61A Lecture 34

November 21st, 2011

Last week

Last week

`Distributed computing`

Last week

Distributed computing

- Client-server

Last week

Distributed computing

- Client-server
- Peer-to-peer

Last week

Distributed computing

- Client-server
- Peer-to-peer
- Message passing

Last week

Distributed computing

- Client-server
- Peer-to-peer
- Message passing
- Modularity

Last week

Distributed computing

- Client–server
- Peer–to–peer
- Message passing
- Modularity
- Interfaces

Last week

Distributed computing

- Client-server
- Peer-to-peer
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- Modularity
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Parallel computing

Last week

Distributed computing

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

Parallel computing

- Threads

Last week

Distributed computing

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

Parallel computing

- Threads
- Shared memory

Last week

Distributed computing

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

Parallel computing

- Threads
- Shared memory
- Problems: Synchronization and stale data

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)

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

Sequential data

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

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DNA sequences

Sequential data

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DNA sequences

Web and cell-phone traffic streams

Sequential data

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DNA sequences

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The social data stream

Sequential data

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DNA sequences

Web and cell-phone traffic streams

The social data stream

Series of measurements from instruments on a robot

Sequential data

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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

So far: the sequence abstraction

Sequences have

So far: the sequence abstraction

Sequences have

- Length

So far: the sequence abstraction

Sequences have

- Length
- Element selection

So far: the sequence abstraction

Sequences have

- Length
- Element selection
- In python

So far: the sequence abstraction

Sequences have

- Length
- Element selection
- In python
    - Membership testing

So far: the sequence abstraction

Sequences have

- Length
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  - Slicing

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Data structures that support the sequence abstraction

So far: the sequence abstraction

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- Length
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Data structures that support the sequence abstraction

- Nested tuples

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Data structures that support the sequence abstraction

- Nested tuples
- Tuples

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Data structures that support the sequence abstraction

- Nested tuples
- Tuples
- Strings

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

Problems with sequences

`Memory`

Problems with sequences

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- Each item must be explicitly represented

Problems with sequences

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

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Up-front computation

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Up-front computation

- Have to compute all items up-front

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Can’t be infinite

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- Why care about “infinite” sequences?

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  - Internet and cell phone traffic

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  - Instrument measurement feeds, real-time data

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Up-front computation

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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

Finding prime numbers

```
Sieve of Erastothenes
```

Finding prime numbers

Sieve of Erastothenes

- Find prime numbers by walking down integers

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- For each integer, eliminate all multiples of that integer

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Working example: finding prime numbers

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def primes_sieve(limit):
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def primes_sieve(limit):
    # mark all numbers as prime at first
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def primes_sieve(limit):
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        if prime[i]:
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Working example: finding prime numbers

sequence

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```
primes_sieve(1000000000) anyone?
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Working example: finding prime numbers

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primes_sieve(1000000000) anyone?
1 billion

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sequence

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primes_sieve(1000000000) anyone?

1 billion

each number = 64 bits = 8 bytes

Working example: finding prime numbers

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primes_sieve(1000000000) anyone?

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each number = 64 bits = 8 bytes

8 bytes * 1 billion * 2 = 16 billion bytes

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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: another abstraction for sequential data

`Iterators`

Iterators: another abstraction for sequential data

Iterators

- Store how to compute items instead of items themselves

Iterators: another abstraction for sequential data

Iterators

- Store how to compute items instead of items themselves
- Give out one item at a time

Iterators: another abstraction for sequential data

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- Store how to compute items instead of items themselves
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- Save the next until asked (lazy evaluation)

Iterators: another abstraction for sequential data

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Compared with sequences

Iterators: another abstraction for sequential data

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Compared with sequences

- Length not explicitly defined

Iterators: another abstraction for sequential data

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- Store how to compute items instead of items themselves
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Compared with sequences

- Length not explicitly defined
- Element selection not supported

Iterators: another abstraction for sequential data

Iterators

- Store <u>how to compute items</u> instead of items themselves
- Give out one item at a time
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Compared with sequences

- Length not explicitly defined
- Element selection not supported
  - Element selection -- random access

Iterators: another abstraction for sequential data

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  - Element selection -- random access
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Iterators: another abstraction for sequential data

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  - Element selection -- random access
  - Iterators -- sequential access
- No up-front computation of all items

Iterators: another abstraction for sequential data

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  - Iterators -- sequential access
- No up-front computation of all items
- Only one item stored at a time
- CAN be infinite

