



# 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:

## 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):

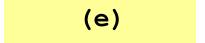
## The key point

Evaluate an expression e to get a result:

е

- A function that when called, evaluates e and returns result
  - Zero-argument function for "thunking"

Evaluate e to some thunk and then call the thunk



- 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

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 ((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

## 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

# 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 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