61A LECTURE 18 – SCHEME

Steven Tang and Eric Tzeng

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What's happening today?

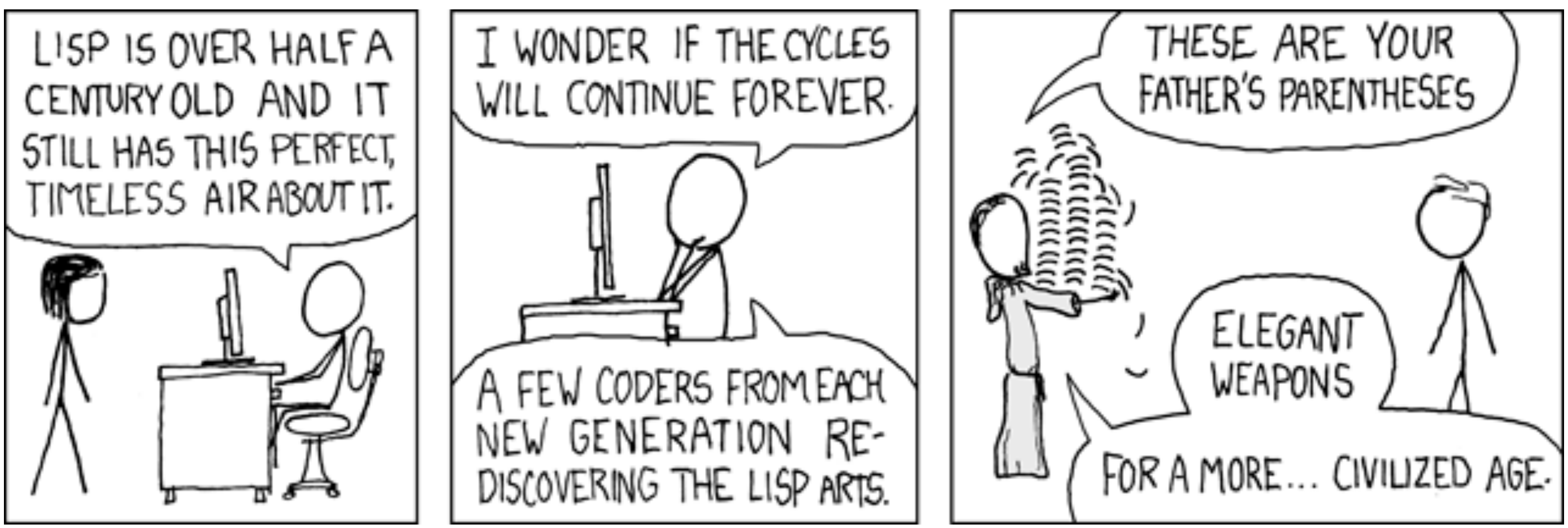
- We're learning a new language!
- After you know one language (Python), learning your second (Scheme) is much faster
- Learn by doing – have a sheet of paper ready
- Solutions in the code supplement for this lecture

Scheme Is a Dialect of Lisp

“The greatest single programming language ever designed.”
-Alan Kay, co-inventor of OOP

“The most powerful programming language is Lisp. If you don't know Lisp (or its variant, Scheme), you don't appreciate what a powerful language is. Once you learn Lisp you will see what is missing in most other languages.”
-Richard Stallman, founder of the Free Software movement

“Probably my favorite programming language.”
~~-Eric Tzeng, CS61A Instructor~~ -Steven Tang, CS61A Instructor



http://imgs.xkcd.com/comics/lisp_cycles.png

Scheme Fundamentals

Scheme programs consist of expressions, which can be:

- Primitive expressions: **`2`**, **`3.3`**, **`true`**, **`+`**, **`quotient`**, ...
- Combinations: **`(quotient 10 2)`**, **`(not true)`**, ...

