Automated Property-Based Testing for OCaml Modules

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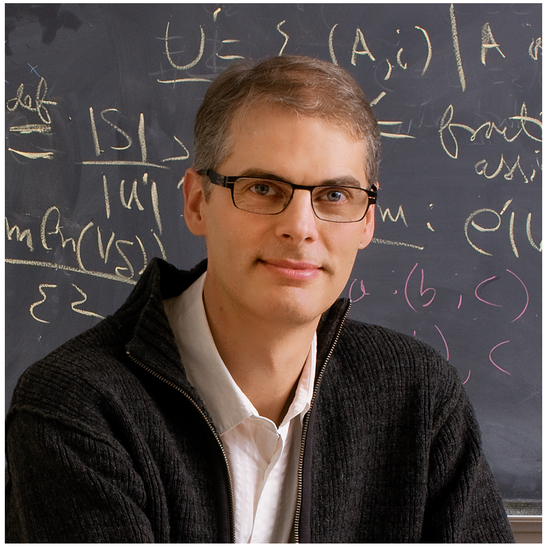
Advisors

Harry Goldstein
4th Year PhD



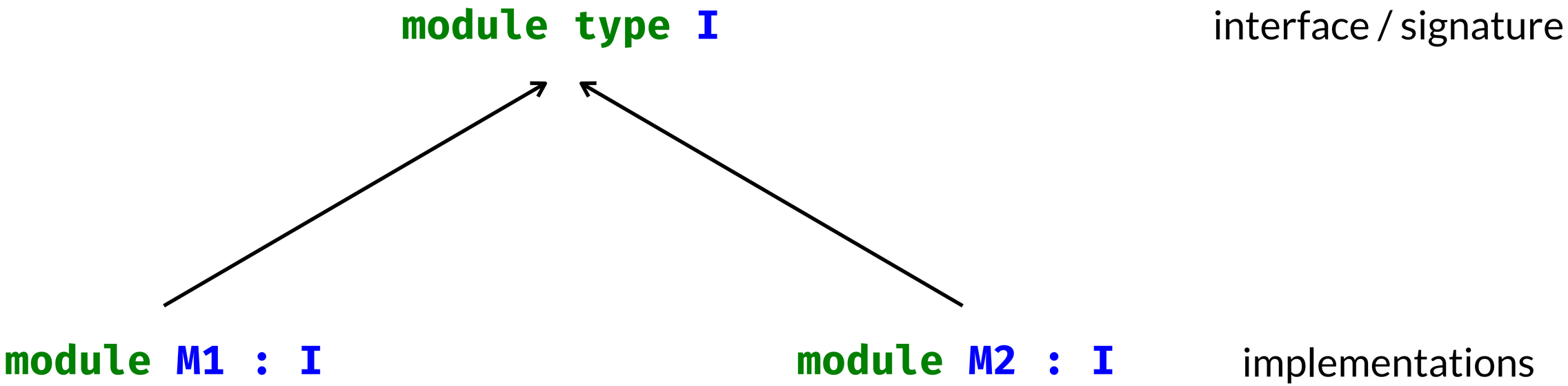
Benjamin C. Pierce
Professor

MOTIVATION

MODULES MATTER MOST

- Bob Harper (2011)

https://existentialtype.wordpress.com/2011/04/16/modules-matter-most/


module type I
interface / signature
module M1 : I
module M2 : I
implementations

Example: **Finite Sets**

```
module type SetIntf = sig
  type 'a t
  val empty     : 'a t
  val add       : 'a → 'a t → 'a t
  val intersect : 'a t → 'a t → 'a t
  …
  val invariant : 'a t → bool
end
```

