Programming Abstractions

Lecture 22: Variable Bindings

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Announcements

HW 6—MiniScheme A–E—due Friday

Office Hours: Friday 13:30–14:30

Lexical Binding

Variable usage

There are two ways a variable can be used in a program:

- As a declaration
- As a "reference" or use of the variable

Scheme has two kinds of variable declarations

- the bindings of a let-expression and
- the parameters of a lambda-expression

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

Java example

What is the scope of y in this Java program?

Could we print y instead of x in the last line?

```
public static void main(String[] args) {
    int x = 1;
    while (x < 10) {
        int y = x;
        System.out.println(y);
        x += 1;
    }
    System.out.println(x);
}
```

Scope in Scheme

Scope of variables bound (declared) in a `let` is the body of the `let`
Scope of parameters in a λ is the body of the λ

```
(let ([x 5]
      [y 10])
  (* ((λ (z) (+ z y)) 7)
     x
     y))
```

Shadowing bindings

Shadowing: Declaring a new variable with the same name as an existing variable in an enclosing scope

```
(let ([x 5]
      [y 10])
  (* ((λ (x) (+ x y)) 7)
     x
     y))
```

We say that the inner binding for x *shadows* the outer binding for x

Determining the appropriate binding

Start at the use of a variable

Search the enclosing regions starting with the innermost and working outward looking for a binding (declaration) of the variable

The first binding you find is the appropriate binding

(If there are no such bindings, we say the variable is *free*; Racket requires all variables be bound)

```
1. (λ (x y z)
2.   (if x
3.       (let ([y 10]
4.             [z 20])
5.         (+ x y z))
6.       (- y z)))
```

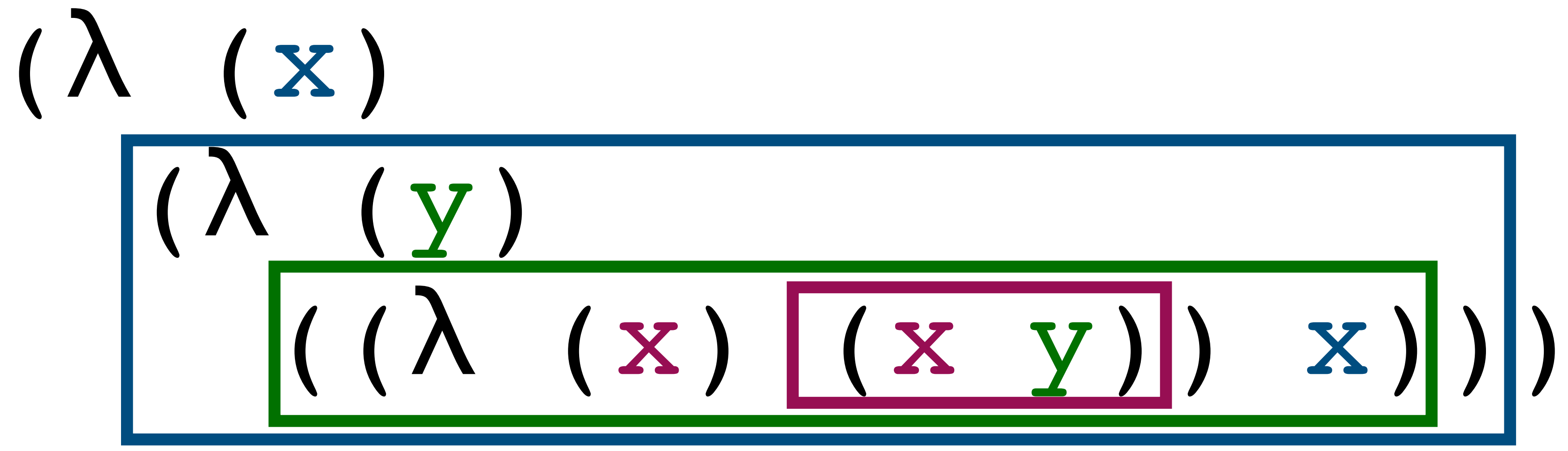
Which row of the table corresponds to line numbers where the variable indicated in the column was bound?

E.g., E indicates that the variables used in line 5 are bound in lines 1, 3, and 4 and the variables used in line 6 are bound in lines 3 and 4.

	Line 5 x	**Line 5 y**	**Line 5 z**	**Line 6 y**	**Line 6 z**
A	1	1	1	1	1
B	2	3	4	3	4
C	2	3	4	1	1
D	1	3	4	1	1
E	1	3	4	3	4

