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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:

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- 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)

```
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

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

---

```
>>> 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 1

```
>>> 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]
```

# Iterators and Generators: `itertools` module 2

```
>>> 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 1

```
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 2

```
>>> from promises import *
>>> p = Promise(slow_random)
>>> p
<promises.Promise object at 0x18ebb10>
>>> p.val
AttributeError: 'Promise' object has no attribute 'val'
>>> p()         # Eventually get the result
370754137
>>> 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

```
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 1

```
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 2

```
>>> 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
```

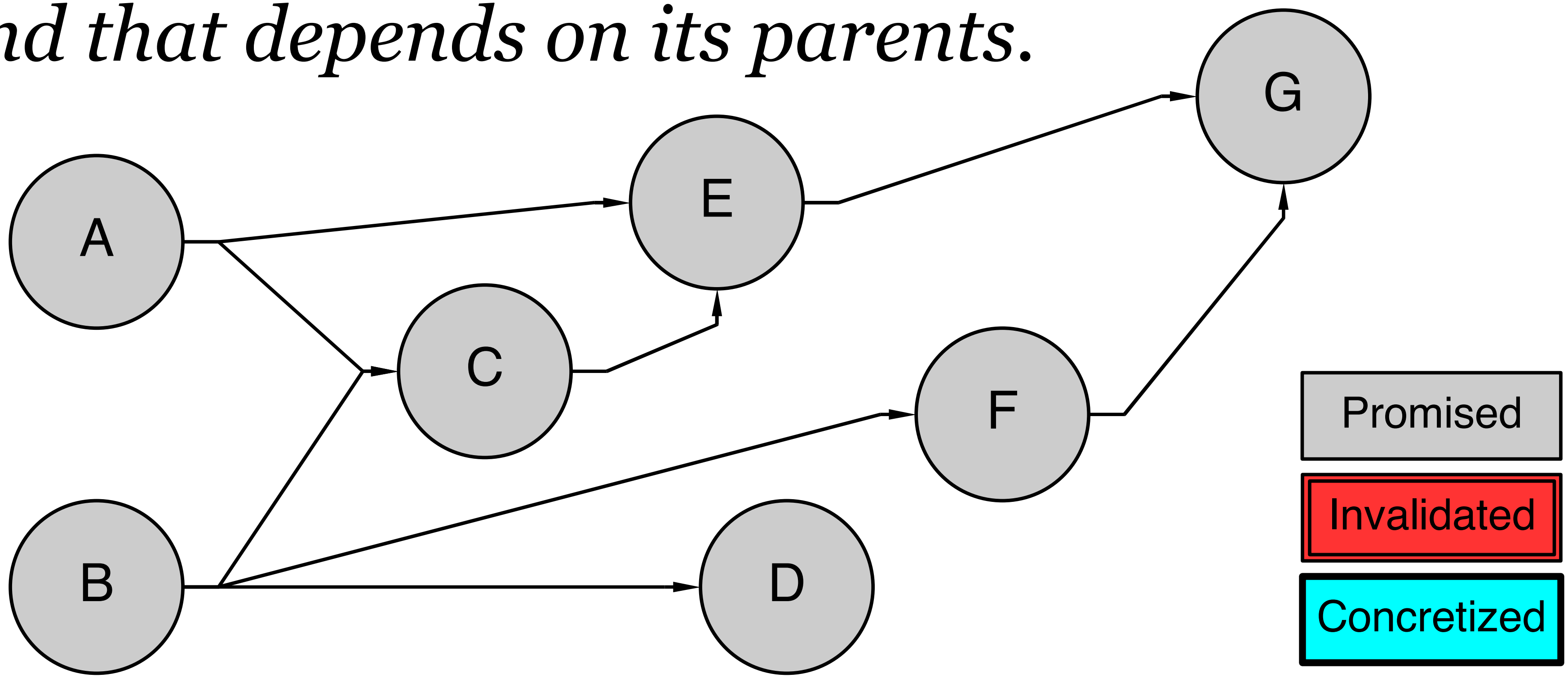
(if we want **`WeakPromise`** fulfilled anew, **`del wp.val`**)

# Trading memory for computation (memoization)

```
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)

