

Programming Abstractions

Week 3-1: Map and Apply

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Map: the simple case

(map proc lst)

map applies the procedure `proc` to every element in list `lst`

```
(map f '(1 2 3 4)) => (list (f 1) (f 2) (f 3) (f 4))
```

```
(map sub1 '(10 15 20)) => '(9 14 19)
```

```
(map (λ (x) (list x x)) '(a b c)) => '((a a) (b b) (c c))
```

```
(map first '((a 5) (b 6) (c 7))) => '(a b c)
```

What is the result of this?

```
(map rest '( (a 5) (b 6) (c 7) ))
```

A. '((5) (6) (7))

B. '(5 6 7)

C. '((b 6) (c 7))

D. '(5) '(6) '(7)

E. '(b c)

What is the result of this?

```
(map (λ (lst) (cons (first lst) lst))  
      '((1 2) (3 4)))
```

A. ' (1 3)

B. ' ((1 1 2) (3 3 4))

C. ' ((1 (1 2)) (3 (3 4)))

D. ' ((1 4) (2 3))

E. ' ((1 3) (2 4))

How would we implement map?

Non-tail-recursive

- Simple, clear

Tail-recursive

- Use an accumulator to hold the reversed results, then reverse

General map

(map proc lst1 lst2 ... lstn)

If `proc` is a procedure of n arguments, then `map` will apply `proc` to corresponding elements n lists (which all have the same length)

`(map f '(a b c) '(1 2 3)) => (list (f 'a 1) (f 'b 2) (f 'c 3))`

`(map cons '(a b c) '(x y z)) => '((a . x) (b . y) (c . z))`

`(map list '(a b) '(c d) '(e f)) => '((a c e) (b d f))`

`(map * '(0 1 2) '(3 4 5) '(6 7 8)) => '(0 28 80)`

How would we implement the general map?

Two issues

- ▶ How do we write a procedure that takes a variable number of arguments?
- ▶ How do we apply a procedure to a variable number of arguments?

Aside: parameters vs. arguments

```
(define (foo x y z) ...)
```

```
(foo 1 5 'blarg)
```

Parameters

Arguments

Parameters: The **identifiers** that appear in the definition of procedures

Arguments: The **values** that are passed to the procedure

When a procedure is called, the parameters will be bound to the corresponding arguments

Variable argument procedure

```
(define foo ( $\lambda$  params body))
```

When `params` is a **list of identifiers**, the identifiers are bound to the values of the procedure's arguments

When `params` is an **identifier** (i.e., not a list), then the identifier is bound to a list of the procedure's arguments

```
(define count-args  
  ( $\lambda$  params  
    (length params)))  
  
(count-args 'a 2 #f) => 3
```

```
(define list  
  ( $\lambda$  elements elements))
```

Required parameters + variable parameters

```
(define foo ( $\lambda$  (x y z . params) body))
```

Separate the required parameters from the list of variable parameters with a period

```
(define drop-2  
  ( $\lambda$  (x y . lst) lst))
```

```
(drop-2 1 2 3 4)
```

- ▶ x is bound to 1
- ▶ y is bound to 2
- ▶ lst is bound to (list 3 4)

Aside: The period syntax make some sense

Recall that `' (x . y)` is a pair (i.e., `(cons 'x 'y)`)

A list is either empty or it's a pair `(x . lst)` where `lst` is a list

The list `' (x y z)` is the shorthand notation for `' (x . (y z))`

`' (y z)` is shorthand for `' (y . (z))` and `' (z)` is shorthand for `' (z . ())`

Lots of equivalent ways to write `' (x y z)`

- ▶ `' (x . (y z))`
- ▶ `' (x y . (z))`
- ▶ `' (x y z . ())`
- ▶ `' (x . (y . (z . ())))`
- ▶ `' (x y . (z . ()))`

Variable argument procedure with define

```
(define (foo . params) body)
```

```
(define (count-args . args)  
  (length args))
```