Contour diagrams

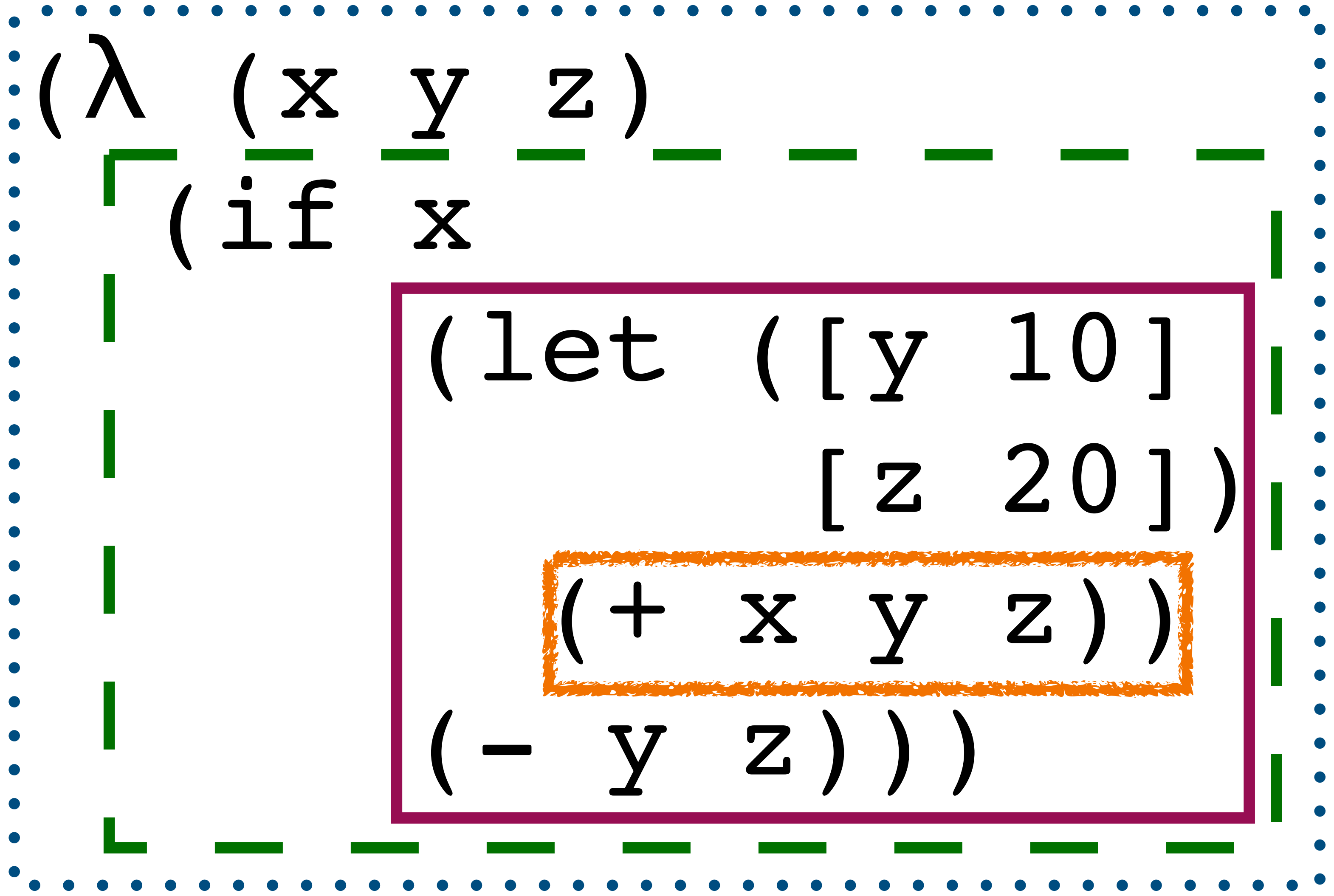
Draw the boundaries of the regions in which variable bindings are in effect



```
(λ (x)
  (λ (y)
    ((λ (x) (x y)) x)))
```

The body of a let or a lambda expression determines a contour

Each variable refers to the innermost declaration *outside* its contour



```
(λ (x y z)
  (if x
      (let ([y 10]
               [z 20])
         (+ x y z))
      (- y z)))
```

