CS3:
Introduction to Symbolic Programming

Lecture 9:
More higher-order functions,
`lambda`, tic-tac-toe

Spring 2007

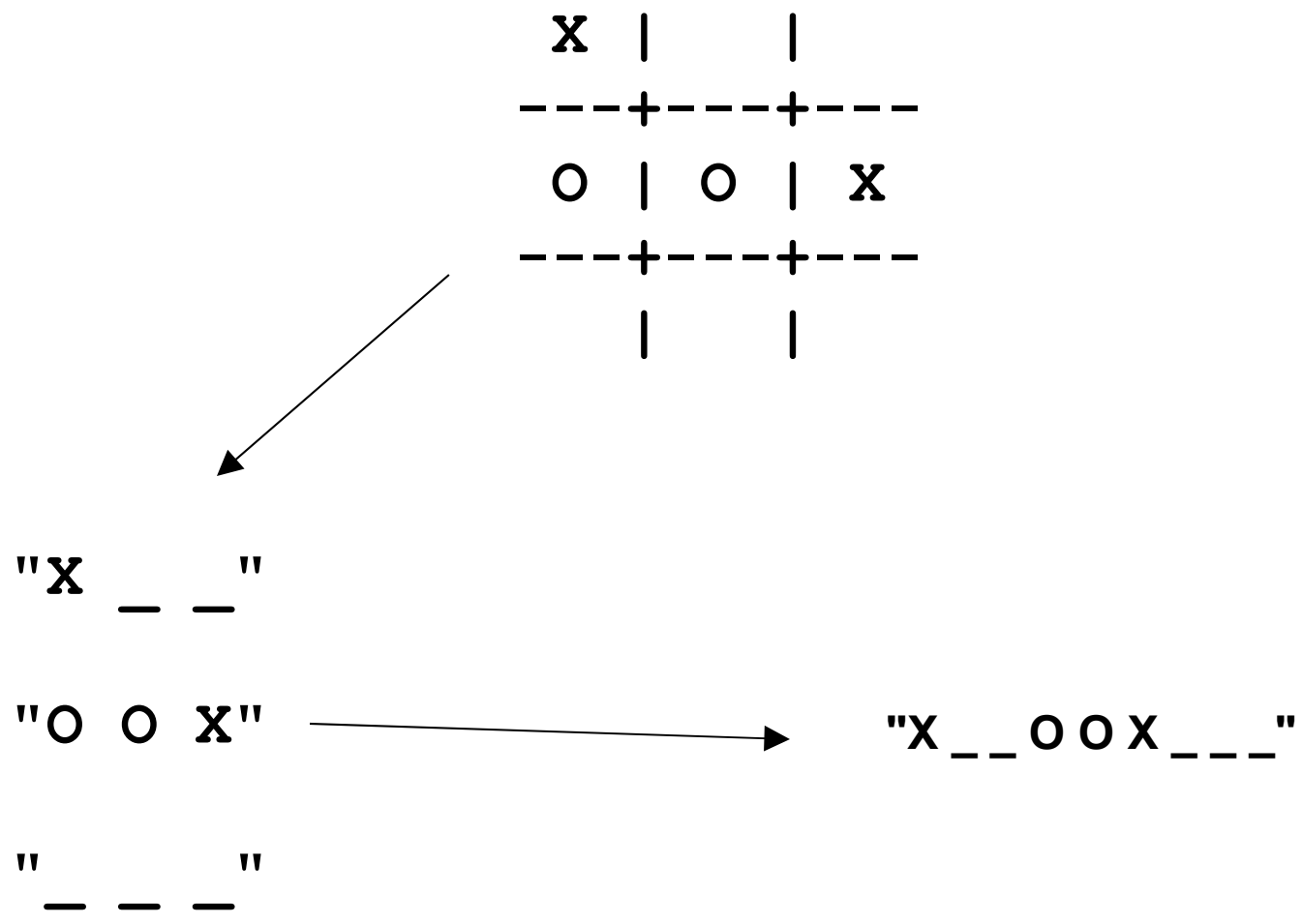
Nate Titterton
nate@berkeley.edu

Schedule

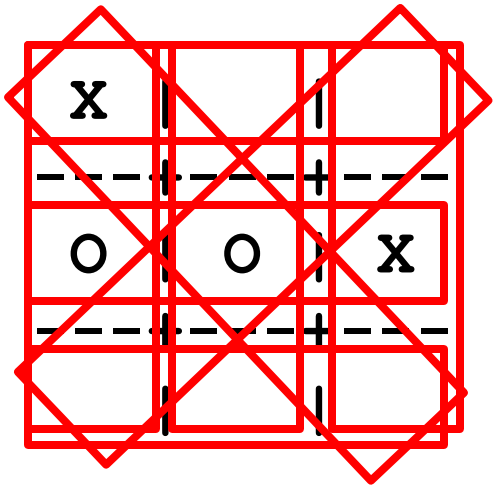
9	Mar 12-16	Lecture: Higher order functions, lambda Reading: Simply Scheme, Ch 9, 10 "DbD" HOF version Lab: Higher order functions, tic-tac-toe
10	Mar 19-23	Lecture: Higher-order function review Lab: More Higher order functions Miniproject #3 assigned
	Mar 26-30	*Spring Break*
11	April 2	Lecture: Midterm review, tree recursion Lab: Lists, tree-recursion Miniproject #3 due Tuesday
12	April 9	*Midterm #2*

Tic Tac Toe

The board



Triples (another representation of a board)



"X__OOX___"

(x23 oox 789 xo7 2o8 3x9 xo9 3o7)

Tic-tac-toe hints

- **Read the chapter!**
- **You will need to be familiar with vocabulary**
  - **positions, triples, "forks", "pivots", and so on**
- **This chapter in the book comes *before* recursion.**
  - **You would solve things differently if you used recursion**
- **The code (at the end of the chapter) has no comments.**

Higher-order functions: review

Higher order function (HOFs)

- **A HOF is a procedure that takes a procedure as an argument.**
- **There are three main ones that work with words and sentences:**

  - `every`
    - take a one-argument procedure that returns a word
    - do something to each element
  - `keep`
    - takes a one-argument predicate
    - return only certain elements
  - `accumulate`
    - takes a two-argument procedure