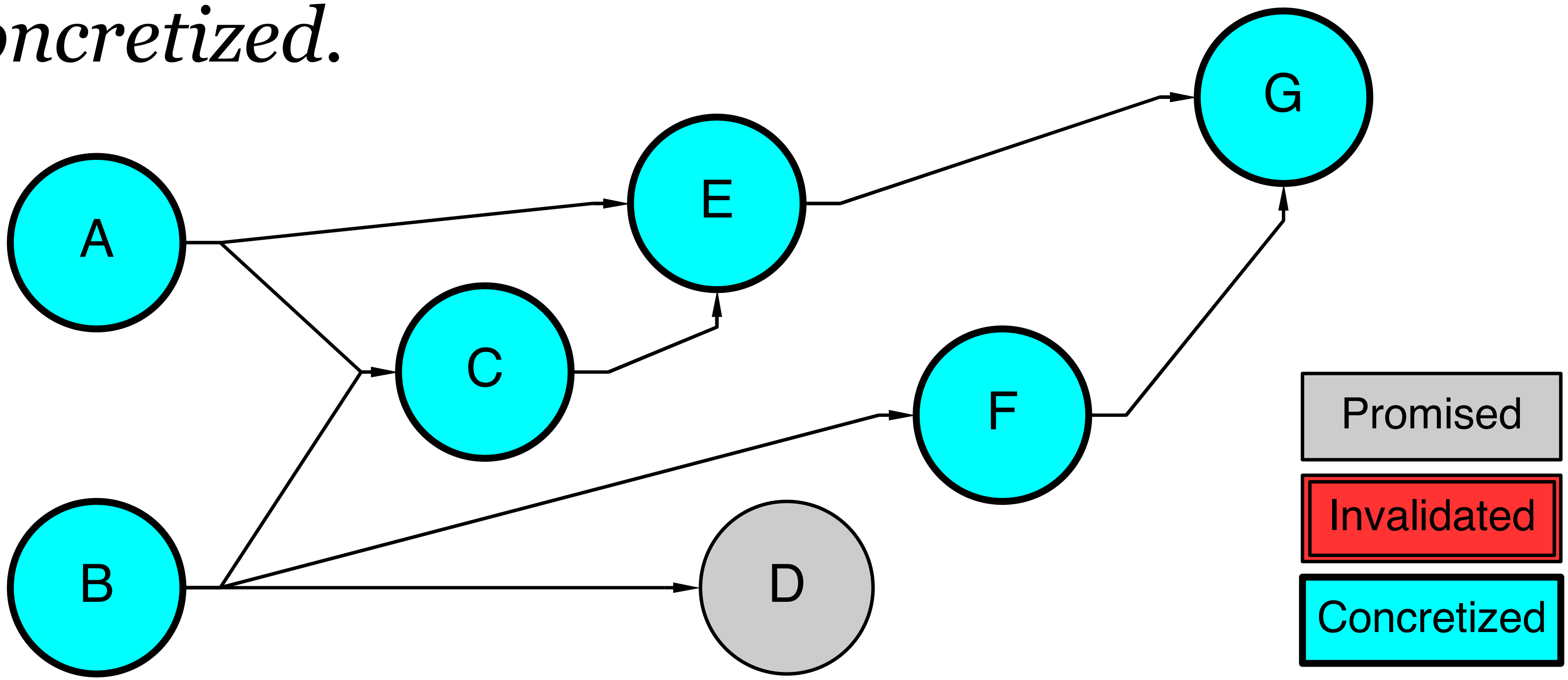
# Promises in a directed acyclic graph. *Each node has a value that is expensive to calculate and that depends on its parents.*




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

(A node holds a **`Promise`**, and pointers to parents and children)

