Programming Abstractions

Lecture 23: Parameter Passing

Stephen Checkoway

Dynamic binding vs. lexical binding

Scope of a declaration

The scope of a declaration is the portion of the expression or program to which that declaration applies

Lexical binding

- Scope of a variable is determined by textual layout of the program
- C, Java, Scheme/Racket use lexical binding

Dynamic binding

- Scope of a variable is determined by most recent *runtime* declaration
- Bash and classic Lisp use dynamic binding

What is the value of y in the body of `(f 2)`

```
(let ([y 3])
  (let ([f (λ (x) (+ x y))])
    (let ([y 17])
      (f 2))))
```

With lexical (also called static) binding: `y` is 3

- The value of `y` comes from the closest lexical binding of `y`, namely `[y 3]`

With dynamic binding: `y` is 17

- The value of y comes from the most-recent *run-time* binding of `y`, namely `[y 17]`

Lambdas in a lexically-scoped language

A lambda expression evaluates to a closure which is a triple containing

- the environment at the time the lambda is evaluated
- the parameters
- the body of the lambda

When we apply the closure to argument expressions

- we evaluate the arguments in the current environment
- extend the **closure's** environment with bindings of parameters to argument values
- evaluate the closure's body in the extended environment

Lexical binding example

```
(let ([y 3])
  (let ([f (λ (x) (+ x y))])
    (let ([y 17])
      (f 2))))
```

Lexical binding example

```
(let ([y 3])
  (let ([f (λ (x) (+ x y))])
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      (f 2))))
```

Variable	Value
y	3

Lexical binding example

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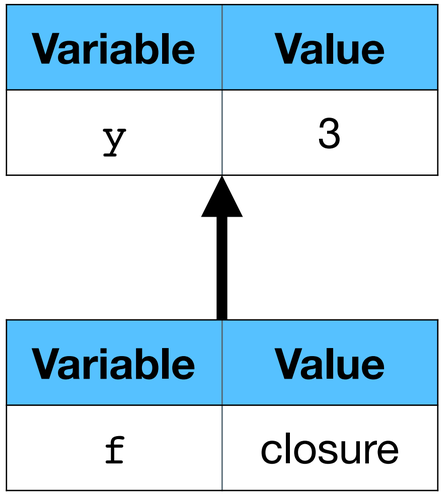
(let ([y 3])
  (let ([f (λ (x) (+ x y))])
    (let ([y 17])
      (f 2))))
```



Lexical binding example

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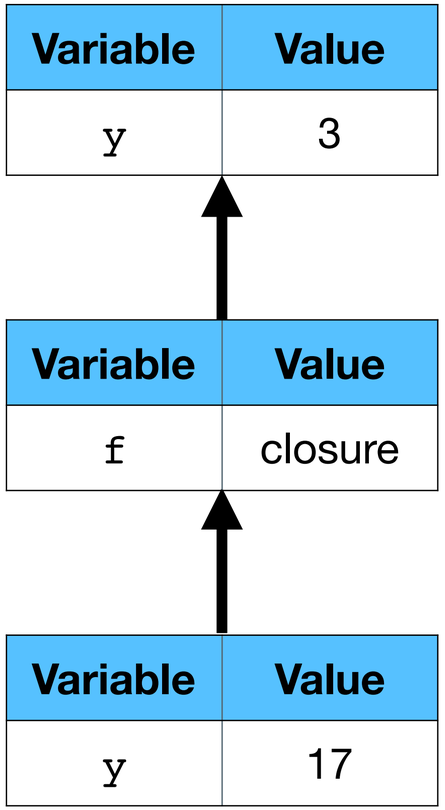

Lexical binding example

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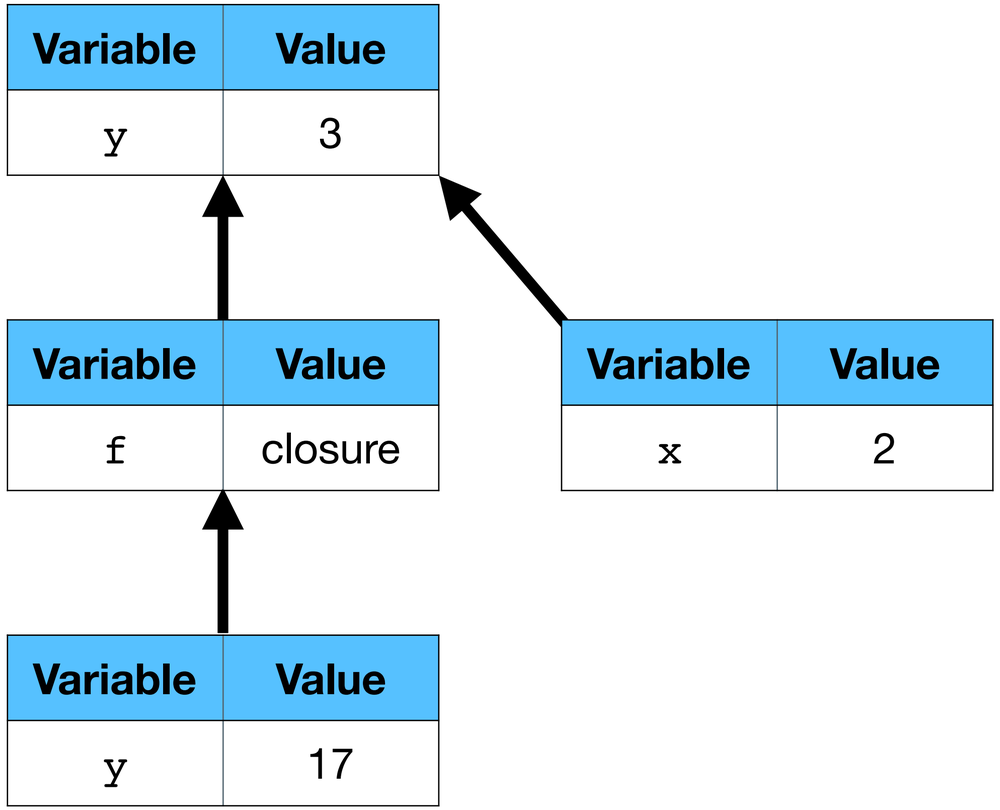

Lambdas in a dynamically-scoped language

A lambda expression evaluates to a procedure which is just a pair containing

- the parameters
- the body of the lambda

When we apply the procedure to argument expressions

- we evaluate the arguments in the current environment
- extend the **current** environment with bindings of parameters to argument values
- evaluate the lambda's body in the extended environment

Dynamic binding example