    - combine the elements

A definition of every

```
(define (my-every proc ws)
  (if (empty? ws)
      '()
      (se (proc (first ws))
          (my-every (bf ws))
          )))
```

- HOFs do a lot of work for you:
  - Checking the conditional
  - Returning the proper base case
  - Combing the various recursive steps
  - Invoking itself recursively on a smaller problem

Accumulate (1/2)

- The *direction* matters: right to left
  - `(accumulate / '(4 2 2))` does not equal `1`, but `4`.

- Think about expanding an accumulate

```
(accumulate + '(1 2 3 4))
  ➔ (+ 1 (+ 2 (+ 3 4)))

(accumulate / '(4 2 2))
  ➔ (/ 4 (/ 2 2))
```

accumulate (2/2)

- **`accumulate` can return a sentence…**

```
(accumulate ?? '(a b c d))
        ➔ (ab bc cd)
```

  - the *first* time accumulate is run, it reads the last two words of the input sentence

  - in *later* calls, it uses the return value of its procedure (which is a sentence) as one of its arguments

Any questions from last week?

- You wrote and played with `every`, `keep`, and `accumulate`
- You used them in combination:

```
(gpa '(A A F C B))
   ➔ 2.6   (average of 4, 4, 0, 2, 3)

(gpa-with-p/np '(A A F NP P C B))
   ➔ 2.6   (average of 4, 4, 0, 2, 3)

(true-for-all? even? '(2 4 6 8))
   ➔ #t
```

Which HOFs would you use? (1/2)

1) **capitalize-proper-names**

```
(c-p-n '(mr. smith goes to washington))
    ➔ (mr. Smith goes to Washington)
```

3) **count-if**

```
(count-if odd? '(1 2 3 4 5)) ➔ 3
```

5) **longest-word**

```
(longest-word '(I had fun on spring
   break)) ➔ spring
```

