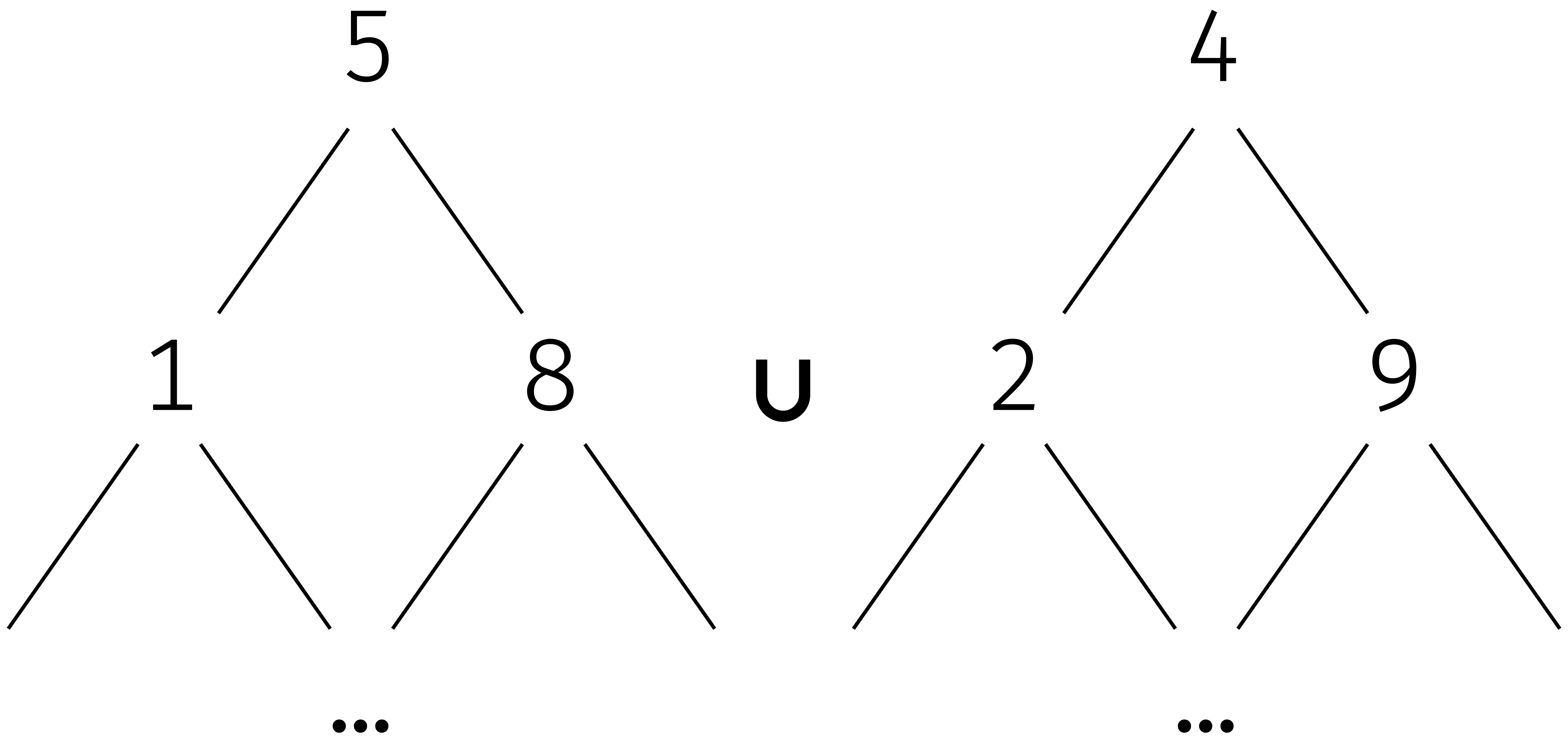
```
type 'a tree =
  | Empty
  | Node of 'a tree * 'a * 'a tree
```

```
module BSTSet : SetIntf = struct
  type 'a t = 'a tree
  (* BST invariants *)
  …
end
```

Are these equivalent?

`{1, 5, 8} ∪ {2, 4, 9}`

```
[1; 5; 8] ++ [2; 4; 9]
```



Observational equivalence

equivalent ***inputs*** $\mapsto$ equivalent ***outputs***

How do we test for ***observational equivalence*** ?