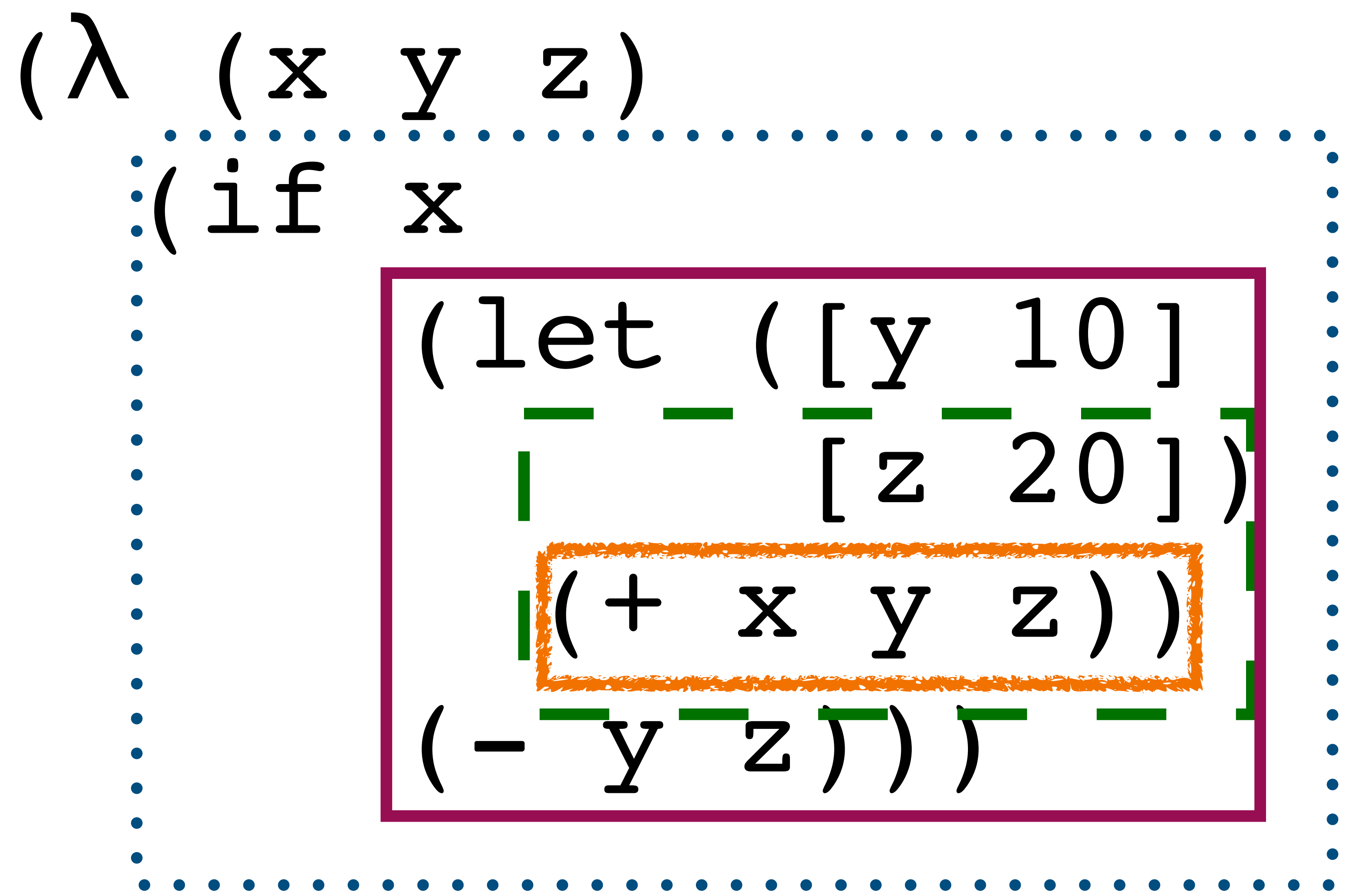
Which is the correct contour for the variable x?

A. Blue dotted rectangle

B. Green dashed rectangle

C. Purple solid rectangle

D. Orange fuzzy rectangle?



```
(λ (x y z)
 (if x
   (let ([y 10]
         [z 20])
    (+ x y z))
   (- y z)))
```

Which is the correct contour for the inner variable y?

A. Blue dotted rectangle

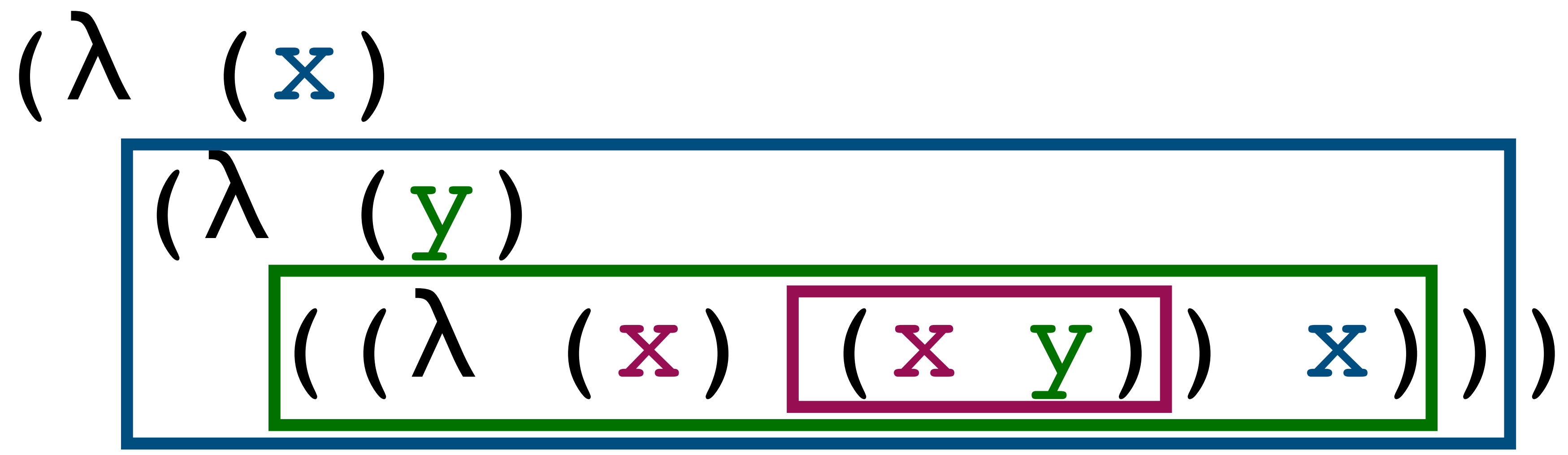
B. Green dashed rectangle

C. Purple solid rectangle

D. Orange fuzzy rectangle?

Lexical depth

The lexical depth of a variable reference is 1 less than the number of contours crossed between the reference and the declaration it refers to



```
(λ (x)
 (λ (y)
  ((λ (x) (x y)) x)))
```

