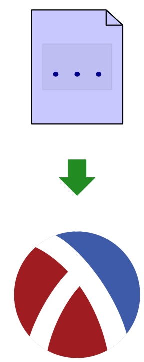
Part 1

From Shplait to Machine Code



From Shplait to Machine Code

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From Shplait to Machine Code

- Everything must be a number
- No **`type`** or **`match`**
- No implicit continuations
- No implicit allocation

Part 2

Variable Names at Run Time

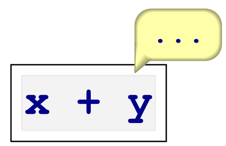
```
let x = 1:
  let y = 2:
    x + y
```

Identifier Address

Suppose that

```
let x = 88:
  x + y
```

appears in a program; the body is eventually evaluated:



where will **x** be in the environment?

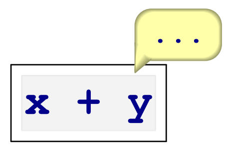
Answer: always at the beginning:

Identifier Address

Suppose that

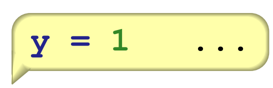
```
let y = 1:
  x + y
```

appears in a program; the body is eventually evaluated:



where will **y** be in the environment?

Answer: always at the beginning:



Identifier Address

Suppose that

```
let y = 1:
  let x = 2:
    x + y
```

appears in a program; the body is eventually evaluated:

```
x + y      ...
```

where will **y** be in the environment?

Answer: always second:

```
x = 2   y = 1   ...
```

Identifier Address

Suppose that

```
let y = 1:
  let x = 88:
    (x + y) * 17
```

appears in a program; the body is eventually evaluated:

```
...
x + y
```

where will **x** and **y** be in the environment?

Answer: always first and second:

```
x = 88   y = 1   ...
```

Identifier Address

Suppose that

```
let y = 1:
  let w = 10:
    let z = 9:
      let x = 0:
        x + y
```

appears in a program; the body is eventually evaluated:

```
...
x + y
```

where will `x` and `y` be in the environment?

Answer: always first and fourth:

```
x = 0    z = 9    w = 10    y = 1    ...
```

Identifier Address

Suppose that

```
let y = (let r = 9: r * 8):
  let w = 10:
    let z = (let q = 9: q):
      let x = 0:
        x + y
```

appears in a program; the body is eventually evaluated:

```
...
x + y
```

where will **x** and **y** be in the environment?

Answer: always first and fourth:

```
x = 0    z = 9    w = 10    y = 1    ...
```

Lexical Scope

- For any expression, we can tell which identifiers will be in the environment at run time
- The order of the environment is predictable

Part 3

Compilation of Variables

A compiler can transform an **Exp** expression to an expression without identifiers — only lexical addresses

```
compile :: (Exp, ...) -> ExpD
```

```
type Exp
| intE(n :: Int)
| addE(l :: Exp,
       r :: Exp)
| multE(l :: Exp,
        r :: Exp)
| idE(n :: Symbol)
| funE(n :: Symbol,
       body :: Exp)
| appE(fn :: Exp,
       arg :: Exp)
```

```
type ExpD
| intD(n :: Int)
| addD(l :: ExpD,
       r :: ExpD)
| multD(l :: ExpD,
        r :: ExpD)
| atD(pos :: Int)
| funD(body :: ExpD)
| appD(fn :: ExpD,
       arg :: ExpD)
```

Compile Examples

```
compile(1, ...) ⇒ 1

compile(1 + 2, ...) ⇒ 1 + 2

compile(x, ...) ⇒
```
compile: free identifier

```
compile(fun (x): 1 + x, ...)
⇒ fun: 1 + at(0)

compile(fun (y): fun (x): x + y, ...)
  ⇒ fun: fun: at(0) + at(1)
```