With some required parameters

```
(define (drop-2 x y . others)  
  others)
```

Applying a procedure to a list of arguments

`(apply proc lst)`

Applies `proc` to the arguments in `lst`

```
(define (maximum lst)
```

```
  (apply max lst))
```

```
(maximum '(1 3 4 2)) => (apply max '(1 3 4 2))
```

```
                    => (max 1 3 4 2)
```

```
                    => 4
```

```
(define (sum lst)
```

```
  (apply + lst))
```

```
(sum '(1 2 3)) => (apply + '(1 2 3)) => (+ 1 2 3) => 6
```

Applying with some fixed arguments

`(apply proc v... lst)`

`apply` takes a variable number of arguments where the final one is a list and applies `proc` to all of those arguments

`(apply proc 1 2 3 '(4 5 6)) => (proc 1 2 3 4 5 6)`

If `lst` is a list of integers and you want to get a list with all of the integers doubled (i.e., `' (1 2 3) -> ' (2 4 6)`), which should you use?

A. `(* 2 lst)`

B. `(apply (λ (x) (* 2 x)) lst)`

C. `(map (λ (x) (* 2 x)) lst)`

D. `(apply * 2 lst)`

E. `(map * 2 lst)`

How would you write a procedure that maps a procedure over each of a variable number of arguments, returning the result as a list? E.g.,

```
(map-over add1 1 3 5 7) -> '(2 4 6 8)
```

A.

```
(define (map-over f lst)
  (map f lst))
```

B.

```
(define (map-over f lst)
  (apply f lst))
```

C.

```
(define (map-over f . lst)
  (map f lst))
```

D.

```
(define (map-over f . lst)
  (apply f lst))
```


If `foo` is a procedure that takes a variable number of arguments and `lst` is a list of arguments you want to pass to `foo`, how do you do it?

E.g., if `lst` is `'(a b c)`, you want to call `(foo 'a 'b 'c)`.

A. `(map foo lst)`

B. `(apply foo lst)`

C. `(map (λ (x) (apply foo x)) lst)`

D. `(apply (λ (x) (map foo x)) lst)`

E. This is not possible

Distance of a 2-d point from the origin

Recall that a point (x, y) lies $\sqrt{x^2 + y^2}$ from the origin

Let's make a procedure to compute this

```
(define (distance-from-origin x y)
  (sqrt (+ (* x x) (* y y))))
```

```
(distance-from-origin 3 4) => 5
```

Distance of a 2-d point from the origin

```
(define (distance-from-origin x y)
  (sqrt (+ (* x x) (* y y))))
```

If we have a point

```
(define p '(5 -8))
```

how can we get its distance from the origin? We can't use

```
(distance-from-origin p)
```

We can use apply

```
(apply distance-from-origin p)
```

Of course, we could also do

```
(distance-from-origin (first p) (second p))
```

Using map and apply together

Let's sum up all numbers in a structured (i.e., non-flat) list

```
(define (sum-all x)
  (cond [(number? x) x]
        [(list? x) (apply + (map sum-all x))]
        [else
         (error 'sum-all
                "~v isn't a number or list"
                x)]))
```

```
(sum-all '(1 2 (3 4 (5) () 6) 8)) => 29
```

```
(sum-all '(1 2 (x))) => sum-all: 'x isn't a number or list
```

Thinking through the general map

```
(map proc lst1 lst2 ... lstn)
```

We can use a variable-argument procedure definition for map

```
(define (map proc . lsts) ...)
```

Now `lsts` is the list `(list lst1 lst2 ... lstn)`

At each step of map, we need to compute

```
(proc (first lst1) (first lst2) ... (first lstn))
```

The problem is we don't have a fixed number of lists, we just have a list of lists

Solution: write a procedure `map1` that just works with a single list

```
(apply proc (map1 first lsts))
```

gives a list containing the first element of each list

General map implementation

Give this a try on your own!

Hints

- ▶ Define a helper function `(map1 f lst)` that applies a single-argument procedure `f` to the elements of `lst`
- ▶ Write `(define (map proc . lsts) ...)`
 - Use `map1` to get the heads and tails of elements in `lsts`
 - Use `apply` to apply `proc` to the heads and cons the result onto an appropriate recursive call of `map`

```
(define (map1 f lst) ...)  
(define (map proc . lsts)  
  ... (apply proc heads) ...)
```

Now try making `map1` and `map` tail-recursive!