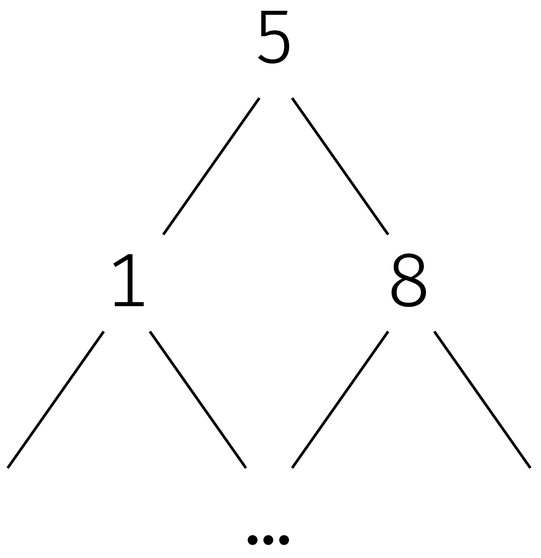
$$\{1,\ 5,\ 8,\ \ldots\} \rightsquigarrow [1;\ 5;\ 8;\ \ldots]$$

```
module ListSet : SetIntf = struct
  type 'a t = 'a list

  (* No duplicates in list *)
  let invariant s =  ...

   ...
end
```

{1, 5, 8, …} ⇝




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

```
module BSTSet : SetIntf = struct
  type 'a t = 'a tree

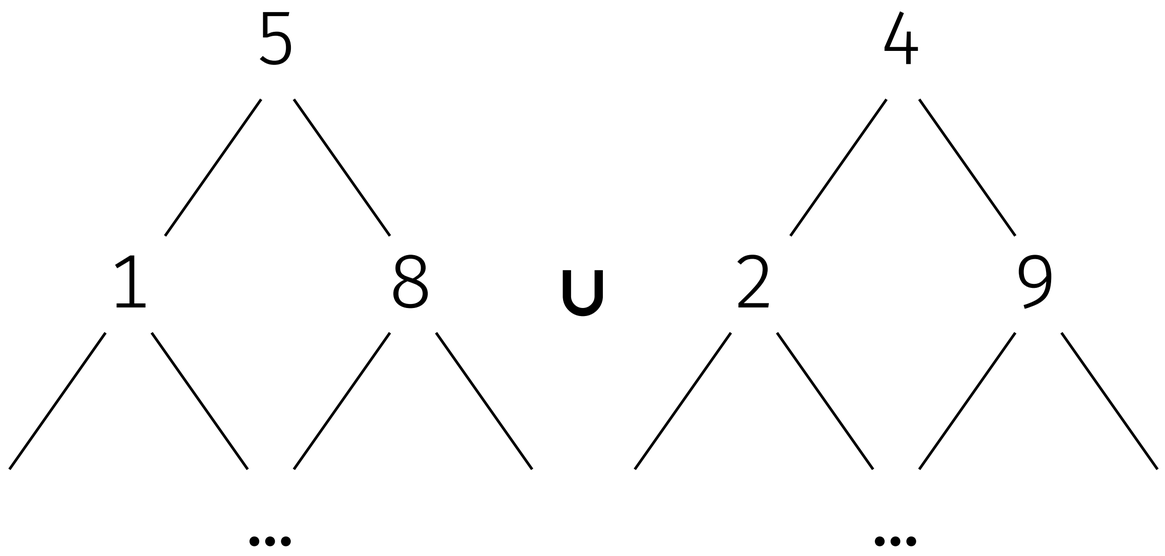
  (* BST invariant *)
  let invariant s = ...

  …
end
```

Are these equivalent?

