Lecture 29: Streams and Lazy Evaluation

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.
Finite to Infinite

Currently, all our sequence data structures share common limitations:

- Each item must be explicitly represented, even if all can be generated by a common formula or function.
- Sequence must be complete before we start iterating over it.
- Can’t be infinite. Who cares?
  - “Infinite” in practical terms means “having an unknown bound”.
  - Such things are everywhere.
  - Internet and cell phone traffic.
  - Instrument measurement feeds, real-time data.
  - Mathematical sequences.
Review: Iterables

- The Python `for` loop

```python
for x in L:
    BODY
```

can use one of two strategies:

<table>
<thead>
<tr>
<th>Iterator</th>
<th>Counter</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>_ITER = L.__iter__()</code></td>
<td><code>_I, _L = 0, L</code></td>
</tr>
<tr>
<td>while True:</td>
<td>while True:</td>
</tr>
<tr>
<td>try:</td>
<td>try:</td>
</tr>
<tr>
<td>x = <code>_ITER.__next__()</code></td>
<td>x = <code>_L[_I]</code></td>
</tr>
<tr>
<td>BODY</td>
<td>BODY</td>
</tr>
<tr>
<td>except StopIteration:</td>
<td>_I += 1</td>
</tr>
<tr>
<td>break</td>
<td>except IndexError:</td>
</tr>
<tr>
<td></td>
<td>break</td>
</tr>
</tbody>
</table>

- Crucial point: Iterators don’t compute items in a sequence until they are asked to. They are *lazy* (a technical term!).
Iterables and Iterators

- Lists, dictionaries, and tuples are iterables; The \_\_iter\_\_ method on them yields an iterator.

- On standard iterators, the \_\_iter\_\_ method yields itself:

  ```
  >>> L = [1, 2, 3]
  >>> it = L.__iter__()
  >>> it is it.__iter__()
  True
  ```

- This is useful, because several standard procedures (\_\_map\_, \_\_zip\_, \_\_re\_.\_\_finditer\_) return iterators, and several functions (like \_\_sum\_) use them:

  ```
  >>> L, P = [1, -2, 3], [2, 0, 4]
  >>> map(abs, L)
  <map object at 0x7f5f260dc2b0>
  >>> sum(map(abs, L))
  6
  >>> map(abs, L)[0]
  ERROR (an iterator, not an iterable)
  ```
Generators: Another Kind of Iterator

- Generators provide a concise and elegant way to write iterators.
- Example: generator returning lists [0], [0, 1], [0, 1, 2], ...

```python
def triangle(n):
    """Generates all lists of the form [0], [0,1], ..., up to [0,...n-1].""
    L = []
    for i in range(0, n):
        L += [i]
        yield L
```

```python
>>> for p in triangle(3):
...     print(p)
[0]
[0, 1]
[0, 1, 2]
```
Generators, explained

• A generator function is one that contains a `yield` statement.
• When called, a generator function returns a generator object.
• The generator object defines `__next__`, and acts like an iterator.
• When called, this `__next__` function executes the body of the generator up to the next call to `yield` and then returns the result.
• On each subsequent call, starts from after the `yield` statement.
• Stops iterating on exit from the generator function.
Example With Trees

• Suppose we want to generate the labels of a tree in post-order (i.e., labels of children first, then label of node):

```python
def tree_labels(t):
    for c in t.children:
        for lab in tree_labels(c):
            yield lab
    yield t.label
```

• More succinctly, can write this as

```python
def tree_labels(t):
    for c in t.children:
        yield from tree_labels(c)
    yield t.label
```

• Now we can print all labels in a tree with

```python
for lab in tree_labels(t): print(lab)
```
We'll define a *Stream* to look like an rlist whose *rest* is computed lazily.

class Stream(object):
    """A lazily computed recursive list.""
    empty = ...  # Some object representing an empty stream

    def __init__(self, first, compute_rest=lambda: Stream.empty):
        self.first, self._compute_rest = first, compute_rest

    @property
    def rest(self):
        """Return the rest of the stream, computing it once.""
        if self._compute_rest is not None:
            self._rest = self._compute_rest()
            self._compute_rest = None
        return self._rest

    def __repr__(self):
        return 'Stream({0}, <...>)'.format(repr(self.first))
Basic Stream Operations

```python
>>> s1 = Stream(1, lambda: Stream(2))
>>> s1.first
1
>>> s1.rest.first
2
>>> s1.rest.rest
Stream.empty
```

```python
>>> def print_first(x):
...     print("called"); return x
>>> s2 = Stream(1, lambda: print_first(Stream(2)))
>>> s2.rest.first
called
2
>>> s2.rest.first # .rest only computed first time called
2
```
Examples

An infinite stream of the same value.

```
def make_const_stream(x):
    """An infinite stream of X’s.""
    return Stream(x, lambda: make_const_stream(x))
```

The positive integers (all of them)

```
def make_integer_stream(first=1):
    """The infinite stream FIRST, FIRST+1, ...""
    def compute_rest():
        return make_integer_stream(first+1)
    return Stream(first, compute_rest)
```

```python
>>> ints = make_integer_stream(1)
>>> ints.first
1
>>> ints.rest.first
2
```
Mapping Streams

Familiar operations on other sequences can be extended to streams:

```python
def map_stream(fn, s):
    """Stream of values of FN applied to the elements of stream S."
    if s is Stream.empty:
        return s
    def compute_rest():
        return map_stream(fn, s.rest)
    return Stream(fn(s.first), compute_rest)

def add_streams(s0, s1):
    """Stream of the sums of respective elements of S0 and S1."
    def compute_rest():
        return add_streams(s0.rest, s1.rest)
    if s0 is Stream.empty or s1 is Stream.empty:
        return Stream.empty
    else:
        return Stream(s0.first + s1.first, compute_rest)
```
Filtering Streams

Another example:

def filter_stream(fn, s):
    """Return a stream of the elements of S for which FN is true."""
    if s is Stream.empty:
        return s
    def compute_rest():
        return filter_stream(fn, s.rest)
    if fn(s.first):
        return Stream(s.first, compute_rest)
    return compute_rest()
Streams to Lists

To look at streams a bit more conveniently, let's also define:

def stream_to_list(s, n):
    """A list containing the elements of stream S,
    up to a maximum of N.""
    r = []
    while n > 0 and s is not Stream.empty:
        r.append(s.first)
        s = s.rest
        n -= 1
    return r
def primes(pos_stream):
    """Return a stream of members of POS_STREAM that are not evenly divisible by any previous members of POS_STREAM. POS_STREAM is a stream of increasing positive integers."

>>> p1 = primes(make_integer_stream(2))
>>> stream_to_list(p1, 7)
[2, 3, 5, 7, 11, 13, 17]
"""

def not_divisible(x):
    return x % pos_stream.first != 0
def compute_rest():
    return primes(filter_stream(not_divisible, pos_stream.rest))
return Stream(pos_stream.first, compute_rest)
Recursive Streams

What do you suppose we get from these?

c1 = Stream(1, lambda: c1)
stream_to_list(c1, 5)

f1 = add_streams(c1, Stream(0, lambda: f1))
stream_to_list(f1, 5)

f2 = Stream(1,
    lambda: Stream(1,
        lambda: add_streams(f2, f2.rest)))
stream_to_list(f2, 6)
Recursive Streams

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[1, 2, 3, 4, 5]

f2 = Stream(1,
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[1, 2, 3, 4, 5]

f2 = Stream(1,
    lambda: Stream(1,
        lambda: add_streams(f2, f2.rest)))
stream_to_list(f2, 6)
[1, 1, 2, 3, 5, 8]