Implementation: nested delayed evaluation

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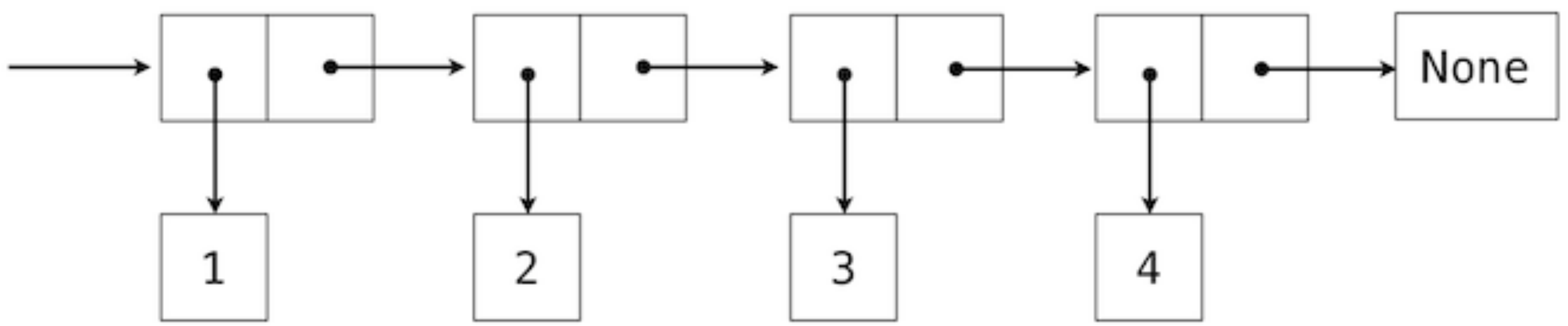
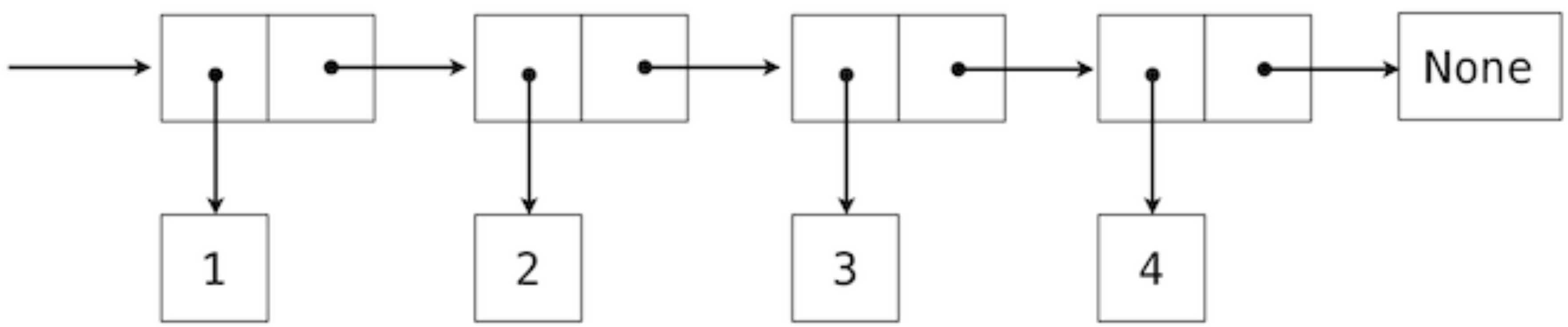
`Nested pairs`