```
(let ([y 3])
  (let ([f (λ (x) (+ x y))])
    (let ([y 17])
      (f 2))))
```

Dynamic binding example

```
(let ([y 3])
  (let ([f (λ (x) (+ x y))])
    (let ([y 17])
      (f 2))))
```

Variable	Value
y	3

Dynamic binding example

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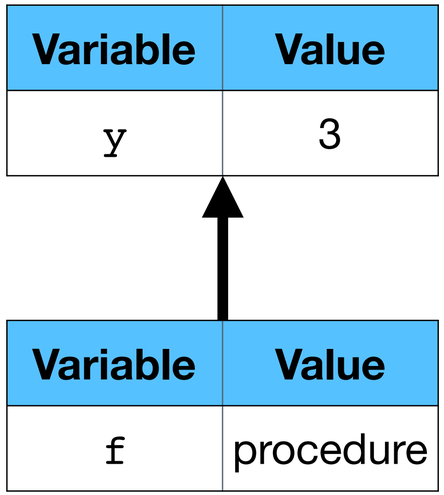

Dynamic binding example

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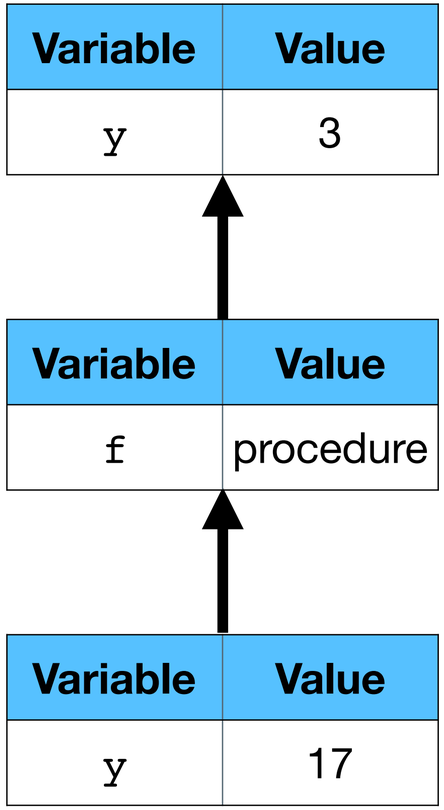

