Next: Variables

Variables and Bindings

Q: How to use variables in ML ?

Q: How to "assign" to a variable ?

```
# let x = 2+2;;
val x : int = 4
```

`let x = e;;`

"Bind the value of expression e

to the variable x"

Variables and Bindings

```
# let x = 2+2;;
val x : int = 4
# let y = x * x * x;;
val y : int = 64
# let z = [x;y;x+y];;
val z : int list = [4;64;68]
```

Later declared expressions can use x

- Most recent "bound" value used for evaluation

Sounds like C/Java ?

NO!

Environments ("Phone Book")

How ML deals with variables

- Variables = "names"
- Values = "phone number"

⋮	⋮
x	*4 : int*
y	*64 : int*
z	*[4;64;68] : int list*
x	*8 : int*

Environments and Evaluation

ML begins in a "top-level" environment

- Some names bound

`let x = e;;`

ML program = Sequence of variable bindings

Program evaluated by evaluating bindings in order

1. Evaluate expr **e** in current env to get value ***v*** : ***t***
2. Extend env to bind **x** to ***v*** : ***t***

(Repeat with next binding)

Environments

"Phone book"

- Variables = "names"
- Values = "phone number"

1. Evaluate:

Find and use most recent value of variable

2. Extend:

Add new binding at end of "phone book"

Example

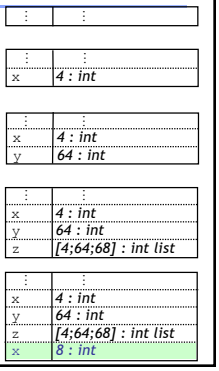
```
# let x = 2+2;;
val x : int = 4

# let y = x * x * x;;
val y : int = 64

# let z = [x;y;x+y];;
val z : int list = [4;64;68]


# let x = x + x ;;
val x : int = 8
```

New binding!



Environments

1. Evaluate: Use most recent bound value of var
2. Extend: Add new binding at end

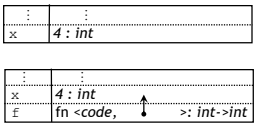
How is this different from C/Java's "store" ?

```
# let x = 2+2;;
val x : int = 4

# let f = fun y -> x + y;
val f : int -> int = fn

# let x = x + x ;
val x : int = 8

# f 0;
val it : int = 4
```



New binding:

- No change or mutation
- Old binding frozen in `f`

Environments

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val it : int = 4
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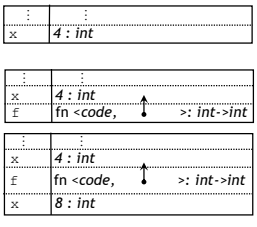

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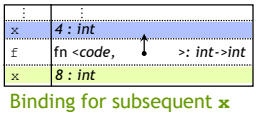
```

Binding used to eval `(f …)`



Binding for subsequent `x`

Cannot change the world

Cannot "assign" to variables

- Can extend the env by adding a fresh binding
- Does not affect previous uses of variable

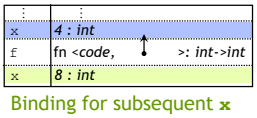
Environment at fun declaration frozen inside fun "value"

- Frozen env used to evaluate application `(f …)`

Q: Why is this a good thing ?

```
# let x = 2+2;;
val x : int = 4
# let f = fun y -> x + y;;
val f : int -> int = fn
# let x = x + x ;;
val x : int = 8;
# f 0;;
val it : int = 4
```

Binding used to eval `(f …)`



Binding for subsequent `x`

Cannot change the world

Q: Why is this a good thing ?

A: Function behavior frozen at declaration

- Nothing entered afterwards affects function
- Same inputs always produce same outputs
  - Localizes debugging
  - Localizes reasoning about the program
  - No "sharing" means no evil aliasing

Examples of no sharing

Remember: No addresses, no sharing.

- Each variable is bound to a "fresh instance" of a value

Tuples, Lists …

- Efficient implementation without sharing ?
  - There is sharing and pointers but hidden from you
- Compiler's job is to optimize code
  - Efficiently implement these "no-sharing" semantics
- Your job is to use the simplified semantics
  - Write correct, cleaner, readable, extendable systems

Recap: Environments

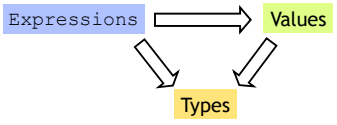
"Phone book"

- Variables = "names"
- Values = "phone number"

1. Evaluate:
Find and use most recent value of variable

2. Extend: `let` *x* = ***e*** `;;`
Add new binding at end of "phone book"

Next: Functions



Functions

expr

Functions are values, can bind using `let`

