61A Lecture 34

November 21st, 2011

Last week

Distributed computing
- Client-server
- Peer-to-peer
- Message passing
- Modularity
- Interfaces

Parallel computing
- Threads
- Shared memory
- Problems: Synchronization and stale data
- Solutions: Locks, semaphores (and conditions)
- Deadlock

Sequential data

Some of the most interesting real-world problems in computer science center around sequential data.

DNA sequences

Web and cell-phone traffic streams

The social data stream

Series of measurements from instruments on a robot

Stock prices, weather patterns

So far: the sequence abstraction

Sequences have
- Length
- Element selection
- In python
  - Membership testing
  - Slicing

Data structures that support the sequence abstraction
- Nested tuples
- Tuples
- Strings
- Lists (mutable)

Problems with sequences

Memory
- Each item must be explicitly represented
- Even if all can be generated by a common formula or function

Up-front computation
- Have to compute all items up-front
- Even if using them one by one

Can't be infinite
- Why care about "infinite" sequences?
  - They're everywhere!
  - Internet and cell phone traffic
  - Instrument measurement feeds, real-time data
  - Mathematical sequences

Finding prime numbers

Sieve of Erastothenes
- Find prime numbers by walking down integers
- For each integer, eliminate all multiples of that integer
- Left with indivisible numbers
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13
- 2 3 4 5 6 7 8 9 10 11 12 13

Working example: finding prime numbers

```
def primes_sieve(limit):
    # mark all numbers as prime at first
    prime = [True] * (limit+1)
    primes = []
    # eliminate multiples of previous numbers
    for i in range(2, limit+1):
        if prime[i]:
            primes.append(i)
            multiple = i*i
            while multiple <= limit :
                prime[multiple] = False
                multiple += i
    return primes
```

sequence

sequence

primes_sieve(1000000000) anyone?
1 billion
each number = 64 bits = 8 bytes
8 bytes * 1 billion * 2 = 16 billion bytes
= ~14.9 GB of memory

Iterators: another abstraction for sequential data

Iterators

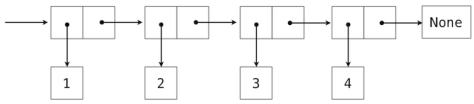
- Store how to compute items instead of items themselves
- Give out one item at a time
- Save the next until asked (lazy evaluation)

Compared with sequences

- Length not explicitly defined
- Element selection not supported
  - Element selection -- random access
  - Iterators -- sequential access
- No up-front computation of all items
- Only one item stored at a time
- CAN be infinite

Implementation: nested delayed evaluation

Nested pairs



Stream

now, explicit

store how to compute it
compute when asked

Streams


```
class Stream(object):

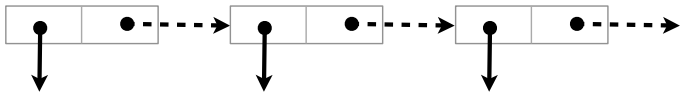
    def __init__(self, first, compute_rest, empty= False):
        self.first = first
        self._compute_rest = compute_rest
        self.empty = empty
        self._rest = None
        self._computed = False

    @property
    def rest(self):
        assert not self.empty, 'Empty streams have no rest.'
        if not self._computed:
            self._rest = self._compute_rest()
            self._computed = True
        return self._rest

empty_stream = Stream(None, None, True)
```


Sequential data: nested streams

Nest streams inside each other
Only compute one element of a sequence at a time



```
def make_integer_stream(first=1):
    def compute_rest():
        return make_integer_stream(first+1)
    return Stream(first, compute_rest)
```

live example

Prime numbers with nested streams

```
def filter_stream(filter_func, stream):
    def make_filtered_rest():
        return filter_stream(filter_func, stream.rest)
    if stream.empty:
        return stream
    if filter_func(stream.first):
        return Stream(s.first, make_filtered_rest)
    else:
        return filter_stream(filter_funct, stream.rest)

def primes(positive_ints):
    def not_divible(x):
        return (x % positive_integers.first) != 0
    def sieve():
        return primes(filter_stream(not_divible, positive_ints.rest))
    return Stream(pos_stream.first, sieve)
```