Dynamic binding example

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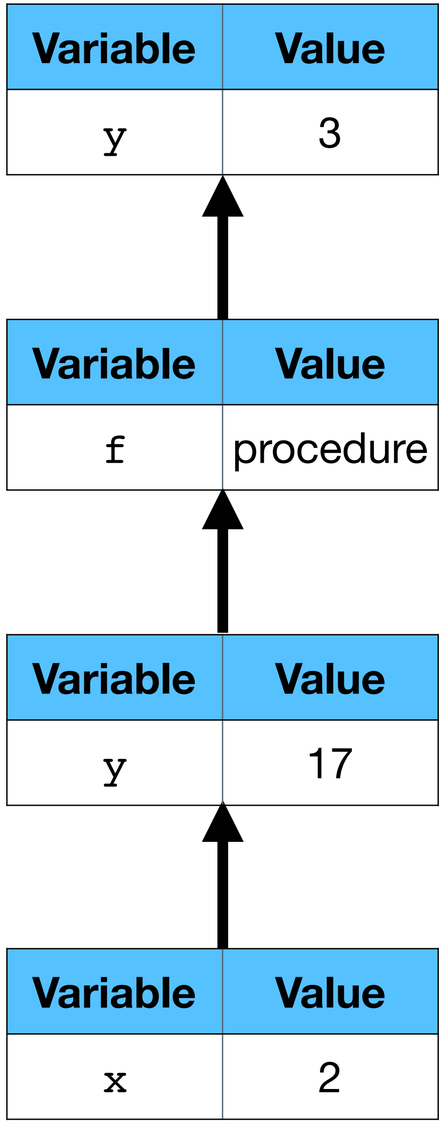

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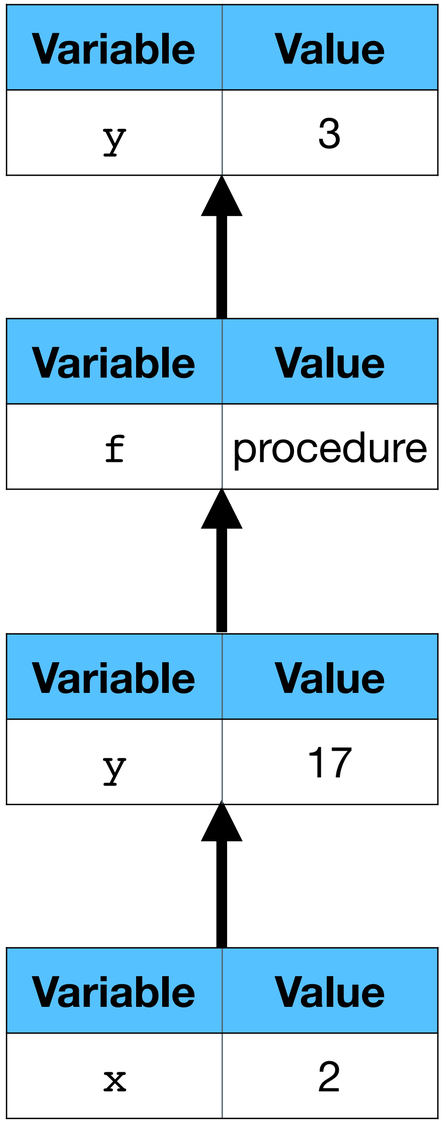
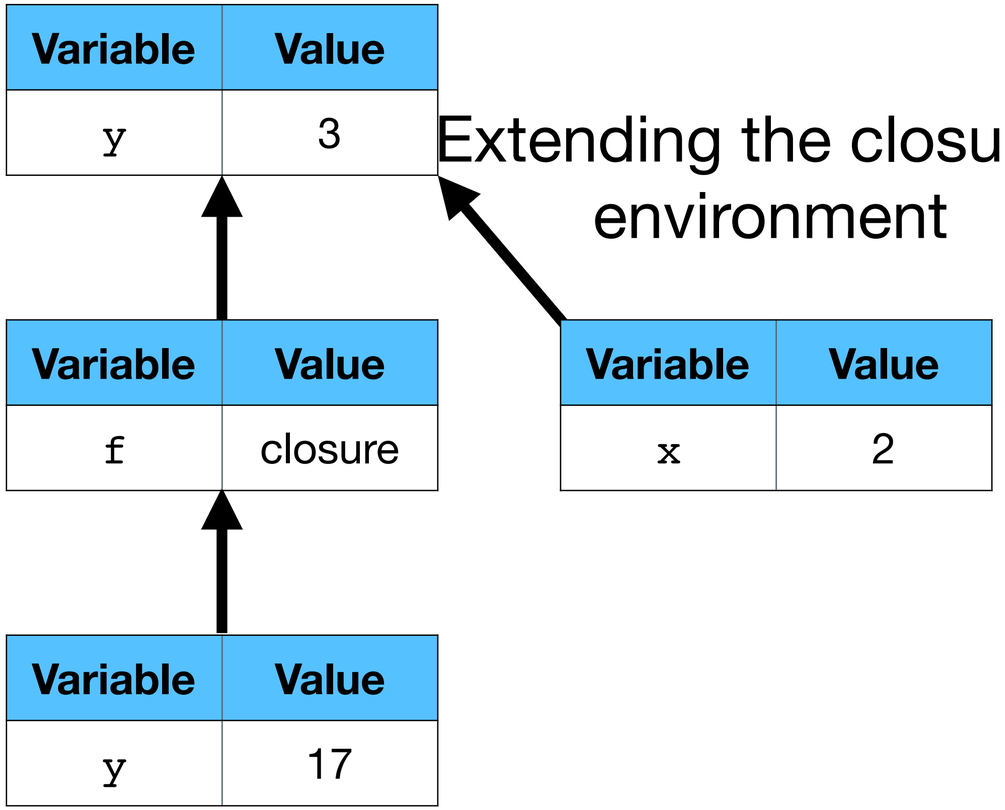
Dynamic binding



Extending the current environment

Lexical binding



Extending the closure's environment