7) **count-vowels-in-each**

```
(c-e-l '(I have forgotten everything))
   ➔ (1 2 3 3)
```

Which HOFs would you use? (2/2)

1) **squares-greater-than-100**

```
(s-g-t-100 '(2 9 13 16 9 45))
   ➔ (169 256 2025)
```

3) **root of the sum-of-squares**

```
(sos '(1 2 3 4 5 6 7))
   ➔ (sqrt (+ (* 1 1) (* 2 2) …)
   ➔ 30
```

5) **successive-concatenation**

```
(sc '(a b c d e))
   ➔ (a ab abc abcd abcde)
```

defining variables, `let`, and `lambda`

Three ways to define a variable

1. In a procedure call (e.g., the variable `proc`):

```
(define (doit proc value)
     ;; proc is a procedure here…
     (proc value))
```

3. As a global variable

```
(define *alphabet* '(a b c d e … ))
(define *month-name* '(january … ))
```

5. With `let`

Using `let` to define temporary variables

- **`let` lets you define variables within a procedure:**

```
(define (scramble-523 wd)
   (let ((second (first (bf wd)))
         (third (first (bf (bf wd))))
         (fifth (item 5 wd))
         )
     (word fifth second third) ) )


(scramble-523 'meaty) ➔ yea
```

Any differences?

```
(define pi 3.14159265)
(define ( alpha beta pi zeta)
    … lots of code here …
    (* pi radius)
    … more code here …
```

YES!

```
(define ( alpha beta pi zeta)
  (let ((pi 3.14159265)) )
    … lots of code here …
    (* pi radius)
    … more code here …
```

In Scheme, procedures are *first-class* objects

- You can assign them a name
- You can pass them as arguments to procedures
- You can return them as the result of procedures
- You can include them in data structures

1. Well, you don't know how to do all of these yet.

3. What else in scheme is a *first-class* object?

The "hard" one is #3: returning procedures

```
;; this returns a procedure
(define (make-add-to number)
   (lambda (x) (+ number x)))

;; this also returns a procedure
(define add-to-5 (make-add-to 5))


;; hey, where is the 5 kept!?
(add-to-5 8) ➔ 13

((make-add-to 3) 20) ➔ 23
```

the `lambda` form

- **"`lambda`" is a special form that returns a function:**

```
(lambda (arg1 arg2 …)
   statements
      )
```

```
(lambda          (x)          (*     x     x))
```

⇨ ⇨ ⇨ ⇨ ⇨

a procedure that takes one argument and multiplies it by itself

Using `lambda` with `define`

- **These are the same:**

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

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

Using `lambda` with `define`

- **These are VERY DIFFERENT:**

```
(define (adder-1 y)
   (lambda (x) (+ x 1)))
```

```
(define adder-2
   (lambda (x) (+ x 1)))
```

Can a `lambda`-defined function be recursive?

```
(lambda (sent)
  (if (empty? sent)
      '()
      (se (square (first sent))
          (???? (bf sent)))))
```

When do you NEED lambda?

1. **When you need the context (inside a two-parameter procedure)**

```
(add-suffix '-is-great '(haddad sam mary))
    ➔ (haddad-is-great sam-is-great
       mary-is-great)
```