Numbers are self-evaluating; symbols are bound to values

Call expressions have an operator and 0 or more operands

```
> (quotient 10 2)
5
> (quotient (+ 8 7) 5)
3
> (+ (* 3
        (+ (* 2 4)
           (+ 3 5)))
     (+ (- 10 7)
        6))
57
```

"quotient" names Scheme's built-in integer division procedure (i.e., function)

Combinations can span multiple lines
(spacing doesn't matter)

Special Forms

A combination that is not a call expression is a *special form*:

- **If** expression: (if <predicate> <consequent> <alternative>)
- **And** and **or**: (and <e_1> ... <e_n>), (or <e_1> ... <e_n>)
- Binding names: (define <name> <expression>)
- New procedures: (define (<name> <formal parameters>) <body>)

```
> (define pi 3.14)
> (* pi 2)
6.28
```

The name “pi” is bound to 3.14 in the global frame

```
> (define (abs x)
    (if (< x 0)
        (- x)
        x))
> (abs -3)
3
```

A procedure is created and bound to the name “abs”

Try it!

- Translate the following Python functions into Scheme:

```
def one():
    return 1

def two(x, y, z):
    return x + y * z

def three(n):
    if n == 0:
        return 0
    return (n % 10) + 2 * three(n // 10)
```

In Scheme: `remainder`

In Scheme: `quotient`

Lambda Expressions

Lambda expressions evaluate to anonymous procedures

```
(lambda (<formal-parameters>) <body>)
```

Two equivalent expressions:

```
(define (plus4 x) (+ x 4))

(define plus4 (lambda (x) (+ x 4)))
```

An operator can be a combination too:

```
((lambda (x y z) (+ x y (square z))) 1 2 3)
```

Evaluates to the *add-x-&-y-&-z²* procedure

Syntactic sugar: defining procedures

- In Python, `lambda` expressions are fundamentally different than `def` statements:
  - The body of a lambda must be a single expression
  - The value of that expression is always returned
- In Scheme, defining procedures is actually syntactic sugar for a `define` statement and a `lambda` expression

```
(define (square x)
  (* x x))
```

"Define the function square"

```
(define square
  (lambda (x) (* x x)))
```

"Define a function and give it the name square"

Practice with lambdas

- Complete the definition of `f` so that `(((f) 3))` evaluates to 1.

```
(define (f) ???)
```

- Complete the definition of `g` so that `((g g) g)` evaluates to 42.

```
(define g ???)
```

Pairs

We can implement pairs functionally:

```
(define (pair x y) (lambda (m) (if (= m 0) x y)))
(define (first p) (p 0))
(define (second p) (p 1))
```

Scheme also has built-in pairs that use weird names:

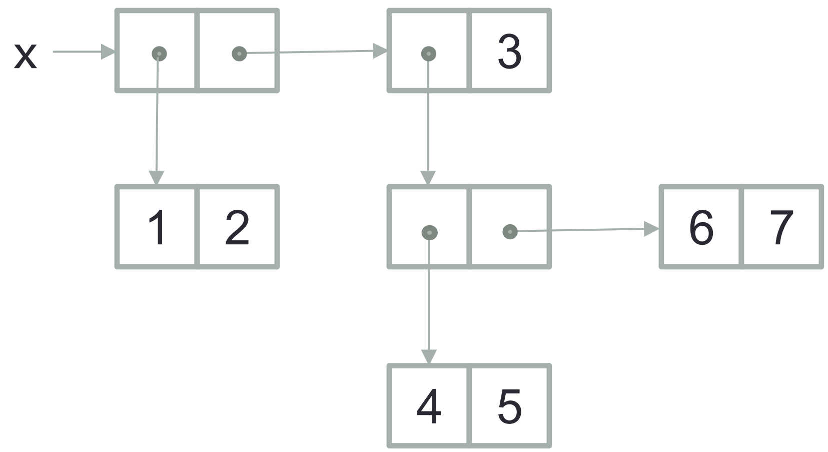
- **`cons`**: Two-argument procedure that **creates a pair**
- **`car`**: Procedure that returns the **first element** of a pair
- **`cdr`**: Procedure that returns the **second element** of a pair

A pair is represented by a dot between the elements, all in parens

```
> (cons 1 2)
(1 . 2)
> (car (cons 1 2))
1
> (cdr (cons 1 2))
2
```

Pairs practice

- Suppose x is the following pair:



- How would you select 1 from x?
- 3?
- 7?
- How would you define x in the first place?