```
(let* ([x 10]
       [f (λ (x) (+ x x))])
  (f (- x 5)))
```

What is the value of this expression assuming lexical binding? What about dynamic binding?

A. Lexical: 10
   Dynamic: 10

B. Lexical: 10
   Dynamic: 20

C. Lexical: 20
   Dynamic: 10

D. Lexical: 20
   Dynamic: 20

E. None of the above

```
(define f
  (let ([z 100])
    (λ (x) (+ x z))))

(let ([z 10])
  (f 2))
```

What is the value of this let expression assuming lexical binding? What about dynamic binding?

A. Lexical: 12
   Dynamic: 12

B. Lexical: 12
   Dynamic: 102

C. Lexical: 102
   Dynamic: 12

D. Lexical: 102
   Dynamic: 102

E. None of the above

Why was dynamic binding ever used?

It's easy to implement

- Dynamic binding was understood several years before static binding

It made sense to some people that `(λ (x) (+ x y))` should use whatever the latest, runtime version of y is

Why do we now use lexical binding?

Most languages are derived from Algol-60 which used lexical binding

Compilers can use lexical addresses known at compile time for all variable references

Code from lexically-bound languages is easier to verify

- E.g., in Racket, we can ensure a variable is declared before it is used *before* we run the program
- It makes more sense to most people

Python example

```
def fun(x):
    return lambda y: x + y

def main():
    f = fun(10)
    print(f(7))      # Prints 17
    x = 20
    print(f(7))      # Prints 17

main()
```

Bash example

```
#!/bin/bash

x=0

setx() {
  x=$1
}

printx() {
  echo "${x}"
}

main() {
  printx  # prints 0
  setx 10
  printx  # prints 10
  local x=25
  printx  # prints 25!
  setx 100
  printx  # prints 100!
}

main
printx    # prints 10
```

Parameter-passing mechanisms

Three mechanisms

Pass by value

- Arguments are evaluated in the caller's environment
- Argument values are bound to parameters

Pass by reference

- Arguments must be variables
- Addresses of arguments are bound to the parameters

Pass by name

- Arguments are not evaluated
- The text of the arguments is passed to the function and replaces the parameters in the function's body

Aside: Mutation and sequencing

To see the difference between pass by value and pass by reference, we need to be able to mutate (modify) variables

In Scheme, `(set! var value)`

```
(let ([v 10])
  (begin (displayln v)   ; prints 10
         (set! v 20)
         (displayln v))) ; prints 20
```

`(begin exp1 ... expn)`

- Evaluates each expression and returns the value of the final one
- The other n-1 expressions are only useful for their *side effects* like printing or modifying variables
- `begin` isn't actually needed here, `let` allows multi-expression bodies

Pass by value vs. by reference

```
(let ([v 0]
      [f (λ (x) (set! x 34))])
  (f v)
  v)
```

Pass by value

- When evaluating `(f v)`, `x` is initially bound to 0
- The `(set! x 34)` sets the value of `x` to 34; `v` remains bound to 0
- The final `v` evaluates 0 and thus the whole expression evaluates to 0

Pass by reference

- When evaluating `(f v)`, `x` and `v` refer to the same variable with value 0
- The `(set! x 34)` sets the value of that variable to 34
- The final `v` (and the whole expression) evaluates to 34