3. **When you need to make a function on the fly**

Problems

Hangman-status

```
(hangman-status 'joebob 'abcde)
  → __eb_b
```

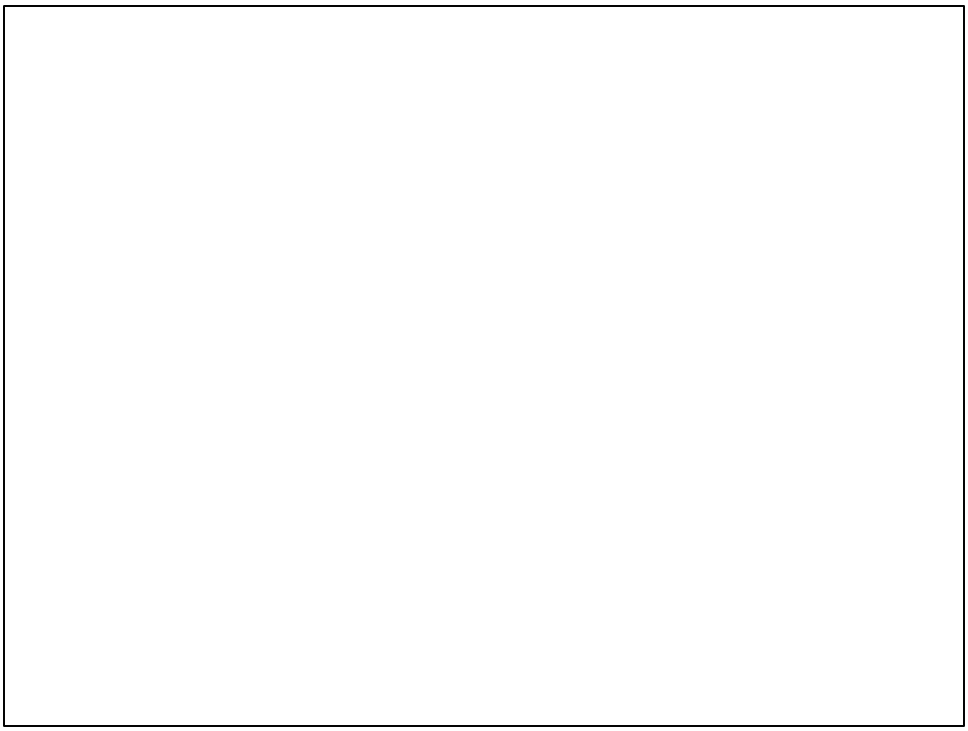
```
(define (hangman-status secret-wd ltrs)
   ???
   )
```

Write successive-concatenation

```
(sc '(a b c d e))
➔  (a ab abc abcd abcde)

(sc '(the big red barn))
➔ (the thebig thebigred thebigredbarn)
```

```
(define (sc sent)
   (accumulate
      (lambda ??
         )
      sent))
```



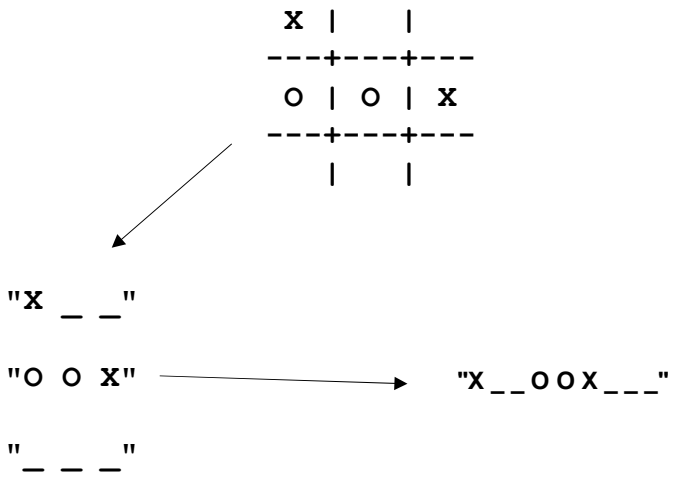
Schedule

9	Mar 12-16	Lecture: Higher order functions, lambda Reading: Simply Scheme, Ch 9, 10 "DbD" HOF version Lab: Higher order functions, tic-tac-toe
10	Mar 19-23	Lecture: Higher-order function review Lab: More Higher order functions Miniproject #3 assigned
	Mar 26-30	*Spring Break*
11	April 2	Lecture: Midterm review, tree recursion Lab: Lists, tree-recursion Miniproject #3 due Tuesday
12	April 9	*Midterm #2*

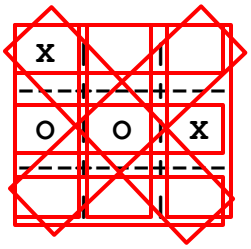
Tic Tac Toe

Click to add text

The board



Triples (another representation of a board)



"X__OOX___"

(x23 oox 789 xo7 2o8 3x9 xo9 3o7)

(find-triples 'x__oox___) ➔ (x23 oox 789 xo7 "2o8" "3x9" xo9 "3o7")

Tic-tac-toe hints

- Read the chapter!
- You will need to be familiar with vocabulary
  - positions, triples, "forks", "pivots", and so on
- This chapter in the book comes *before* recursion.
  - You would solve things differently if you used recursion
- The code (at the end of the chapter) has no comments.