Prime numbers with nested streams

```
def primes(positive_ints):
    def not_divible(x):
        return (x % positive_integers.first) != 0
    def sieve():
        return primes(filter_stream(not_divible, positive_ints.rest
    return Stream(pos_stream.first, sieve)
```

```
>>> p = primes(make_integer_stream(5))
>>> p.first
5
>>> p.rest
<Stream instance at ... >
>>> p.rest.first
7
```


Native python iterators

Python natively supports iterators

The Iterator interface in python:

- __iter__
  - should return an iterator object
- __next__
  - should return a value OR
- raise StopIteration
  - when end of sequence is reached
  - on all subsequent calls

Native python iterators: example

```
class Letters(object):
    def __init__(self, start, finish):
        self.current = start
        self.finish = finish

    def __next__(self):
        if self.current > self.finish:
            raise StopIteration
        result = self.current
        self.current = chr(ord(result)+1)
        return result

    def __iter__(self):
        return self
```

```
>>> letters = Letters('a', 'd')
>>> letters.__next__()
'a'
>>> letters.__next__()
'b'
>>> letters.__next__()
'c'
>>> letters.__next__()
'd'
>>> letters.__next__()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<stdin>", line 12, in next
StopIteration
```


From a native python iterator to a nested stream

```
empty_stream = Stream(None, None, True)

def iterator_to_stream(iterator):
    def streamify():
        try:
            first = iterator.__next__()
            return Stream(first, streamify)
        except:
            return empty_stream
    stream = streamify()
    return stream
```


More support: for loops!

```
for item in obj:
  do stuff
```

"for" loops use iterators

- Step 1: get an iterator
  - iterator = obj.__iter__()
- Step 2:
  - try iterator.__next__()
  - assign value to "item"
  - do body of loop
  - until StopIteration is raised

```
def for_each(sequence, function):
    iterator = sequence.__iter__()
    try:
        while True :
            element = iterator.__next__()
            function(element)
    except StopIteration as e:
        pass
```

live example

Even more support: generator functions

```
class Letters(object):
    def __init__(self, start, finish):
        self.current = start
        self.finish = finish

    def __next__(self):
        if self.current > self.finish:
            raise StopIteration
        result = self.current
        self.current = chr(ord(result)+1)
        return result

    def __iter__(self):
        return self
```

Generator version

```
def letters(start, finish):
    current = start
    while current <= finish:
        yield current
        current = chr(ord(current)+1)
```

Yield: a built-in flow-control statement

```
def letters(start, finish):
    current = start
    while current <= finish:
        yield current
        current = chr(ord(current)+1)
```

Generator function.
When called, creates a Generator object

```
>>> l = letters('a', 'd')
>>> l
<generator instance at..>
```

Automatically creates:

```
l.__iter__()
l.__next__()
```

Does nothing at first

when __next__() is called, starts

Goes through executing body of function

Pauses at "yield" -- returns value

All local state is preserved

When __next__() is called, resumes.

Iterators get used up

```
>>> letters = Letters('a', 'd')
>>> letters.__next__()
'a'
>>> letters.__next__()
'b'
>>> letters.__next__()
'c'
>>> letters.__next__()
'd'
>>> letters.__next__()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<stdin>", line 12, in next
StopIteration
>>> letters.__next__()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<stdin>", line 12, in next
StopIteration
>>> letters.__next__()
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The Iterator interface in python:

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Iterables -- new iterator for every __iter__()

```
class Letters(object):
    def __init__(self, start, finish):
        self.current = start
        self.finish = finish

    def __next__(self):
        if self.current > self.finish:
            raise StopIteration
        result = self.current
        self.current = chr(ord(result)+1)
        return result

    def __iter__(self):
        return self
```

```
class LetterSequence(object):
    def __init__(self, start, finish):
        self.start = start
        self.finish = finish

    def __iter__(self):
        return self.forward()

    def forward(self):
        current = self.start
        if current < self.finish:
            yield current
            current = chr(ord(current)+1)
```

a generator function

a new generator object every time

Any questions?

Processing pipelines for sequential data

Next time