



CSE341: Programming Languages Lecture 14 Thunks, Laziness, Streams, Memoization

Dan Grossman Spring 2016

Delayed evaluation

For each language construct, the semantics specifies when subexpressions get evaluated. In ML, Racket, Java, C:

- Function arguments are eager (call-by-value)
 - Evaluated once before calling the function
- Conditional branches are not eager

It matters: calling factorial-bad never terminates:

Thunks delay

We know how to delay evaluation: put expression in a function!

- Thanks to closures, can use all the same variables later

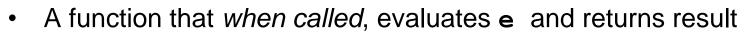
A zero-argument function used to delay evaluation is called a *thunk*

- As a verb: thunk the expression

This works (but it is silly to wrap if like this):

The key point

• Evaluate an expression **e** to get a result:



- Zero-argument function for "thunking"

(lambda () e)

e

• Evaluate e to some thunk and then call the thunk

(e)

- Next: Powerful idioms related to delaying evaluation and/or avoided repeated or unnecessary computations
 - Some idioms also use mutation in encapsulated ways

Spring 2016

Avoiding expensive computations

Thunks let you skip expensive computations if they are not needed

Great if take the true-branch:

(define (f th) (if (...) 0 (... (th) ...)))

But worse if you end up using the thunk more than once:

```
(define (f th)
  (... (if (...) 0 (... (th) ...))
      (if (...) 0 (... (th) ...))
      ...
      (if (...) 0 (... (th) ...))))
```

In general, might not know many times a result is needed

Spring 2016

CSE341: Programming Languages

Best of both worlds

Assuming some expensive computation has no side effects, ideally we would:

– Not compute it *until needed*

- Remember the answer so future uses complete immediately Called *lazy evaluation*

Languages where most constructs, including function arguments, work this way are *lazy languages*

– Haskell

Racket predefines support for promises, but we can make our own

– Thunks and mutable pairs are enough

Delay and force

```
(define (my-delay th)
 (mcons #f th))
(define (my-force p)
 (if (mcar p)
    (mcdr p)
    (begin (set-mcar! p #t)
        (set-mcdr! p ((mcdr p)))
        (mcdr p))))
```

An ADT represented by a mutable pair

- **#f** in *car* means *cdr* is unevaluated thunk
 - Really a one-of type: thunk or result-of-thunk
- Ideally hide representation in a module

Using promises

(define (f p) (... (if (...) 0 (... (my-force p) ...)) (if (...) 0 (... (my-force p) ...)) ... (if (...) 0 (... (my-force p) ...))))

(f (my-delay (lambda () e)))

Lessons From Example

See code file for example that does multiplication using a very slow addition helper function

- With thunking second argument:
 - Great if first argument 0
 - Okay if first argument 1
 - Worse otherwise
- With precomputing second argument:
 - Okay in all cases
- With thunk that uses a promise for second argument:
 - Great if first argument 0
 - Okay otherwise

Streams

- A stream is an *infinite sequence* of values
 - So cannot make a stream by making all the values
 - Key idea: Use a thunk to delay creating most of the sequence
 - Just a programming idiom
- A powerful concept for division of labor:
 - Stream producer knows how to create any number of values
 - Stream consumer decides how many values to ask for

Some examples of streams you might (not) be familiar with:

- User actions (mouse clicks, etc.)
- UNIX pipes: cmd1 | cmd2 has cmd2 "pull" data from cmd1
- Output values from a sequential feedback circuit

Using streams

We will represent streams using pairs and thunks

Let a stream be a thunk that *when called* returns a pair: (next-answer . next-thunk)

So given a stream s, the client can get any number of elements

- First: (car (s))
- Second: (car ((cdr (s))))
- Third: (car ((cdr ((cdr (s))))))

(Usually bind (cdr (s)) to a variable or pass to a recursive function)

Example using streams

This function returns how many stream elements it takes to find one for which tester does not return **#f**

- Happens to be written with a tail-recursive helper function

- (stream) generates the pair
- So recursively pass (cdr pr), the thunk for the rest of the infinite sequence



Coding up a stream in your program is easy

- We will do functional streams using pairs and thunks

Saw how to use them, now how to make them...

- Admittedly mind-bending, but uses what we know

Making streams

- How can one thunk create the right next thunk? Recursion!
 - Make a thunk that produces a pair where cdr is next thunk
 - A recursive function can return a thunk where recursive call does not happen until thunk is called

```
(define ones (lambda () (cons 1 ones)))
(define nats
  (letrec ([f (lambda (x)
                         (cons x (lambda () (f (+ x 1))))])
      (lambda () (f 1))))
(define powers-of-two
  (letrec ([f (lambda (x)
                         (cons x (lambda () (f (* x 2))))])
      (lambda () (f 2))))
```

Getting it wrong

• This uses a variable before it is defined

(define ones-really-bad (cons 1 ones-really-bad))

• This goes into an infinite loop making an infinite-length list

(define ones-bad (lambda () cons 1 (ones-bad)))
(define (ones-bad) (cons 1 (ones-bad)))

• This is a stream: thunk that returns a pair with cdr a thunk

(define ones (lambda () (cons 1 ones)))
(define (ones) (cons 1 ones))

Memoization

- If a function has no side effects and does not read mutable memory, no point in computing it twice for the same arguments
 - Can keep a cache of previous results
 - Net win if (1) maintaining cache is cheaper than recomputing and (2) cached results are reused
- Similar to promises, but if the function takes arguments, then there are multiple "previous results"
- For recursive functions, this *memoization* can lead to *exponentially* faster programs
 - Related to algorithmic technique of dynamic programming

How to do memoization: see example

- Need a (mutable) cache that all calls using the cache share
 So must be defined *outside* the function(s) using it
- See code for an example with Fibonacci numbers
 - Good demonstration of the idea because it is short, but, as shown in the code, there are also easier less-general ways to make fibonacci efficient
 - (An association list (list of pairs) is a simple but sub-optimal data structure for a cache; okay for our example)

assoc

• Example uses **assoc**, which is just a library function you could look up in the Racket reference manual:

(assoc v lst) takes a list of pairs and locates the first element of lst whose car is equal to v according to isequal?. If such an element exists, the pair (i.e., an element of lst) is returned. Otherwise, the result is #f.

 Returns #f for not found to distinguish from finding a pair with #f in cdr