Valex:
Dynamic Type Checking
and Desugaring

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A New Mini-Language: Valex

Valex extends Bindex in the following ways:

- In addition to integer values, Valex also has boolean, character, string, symbol, and list values.
    - A Valex program still takes a list of integers as arguments, but the result and intermediate values may be of any type.
- Valex has an easy-to-extend library of primitive operators for manipulating values of different types
- Valex has a generalized primitive operator application mechanism that performs dynamic type checking on the operands of primitive operators
- Valex has a conditional (`if`) expression.
- Valex desugars numerous special forms into a small set of five kernel constructs: literals, variable references, primitive applications, bind expressions, conditional expressions.

Valex Booleans

```
valex> (< 3 4)
#t

valex> (= 3 4)
#f

valex> (!= 3 4)
#t

valex> (not (= 3 4))
#t

valex> (and (< 3 4) (>= 5 5))
#t

valex> (and (< 3 4) (> 5 5))
#f

valex> (or (< 3 4) (> 5 5))
#t
```

```
valex> (or (> 3 4) (> 5 5))
#f

valex> (and (< 4 3)
            (< 5 (/ 1 0)))
Error: Division by 0: 1

valex> (&& (< 4 3)
           (< 5 (/ 1 0)))
#f ; && is short-circuit and

valex> (or (> 4 3)
           (< 5 (/ 1 0)))
Error: Division by 0: 1

valex> (|| (> 4 3)
           (< 5 (/ 1 0)))
#t ; || is short-circuit or
```

Dynamic Type Checking of Primapps

Valex dynamically checks the number and types of operands to primitive applications and reports dynamic type errors.

```
valex> (< 5)
Error: Expected two arguments but got: (5)

valex> (= 5 6 7)
Error: Expected two arguments but got: (5 6 7)

valex> (+ 1 #t)
Error: Expected an integer but got: #t

valex> (and #t 3)
Error: Expected a boolean but got: 3

valex> (= #t #f)
Error: Expected an integer but got: #t

valex> (bool= #t #f)
#f
```

Conditional (`if`) expresssions

```
valex> (if (< 1 2) (+ 3 4) (* 5 6))
7

valex> (if (> 1 2) (+ 3 4) (* 5 6))
30

valex> (if (< 1 2) (+ 3 4) (/ 5 0))
7 ; only evaluates then branch

valex> (if (> 1 2) (+ 3 4 5) (* 5 6))
30 ; only evaluates else branch

valex> (if (- 1 2) (+ 3 4) (* 5 6))
Error: Non-boolean test value -1 in if expression

racket> (if (- 1 2) (+ 3 4) (* 5 6))
7
```

Mulitbranch conditionals (cond)

Valex includes a multibranch cond conditional like Racket's cond:

```
(valex (x y)
  (cond ((< x y) -1)
        ((= x y) 0)
        (else 1)))
```

Strings

```
valex> (str= "foo" "bar")
#f

valex> (str< "bar" "foo")
#t

valex> (str< "foo" "bar")
#f

valex> (strlen "foo")
3

valex> (strlen "")
0

valex> (str+ "foo" "bar")
"foobar”
```

```
valex> (toString (* 3 4))
"12"

valex> (toString (= 3 4))
"#f"
```

Notes:

- The only string comparison ops are `str=` and `str<`, though it would be easy to add others
- `toString` turns any Valex value into a string.

Characters

```
valex> (char= 'a' 'b')
#f

valex> (char< 'a' 'b')
#t

valex> (char->int 'a')
97

valex> (int->char (- (char->int 'a') 32))
'A'
```

The only character comparison ops are `char=` and `char<`, though it would be easy to add others

Symbols

Valex has Racket-like symbols that can only be
  (1) tested for equality and
  (2) converted to/from strings.

```
valex> (sym= (sym foo) (sym foo))
#t

valex> (sym= (sym foo) (sym bar))
#f

valex> (sym->string (sym baz))
"baz"

valex> (string->sym "quux")
(sym quux)
```