In `(x y)`

- `x` has lexical depth 0
- `y` has lexical depth 1

The other `x` has lexical depth 1

What is the lexical depth of `m` in the expression `(* m x)` in this procedure?

```
(define fun
  (λ (m lst)
    (foldl (λ (x acc) (+ (* m x) acc))
           0
           lst)))
```

A. 0

B. 1

C. 2

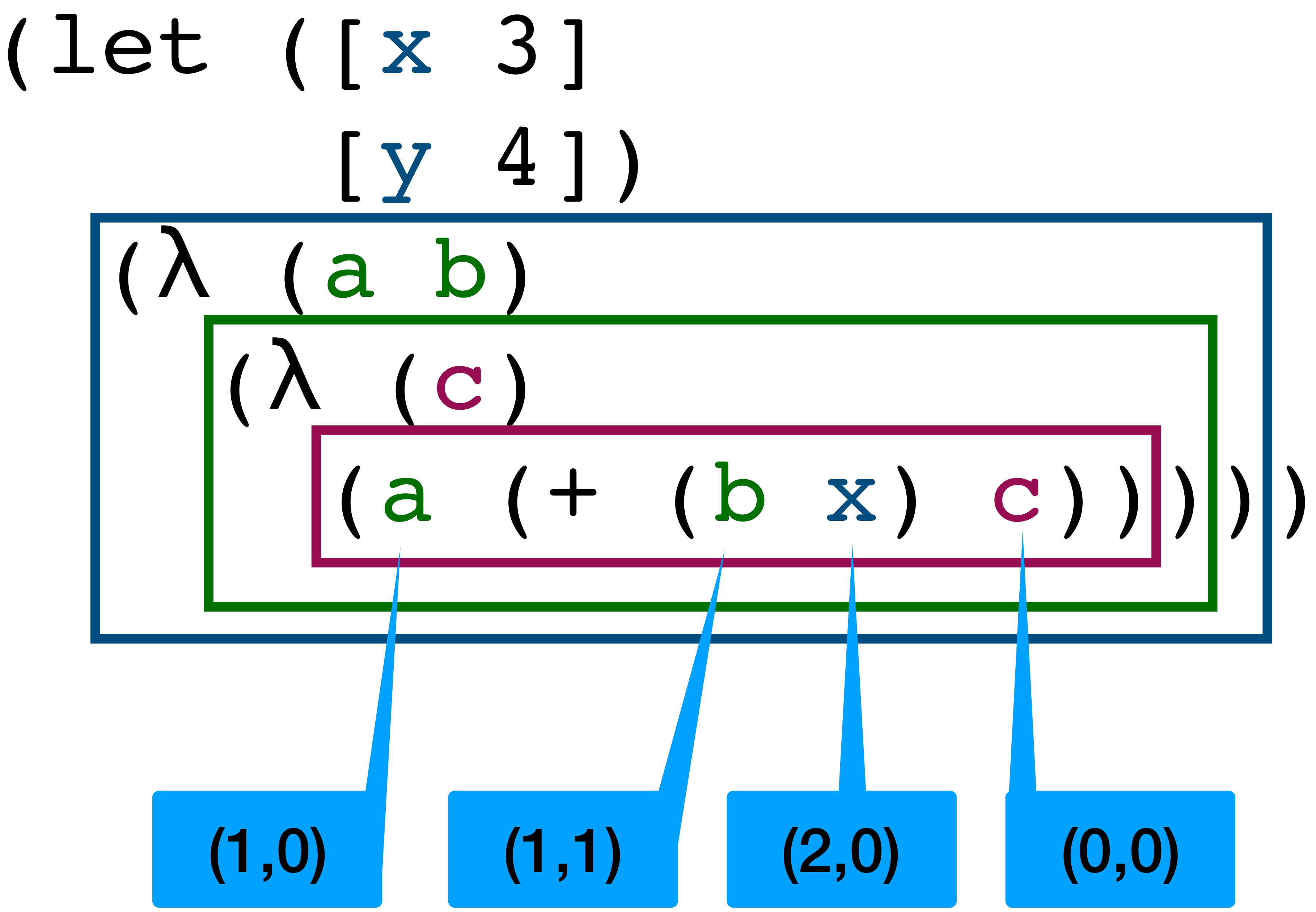
D. 3

E. 4

Lexical addresses

(depth, position)

We can use the lexical depth of a variable along with the 0-based position of the variable in its declaration to come up with a *lexical address* of the variable



```
(let ([x 3]
      [y 4])
  (λ (a b)
    (λ (c)
      (a (+ (b x) c)))))
```

Lexical addresses are essentially pointers to where the variable can be found on the run-time stack; can eliminate names

