CSc 520

Principles of Programming Languages

7: Scheme — List Processing

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Constructing Lists

- The most important data structure in Scheme is the list.
- Lists are constructed using the function `cons`:

```
(cons first rest)
```

`cons` returns a list where the first element is `first`, followed by the elements from the list `rest`.

```
> (cons 'a '())
(a)
> (cons 'a (cons 'b '()))
(a b)
> (cons 'a (cons 'b (cons 'c '())))
(a b c)
```


Constructing Lists. . .

- There are a variety of short-hands for constructing lists.
- Lists are heterogeneous, they can contain elements of different types, including other lists.

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

> '(1 a "hello")
(1 a "hello")
```


Examining Lists

- `(car L)` returns the first element of a list. Some implementations also define this as `(first L)`.
- `(cdr L)` returns the list `L`, without the first element. Some implementations also define this as `(rest L)`.
- Note that `car` and `cdr` do not destroy the list, just return its parts.

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

Examining Lists...

- Note that `(cdr L)` always returns a list.

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


Examining Lists...

- A shorthand has been developed for looking deep into a list:

  `(clist of "a" and "d"r L)`

  Each `"a"` stands for a `car`, each `"d"` for a `cdr`.
- For example, `(caddar L)` stands for

  `(car (cdr (cdr (car L))))`

```
> (cadr '(a b c))
'b
> (cddr '(a b c))
'(c)
> (caddr '(a b c))
'c
```


Lists of Lists

- Any S-expression is a valid list in Scheme.
- That is, lists can contain lists, which can contain lists, which...

```
> '(a (b c))
(a (b c))
> '(1 "hello" ("bye" 1/4 (apple)))
(1 "hello" ("bye" 1/4 (apple)))
> (caaddr '(1 "hello" ("bye" 1/4 (apple))))
"bye"
```


List Equivalence

- `(equal? L1 L2)` does a structural comparison of two lists, returning `#t` if they "look the same".
- `(eqv? L1 L2)` does a "pointer comparison", returning `#t` if two lists are "the same object".

```
> (eqv?  '(a b c) '(a b c))
false
> (equal?  '(a b c) '(a b c))
true
```

List Equivalence. . .

- This is sometimes referred to as deep equivalence vs. shallow equivalence.

```
> (define myList '(a b c))
> (eqv? myList myList)
true
> (eqv? '(a (b c (d))) '(a (b c (d))))
false
> (equal? '(a (b c (d))) '(a (b c (d))))
true
```


Predicates on Lists

- `(null? L)` returns `#t` for an empty list.
- `(list? L)` returns `#t` if the argument is a list.

```
> (null? '())
#t
> (null? '(a b c))
#f
> (list? '(a b c))
#t
> (list? "(a b c)")
#f
```


List Functions — Examples. . .

```
> (memq 'z '(x y z w))
#t
> (car (cdr (car '((a) b (c d)))))
(c d)
> (caddr '((a) b (c d)))
(c d)
> (cons 'a '())
(a)
> (cons 'd '(e))
(d e)
> (cons '(a b) '(c d))
((a b) (c d))
```


Recursion over Lists — cdr-recursion

- Compute the length of a list.
- This is called cdr-recursion.

```
(define (length x)
   (cond
      [(null? x) 0]
      [else (+ 1 (length (cdr x)))]
   )
)

> (length '(1 2 3))
3
> (length '(a (b c) (d e f)))
3
```

ecursion over Lists — car-cdr-recursion

- Count the number of atoms in an S-expression.
- This is called car-cdr-recursion.

```
(define (atomcount x)
   (cond
      [(null?  x) 0]
      [(list?  x)
            (+ (atomcount (car x))
               (atomcount (cdr x)))]
      [else 1]
   ))
> (atomcount '(1))
1
> (atomcount '("hello" a b (c 1 (d))))
6
```


Recursion Over Lists — Returning a List

- Map a list of numbers to a new list of their absolute values.
- In the previous examples we returned an atom —here we're mapping a list to a new list.

```
(define (abs-list L)
   (cond
      [(null?  L) '()]
      [else (cons (abs (car L))
                  (abs-list (cdr L)))]
   )
)

> (abs-list '(1 -1 2 -3 5))
(1 1 2 3 5)
```


Recursion Over Two Lists

- (atom-list-eq? L1 L2) returns #t if L1 and L2 are the same list of atoms.