Higher-order functions: review

Click to add text

Higher order function (HOFs)

- **A HOF is a procedure that takes a procedure as an argument.**
- **There are three main ones that work with words and sentences:**

  - `every`
    - take a one-argument procedure that returns a word
    - do something to each element
  - `keep`
    - takes a one-argument predicate
    - return only certain elements
  - `accumulate`
    - takes a two-argument procedure
    - combine the elements

A definition of every

```
(define (my-every proc ws)
  (if (empty? ws)
    '()
    (se (proc (first ws))
        (my-every (bf ws))
        )))
```

- HOFs do a lot of work for you:
  - Checking the conditional
  - Returning the proper base case
  - Combing the various recursive steps
  - Invoking itself recursively on a smaller problem

Accumulate (1/2)

- The *direction* matters: right to left
  - `(accumulate / '(4 2 2))` does not equal `1`, but `4`.

- Think about expanding an accumulate

```
(accumulate + '(1 2 3 4))
  ➔ (+ 1 (+ 2 (+ 3 4)))

(accumulate / '(4 2 2))
  ➔ (/ 4 (/ 2 2))
```

accumulate (2/2)

- **`accumulate` can return a sentence…**

```
(accumulate ?? '(a b c d))
        ➔ (ab bc cd)
```

  - **the *first* time accumulate is run, it reads the last two words of the input sentence**
  - **in *later* calls, it uses the return value of its procedure (which is a sentence) as one of its arguments**

```
(define (concat-pairs sent)
  (accumulate (lambda (wd so-far)
                (if (word? so-far)
                    (se (word wd so-far))
                    (se (word wd (first (first so-far))) so-far))
                )
              sent))
```

Any questions from last week?

- You wrote and played with `every`, `keep`, and `accumulate`
- You used them in combination:

```
(gpa '(A A F C B))
   ➔ 2.6   (average of 4, 4, 0, 2, 3)

(gpa-with-p/np '(A A F NP P C B))
   ➔ 2.6   (average of 4, 4, 0, 2, 3)

(true-for-all? even? '(2 4 6 8))
   ➔ #t
```

Which HOFs would you use? (1/2)

1) capitalize-proper-names

```
(c-p-n '(mr. smith goes to washington))
    ➔ (mr. Smith goes to Washington)
```

3) count-if

```
(count-if odd? '(1 2 3 4 5)) ➔ 3
```

5) longest-word

```
(longest-word '(I had fun on spring
   break)) ➔ spring
```

7) count-vowels-in-each

```
(c-e-l '(I have forgotten everything))
   ➔ (1 2 3 3)
```

1) Every
2) Keep
3) Accumulate (longest-word needs to compare elements of the sentence; it can't consider each element in isolation)
4) Every containing a keep (count-if)

Which HOFs would you use? (2/2)

1) squares-greater-than-100

```
(s-g-t-100 '(2 9 13 16 9 45))
  ➔ (169 256 2025)
```

3) root of the sum-of-squares

```
(sos '(1 2 3 4 5 6 7))
  ➔ (sqrt (+ (* 1 1) (* 2 2) …)
  ➔ 30
```

5) successive-concatenation

```
(sc '(a b c d e))
  ➔ (a ab abc abcd abcde)
```

1) Keep containing an every
2) Accumulate containing an every
3) Just accumulate. This isn't an every, although it looks like it at first glance, because you can't process the non-first elements without determining the elements that came before!