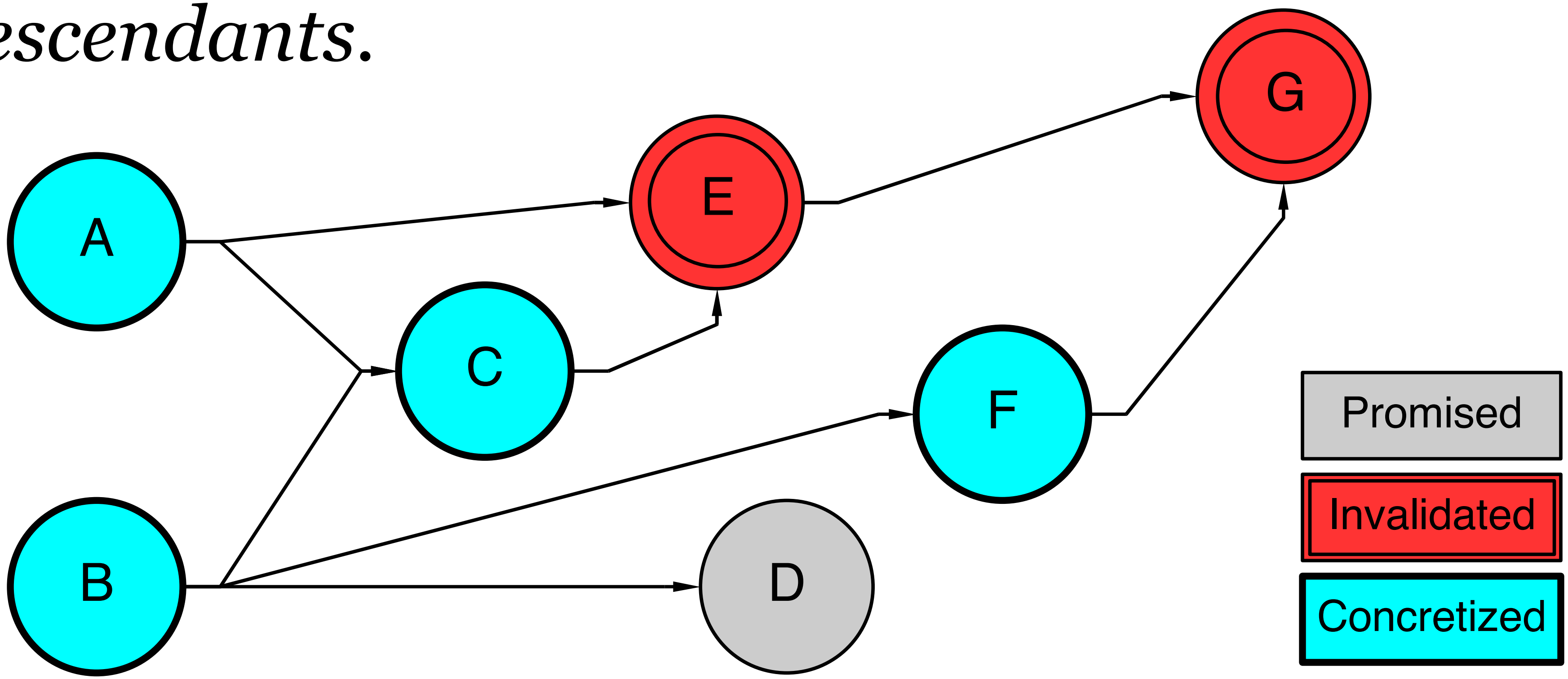
# Promises in a directed acyclic graph. *When a node is queried, its ancestors must be concretized.*




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

(A **`Promise`** is fulfilled by gaining a **`val`** attribute)

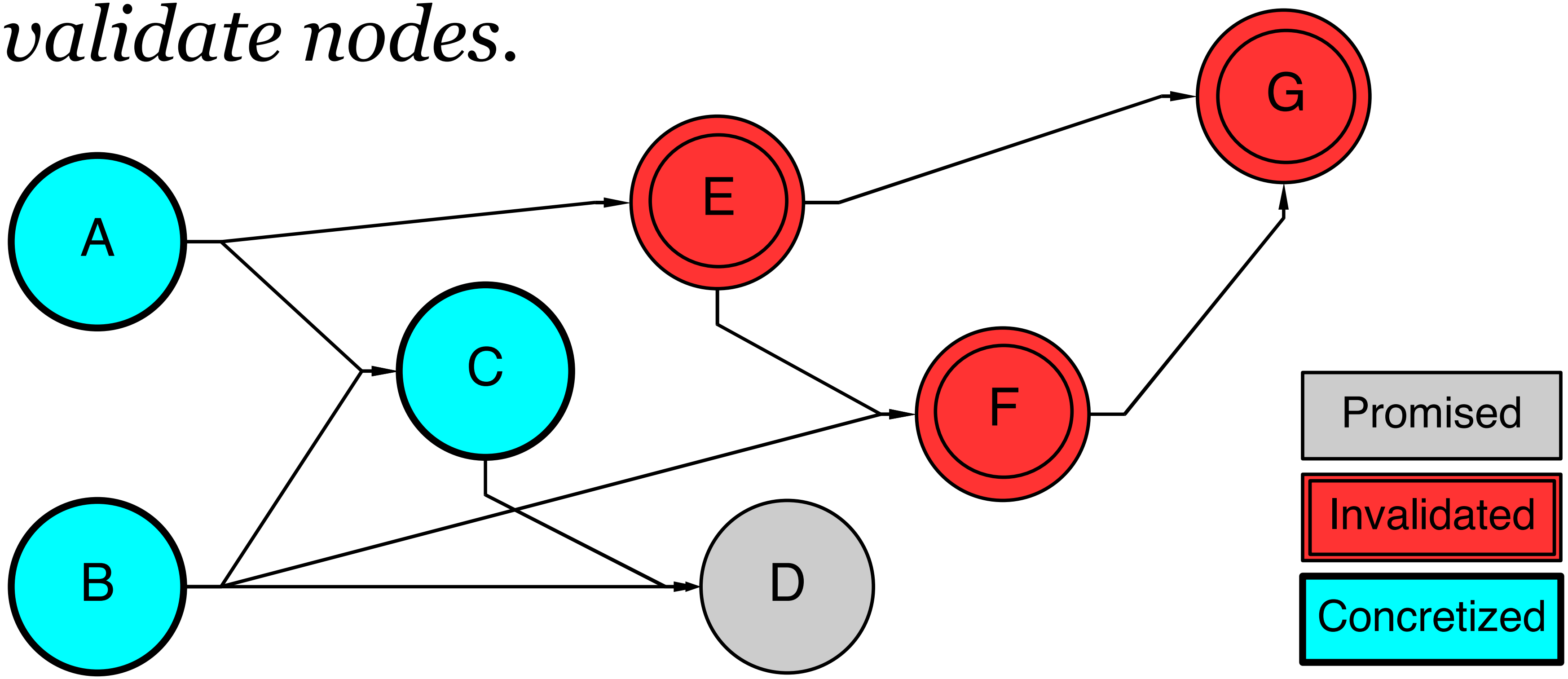
# Promises in a directed acyclic graph. *Changing the value of a node invalidates its descendants.*




