

Interpreting and Compiling Intex



CS251 Programming Languages
Spring 2019, Lyn Turbak

Department of Computer Science
Wellesley College

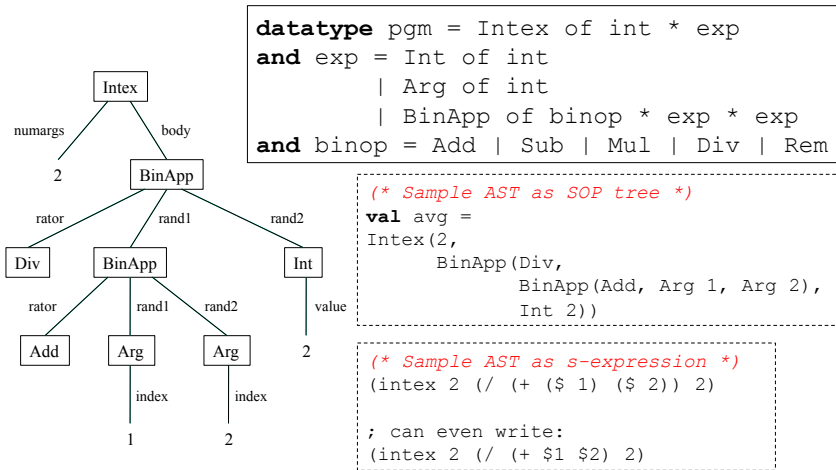
A New Mini-Language: Intex

Intex programs are simple arithmetic expressions on integers that can refer to integer arguments.

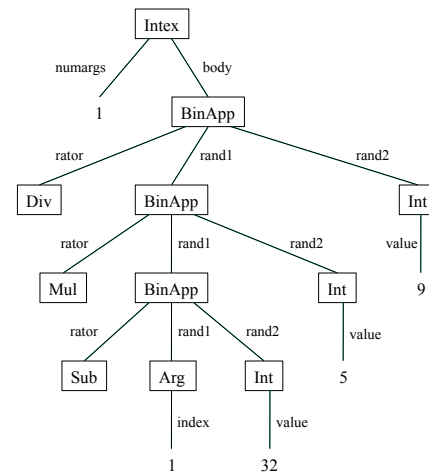
Intex is the first in a sequence of mini-languages that can be extended to culminate in something that is similar to Racket. At each step along the way, we can add features that allow us to study different programming language dimensions.

- **Intex**: integer expressions, positional program arguments
- **Bindex**: Intex + named arguments & local naming
- **Valex**: Bindex + conditionals, multiple kinds of values (booleans, strings, lists), dynamic type checking, and syntactic sugar
- **HOFL** (Racket-like language): Valex + first-class functions
- **HOILEC**: HOFL + SML-like explicit mutable cells
- **HOILIC**: HOFL + Racket-like implicit mutable cells

Intex Syntax Trees & Syntactic Data Types



How do we write this Intex program as SML SOP tree? As an s-expression?



Intex Implementation #1: Intex Interpreter in SML

Given an [avg-in-Intex program](#), how can we execute it?

```
avg machine (I)
  □ avg-in-Intex program
  □ Intex interpreter machine (I)
    ✦ Intex-interpreter-in-SML program
    ✦ SML interpreter machine in csenv/wx VM (ignore details)
```

Intex 5



Intex Interpreter Without Error Checking: Skeleton

```
(* val run: Intex.pgm -> int list -> int *)
fun run (Intex(numargs, exp)) args =

(* val eval: Intex.exp -> int list -> int *)
and eval (Int i) args =
  | eval (Arg index) args =
  | eval (BinApp(binop, exp1, exp2)) args =

(* val binopToFun: Intex.binop -> int * int -> int *)
and binopToFun Add = op+
  | binopToFun Mul = op*
  | binopToFun Sub = op-
  | binopToFun Div = (fn(x,y) => x div y)
  | binopToFun Rem = (fn(x,y) => x mod y)
```

Intex 6

Intex Interpreter With Error Checking

```
exception EvalError of string

(* val run: Intex.pgm -> int list -> int *)
fun run (Intex(numargs, exp)) args =
  if numargs <> length args
  then raise EvalError
    "Mismatch between expected and actual number of args"
  else eval exp args

(* val eval: Intex.exp -> int list -> int *)
and eval (Int i) args = i
  | eval (Arg index) args =
    if (index <= 0) orelse (index > length args)
    then raise EvalError "Arg index out of bounds"
    else List.nth(args, index-1)
  | eval (BinApp(binop, exp1, exp2)) args =
    let val i1 = eval exp1 args
        val i2 = eval exp2 args
    in (case (binop, i2) of
        (Div, 0) => raise EvalError "Division by 0"
        | (Rem,0) => raise EvalError "Remainder by 0"
        | _ => (binopToFun binop) (i1, i2))
    end
```