defining variables, `let`, and `lambda`

Click to add text

Three ways to define a variable

1. **In a procedure call (e.g., the variable `proc`):**

```
(define (doit proc value)
     ;; proc is a procedure here…
     (proc value))
```

3. **As a global variable**

```
(define *alphabet* '(a b c d e … ))
(define *month-name* '(january … ))
```

5. **With `let`**

Using `let` to define temporary variables

- **`let` lets you define variables within a procedure:**

```
(define (scramble-523 wd)
   (let ((second (first (bf wd)))
         (third (first (bf (bf wd))))
         (fifth (item 5 wd))
         )
     (word fifth second third) ) )


(scramble-523 'meaty) ➔ yea
```

Any differences?

```
(define pi 3.14159265)
(define ( alpha beta pi zeta)
   … lots of code here …
   (* pi radius)
   … more code here …
```

YES!

```
(define ( alpha beta pi zeta)
  (let ((pi 3.14159265)) )
   … lots of code here …
   (* pi radius)
   … more code here …
```

In Scheme, procedures are *first-class* objects

- You can assign them a name
- You can pass them as arguments to procedures
- You can return them as the result of procedures
- You can include them in data structures

1. Well, you don't know how to do all of these yet.

3. What else in scheme is a *first-class* object?

First-class objects (in scheme) can:

-Be named

-Be an parameter to functions

-Be returned from functions

-Be stored in other data structures

The "hard" one is #3: returning procedures

```
;; this returns a procedure
(define (make-add-to number)
   (lambda (x) (+ number x)))

;; this also returns a procedure
(define add-to-5 (make-add-to 5))


;; hey, where is the 5 kept!?
(add-to-5 8) ➔ 13

((make-add-to 3) 20) ➔ 23
```

the `lambda` form

- "`lambda`" is a special form that returns a function:

```
(lambda (arg1 arg2 …)
   statements
      )
```

```
(lambda          (x)          (*     x     x))
```

⇨ a procedure ⇨ that takes one argument ⇨ and multiplies ⇨ it ⇨ by itself

Using `lambda` with `define`

- **These are the same:**

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


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

The top form is just a shortcut, really, for the bottom form. We would get tired having to type l-a-m-b-d-a all the time, so the above form is quicker.

Using `lambda` with `define`

- **These are VERY DIFFERENT:**

```
(define (adder-1 y)
   (lambda (x) (+ x 1)))


(define adder-2
   (lambda (x) (+ x 1)))
```

adder1 takes a single argument and returns a procedure (that takes a single argument and returns 1 more than it)

adder2 takes a single argument and returns one more than it.

Can a `lambda`-defined function be recursive?

```
(lambda (sent)
  (if (empty? sent)
      '()
      (se (square (first sent))
          (???? (bf sent)))))
```

In cs3, nope.

But, you will find a way to make recursive lambda (non-named) functions if you continue in CS. (You might google for '"anonymous recursion" in scheme' or something like that).

When do you NEED lambda?

1. **When you need the context (inside a two-parameter procedure)**

```
(add-suffix '-is-great '(haddad sam mary))
    ➔ (haddad-is-great sam-is-great
       mary-is-great)
```

3. **When you need to make a function on the fly**

```
(define (add-suffix suf sent)
  (every
    (lambda (wd)
      (word wd suf)
                )
    sent))
```

Problems

Click to add text

Hangman-status

```
(hangman-status 'joebob 'abcde)
  → __eb_b
```

```
(define (hangman-status secret-wd ltrs)
   ???
   )
```

```
(define (hangman-status secret-wd ltrs)
  (accumulate
   word
   (every (lambda (ltr)
                  (if (member? ltr ltrs)
                              ltr
                              '_))
                secret-wd)
  ) )
```

Write `successive-concatenation`

```
(sc '(a b c d e))
➔  (a ab abc abcd abcde)

(sc '(the big red barn))
➔ (the thebig thebigred thebigredbarn)
```

```
(define (sc sent)
   (accumulate
      (lambda ??
         )
      sent))
```

Email me for the solution if you want it before next lecture!