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Giving a Name to a Function

The problem with the use of lambda expressions is that the function specified by a lambda expression has to be re-specified every time it is used.

What is needed is a way of associating a name to a function defined in terms of a list of atoms that specify function arguments and a body that is the function definition itself, without immediately evaluating the list of arguments or the body.

defun -- this special form function returns the name of a function just defined and as a side effect associates the function with the name:

```
(defun name arg-list   s-exprs )
```


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Examples

```
-->(defun  abs  (n)  ( if  ( > n 0 ) n ( -n)))
abs
-->  (abs 6)
6
-->  (abs  (- 6)
6
```

A `defun`-ed function can be used like any built-in or predefined function

Another example:

```
-->  (defun fact  (x)
     (cond
       ((= x   1)  1)
       (t (* x  (fact  (- x 1))))))
fact
-->  (fact 5)
120
```


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Optional Parameters

Optional parameters for a function can be defined by marking the optional parameters with the special symbol `&optional`. For example

```
--> (defun root (x &optional n)
      (if n
         (expt x (/ 1 n))
         (sqrt x)))
root
--> (root 9)
3.0              ;; n is bound to nil
--> (root 27 3)
?
```

There are a number of other special-purpose parameter types, including `&rest`, which allows the binding of a variable number of arguments to a single parameter. For example, if

```
(defun raise (x &rest numbers)
   (raiseAux x numbers)
```

`(raise (2 3 5))` calls `(raiseAux 2 (3 5))`

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Recursion

Lisp uses recursion as a basic control facility in the same way other, more conventional, languages use iteration of one form or another.

A recursive function `f` includes in its definition directly or indirectly forms that use `f`.

For a form evaluation involving a recursive function to eventually terminate, the *size* of the arguments of recursive function calls should be "smaller" than the original call.

For example,

```
(defun fact (x)
    (cond
      ((= x  1)  1)
      (t    (* x (fact (- x 1))))))
```


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Writing Recursive Functions

The body of a simple recursive function has the following structure:

```
(cond (simpleCase1 nonRecursiveValue1)
      (simpleCase2 nonRecursiveValue2)
                   .  .  .
      (hardCase1 f1 Ô recursiveCall1)
      (hardCase2 f2 Ô recursiveCall2)
                   .  .  .
   )
```

Where Ô is a composition operator. For example, the body of `fact`:

```
(cond  ((= x 1)  1  )
       (t        (* n (fact (-  n 1)))))
```

Here the composition operator is `*`

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Writing Recursive Functions: The Simple Cases

All recursive functions consist of one or more *simple cases* that require no further recursion.

The *simple case* in `fact` is `(= x 1)`.

The *non-recursive value* is `1` (according to the definition of factorial).

Trivial cases are often defined in terms of `atom`, `nil`, `0`, `1`, along with some builtin function

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Writing Recursive Functions: Reduction Operators

Hard Cases are dealt through reduction and composition

• Reduce the hard case to a somewhat less hard case.

For example we know how to compute `(fact x)` in terms of `(fact (- x 1))`, or we know that to search for something in a list we have to look at the head and then the rest of the list. Here the reduction operator is subtraction.

More generally, we can try to apply a reduction operator to the value of the parameters, hoping that if repeatedly applied, will eventually turn into a simple case.

For example, in `fact` the reduction operator is to decrement `x` by `1`. When searching a list, the reduction operator could be `rest`

Reduction Operator: `car`, `cdr`, `−1`, `÷2`,

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Writing Recursive Functions: Composition Operators

• Apply a composition operator to the value returned by the somewhat less hard case and return the result.

For example, in `fact` the composition operator is to multiply by `x`. When searching a list, the composition operator simply returns the recursive call case, i.e., is the identity function.

Composition Operator: `cons`, `+`, `*`, identity function,...

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Types of Recursion: `car` Recursion

Reduction by `first` (`car`): Trivial case is typically an atom.

For example: The **`very-first`** function finds the very first atom of an s-expr

```
very-first of a                is a
very-first of ((b) (a c))      is b
very-first of (() (((v) v)))   is nil
```

```
(defun very-first (x)
   (cond    ((atom x) x)
            (t    (very-first (car x)))))
```

```
very-first of ((b) (a c))
   very-first of (b)
      very-first of b
         returns    b
      returns    b
   returns    b
```


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Types of Recursion: `cdr` Recursion

Trivial case is typically the empty list. For example, `append` is a function with two arguments `l1` and `l2`:

```
(append '(a b c) '(d e) )  is  (a b c d e)
(append () '(x y) )        is  (x y)
(append  '((a) b) () )     is  ((a) b)
```

• **Trivial Case:** If `l1` is null, then the value is `l2`

• **Reduction Operator:** Assume `append` can append the rest of `l1`.