{1, 5, 8} ∪ {2, 4, 9}

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



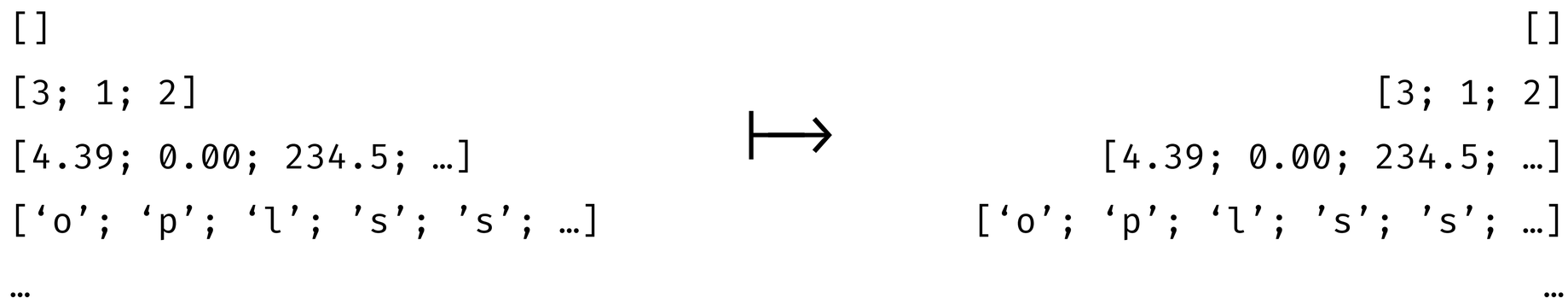
OBSERVATIONAL EQUIVALENCE

equivalent ***inputs*** $\longmapsto$ equivalent ***outputs***

How do we test for *observational equivalence*?

PROPERTY-BASED TESTING

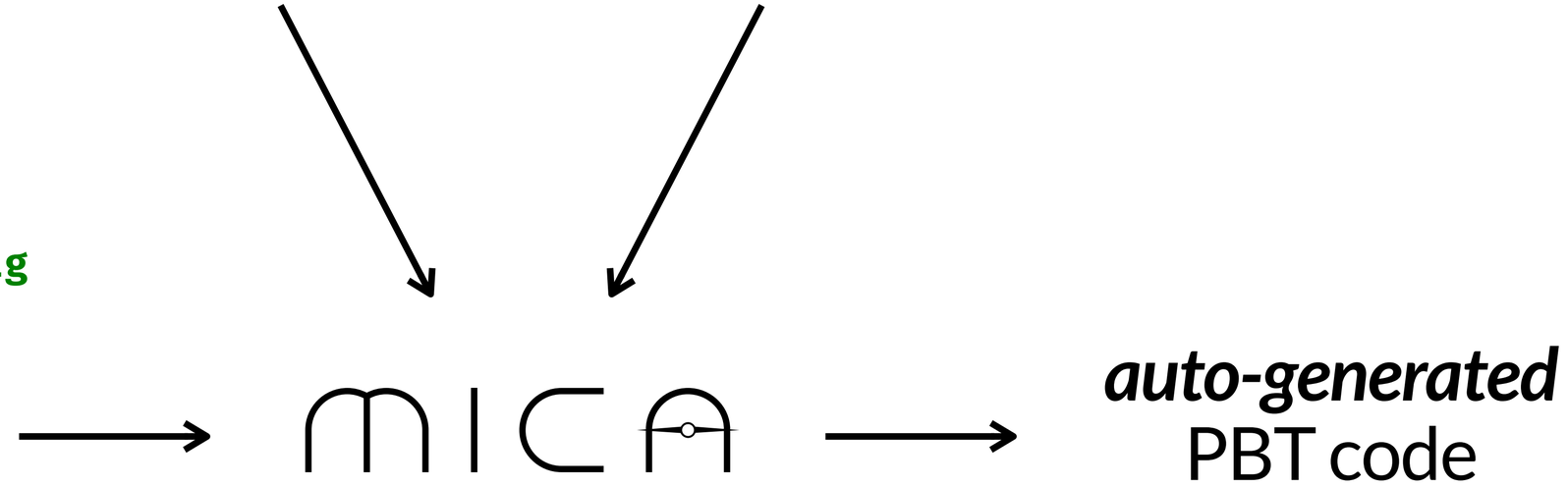
```
rev (rev lst) = lst
```



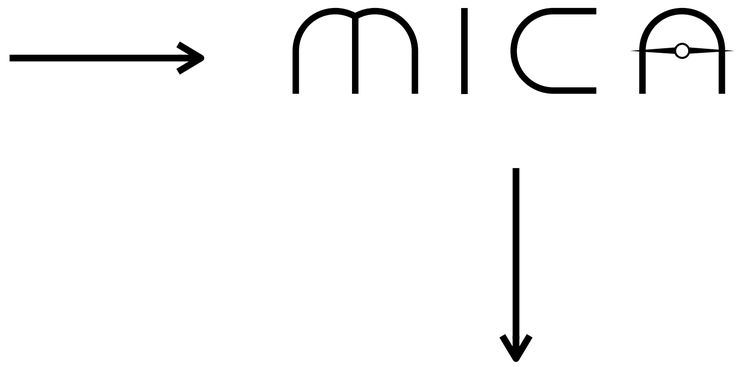
Problem:
writing PBT code for different modules is time-consuming!