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))))
```

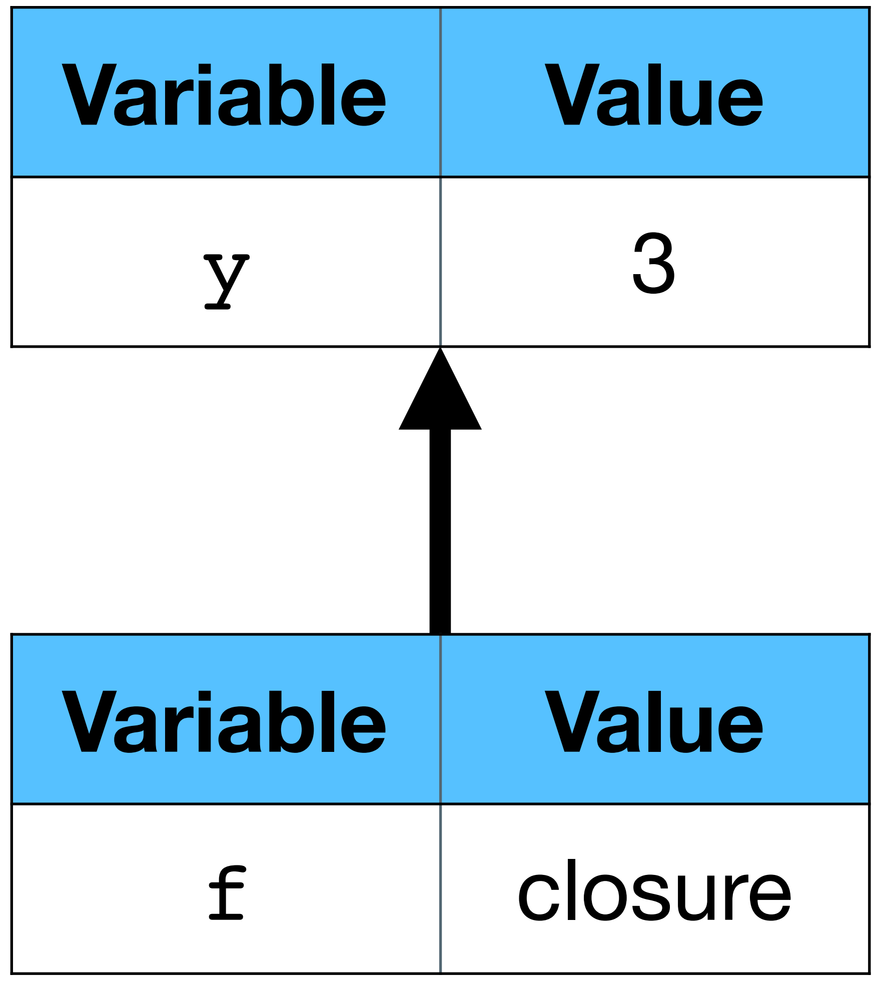
Lexical binding example

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

Variable	Value
y	3

Lexical binding example

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

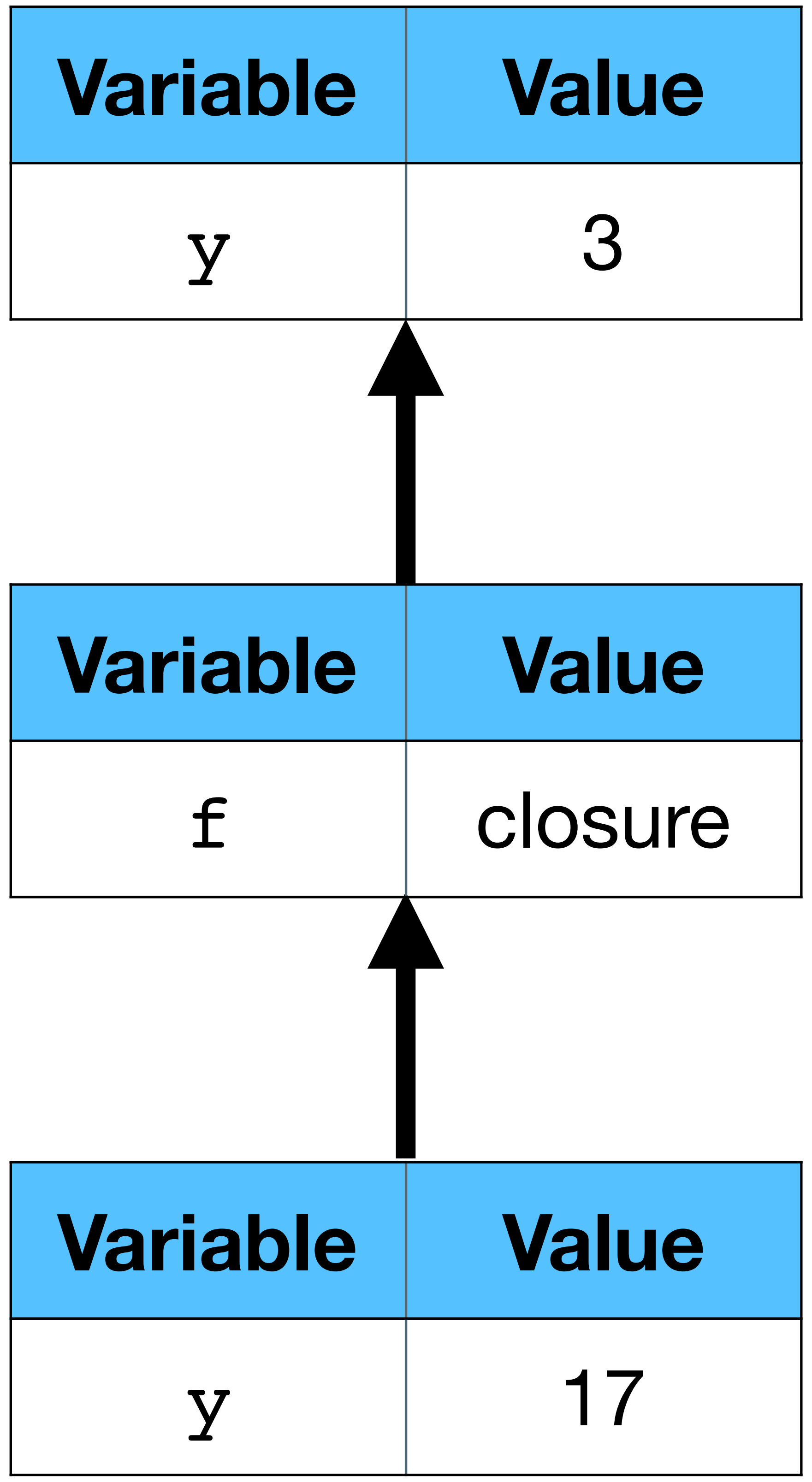


Variable	Value
y	3

Variable	Value
f	closure

Lexical binding example

