CSE341: Programming Languages

Lecture 14
Thunks, Laziness, Streams, Memoization

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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:

```
(define (my-if-bad x y z)   
  (if x y z))

(define (factorial-bad n)   
  (my-if-bad (= n 0)  
    1  (* n (factorial-bad (- n 1)))))
```
**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):

```
(define (my-if x y z)
  (if x (y) (z)))

(define (fact n)
  (my-if (= n 0)
    (lambda() 1)
    (lambda() (* n (fact (- n 1)))))
```
The key point

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

  $e$

• A function that *when called*, evaluates $e$ and returns result
  – Zero-argument function for “thunking”

  `(lambda () 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
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
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 \texttt{s}, the client can get any number of elements

- First: \texttt{(car (s))}
- Second: \texttt{(car ((cdr (s))))}
- Third: \texttt{(car ((cdr ((cdr (s))))))}

(Usually bind \texttt{(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

```
(define (number-until stream tester)
  (letrec ([f (lambda (stream ans)
                (let ([pr (stream)])
                  (if (tester (car pr))
                      ans
                      (f (cdr pr) (+ ans 1)))))])
    (f stream 1)))
```

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

Coding up a stream in your program is easy
  – We will do functional streams using pairs and thunks

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

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 \texttt{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 **is-equal?**. 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