```
(define (f x y)
  (set! x (* y 2))
  (set! y (* x 3)))
(let ([a 1] [b 2])
  (f a b)
  (list a b))
```

What is the value of the let expression assuming pass by value? What about pass by reference?

A. Value: `'(1 2)`
   Reference: `'(1 2)`

B. Value: `'(1 2)`
   Reference: `'(4 3)`

C. Value: `'(4 3)`
   Reference `'(1 2)`

D. Value: `'(1 2)`
   Reference: `'(4 12)`

Pass by reference in Scheme (sort of)

We create a box which holds a value

The value of the box itself is the address of the variable and can be passed to functions

The value inside the box can be mutated via `set-box!` and retrieved via `unbox`

```
(let ([v (box 0)]
      [f (λ (x) (set-box! x 34))])
  (f v)
  (unbox v)) ; Returns 34
```

Pass by value vs name

Pass by value

```
(let* ([v 0]
       [f (λ (x) ; Don't need begin in λ body
            (set! v (+ v 1))
            x)])
  (f (+ v 5)))
```

Pass by value

- `f` is called with value 5 so `x` is bound to 5
- `v` is set to 1
- `x = 5` is returned

Pass by value vs name

Pass by name

```
(let* ([v 0]
       [f (λ (x) ; Don't need begin in λ body
            (set! v (+ v 1))
            x)])
  (f (+ v 5)))
```

Pass by name

- The text of `f`'s body becomes the two expressions (by replacing `x` with the text of the argument)

  ```
  (set! v (+ v 1))
  (+ v 5)
  ```

- `v` is set to 1 and then 6 is returned

Pass by name in Scheme: macros

`(define-syntax-rule (name param1 ... paramn) body)`

We can create macros where the arguments are substituted textually for the parameters (we'll discuss this more later in the semester)

```
(let ([v 0])
  (define-syntax-rule (f x)
    (begin
      (set! v (+ v 1))
      x))
  (f (+ v 5)))
```

This isn't quite the same as pass by name because Scheme macros don't allow free variables (here, `v` always refers to the `v` in the let expression)

Pass by x

Pass by value

- Easiest to understand and most common
- Used by Scheme, Java, C, Python, Bash, and most other languages

Pass by reference

- Allows modifying passed in variables which can be useful in languages that don't support returning multiple values
- Supported by C++, C#, Rust, and others

Pass by name

- Least common mechanism and by far the most difficult to reason about
- Used by macro languages like TeX, m4, and C's preprocessor
- Macro constructs in languages like Scheme and Rust

Pass by name in TeX

TeX is a macro language for writing documents

```
\def\work#1#2{%
  All work and no play makes #1 a dull #2.\par
}
\def\sad#1#2dull{%
  #1 a sad%
}
\work{Jack}{boy}
\work{\sad{Steve}}{professor}
\bye
```

All work and no play makes Jack a dull boy.
All work and no play makes Steve a sad professor.

Pass by name in the C preprocessor

```c
#include <stdio.h>

#define swap(x, y) \
  int tmp = x; \
  x = y; \
  y = tmp

int main() {
  int arr[5] = {4, 4, 4, 4, 4};
  int idx = 2;
  swap(idx, arr[idx]);
  printf("%d\n", idx);
  printf("{%d, %d, %d, %d, %d}\n",
         arr[0], arr[1], arr[2], arr[3], arr[4]);
  return 0;
}
```

`swap` sets `idx` to 4 and then `arr[4]` to 2, `arr[2]` is unchanged!

Rust

```rust
fn by_value(mut x: u32) {
    x += 1;
}

fn by_ref(x: &mut u32) {
    *x += 1;
}

fn main() {
    let mut v = 0;

    macro_rules! by_name {
        ($x:stmt) => {
            v += 1;
            $x
        }
    }

    by_value(v);
    println!("{}", v);
    by_ref(&mut v);
    println!("{}", v);
    by_name!(v += 5);
    println!("{}", v);
}
```

Prints

0

1

7

Implementing pass by reference

MiniScheme implements pass-by-value (or will, once you implement lambdas in the next homework)

We can make it pass-by reference by

- storing each value in a box;
- when calling functions, do not unbox the values, but pass the boxes as normal;
- unbox when performing primitive procedures

Implementing pass by name

We can make MiniScheme pass by name via function re-writing

- Don't evaluate arguments at all
- In `(apply-proc p args)`, rewrite the procedure's body (which is a parse tree) replacing each use of a parameter with the parse tree for the corresponding argument