Lists

```
valex> (prep 1 (prep 2 (prep 3 #e)))
(list 1 2 3)

valex> (prep (+ 3 4)
             (prep (= 3 4) (prep (str+ "foo" "bar") #e)))
(list 7 #t "foo"))

valex> (list (+ 3 4) (= 3 4) (str+ "foo" "bar"))
(list 7 #f "foobar")

valex> (head (list 7 #t "foo"))
7

valex> (tail (list 7 #t "foo"))
(list #t "foo")

valex> (head (tail (list 7 #t "foo")))
#t

valex> (head #e)
EvalError: Head of an empty list
```

More Lists

```
valex> (empty? #e)
#t

valex> (empty? (list 7 #t "foo"))
#f

valex> (nth 1 (list 7 #t "foo"))
7

valex> (nth 2 (list 7 #t "foo"))
#t

valex> (nth 3 (list 7 #t "foo"))
"foo"

valex> (nth 0 (list 7 #t "foo"))
EvalError: nth -- out-of-bounds index 0

valex> (nth 4 (list 7 #t "foo"))
EvalError: nth -- out-of-bounds index 4
```

Explode and implode

```
valex> (explode "foobar")
(list 'f' 'o' 'o' 'b' 'a' 'r')

valex> (implode (list 'C' 'S' '2' '5' '1'))
"CS251"
```

Type Predicates

```
valex> (int? 3)
#t

valex> (int? #t)
#f

valex> (bool? #t)
#t

valex> (bool? 3)
#f

valex> (char? ’a’)
#t

valex> (char? "a")
#f

valex> (char? (sym a))
#f

valex> (string? 'a')
#f
```

```
valex> (string? 'a')
#f

valex> (string? "a")
#t

valex> (string? (sym a))
#f

valex> (sym? 'a')
#f

valex> (sym? "a")
#f

valex> (sym? (sym a))
#t

valex> (list? #e)
#t

valex> (list? (list 7 #f "foobar"))
#t

valex> (list? "foo")
#f
```

General Equality

```
valex> (equal? 3 3)
#t

valex> (equal? 3 (+ 1 2))
#t

valex> (equal? (> 2 3) (< 6 5))
#t

valex> (equal? (> 2 3) (< 5 6))
#f

valex> (equal? (+ 1 2) (< 1 2))
#f

valex> (equal? (list 5 6) (list (+ 2 3) (* 2 3)))
#t

valex> (equal? (list #t) (list (< 1 2) (> 1 2)))
#f
```

User-signaled errors

The Valex `error` operator takes a string message and any value and halts computation with an error message including this value:

```
valex> (bind x 3 (if (< x 0)
                     (error "negative!" x)
                     (* x x)))
9

valex> (bind x -3 (if (< x 0)
                      (error "negative!" x)
                      (* x x)))
EvalError: Valex Error -- negative!: -3
```

Racket-like `quote`

```
valex> (quote CS251)
(sym CS251)

valex> (quote 42)
42

valex> (quote #t)
#t

valex> (quote "bunny")
"bunny"

Valex> (quote 'c')
'c'

valex> (quote (CS251 42 #t "bunny" 'c' (just like Racket!)))
(list (sym CS251) 42 #t "bunny" 'c'
      (list (sym just) (sym like) (sym Racket!)))
```