For example, consider `append` of `(a b c)` and `(d e)`. Reduce the problem by using `rest` to append `(b c)` and `(d e)`:

• **Composition Operator:** `cons` will do!
`(cons (car l1) *reduced-value*)`
e.g., `(cons 'a '(b c d e))` is `(a b c d e)`

```
(defun  append  (l1 l2)
  (cond ((null l1) l2)
     (t (cons   (first  l1)
           (append  (rest  l1) l2)))))
```


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Types of Recursion: Double Recursion with `car/cdr` Reduction

Reduction by `car` and `cdr`. Trivial case is an atom or the empty list. For example, `equal` (discussed earlier) can be defined as follows:

```
(defun mequal(x y)
 (cond
     ((atom x) (cond
                  ((atom y)(eql x y))
                  (t nil)))
     ((atom y)  nil)
     ((mequal (car x) (car y))
             (mequal (cdr x) (cdr y)))
     ( t      nil)  ))
```

The first two `cond` forms are simple cases, the third clause is a conjunction of reduced cases:

```
(defun  mequal  (x y)
  (cond ((atom x)(and (atom y) (eql x y)))
        ((atom y)  nil)
        (t (and  (mequal (car x)  (car y))
           (mequal (cdr x)  (cdr y)) )) ))
```


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Types of Recursion: Tail Recursion

The composition function here is the identity function. Functions with tail recursion may also be categorized as using `cdr` recursion, `car` recursion or `cdr/car` recursion. These functions have (potentially) efficient execution.

For example `all-atomp` determines whether each member of a list is an atom:

```
(all-atomp  '(a b c))      is    t
(all-atomp  '(a (b c)))    is    nil
(all-atomp   nil)          is    t

(defun     all-atomp  (s)
 (cond  ((null  s)   t)
        ((not (atom (first s)))   nil)
        (t  (all-atomp ( rest s)))))
```

Note that `all-atomp` uses `rest` recursion.

Tail recursion is efficient as the value returned by the innermost `all-atomp` call is simply passed to the outermost `all-atomp` call.

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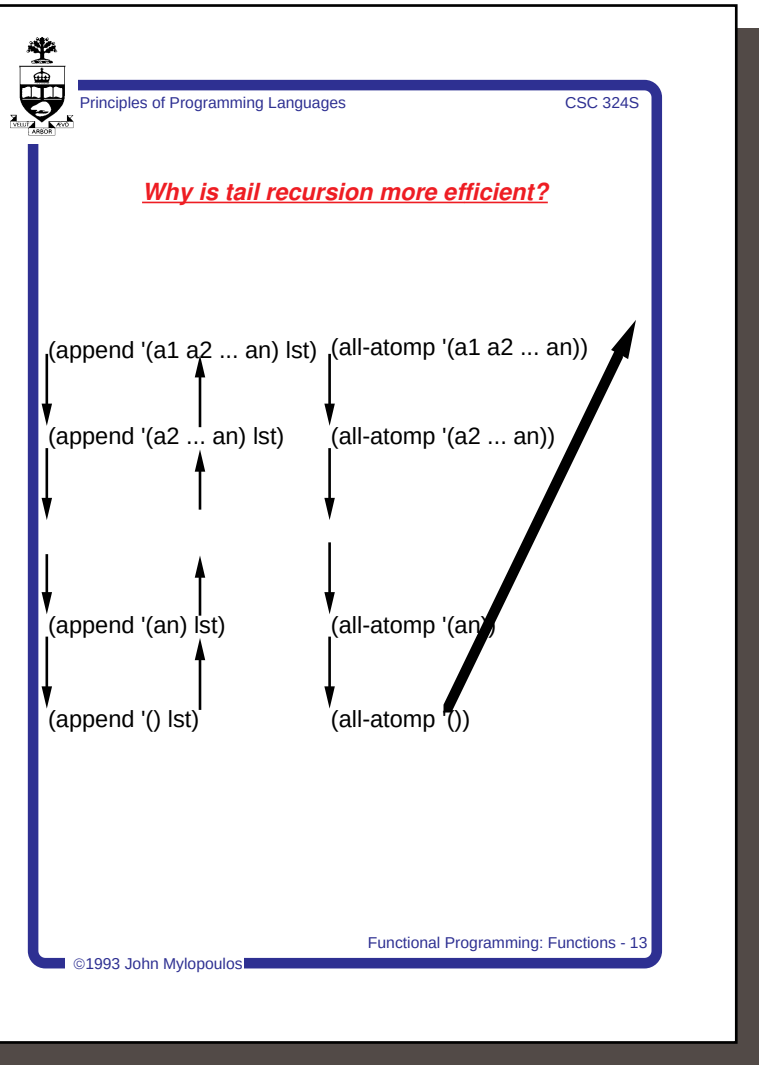
Principles of Programming Languages
CSC 324S
Why is tail recursion more efficient?
(append '(a1 a2 ... an) lst)
(append '(a2 ... an) lst)
(append '(an) lst)
(append '() lst)
(all-atomp '(a1 a2 ... an))
(all-atomp '(a2 ... an))
(all-atomp '(an))
(all-atomp '())
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