Implementation: nested delayed evaluation

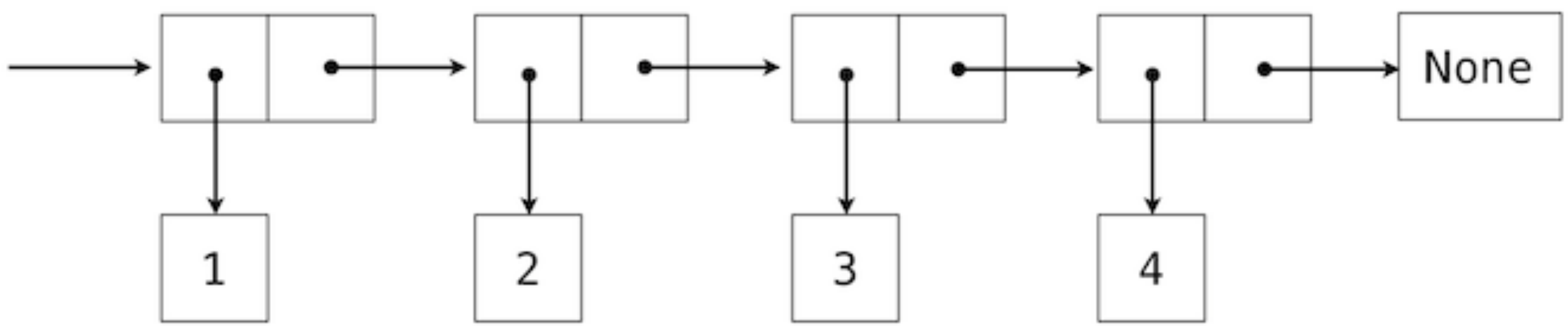
```
Nested pairs
```




```
Stream
```

Implementation: nested delayed evaluation

Nested pairs



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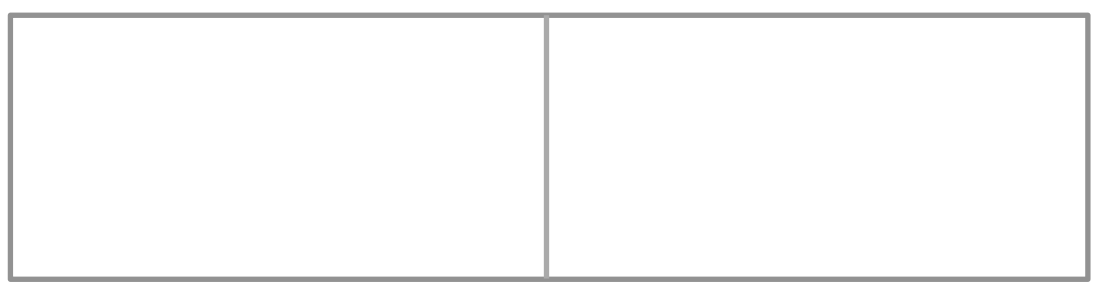

Implementation: nested delayed evaluation

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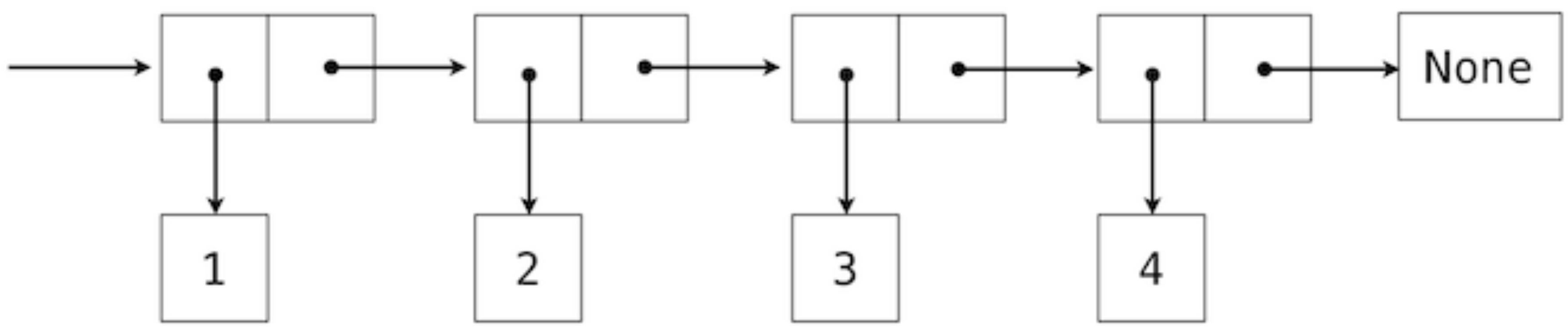