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



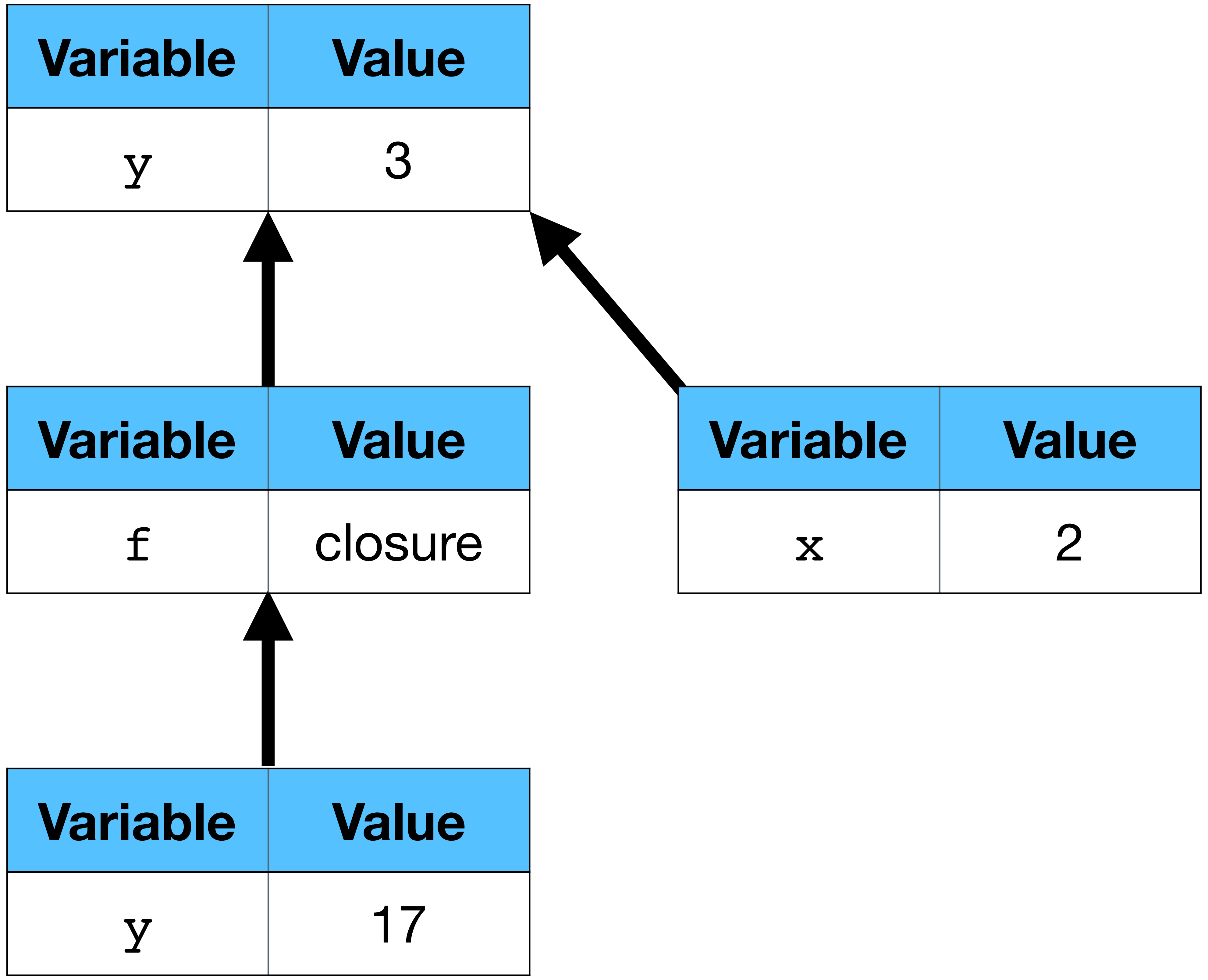
Variable	Value
y	3

Variable	Value
f	closure

Variable	Value
y	17

Lexical binding example

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



Variable	Value
y	3

Variable	Value
f	closure

Variable	Value
x	2

Variable	Value
y	17

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))))
```

