CS450

Structure of Higher Level Languages

Lecture 10: Function evaluation, the AST

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Today we will learn...

- (revisit) evaluation
- (revisit) the abstract syntactic tree

Evaluation recap

Exercise 1

What is the output of this program?

```
(define x 10)
(define (f x)
  (+ x 20))
(f 30)
```

Exercise 1

What is the output of this program?

```
(define x 10)
(define (f x)
  (+ x 20))
(f 30)
```

Output: 50

Because, parameter x shadows the outermost definition.

Exercise 2

What is the output of this program?

```
(define x 10)
(define f (lambda (x) (+ x 20)))
(f 30)
```

Exercise 2

What is the output of this program?

```
(define x 10)
(define f (lambda (x) (+ x 20)))
(f 30)
```

Output: 50

The code above is **equivalent** to the code below:

```
(define (f x) (+ x 20))
```

Exercise 3

What is the output of this program?

```
(define (factory k)
  (lambda () k))

(factory 10)
```

Exercise 3

What is the output of this program?

```
(define (factory k)
  (lambda () k))

(factory 10)
```

Output: #<procedure>

Although if Racket displayed code, we would get: `(lambda () 10)`

```
((factory 10))
; Outputs: 10
```

Exercise 3

Step-by-step evaluation

```
(factory 10) =
( (lambda (k) (lambda () k)) 10) =
; ^^^^^^^^^^^^^^^^^^^^^^^^^^\______ the value *bound* to factory
(lambda () 10)
```

Why is factory replaced by a lambda?

User input

```
(define (factory k)
  (lambda () k))
```

Internal representation

```
(define factory
  (lambda (k)
    (lambda () k)))
```

Exercise 3

Looking at function application more closely

```
(
  (lambda (k)       ; ← parameter k
    (lambda () k)) ; ← body of function
  10                ; ← argument
)
; Remove outer lambda and replace each parameter by argument
; (lambda () k)      ← body of function
;              \___ replace parameter k by argument 10
(lambda () 10)       ; ← return value
```

Exercise 4

Q1: What is the output of this program?

```
(define (f x y)
  (lambda (b)
    (cond [b x] [else y])))

(define g (f 1 2))
g
```

Exercise 4

Q1: What is the output of this program?

```
(define (f x y)
  (lambda (b)
    (cond [b x] [else y])))

(define g (f 1 2))
g
```

Output: `(lambda (b) (cond [b 1] [else 2]))`

Q2: How do I call g to obtain 1?

Exercise 4

Q1: What is the output of this program?

```
(define (f x y)
  (lambda (b)
    (cond [b x] [else y])))

(define g (f 1 2))
g
```

Output: `(lambda (b) (cond [b 1] [else 2]))`

Q2: How do I call `g` to obtain `1`?

Solution: `(g #t)`

The abstract syntactic tree (AST)

Representing code as data structures

The AST of values

```
value = number | void | func-dec
func-dec = (lambda ( variable* ) term+ )
```

Implementation

```
(define (r:value? v)
  (or (r:number? v)
      (r:void? v)
      (r:lambda? v)))
(struct r:void () #:transparent)
(struct r:number (value) #:transparent)
(struct r:lambda (params body) #:transparent)
```

How do we represent?

1. `10`
2. `(void)`
3. `(lambda () 10)`

AST

The AST of values

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value = number | void | func-dec
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(struct r:lambda (params body) #:transparent)
```

How do we represent?

1. `10`
2. `(void)`
3. `(lambda () 10)`

AST

```
(r:number 10)    ; ← 1
(r:void)         ; ← 2
(r:lambda (list) ; ← 3
  (list (r:number 10)))
```

The AST of expressions

```
expression = value | variable | apply
apply = ( expression+ )
```

Implementation

```
(define (r:expression? e)
  (or (r:value? e)
      (r:variable? e)
      (r:apply? e)))
(struct r:variable (name) #:transparent)
(struct r:apply (func args) #:transparent)
```

How do we represent?

1. `x`
2. `(f 10)`

AST

The AST of expressions

```
expression = value | variable | apply
apply = ( expression+ )
```

Implementation

```
(define (r:expression? e)
  (or (r:value? e)
      (r:variable? e)
      (r:apply? e)))
(struct r:variable (name) #:transparent)
(struct r:apply (func args) #:transparent)
```

How do we represent?

1. x
2. (f 10)

AST

```
; 1:
(r:variable 'x)
; 2:
(r:apply
  (r:variable 'f)
  (list (r:number 10)))
```

The AST of terms

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```
term = define | expression
define = ( define identifier expression ) | ( define ( variable+ ) term+)
```

```
(define (r:term? t)
  (or (r:define? t)
      (r:expression? t)))
(struct r:define (var body) #:transparent)
```

Which Racket code is this?

```
(r:define (r:variable 'f)
  (r:lambda (list (r:variable 'y))
    (list
      (r:apply (r:variable '+)
               (list (r:variable 'y) (r:number 10)))))))
```

The AST of terms

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```
term = define | expression
define = ( define identifier expression ) | ( define ( variable+ ) term+)
```

```
(define (r:term? t)
  (or (r:define? t)
      (r:expression? t)))
(struct r:define (var body) #:transparent)
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Which Racket code is this?

```
(r:define (r:variable 'f)
  (r:lambda (list (r:variable 'y))
    (list
      (r:apply (r:variable '+)
               (list (r:variable 'y) (r:number 10)))))))
```

Answer 1

```
(define (f y) (+ y 10))
```

Answer 2

```
(define f
  (lambda (y) (+ y 10)))
```