bind vs. bindpar vs. bindseq

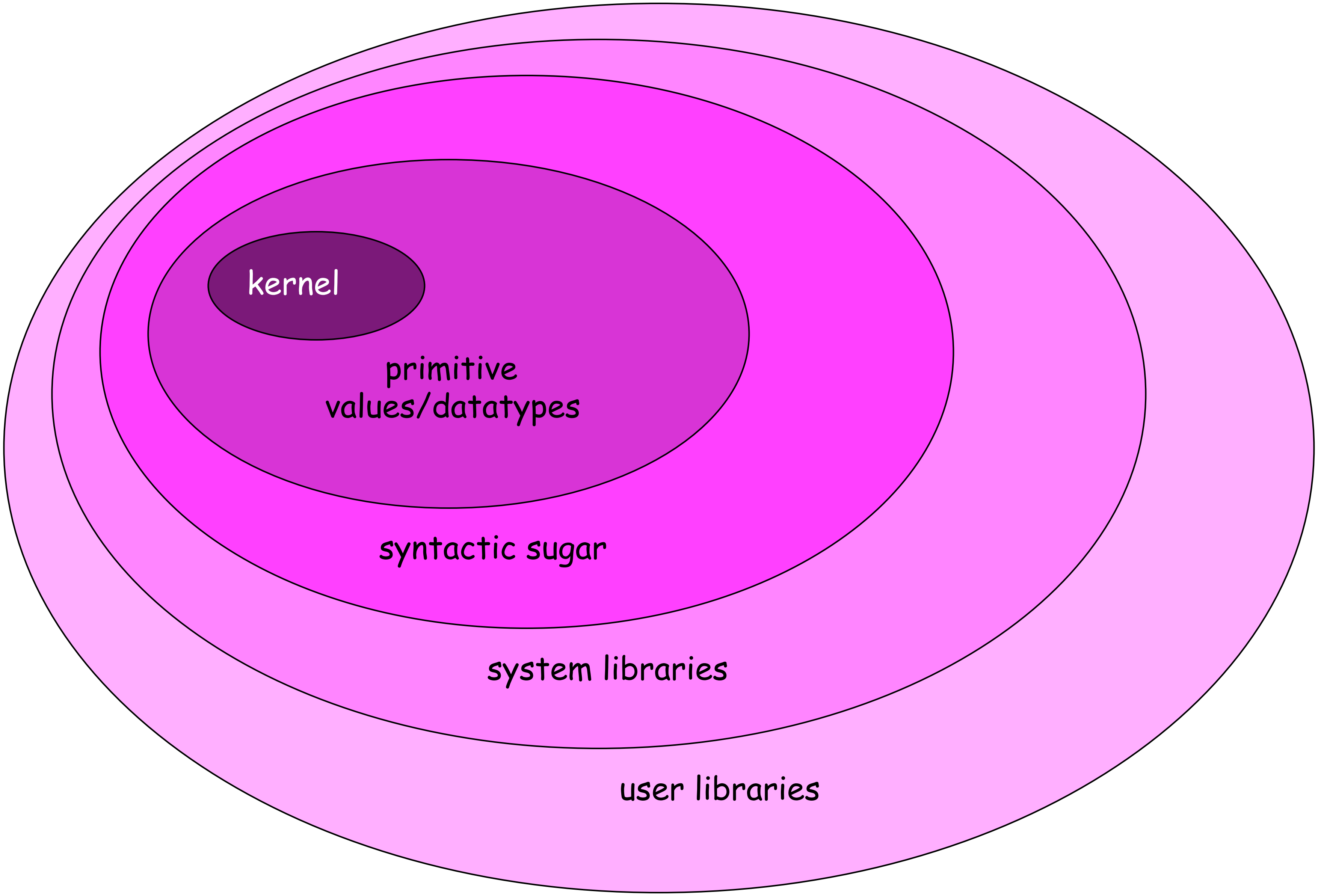
In addition to bind, Valex also has a bindpar construct similar to Racket's let and a bindseq construct similar to Racket's let*.

```
valex> (#args (a 2) (b 3))

valex> (bindpar ((a (+ a b)) (b (* a b))) (list a b))
(list 5 6)

valex> (bindseq ((a (+ a b)) (b (* a b))) (list a b))
(list 5 15)
```

Implementation Strategy



Valex has a Small Kernel

Kernel has only 5 kinds of expressions!

1. Literals: integers, booleans, strings, characters, symbols
2. variable references,
3. primitive applications (unlike in Bindex these can have any number of operands of any type),
4. single-variable local variable declarations (i.e., `bind`),
5. conditional expressions (i.e., `if`).

Unlike Bindex, where the only expression values are integers, Valex has 6 kinds of expression values:

1. Integers
2. Booleans
3. Strings
4. Characters
5. Symbols
6. Lists of values (recursively defined)

Valex datatypes

```
type var = string

datatype pgm = Valex of var list * exp (* param names, body *)

and exp =
   Lit of value
 | Var of var (* variable reference *)
 | PrimApp of primop * exp list (* prim application with rator, rands *)
 | Bind of var * exp * exp (* bind name to value of defn in body *)
 | If of exp * exp * exp (* conditional with test, then, else *)

and value = (* use value rather than val because val is an SML keyword *)
   Int of int
 | Bool of bool
 | Char of char
 | String of string
 | Symbol of string
 | List of value list (* Recursively defined value *)

and primop = Primop of var * (value list -> value)
  (* Valex bakes the primop meaning function into the syntax! *)

fun primopName (Primop(name,_)) = name
fun primopFunction (Primop(_,fcn)) = fcn
```