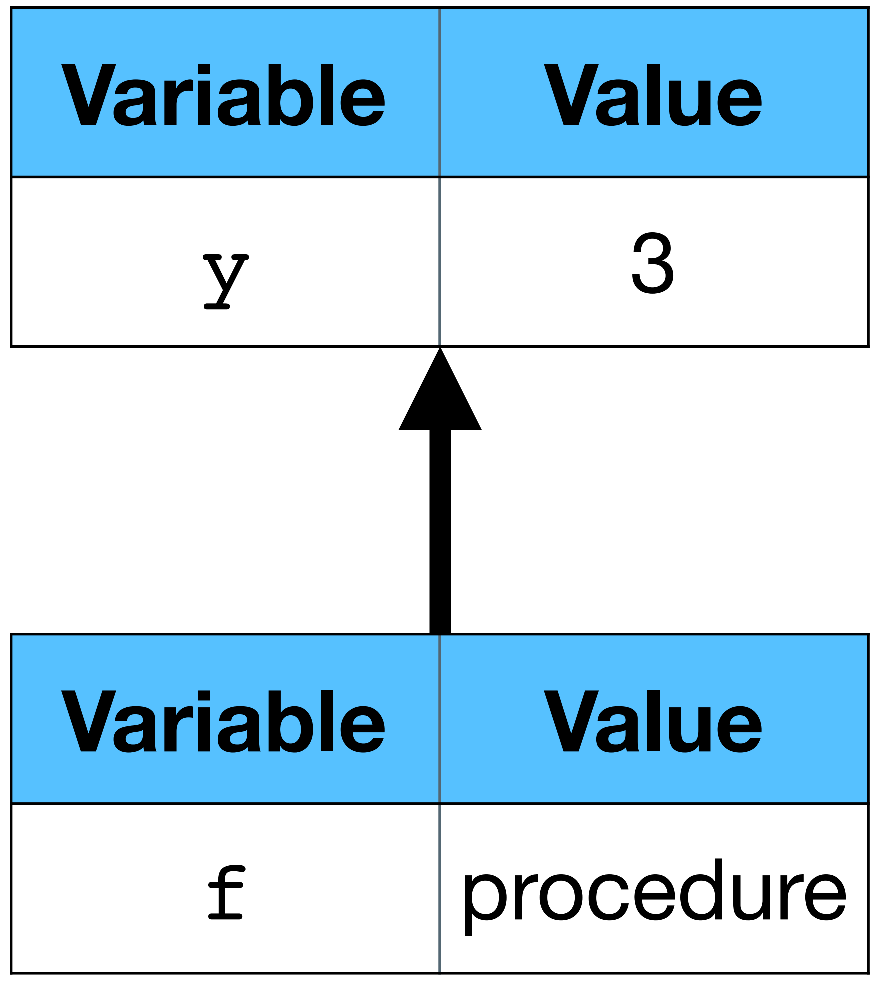
Dynamic binding example

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

Variable	Value
y	3

Dynamic binding example

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

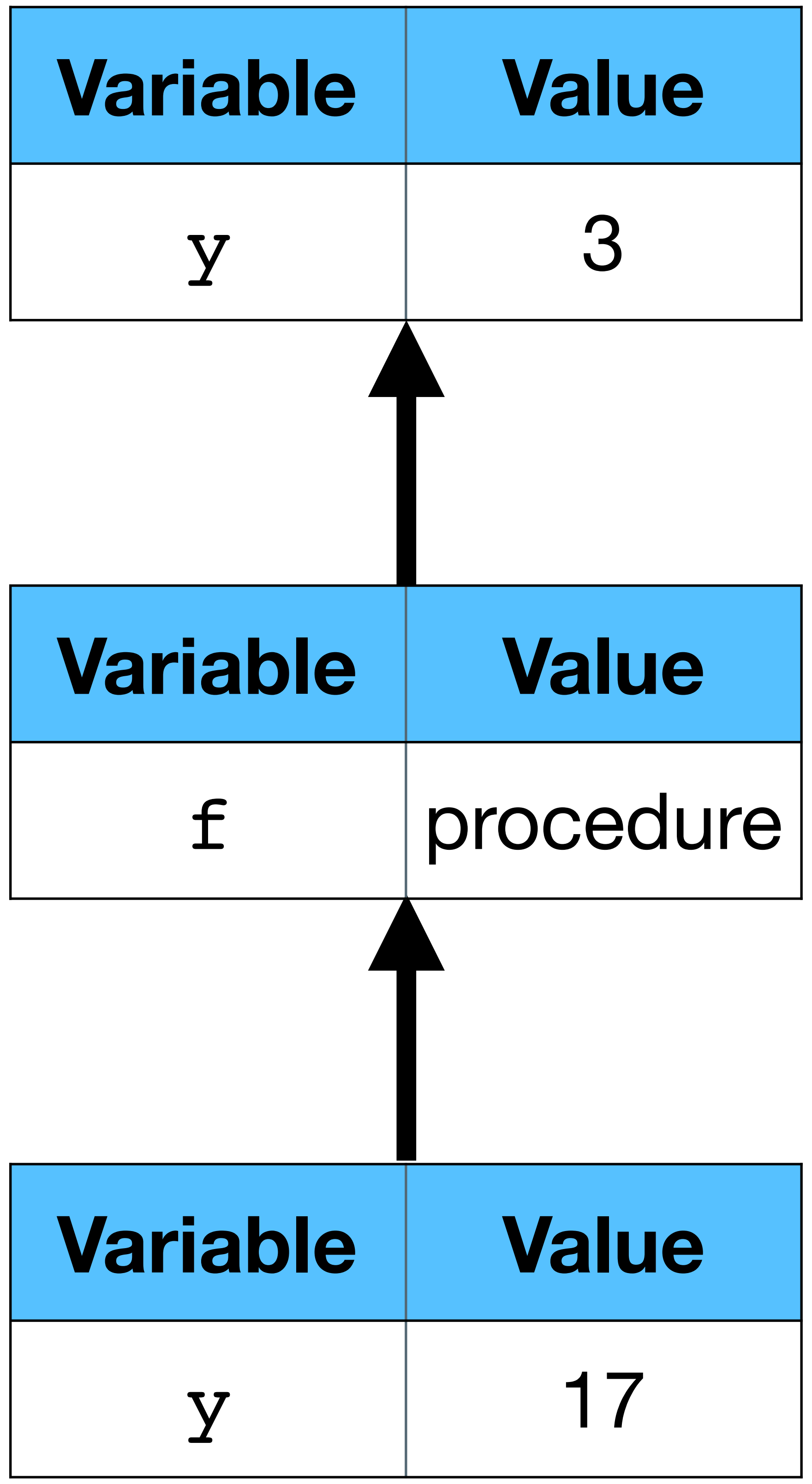


Variable	Value
y	3

Variable	Value
f	procedure

Dynamic binding example