Solution: 

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



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




```
type expr =
  | Empty
  | Add of int * expr
  | Intersect of expr * expr
  …
type ty    = Bool | Int | T
type value =
  | ValBool of bool
  | ValInt of int
  | ValT of int M.t

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

auto-generated
PBT code

DEMO

(time permitting)

automatically produces:

```
type expr =
  | Empty
  | Add of int * expr
  | Intersect of expr * expr
  …
type ty    = Bool | Int | T
type value =
  | ValBool of bool
  | ValInt of int
  | ValT of int M.t
```

ADT definitions representing symbolic commands

 automatically produces:

Generator for **well-typed** sequences
of symbolic comamnds

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

`gen_expr` **T**

well-typed command sequences
that return type **T**

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that return type **T**

```
Intersect (Add 2 Empty) Empty
```

✓

`gen_expr` **T**

well-typed command sequences
that return type **T**

```
Intersect (Add 2 Empty) Empty
```

✓

```
Is_empty (Size Empty)
```

X

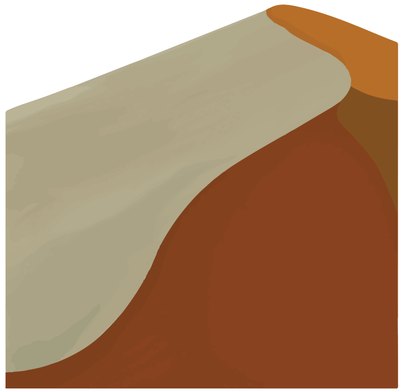
 automatically produces:

Interpreter for symbolic comamnds