Recursive Lists

A recursive list can be represented as a pair in which the second element is a recursive list or the empty list

Scheme lists are recursive lists:

- **`nil`** is the empty list
- A non-empty Scheme list is a pair in which the second element is **`nil`** or a Scheme list

Scheme lists are written as space-separated combinations

```
> (define x (cons 1 (cons 2 (cons 3 (cons 4 nil)))))
> x
(1 2 3 4)
> (cdr x)
(2 3 4)
> (cons 1 (cons 2 (cons 3 4)))
(1 2 3 . 4)
```

Not a well-formed list!

Aside: Booleans and Boolean contexts

Boolean constants

- In Python, we had `True` and `False` as our Boolean constants
- In Scheme, we use `#t` and `#f` instead

Boolean contexts

- In Python, most objects were treated like `True`, but many different objects were treated as `False` (`0`, “”, `[]`, etc.)
- In Scheme, *everything* is treated like `#t`, with the exception of `#f` itself.

```
(define (length lst)
  (if (not lst)
      0
      (+ 1 (length (cdr lst)))))
```

WRONG WRONG WRONG

```
(define (length lst)
  (if (null? lst)
      0
      (+ 1 (length (cdr lst)))))
```

Recursive list practice

- Write a Scheme function `append` that takes two lists and returns a single list that contains the values from the first list and the second list, in order:

```
STk> (append (list 1 2 3) (list 4 5 6))
(1 2 3 4 5 6)
```

Symbolic Programming

Symbols are normally evaluated to produce values; how do we refer to symbols?

```
> (define a 1)
> (define b 2)
> (list a b)
(1 2)
```

No sign of “a” and “b” in the resulting value

Quotation prevents something from being evaluated by Lisp

```
> (list 'a 'b)
(a b)
> (list 'a b)
(a 2)
```

Symbols are now values

Quotation can also be applied to combinations to form lists

```
> (car '(a b c))
a
> (cdr '(a b c))
(b c)
```

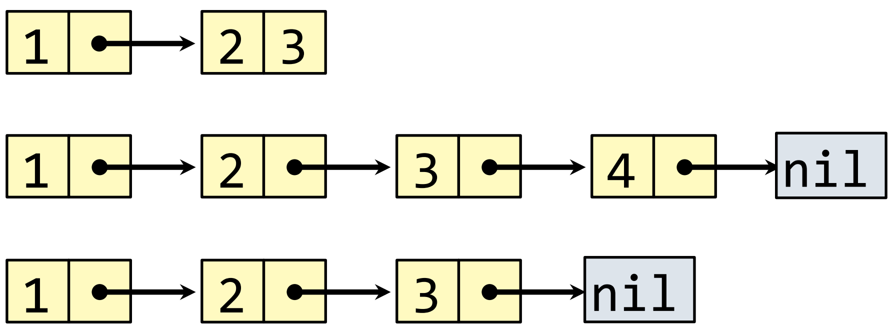
Scheme Lists and Quotation

Dots can be used in a quoted list to specify the second element of the final pair

```
> (cdr (cdr '(1 2 . 3)))
3
```

However, dots appear in the output only of ill-formed lists

```
> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
(1 2 3)
```



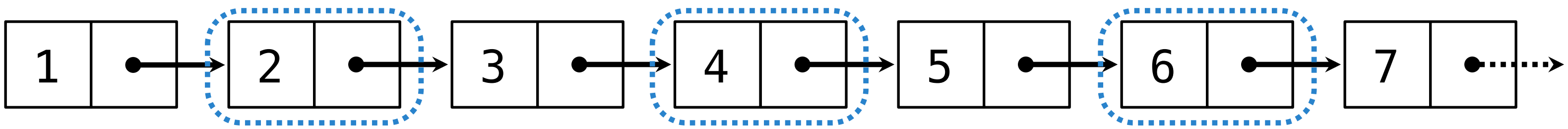
What is the printed result of evaluating this expression?

```
> (cdr '((1 2) . (3 4 . (5))))
(3 4 5)
```