Property-Based Testing (PBT)

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1. Write a ***property***

executable spec
describing
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⇝ x_1 x_2 … x_n

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1. Write a ***property***

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2. Generate ***random inputs***

⇝ x_1 x_2 … x_n

3. Test if random inputs satisfy property

Property-Based Testing (PBT)

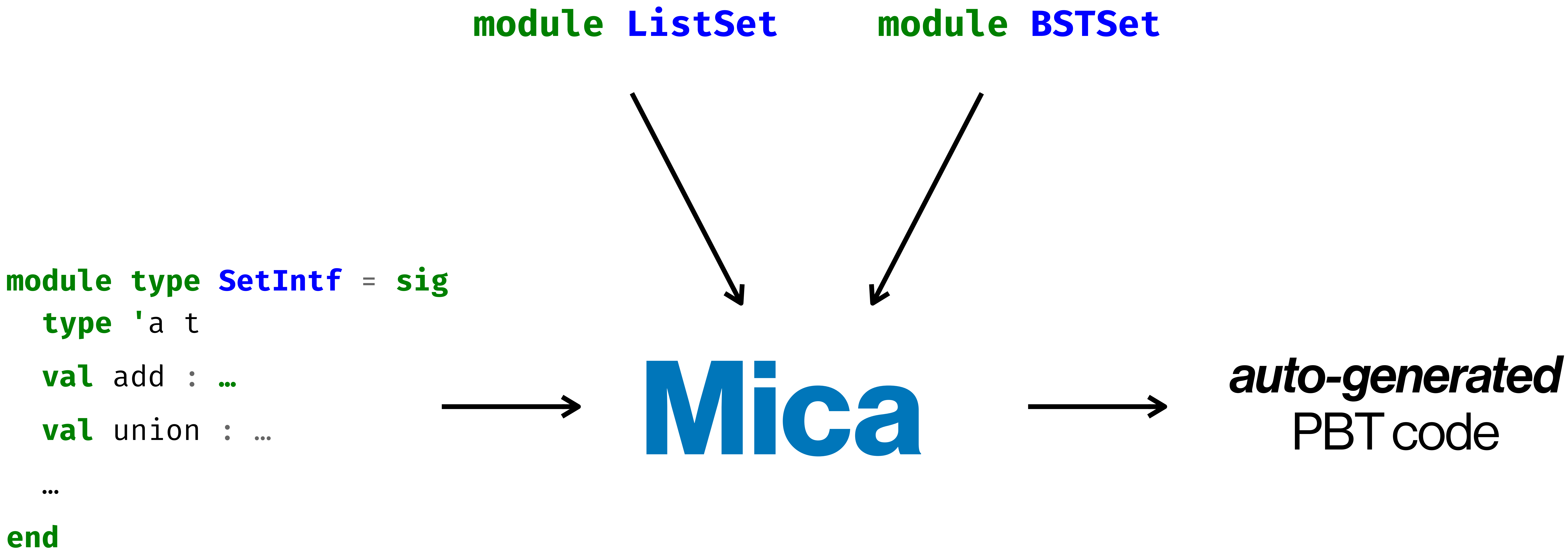
Popularised by **QuickCheck**

[Claessen & Hughes 2000]

Problem :

Writing PBT code for different modules requires ***significant programmer effort***!

Solution : **Mica**



```
module ListSet     module BSTSet
```

```
module type SetIntf = sig
  type 'a t
  val add : …
  val union : …
  …
end
```

Mica

auto-generated
PBT code

All of the following code is
automatically generated by Mica

Symbolic Expressions

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```
module type Set = sig
  type 'a t
  val empty : 'a t
```

↔

```
type expr =
  | Empty
```

Symbolic Expressions

```
module type Set = sig
  type 'a t
  val empty : 'a t

  val add : 'a → 'a t → 'a t
```

```
type expr =
  | Empty

  | Add of int * expr
```

Symbolic Expressions

```
module type Set = sig
  type 'a t
  val empty : 'a t

  val add : 'a → 'a t → 'a t

  val union: 'a t → 'a t → 'a t
  …
end
```

```
type expr =
  | Empty

  | Add of int * expr

  | Union of expr * expr
  …
```

Types & Values

```
type ty =
  | Bool
  | Int
  | T
```

```
type value =
  | ValBool of bool
  | ValInt of int
  | ValT of int M.t
```

Mica automatically produces :

QuickCheck Generator

for **well-typed** symbolic expressions

```
val gen_expr : ty → expr Generator.t
```

`gen_expr` **T**

well-typed symbolic expressions of type **T** `gen_expr` **`T`**

well-typed symbolic expressions of type **T**

`Intersect (Add 2 Empty) Empty` √

`gen_expr` **T**

well-typed symbolic expressions of type **T**

`Intersect (Add 2 Empty) Empty` ✓

`Is_empty (Size Empty)` ✗

Mica automatically produces :

Interpreter for symbolic expressions

```
val interp : expr → value
```

Mica automatically produces :

Executable for testing observational equivalence

CORE_QUICKCHECK

Jane Street

Generator

generate ***random***
symbolic expressions