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



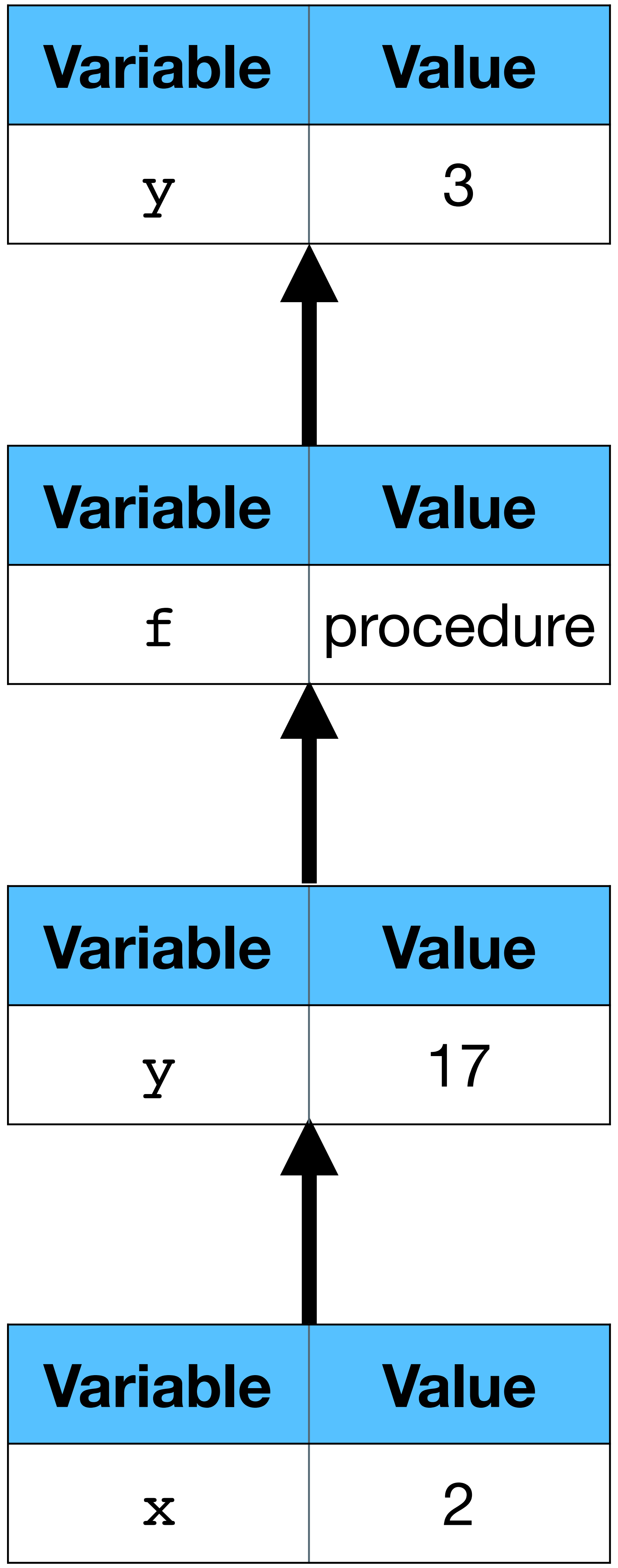
Variable	Value
y	3

Variable	Value
f	procedure

Variable	Value
y	17

Dynamic binding example

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



Variable	Value
y	3

Variable	Value
f	procedure

Variable	Value
y	17

Variable	Value
x	2