The Let Special Form

Let expressions introduce a new frame, with the given bindings

```
(let ((<name> <exp>) ...) <body>)
```



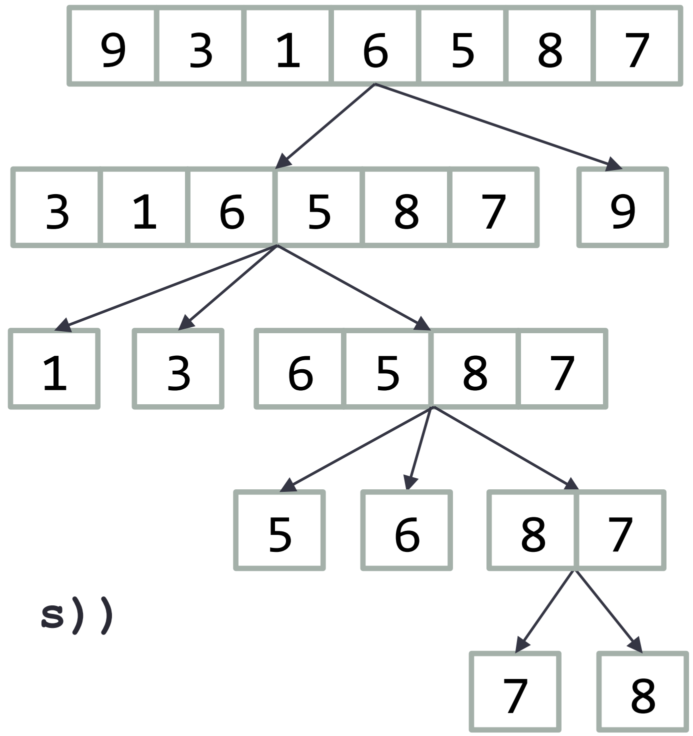

```
(define (filter fn s)
  (if (null? s)
      s
      (let ((first (car s))
            (rest (filter fn (cdr s))))
        (if (fn first)
            (cons first rest)
            rest))))
```

```
> (filter even? '(1 2 3 4 5 6 7))
(2 4 6)
```

Quick Sort

Quick sort algorithm:

1. Choose a pivot (e.g. first element)
2. Partition into three pieces:
   < pivot, = pivot, > pivot
3. Recurse on first and last piece




```
(define (filter-comp comp pivot s)
  (filter (lambda (x) (comp x pivot)) s))

(define (quick-sort s)
  (if (<= (length s) 1)
      s
      (let ((pivot (car s)))
        (append (quick-sort (filter-comp < pivot s))
                (filter-comp = pivot s)
                (quick-sort (filter-comp > pivot s))))))
```

Turtle graphics

Picture by Jonathan Zander

- STk has built in support for basic 2D graphics!
- Turtle sits on the canvas
- As the turtle “walks” around the canvas, it leaves a trail
- Images are drawn by issuing commands to the turtle

```
(define (triangle)
  (forward 100)
  (right 120)
  (forward 100)
  (right 120)
  (forward 100)
  (right 120))
```

Move forward 100 steps

Turn right 120 degrees

- Did we need the last call to `right`? Why?

The Begin Special Form

Begin expressions allow sequencing

```
(begin <exp₁> <exp₂> ... <expₙ>)
```

```
(define (repeat k fn)
  (if (> k 0)
      (begin (fn) (repeat (- k 1) fn))
      'done))

(define (tri fn)
  (repeat 3 (lambda () (fn) (lt 120))))

(define (sier d k)
  (tri (lambda () (if (= k 1) (fd d) (leg d k)))))

(define (leg d k)
  (sier (/ d 2) (- k 1)) (penup) (fd d) (pendown))
```