```
(define (atom-list-eq?  L1 L2)
   (cond
      [(and (null?  L1) (null?  L2)) #t]
      [(or (null?  L1) (null?  L2)) #f]
      [else (and
         (atom?  (car L1))
         (atom?  (car L2))
         (eqv?  (car L1) (car L2))
         (atom-list-eq?  (cdr L1) (cdr L2)))]
   )
)
```


Recursion Over Two Lists. . .

```
> (atom-list-eq?  '(1 2 3) '(1 2 3))
#t
> (atom-list-eq?  '(1 2 3) '(1 2 a))
#f
```

Append

```
(define (append L1 L2)
   (cond
      [(null? L1) L2]
      [else
         (cons (car L1)
            (append (cdr L1) L2))]
   )
)

> (append '(1 2) '(3 4))
(1 2 3 4)
> (append '() '(3 4))
(3 4)
> (append '(1 2) '())
(1 2)
```


Deep Recursion — equal?

```
(define (equal? x y)
   (or (and (atom? x) (atom? y) (eq? x y))
      (and (not (atom? x))
         (not (atom? y))
         (equal? (car x) (car y))
         (equal? (cdr x) (cdr y)))))

> (equal? 'a 'a)
#t
> (equal? '(a) '(a))
#t
> (equal? '((a)) '((a)))
#t
```


Patterns of Recursion — cdr-recursion

- We process the elements of the list one at a time.
- Nested lists are not descended into.

```
(define (fun L)
   (cond
      [(null? L) return-value]
      [else ...(car L) ...(fun (cdr L)) ...]
   )
)
```


Patterns of Recursion — car-cdr-recursion

- We descend into nested lists, processing every atom.

```
(define (fun x)
   (cond
      [(null? x) return-value]
      [(atom? x) return-value]
      [(list? x)
            ...(fun (car x)) ...
            ...(fun (cdr x)) ...]
      [else return-value]
   ))
```

Patterns of Recursion — Maps

- Here we map one list to another.

```
(define (map L)
   (cond
      [(null?  L) '()]
      [else (cons (...(car L) ...)
                  (map (cdr L)))]
   )
)
```


Example: Binary Trees

- A binary tree can be represented as nested lists:

  `(4 (2 () () ( 6 ( 5 () ()) ())))`

- Each node is represented by a triple

  (*data left-subtree right-subtree*)

- Empty subtrees are represented by `()`.

Example: Binary Trees. . .

```
(define (key tree) (car tree))
(define (left tree) (cadr tree))
(define (right tree) (caddr tree))

(define (print-spaces N)
   (cond
      [(= N 0) ""]
      [else (begin
         (display " ")
         (print-spaces (- N 1)))]))

(define (print-tree tree)
   (print-tree-rec tree 0))
```


Example: Binary Trees. . .

```
(define (print-tree-rec tree D)
   (cond
      [(null?  tree)]
      [else (begin
         (print-spaces D)
         (display (key tree)) (newline)
         (print-tree-rec (left tree) (+ D 1))
         (print-tree-rec (right tree) (+ D 1))
)]))

> (print-tree '(4 (2 () ()) (6 (5 () ()) ())))
4
   2
   6
      5
```

Binary Trees using Structures

- We can use structures to define tree nodes.

```
(define-struct node (data left right))

(define (tree-member x T)
   (cond
      [(null?  T) #f]
      [(= x (node-data T)) #t]
      [(< x (node-data T))
         (tree-member x (node-left T))]
      [else
         (tree-member x (node-right T))]
   )
)
```


Binary Trees using Structures. . .

```
(define tree
    (make-node 4
       (make-node 2 '() '())
       (make-node 6
          (make-node 5 '() '())
          (make-node 9 '() '())))))

> (tree-member 4 tree)
true
> (tree-member 5 tree)
true
> (tree-member 19 tree)
false
```


Homework

- Write a function `swapFirstTwo` which swaps the first two elements of a list. Example: `(1 2 3 4)` ⇒ `(2 1 3 4)`.
- Write a function `swapTwoInLists` which, given a list of lists, forms a new list of all elements in all lists, with first two of each swapped. Example: `((1 2 3) (4) (5 6))` ⇒ `(2 1 3 4 6 5)`.