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*The cheapest, fastest and most reliable components of a computer system are those that aren't there.*

This has a parallel in data structures:

*The fastest, most parsimonious, and best performing data structure is one which is never concretized. A promise to create data when—or if—it is needed is often easy to make.*
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Complex lazy data structures may require special design in order to encapsulate more complex promises than one can make with list-like iterators.
Review of laziness

Examples from Functional Programming Languages

Generic *any language* laziness

Iterators and the *itertools* module

Generators and generator expressions

Memoization and the *weakref* module

Laziness in a directed acyclic graph

Miscellaneous exoterica

(but not necessarily in the order listed)
Laziness in a *really* lazy language (Haskell)

```haskell
module Bounce where

bounce :: Int -> Int
bounce n = (n*379 + 522) `mod` 100000

bseq :: Int -> [Int]
bseq init = bounce init : map bounce (bseq init)
```

Bounce> take 8 (bseq 1)
[901,42001,18901,64001,56901,66001,14901,48001]
Bounce> bseq 1 !! 750
50901

(imagine **Bounce** as a really crude stand-in for, e.g. cipher-block chaining)
Laziness by declaration of promises (Scheme)

```
▶ (define (bounce n) (modulo (+ (* n 379) 522) 100000))
▶ (define (bseq n) (let ((next (bounce n)))
                          (cons next (delay (bseq next)))))
▶ (display (car (bseq 1)))
901
▶ (display (cdr (bseq 1)))
#<promise:Bounce:4:53>
▶ (display (force (cdr (bseq 1))))
(42001 . #<promise:Bounce:4:53>)
```
Iterators and Generators (remember 2001?)

Iterators and generators are “sequence-like”

Potentially infinite length
Only need to concretize one element at a time
Hence cannot slice or index (*but wait a few slides*)

An iterator is an object that has the methods `.next()` and `.__iter__()`. That's all!

A generator is a powerful type of iterator: a *resumable function*!

Not quite a continuation, but more than a closure
Iterators and Generators: An iterator example

class Iterator(object):
    def __init__(self, init=1, stop=None):
        self.n, self.stop = init, stop

    def next(self):
        if self.n == self.stop:
            raise StopIteration
        self.n = (self.n*379 + 522) % 100000
        return self.n

    def __iter__(self):
        return self

(remember that this is our crude stand-in for something expensive)
Iterators and Generators: A generator example

```python
def generator(init=1, stop=None):
    n = init
    while n != stop:
        n = (n*379 + 522) % 100000
        yield n
```

```python
>>> for n in generator():  # for n in Iterator():
...    if not something_about(n):
...        break
...    do_stuff(n)  # return n w/ side effect
```
Iterators and Generators: `itertools` module

```python
>>> while n in generator():
...     if not something_about(n): break
...     do_stuff(n)  # return n w/ side effect

>>> from itertools import *

>>> ready = imap(do_stuff, takewhile(
...     something_about, generator()))

>>> ready
<itertools.imap object at 0x19af890>

>>> list(ready)  # for n in ready: print n,
[901, 42001, 18901, 64001, 56901, 66001, 14901, 48001]
```
>>> from itertools import *
>>> slice50_55 = islice(generator(), 50, 55)
>>> slice50_55
<itertools.islice object at 0x19a3ab0>
>>> list(slice50_55)
[50901, 92001, 68901, 14001, 6901]
>>> list(slice50_55)
[]
>>> g = generator(); list(islice(g, 3))

(what do we expect g to do if we keep islice()'ing it?)
Iterators and Generators: generator expressions

# Cannot use listcomp on infinite generator
# E.g. [n**2 for n in generator() if n%3] blows up!
>>> not_div3 = (n**2 for n in generator() if n % 3)
>>> not_div3
<generator object <genexpr> at 0x21bab70>
>>> from itertools import *
>>> list(islice(not_div3, 3, 6))
[2704104001L, 2199703801L, 5776152001L]
Things to avoid doing

(... at this particular moment):

Expensive computations
Concretize large data sets
Time consuming background operations
  Database queries
  Retrieving network resources
  Waiting for external events

(but the last one is the topic of some different presentation)
A minimal class for delaying expensive actions

class Promise(object):
    def __init__(self, func, *args, **kws):
        self.func = func
        self.args = args
        self.kws = kws
    def __call__(self):
        if not hasattr(self, 'val'):
            self.val = self.func(*self.args,**self.kws)
        return self.val
A minimal class for delaying expensive actions

```python
>>> from promises import *
>>> p = Promise(slow_random)
>>> p
<promises.Promise object at 0x18ebb10>
>>> p.val
AttributeError: 'Promise' object has no attribute 'val'
```

```python
>>> p()     # Eventually get the result
370754137
```

```python
>>> p()     # Immediately get the result
370754137
```
A slightly friendlier class for making promises

class Promise2(Promise):
    def forget(self):
        del self.val
    def __repr__(self):
        return repr(self())
    def __iter__(self):
        return iter(self())

#...Some more magic methods could help too

(now we can concretize with print val or for x in val)
Seamless promises inside data structures

```python
class LazyDict(dict):
    def __getitem__(self, key):
        val = dict.__getitem__(self, key)
        if isinstance(val, Promise):
            val = val()
        return val

>>> ld = LazyDict(p=Promise(slow_random), n=99)
>>> print ld, ld['p']
{'p':<Promise object at 0x195f190>, 'n':99} 189636259
```
Making promises forgetfully to save memory

import weakref

class WeakPromise(Promise):
    def __call__(self):
        if not hasattr(self, 'val'):
            val = self.func(*self.args, **self.kws)
            try:
                self.val = weakref.ref(val)
            except TypeError:
                self.val = val
        return self.val()

(notice weakref can only reference object, not int, str, etc.)
Making promises forgetfully to save memory

```python
>>> wp = WeakPromise(module.func, arg1, arg2)
>>> result = wp()
>>> print result
<module.SomeObj object at 0x1979670>
>>> print wp()
<module.SomeObj object at 0x1979670>
>>> del result
>>> print wp()
None
```

(if we want WeakPromise fulfilled anew, del wp.val)
Trading memory for computation (memoization)

```python
def memoize(fn):
    class Cached(object):
        def __init__(self, fn):
            self.fn, self.cache = fn, dict()

        def __call__(self, *args, **kws):
            key = (repr(args), repr(kws))
            self.cache[key] = self.cache.get(key) or self.fn(*args, **kws)
            return self.cache[key]

    return Cached(fn)
```

(the twin of a Promise; compute right away, but only once)
Promises in a directed acyclic graph. Each node has a value that is expensive to calculate and that depends on its parents.

>>> create_graph('A->C; A->E; B->C; ...')

(A node holds a Promise, and pointers to parents and children)
Promises in a directed acyclic graph. When a node is queried, its ancestors must be concretized.

```python
>>> query_value('G')

(A Promise is fulfilled by gaining a val attribute)
Promises in a directed acyclic graph. Changing the value of a node invalidates its descendants.

```python
>>> set_value('C')
```

(An invalid Promise might simply delete its val attribute)
Promises in a directed acyclic graph. Changing the shape of a graph might invalidate nodes.

```python
>>> disconnect('C->E'); connect('E->F; C->D')
```

(Notice that D was unfulfilled, hence has no value to invalidate)
Promises in a directed acyclic graph. Queries fulfill anew the previously invalidated promises of ancestors.

```python
>>> query_value('F')
```
Wrap-up / Questions?

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