```
(Is_empty
    (Intersect (Rem 8 (Add 7 Empty))
               (Union (Add 2 Empty)
                      (Union Empty Empty))
```

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Interpreter

interpret expressions
over modules

```
… → module BSTSet  → …
… → module ListSet → …
```

Generator

generate ***random*** symbolic expressions

```
(Is_empty
    (Intersect (Rem 8 (Add 7 Empty))
               (Union (Add 2 Empty)
                      (Union Empty Empty))
```

Interpreter

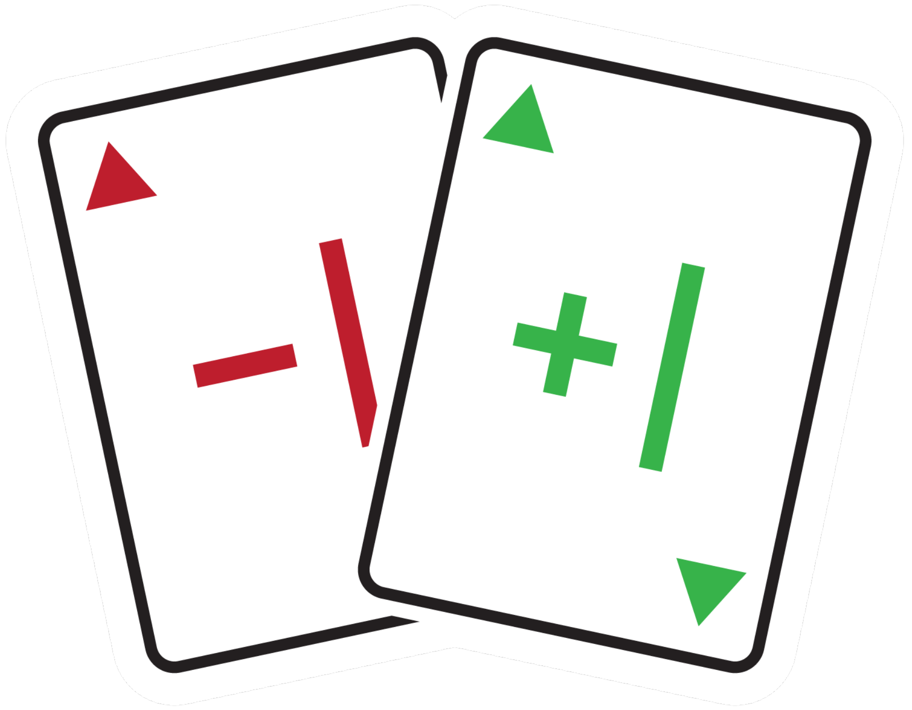
interpret expressions over modules

… → **module BSTSet** → …

… → **module ListSet** → …