Evaluating `if`

```
| eval (If(tst,thn,els)) env =
  (case eval tst env of
     Bool b => if b then eval thn env else eval els env
   | v => raise (EvalError ("Non-boolean test value "
                            ^ (valueToString v)
                            ^ " in if expression"))
```

- Use SML’s `if` to implement Valex’s `if`
- Choose to require that test expression have a boolean value.
- But we could make a different choice. How would we change the above clause to implement Racket semantics (i.e., any non-false value is treated as true)?

Racket-like `if` semantics

```
| eval (If(tst,thn,els)) env =
   (case eval tst env of
      Bool false => eval els env
    | _ => eval thn env) (* any non-false value is truthy *)
```

Primitive Applications & Dynamic Type Checking

```
| eval (PrimApp(primop, rands)) env =
   (primopFunction primop) (map (Utils.flip2 eval env) rands)
```

This clause is deceptively simple. Almost all the details are handled by the primitive function baked into the syntax. E.g. `(+ x 1)` might be represented as:

```
PrimApp(Primop("+",
                (fn [v1, v2] =>
                    (case v1 of
                       Int i1 =>
                         (case v2 of
                            Int i2 => Int (i1 + i2)
                          | _ => raise EvalError
                                   ("Expected an integer but got: "
                                   ^ (valueToString v2)))
                     | _ => raise EvalError
                              ("Expected and integer but got: "
                               ^ (valueToString v1)))
                 | args => raise EvalError
                                ("Expected two arguments but got: "
                                 ^ (valuesToString args))))


         [Var "x", Lit (Int 1)])
```

result if all checks pass

dynamic type checking

Table of primitive operators

```
val primops = [
  (* Arithmetic ops *)
  Primop("+", arithop op+),
  … other arithmetic ops omitted …
  Primop("/", arithop (fn(x,y) =>
                         if (y = 0) then
                           raise (EvalError ("Division by 0: "
                                             ^ (Int.toString x)))
                           else x div y)),
  … other arithmetic ops omitted …
  (* Relational ops *)
  Primop("<", relop op<),
  Primop("<=", relop op<=),
  … other relational ops omitted …
  (* Logical ops *)
  Primop("not", checkOneArg checkBool (fn b => Bool(not b))),
  Primop("and", logop (fn(a,b) => a andalso b)), (* not short-circuit! *)
  Primop("or", logop (fn(a,b) => a orelse b)), (* not short-circuit! *)
  Primop("bool=", logop op=),

  (* Char ops *)
  Primop("char=", checkTwoArgs (checkChar, checkChar)
                               (fn(c1,c2) => Bool(c1=c2))),
  … many other primops omitted …]
```

Some dynamic type checking helper functions

```
fun checkInt (Int i) f = f i
  | checkInt v _ = raise (EvalError ("Expected an integer but got: "
                                     ^ (valueToString v)))

fun checkBool (Bool b) f = f b
  | checkBool v _ = raise (EvalError ("Expected a boolean but got: "
                                       ^ (valueToString v)))

(* Other checkers like checkInt and checkBool omitted *)

fun checkAny v f = f v (* always succeeds *)

fun checkOneArg check f [v] = check v f
  | checkOneArg _ f vs = raise (EvalError ("Expected one argument but got: "
                                           ^ (valuesToString vs)))

fun checkTwoArgs (check1,check2) f [v1,v2] =
    check1 v1 (fn x1 => check2 v2 (fn x2 => f(x1,x2)))
  | checkTwoArgs _ _ vs = raise (EvalError ("Expected two arguments but got: "
                                            ^ (valuesToString vs)))

fun arithop f = checkTwoArgs (checkInt,checkInt) (fn(i1,i2) => Int(f(i1, i2)))
fun relop f = checkTwoArgs (checkInt,checkInt) (fn(i1,i2) => Bool(f(i1, i2)))
fun logop f = checkTwoArgs (checkBool,checkBool) (fn(b1,b2) => Bool(f(b1, b2)))
fun pred f = checkOneArg checkAny (fn v => Bool(f v))
```

Your Turn

Extend Valex with these primitive operators:

- `(max` *`int1 int2`*`)`
  Returns the maximum of two integers

- `(getChar string index)`
  Returns the character at the given index (1-based) in the string.
  Raises an error for an out-of-bounds index.