Intex 7

Try it out

```
- run (Intex(1, BinApp(Mul, Arg 1, Arg 1))) [5];
val it = 25 : int

- run (Intex(1, BinApp(Div, Arg 1, Arg 1))) [5];
val it = 1 : int

- run (Intex(1, BinApp(Div, Arg 1, Arg 1))) [0];
uncaught exception EvalError

- run avg [5,15];
val it = 10 : int

- map (run f2c) [[~40], [0], [32], [98], [212]];
val it = [~40,~18,0,36,100] : int list
```

Intex 8

Handling Errors

```
(* val testRun: Intex.pgm -> int list -> string *)
fun testRun pgm args =
  Int.toString (run pgm args) (* Convert to string so
  same type as error messages below *)
  handle EvalError msg => "EvalError: " ^ msg
  | other => "Unknown exception: " ^ (exnMessage other)
```

```
- testRun (Intex(1, BinApp(Div, Arg 1, Arg 1))) [5];
val it = "1" : string

- testRun (Intex(1, BinApp(Div, Arg 1, Arg 1))) [0];
val it = "EvalError: Division by 0" : string

- map (testRun f2c) [[~40], [0], [32], [98], [212]];
val it = ["~40", "~18", "0", "36", "100"] : string list
```

Intex 9

Intex programs as S-expression strings

```
Intex(1, BinApp(Mul, Arg 1, Arg 1))
```

```
"(intex 1 (* ($ 1) ($ 1))"
```

```
Intex(2,
  BinApp(Div,
    BinApp(Add, Arg 1, Arg 2),
    Int 2))
```

```
"(intex 2 (/ (+ ($ 1) ($ 2)) 2))"
```

```
Intex(1,
  BinApp(Div,
    BinApp(Mul,
      BinApp(Sub, Arg 1, Int 32),
      Int 5),
    Int 9))
```

```
"(intex 1 (/ (* (- ($ 1) 32) 5) 9))"
```

Intex 10

Running Intex programs as S-expression strings

```
(* val testRun': string -> string -> string *)
fun testRun' pgmSexpString argsSexpString =
  testRun (stringToPgm pgmSexpString)
  (sexpStringToIntList argsSexpString)
  handle SexpError (msg, sexp) =>
    ("SexpError: " ^ msg ^ " " ^ (Sexp.sexpToString sexp))
  | Sexp.IllFormedSexp msg =>
    ("SexpError: Ill-formed sexp " ^ msg)
  | other => "Unknown exception: " ^ (exnMessage other)
```

```
- testRun' "(intex 2 (/ (+ ($ 1) ($ 2)) 2))" "(5 15)";
val it = "10" : string

- map (testRun' "(intex 1 (/ (* (- ($ 1) 32) 5) 9))")
= ["(-40)", "(0)", "(32)", "(98)", "(212)"];
val it = ["~40", "~18", "0", "36", "100"] : string list

- map (testRun' "(intex 1 (/ ($ 1) ($ 1)))")=
= ["(-17)", "(0)", "(42)"];
val it = ["1", "EvalError: Division by 0", "1"] : string list
```

Intex 11

A Read-Eval-Print Loop (REPL) in Intex

```
- repl();
intex> (+ 1 2)
3
intex> (#args 6 7)
intex> (+ ($ 1) ($ 2))
13
intex> ( * $1 $2)
42
intex> (#run (intex 2 (/ (+ ($ 1) ($ 2)) 2)) 5 15)
10
intex> (#run "avg.itx" 5 15)
10
intex> (#run avg.itx 5 15)
10
intex> (#quit)
Moriturus te saluto!
```

Intex 12

What do we know about this program?

```
val test = Intex(2,
  BinApp(Sub,
    BinApp(Mul, Arg 1, Arg 3),
    Arg 2))
```

Intex 13

Dynamic vs. Static Checking: Arg Indices

Dynamic check (at runtime) :

```
| eval (Arg index) args =
  if (index <= 0) orelse (index > length args)
  then raise EvalError "Arg index out of bounds"
  else List.nth(args, index-1)
```

Static check (at compile time or checking time, before runtime) :

Idea: We know numargs from program, so can use this to check all argument references without running the program.

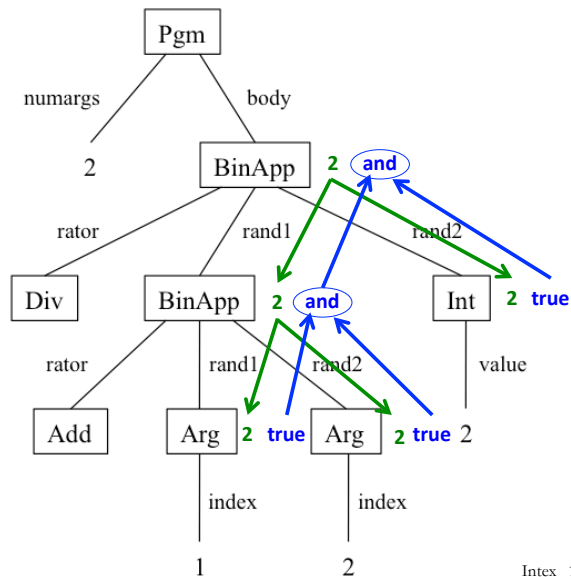
Such checks are done by examining the program syntax tree. Often there is a choice between a *bottom-up* and *top-down* approach to processing the tree.