Implementing the Compiler

```
fun compile(a :: Exp, env :: EnvC):
  match a
  | intE(n): intD(n)
  | plusE(l, r): plusD(compile(l, env),
                       compile(r, env))
  | multE(l, r): multD(compile(l, env),
                       compile(r, env))
  | idE(n): atD(locate(n, env))
  | funE(n, body_expr):
      funD(compile(body_expr,
                   extend_env(bindC(n),
                              env)))
  | appE(fun_expr, arg_expr):
      appD(compile(fun_expr, env),
           compile(arg_expr, env))
```

Compile-Time Environment

Mimics the run-time environment, but without values:

```
type BindingC
| bindC(name :: Symbol)

type EnvC = Listof(BindingC)

fun locate(name, env):
  match env
  | []: error(#'locate, "free variable")
  | cons(b, rst_env): cond
                      | name == bindC.name(b):
                          0
                      | ~else:
                          1 + locate(name, rst_env)
```

`interp` for Compiled

Almost the same as **`interp`** for **`Exp`**:

```
fun interp(a :: ExpD, env :: Listof(Value)):
  match a
  | intD(n): intV(n)
  | plusD(l, r): num_plus(interp(l, env),
                          interp(r, env))
  | multD(l, r): num_mult(interp(l, env),
                          interp(r, env))
  | atD(pos): list_get(env, pos)
  | funD(body_expr):
      closV(body_expr, env)
  | appD(fun_expr, arg_expr):
      def fun_val = interp(fun_expr, env)
      def arg_val = interp(arg_expr, env)
      interp(closV.body(fun_val),
             cons(arg_val,
                  closV.env(fun_val)))
```

Timing Effect of Compilation

Given

```
def c = (fun (x):
           fun (y):
             fun (z): x + x + x + x)(1)(2)(3)
def d = compile(c, mt_env)
```

then

```
interp(d, [])
```

is significantly faster than

```
interp(c, mt_env)
```

Using the built-in `list_get` simulates machine array indexing, but don't take timings too seriously

Part 4

From Shplait to Machine Code

Step 1:

`Exp` → `ExpD`

```
fun (x):
  1 + x
```

```
fun:
  1 + at(0)
```

Eliminates all run-time names

From Shplait to Machine Code

Step 2:

`interp` → `interp` + `continue`

Eliminates implicit continuations

From Shplait to Machine Code

Step 3:

function calls → registers and **`goto`**

From Shplait to Machine Code

Step 3:

function calls → registers and **`goto`**

```
interp(1,
       env,
       plusSecondK(r,
                   env,
                   k))
```

```
exp_reg := 1
k_reg := plusSecondK(r,
                     env_reg,
                     k_reg)
interp()
```

Makes argument passing explicit

Part 5

From Shplait to Machine Code

Step 4:

```
plusSecondK(r,          →  malloc3(1,
            env_reg,                ref(exp_reg, 2),
            k_reg)                  env_reg,
                                    k_reg)
```

From Shplait to Machine Code

Step 4:

```
doneK       → 0
plusSecondK → 1
...
intD        → 8
plusD       → 9
...
intV        → 15
closV       → 16
```

From Shplait to Machine Code

Step 4:

```
match k_reg                          →  match ref(k_reg, 0)
| ....                                  | ....
| multSecondK(r, env, k):               | 3:
    .... r                                  .... ref(k_reg, 1)
    .... env                                .... ref(k_reg, 2)
    .... k ....                             .... ref(k_reg, 3) ....
| ....                                  | ....
```

From Shplait to Machine Code

Step 4:

```
def memory = make_array(1500, 0)
def ptr_reg = 0

fun malloc3(tag, a, b, c):
  memory[ptr_reg] := tag
  memory[ptr_reg + 1] := a
  memory[ptr_reg + 2] := b
  memory[ptr_reg + 3] := c
  ptr_reg := ptr_reg + 4
  ptr_reg - 4
```

Makes all allocation explicit

Makes everything a number