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

(An invalid **Promise** might simply delete its **val** attribute)

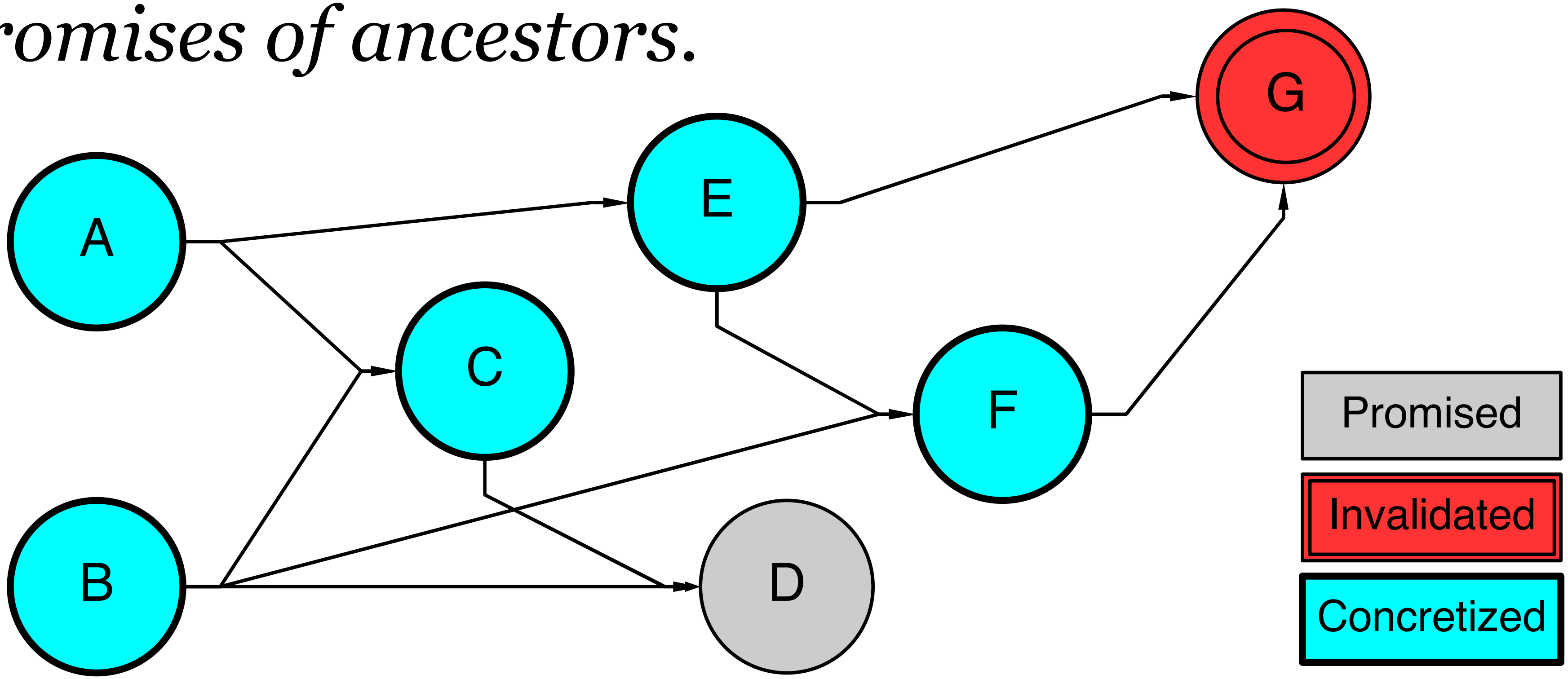
# Promises in a directed acyclic graph. *Changing the shape of a graph might invalidate nodes.*




```
>>> 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.*




```
>>> query_value('F')
```

# Wrap-up / Questions?

- *Review of laziness*
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- *Iterators and the `itertools` module*
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- *Memoization and the `weakref` module*
- *Laziness in a directed acyclic graph*