```
let fname = fun x -> e ;;
```

Problem: Can't define recursive functions !

- `fname` is bound after computing rhs value
- no (or "old") binding for occurences of `fname` inside ***e***

```
let rec fname x = e ;;
```

Occurences of `fname` inside ***e*** bound to "this" definition

```
let rec fac x = if x<=1 then 1 else x*fac (x-1)
```

Functions

Type

f `:` *T1* `->` *T2*

F takes a value of type T1
and returns a value of type T2

Functions

Values

Two questions about function values:

What is the value:

1. … of a function ?

2. … of a function "application" (call) ? (***e1 e2***)

Values of functions: Closures

- "Body" expression not evaluated until application
  - but type-checking takes place at compile time
  - i.e. when function is defined
- Function value =
  - <code + environment at definition>
  - "closure"

```
# let x = 2+2;;
val x : int = 4
# let f = fun y -> x + y;;
val f : int -> int = fn
# let x = x + x ;;
val x : int = 8
# f 0;;
val it : int = 4
```

Binding used to eval `(f …)`

x	*4 : int*
f	fn <code, >: int->int
x	*8 : int*

Binding for subsequent `x`

Values of function application

Application: fancy word for "call"

`(e1 e2)`

- "apply" the argument `e2` to the (function) `e1`

Application Value:

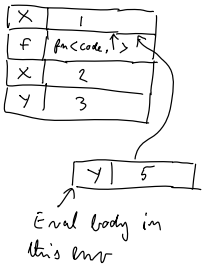
1. Evaluate ***e1*** in current env to get (function) ***v1***
   - ***v1*** is code + env
   - code is (formal `x` + body `e`) , env is ***E***
2. Evaluate ***e2*** in current env to get (argument) ***v2***
3. Evaluate body `e` in env ***E*** extended by binding `x` to ***v2***

Example 1

```
let x = 1;;
let f y = x + y;;
let x = 2;;
let y = 3;;
f (x + y);;
```

Example 1

```
let x = 1;;
let f y = x + y;;
let x = 2;;
let y = 3;;
f (x + y);;
```



Example 2

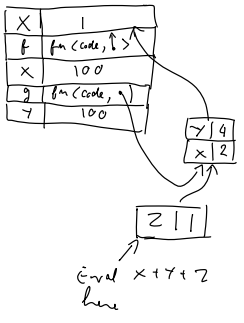
```
let x = 1;;
let f y =
  let x = 2 in
  fun z -> x + y + z
;;

let x = 100;;
let g = (f 4);;
let y = 100;;
(g 1);;
```

Example 2

```
let x = 1;;
let f y =
  let x = 2 in
  fun z -> x + y + z
;;

let x = 100;;
let g = (f 4);;
let y = 100;;
(g 1);;
```



Example 3

```
let f g =
  let x = 0 in
  g 2
;;

let x = 100;;

let h y = x + y;;

f h;;
```

Static/Lexical Scoping

- For each occurrence of a variable,
  - Unique place in program text where variable defined
  - Most recent binding in environment
- Static/Lexical: Determined from the program text
  - Without executing the programy
- Very useful for readability, debugging:
  - Don't have to figure out "where" a variable got assigned
  - Unique, statically known definition for each occurrence

Alternative: dynamic scoping

```
let x = 100

let f y = x + y

let g x = f 0

let z = g 0
(* value of z? *)
```