```
val interp : expr → value
```

automatically produces:

Executable for testing observational equivalence



DUNE

Generator

generate ***random***
command sequences

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

Generator

generate ***random***
command sequences

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

interpret commands
over modules

… → **module BSTSet** → …

… → **module ListSet** → …

Generator

generate ***random***
command sequences

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

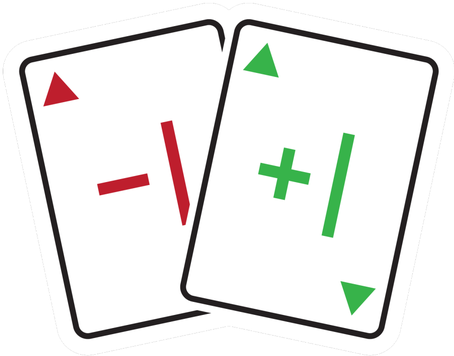
Interpreter

interpret commands
over modules

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

Executable

test for
observational
equivalence



Jane Street

BASE_QUICKCHECK

CORE

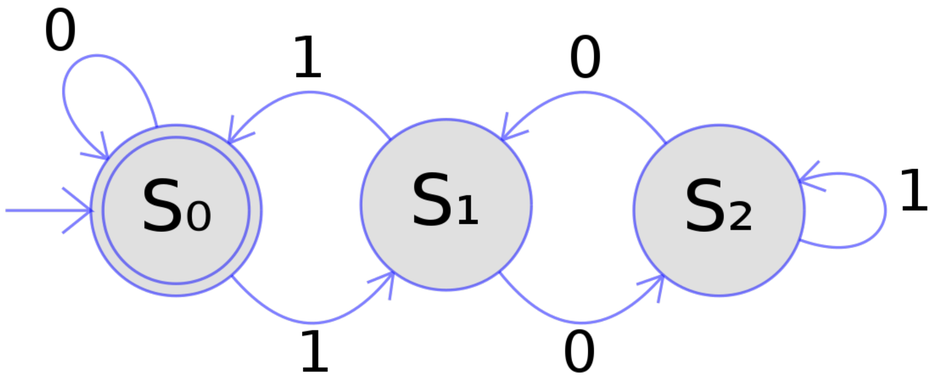
CASE STUDIES

Regex matching

Brzozowski derivatives

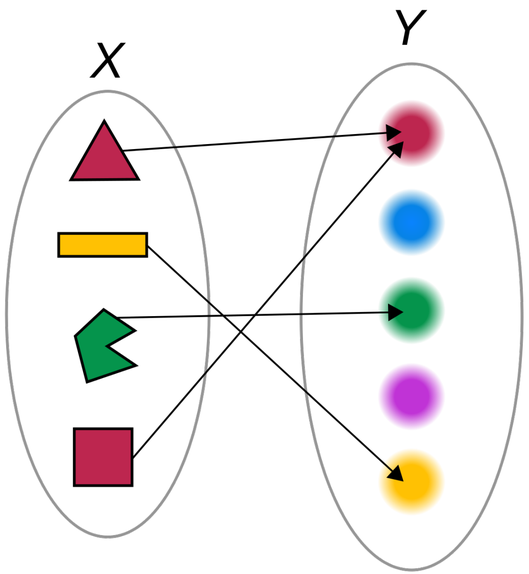
$$u^{-1}S = \{v \in \Sigma^* \mid uv \in S\}$$

DFAs

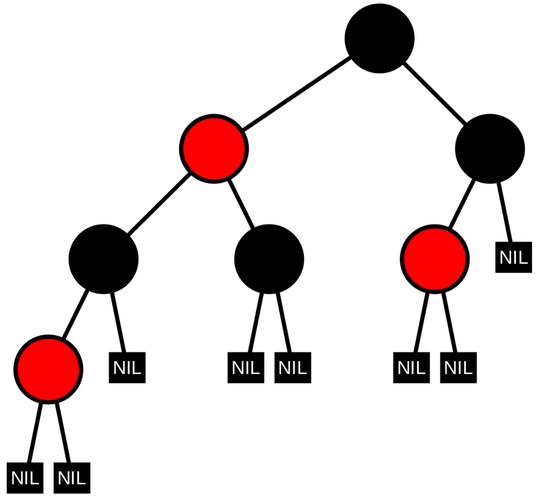


Functional maps

Association lists



Red-Black Trees

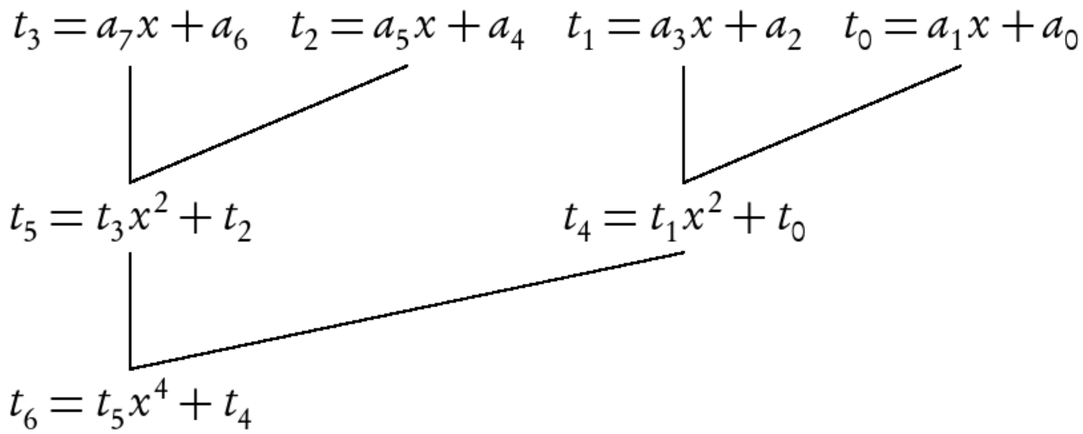


Polynomials

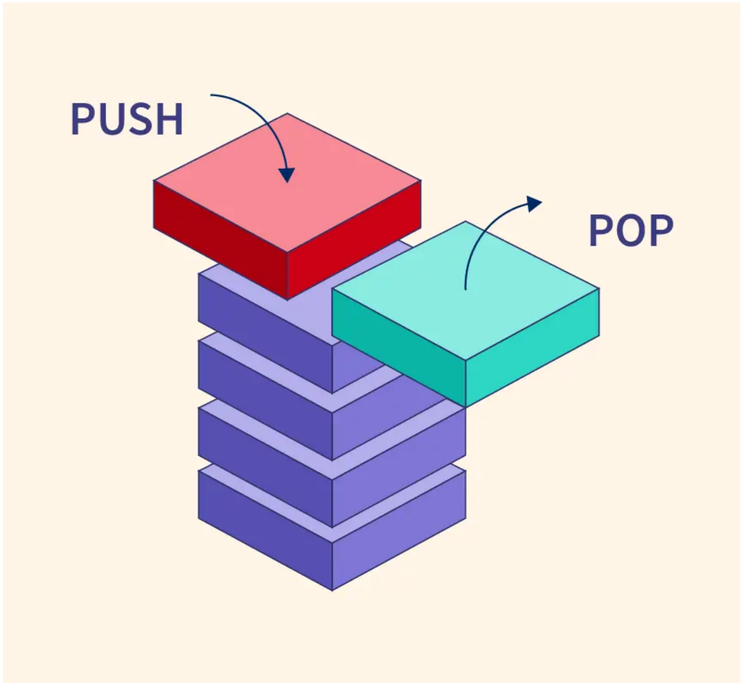
Horner's algorithm

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

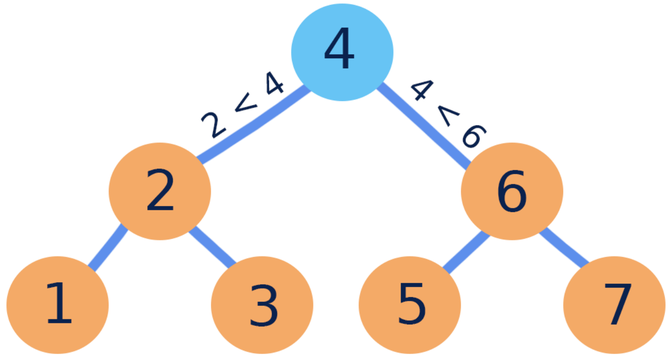
Alternate evaluation algo.



Stacks



Sets (BSTs, lists)



FUTURE WORK

Future work

Encode dependencies in
generated command sequences

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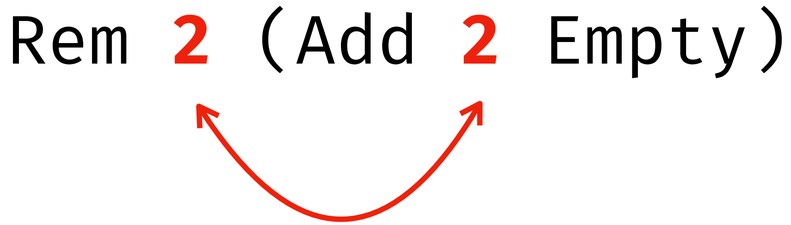
Encode dependencies in generated command sequences



Handle modules with multiple abstract types