Executable

test for observational equivalence



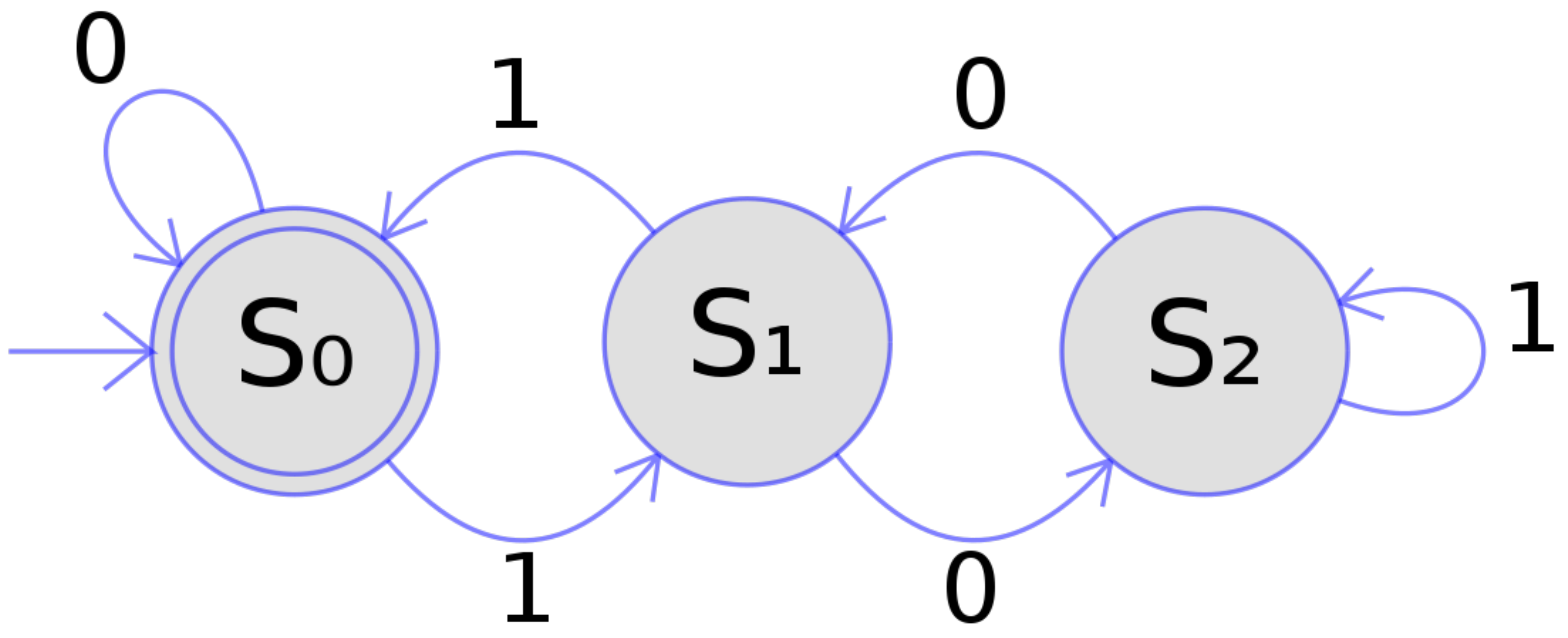
Case studies

Regex matching

Brzozowski derivatives

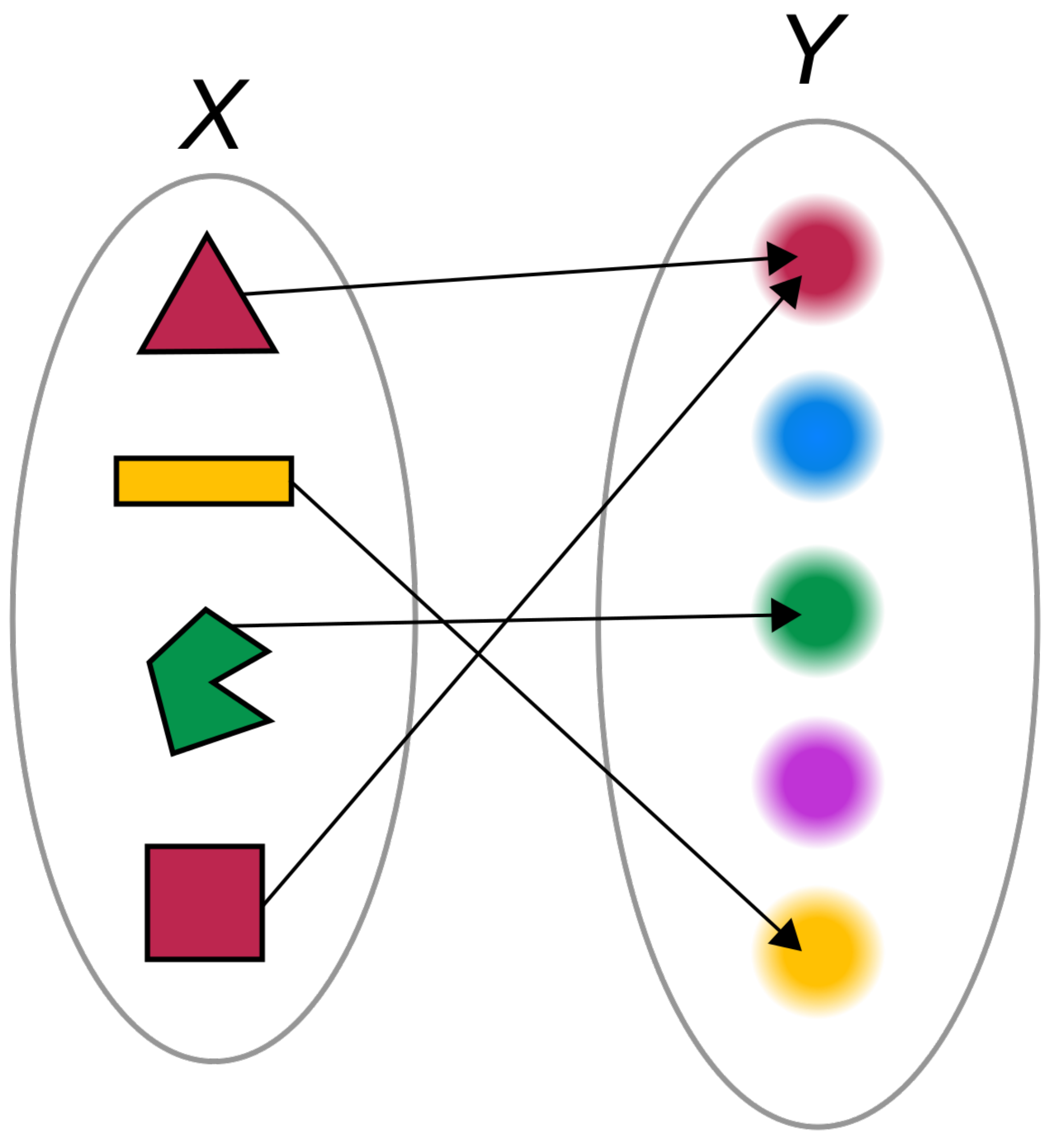
$$u^{-1}S = \{v \in \Sigma^* \mid uv \in S\}$$

DFAs

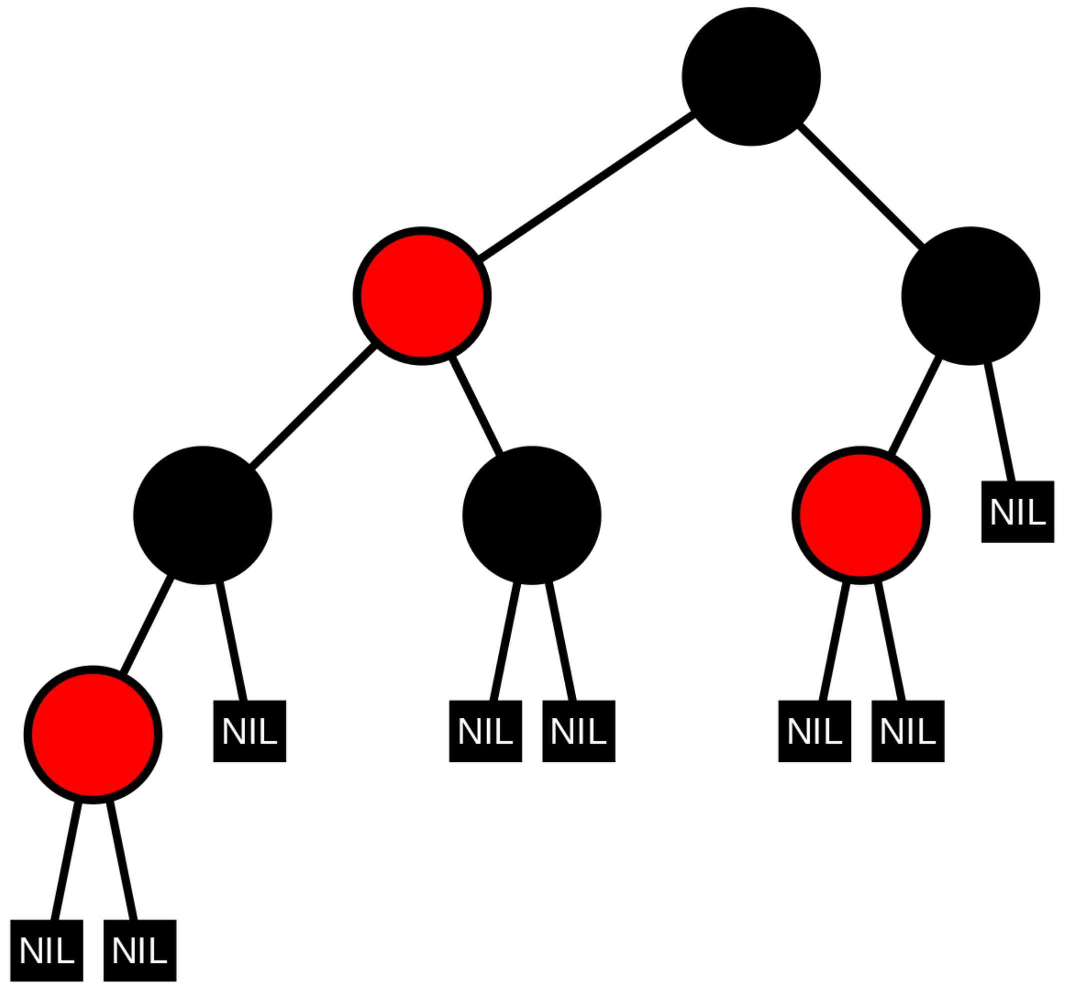


Functional maps

Association lists