You will do both approaches for Arg index checking in PS9.

Intex 14

Static Arg Index Checking: Top Down (PS9)

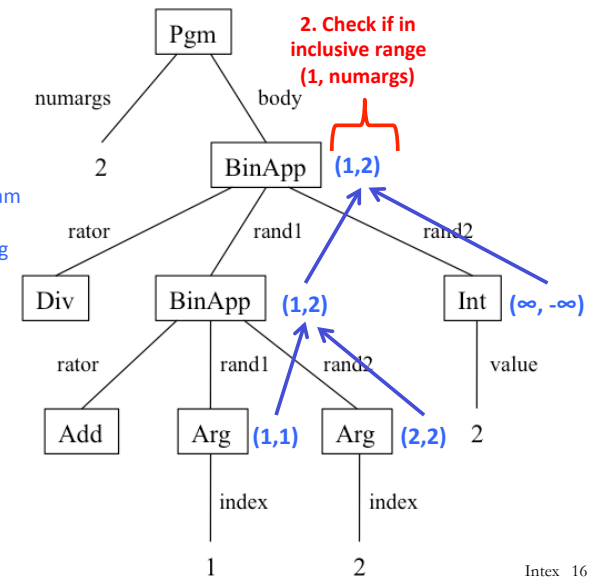
1. In top-down phase, pass numargs to every subexpression in program.
2. Check numargs against every Arg index.
 - 2a. Return **true** for Arg indices that pass test and subexps without arg indices
 - 2b. Return **false** if any Arg index fails test.



Intex 15

Static Arg Index Checking: Bottom Up (PS9)

1. Calculate (min,max) index value for every subexpression in tree in bottom-up fashion
2. Compare (min,max) value at root of program body expression to (1, numargs), returning **true** if a subrange and **false** otherwise



Intex 16

Intex Implementation #2: Intex-to-Postfix-compiler in SML

Given an **avg-in-Intex program**, how can we execute it?

- avg machine (I)
 - ❑ avg-in-PostFix program
 - ✦ avg-in-Intex program
 - ✦ Intex-to-PostFix-compiler machine
 - Intex-to-PostFix-compiler-in-SML program
 - SML interpreter machine in csenv/wx VM (ignore details)
 - ❑ PostFix interpreter machine (I)
 - ✦ PostFix-interpreter-in-SML program
 - ✦ SML interpreter machine in csenv/wx VM (ignore details)

Intex 17

Hand-Compiling Intex to PostFix



Manually translate the following Intex programs to equivalent PostFix programs:

```
(intex 0 (* (- 7 4) (/ 8 2)))  
  
(intex 4 (* (- $1 $2) (/ $3 $4)))
```

Reflection: How did you figure out how to translate
Intex Arg indices into PostFix Nget indices?

Intex 18

Can we automate this process?

Yes! We can define an **intexToPostFix** function with type
Intex.pgm -> PostFix.pgm and then use it like this:

```
fun translateString intexPgmString =  
  PostFix.pgmToString  
  (intexToPostFix (Intex.stringToPgm intexPgmString))
```

```
- translateString "(intex 1 (* ($ 1) ($ 1)))";  
val it = "(postfix 1 1 nget 2 nget mul)" : string  
  
- translateString "(intex 2 (/ (+ ($ 1) ($ 2)) 2))";  
val it = "(postfix 2 1 nget 3 nget add 2 div)" : string  
  
- translateString "(intex 4 (* (- ($ 1) ($ 2)) (/ ($ 3) ($ 4))))";  
val it = "(postfix 4 1 nget 3 nget sub 4 nget 6 nget div mul)" : string
```

Intex 19

intexToPostFix Skeleton



```
(* val intexToPostFix: Intex.pgm -> PostFix.pgm *)  
fun intexToPostFix (Intex.Intex(numargs, exp)) =  
  PostFix.PostFix(numargs, expToCmds exp ???)  
  (* ??? is the initial depth argument *)  
  
(* val expToCmds: Intex.exp -> PostFix.cmd list *)  
(* depth arg statically tracks how many values are on stack  
   above the program arguments *)  
and expToCmds (Intex.Int i) depth =  
  | expToCmds (Intex.Arg index) depth =  
  
  | expToCmds (Intex.BinApp(binop, exp1, exp2)) depth =  
  
  
and binopToArithop Intex.Add = PostFix.Add  
  | binopToArithop Intex.Sub = PostFix.Sub  
  | binopToArithop Intex.Mul = PostFix.Mul  
  | binopToArithop Intex.Div = PostFix.Div  
  | binopToArithop Intex.Rem = PostFix.Rem
```

Intex 20