Answers

Extend Valex with these primitive operators:

- `(max` *`int1 int2`*`)`

  Returns the maximum of two integers

```
Primop("max", arithop (fn(i1, i2) =>
                         if i1 >= i2 then i1 else i2)),
(* Or could use: Primop("max", arithop Int.max), *)
```

- `(getChar string index)`

  Returns the character at the given index (1-based) in the string.

  Raises an error for an out-of-bounds index.

```
Primop("getChar", checkTwoArgs (checkString,checkInt)
                  (fn(s,i) => Char(String.sub(s,i-1)))),
```

Incremental Desugaring Rules

```
(&& E_rand1 E_rand2) ↝ (if E_rand1 E_rand2 #f)
(|| E_rand1 E_rand2) ↝ (if E_rand1 #t E_rand2)

(cond (else E_default)) ↝ E_default
(cond (E_test E_then) ...) ↝ (if E_test E_then (cond ...))

(list) ↝ #e
(list E_head ...) ↝ (prep E_head (list ...))

(quote int) ↝ int
(quote string) ↝ string
(quote char) ↝ char
(quote #t) ↝ #t
(quote #f) ↝ #f
(quote #e) ↝ #e
(quote symbol) ↝ (sym symbol)
(quote (sexp_1 ... Sexp_n))
   ↝ (list (quote sexp_1) ... (quote sexp_n)))
```

Desugaring Rules for `bindseq` and `bindpar`

```
(bindseq () E_body) ↝ E_body
(bindseq ((Id E_defn) ...) E_body)
  ↝ (bind Id E_defn (bindseq (...) E_body))

(bindpar ((Id_1 E_defn_1) ... (Id_n E_defn_n)) E_body)
  ↝ (bind Id_list (* fresh variable name *)
          (list E_defn_1 ... E_defn_n)
             (* eval defns in parallel *)
       (bindseq ((Id_1 (nth 1 Id_list))
                 ...
                 (Id_n (nth n Id_list)))
          E_body))
```

Desugaring Examples in Valex REPL

```
valex> (#desugar (&& (< a b) (< b c)))
(if (< a b) (< b c) #f)

valex> (#desugar (cond ((> a 10) (* a a))
                        ((< b 5) (+ 1 b))
                        (else (+ a b))))
(if (> a 10) (* a a) (if (< b 5) (+ 1 b) (+ a b)))

valex> (#desugar (bindseq ((a (+ a b))
                           (b (* a b)))
                   (list a b)))
(bind a (+ a b) (bind b (* a b) (prep a (prep b #e))))

valex> (#desugar (bindpar ((a (+ a b))
                           (b (* a b)))
                   (list a b)))
(bind vals.0 (prep (+ a b) (prep (* a b) #e))
      (bind a (nth 1 vals.0)
           (bind b (nth 2 vals.0)
                (prep a (prep b #e)))))
```

Desugaring Implementation, Part 1

```
(* Incremental rule-based desugaring *)
 fun desugar sexp =
   let val sexp' = desugarRules sexp in
   if Sexp.isEqual(sexp',sexp)
       then case sexp of
             Seq sexps => Seq (map desugar sexps)
             | _ => sexp
              else desugar sexp'
   end
```

Desugaring Implementation, Part 2

```
and desugarRules sexp =
    case sexp of

    (* Note: the following desugarings for && and || allow
       non-boolean expressions for second argument! *)
       Seq [Sym "&&", x, y] => Seq [Sym "if", x, y, Sym "#f"]
     | Seq [Sym "||", x, y] => Seq [Sym "if", x, Sym "#t", y]

     (* Racket-style cond *)
     | Seq [Sym "cond", Seq [Sym "else", defaultx]] => defaultx
     | Seq (Sym "cond" :: Seq [testx, bodyx] :: clausexs) =>
       Seq [Sym "if", testx, bodyx, Seq(Sym "cond" :: clausexs)]

     … many other rules omitted …

     | _ => sexp (* doesn't match a rule, so unchanged *)
```