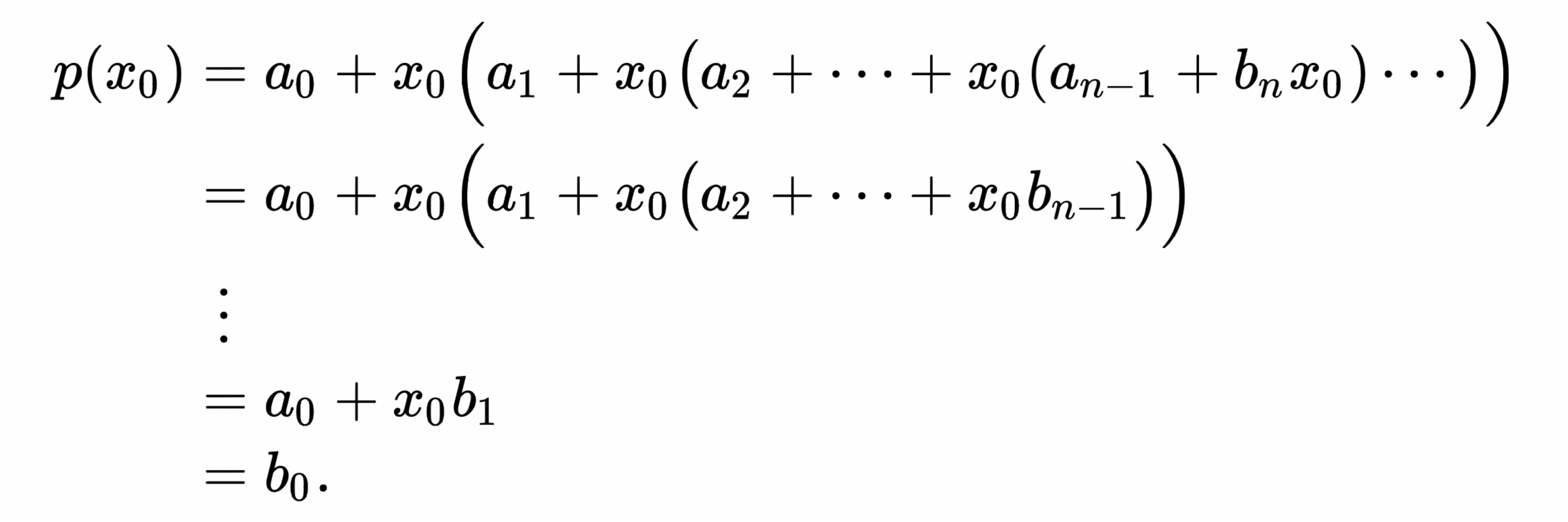


Red-Black Trees



Polynomials

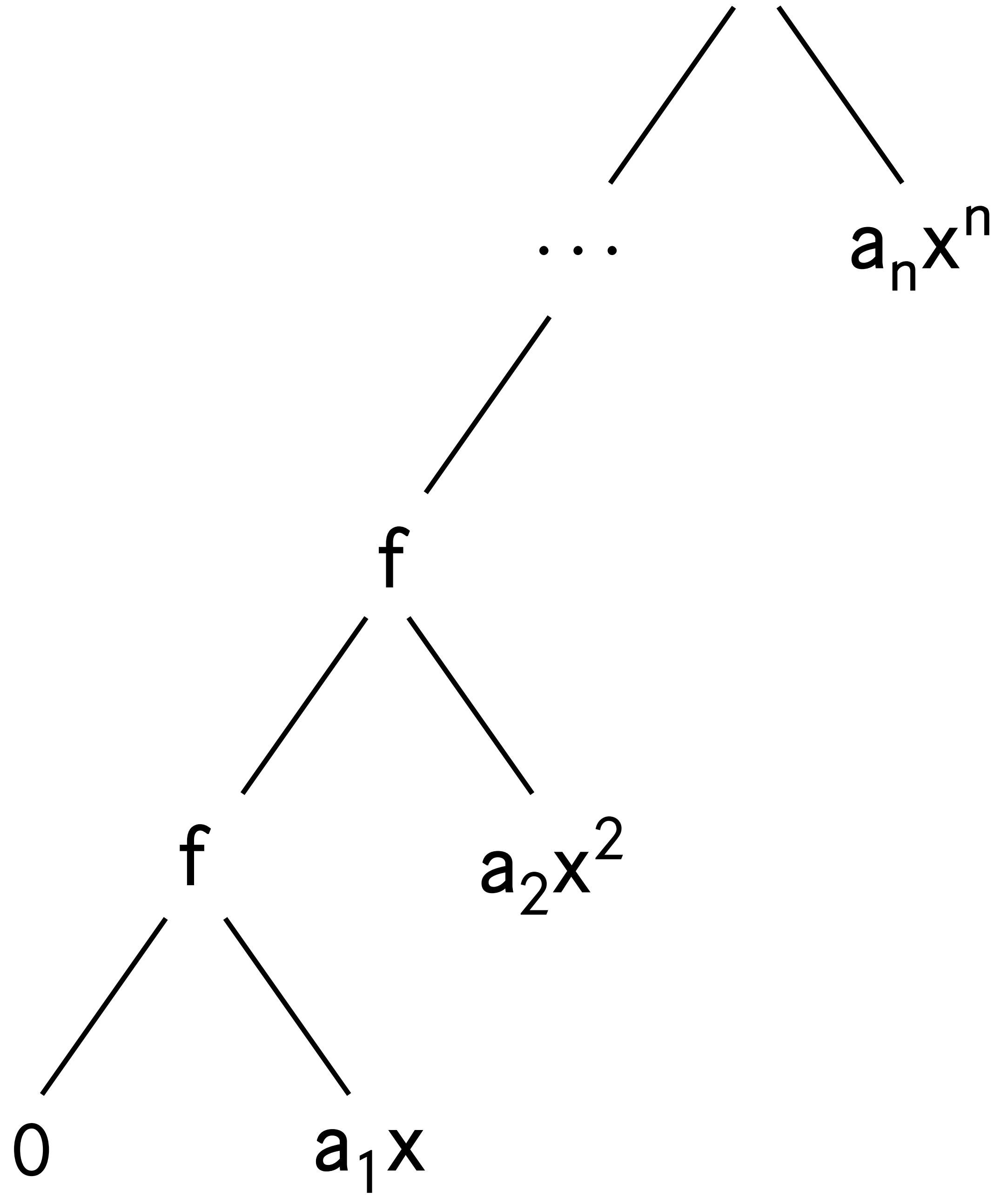
Horner's algorithm



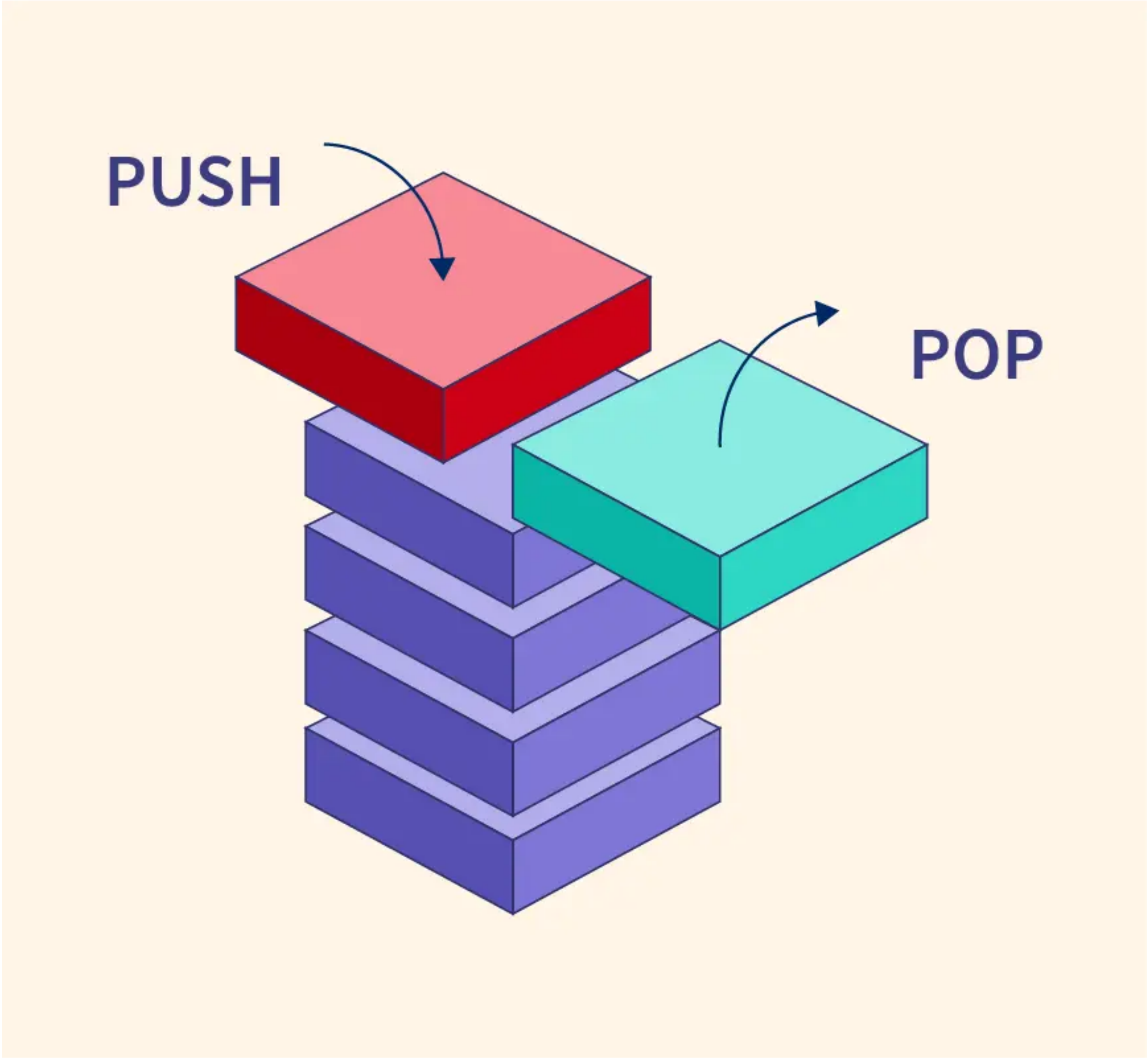
$$\begin{aligned}
p(x_0) &= a_0 + x_0\Big(a_1 + x_0\big(a_2 + \cdots + x_0(a_{n-1} + b_n x_0)\cdots\big)\Big) \\