```
module type M = struct
  type 'a t
  type k
end
```

Future work

Encode dependencies in generated command sequences

```
Rem 2 (Add 2 Empty)
```

Handle modules with multiple abstract types

```
module type M = sig
  type 'a t
  type k
end
```

Empirical evaluation

Docs: ngernest.github.io/mica

CONTENTS

Functions for generating PBT code

```
val imports : Base.string -> Base.string -> Base.string ->
PPrint.document
```

`imports filepath` prints out a PPrint document that imports the requisite modules for the PBT code. The `sigName, modName1, modName2` arguments are the names of the module signatures & the two module implementations, which must be the same as their corresponding `.ml` files.

```
val sexpAnnotation : PPrint.document
```

Document for printing the PPX annotation for S-Expr serialization (indented), followed by a newline

```
val isArrowType : ParserTypes.valDecl -> Base.bool
```

`isArrowType v` returns true if the value declaration `v` has an arrow type

```
val tyIsArrow : ParserTypes.ty -> Base.bool
```

`tyIsArrow ty` returns true if `ty` correspons to an arrow type

```
val extractArgTypes : ParserTypes.valDecl ->
PPrint.document
```

Extracts the argument types of functions defined in the module signature, and generates constructors for the `expr` ADT that take these types as type parameters

Thanks!
(See you at ICFP!)