&= a_0 + x_0\Big(a_1 + x_0\big(a_2 + \cdots + x_0 b_{n-1}\big)\Big) \\
&\ \ \vdots \\
&= a_0 + x_0 b_1 \\
&= b_0 .
\end{aligned}$$

List fold

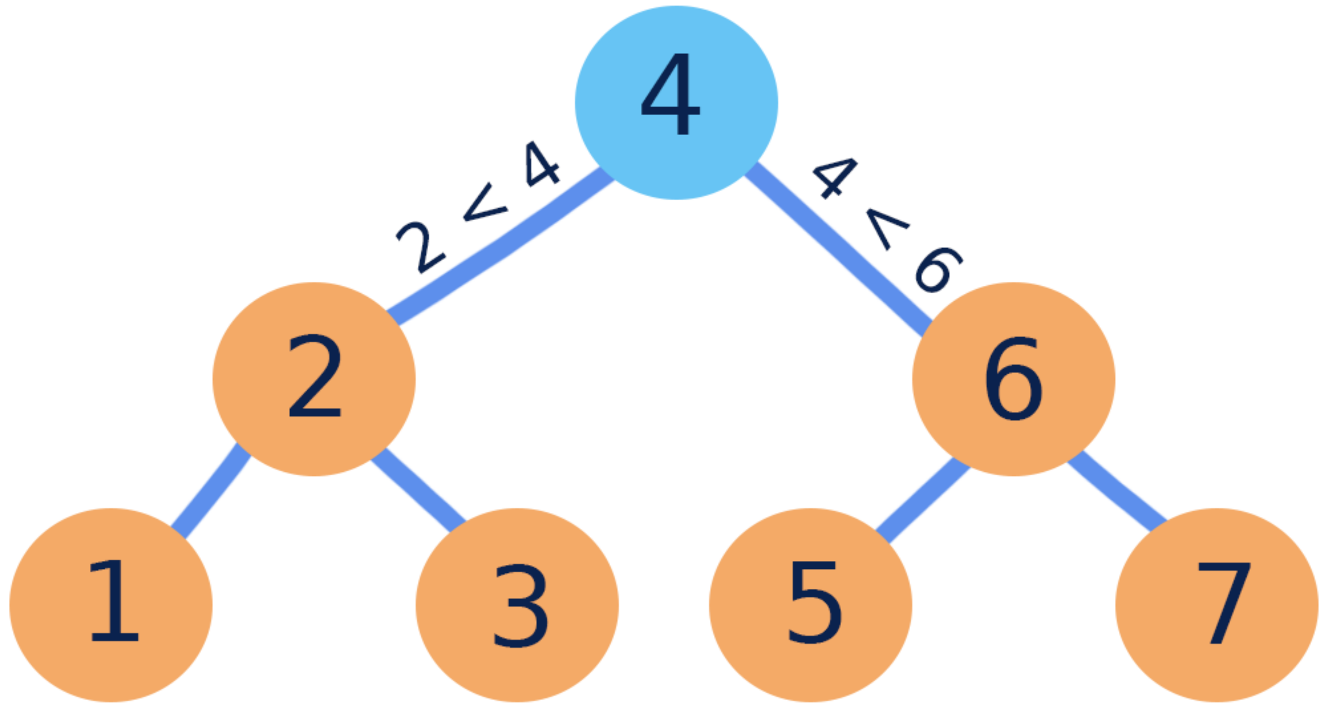
`fold_left f 0` [a_1x, a_2x^2, …, a_nx^n]



Stacks



Sets (BSTs, lists)



Takeaways

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1. Checking observational equivalence requires significant programmer effort

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1. Checking observational equivalence requires significant programmer effort
2. **Mica** can automate this process via PBT !

Thanks!

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