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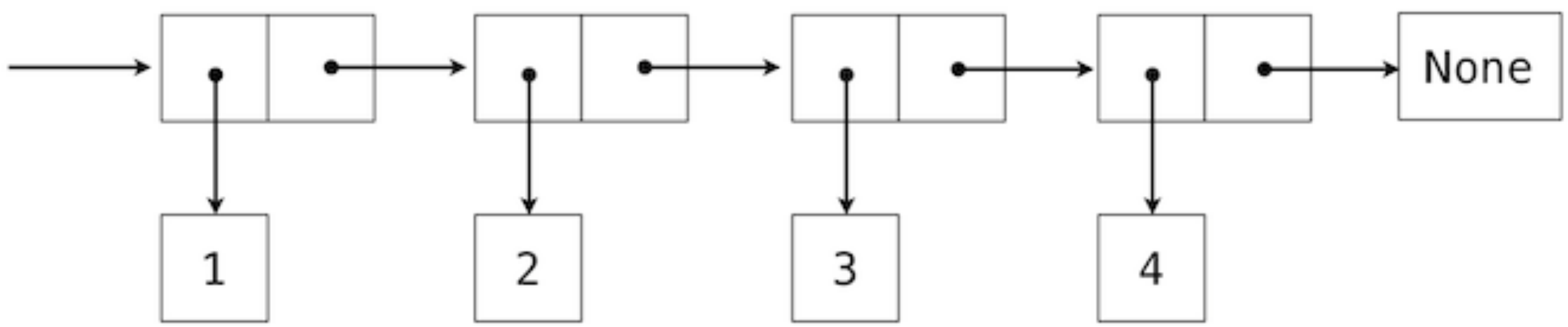

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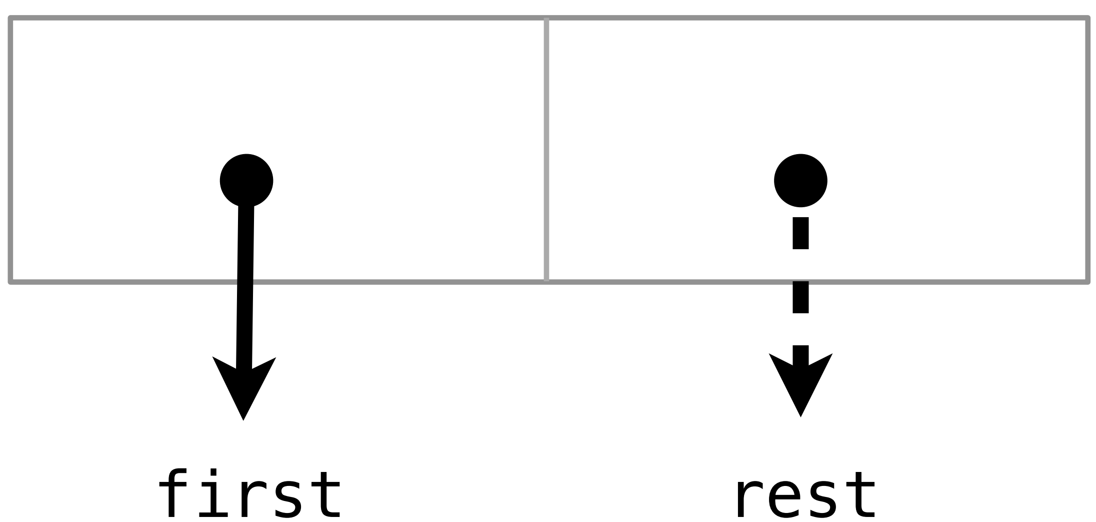
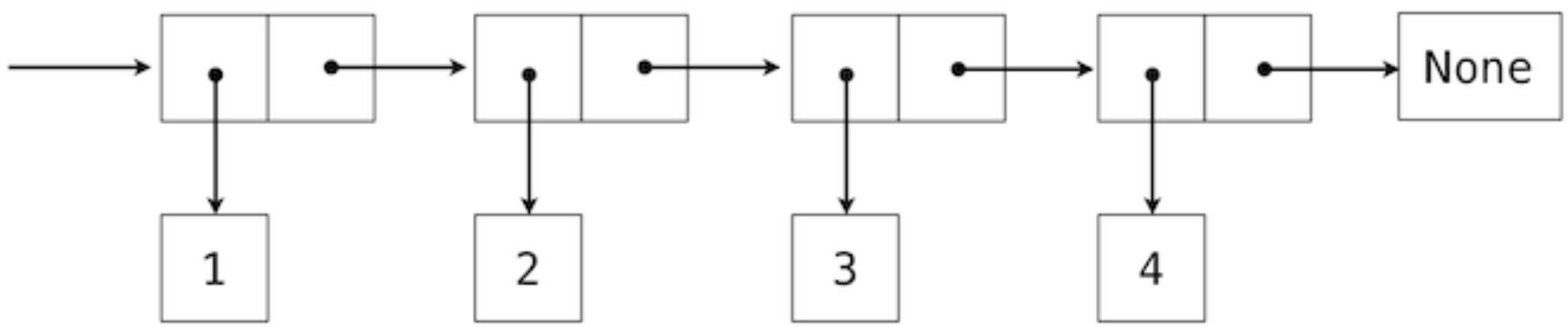
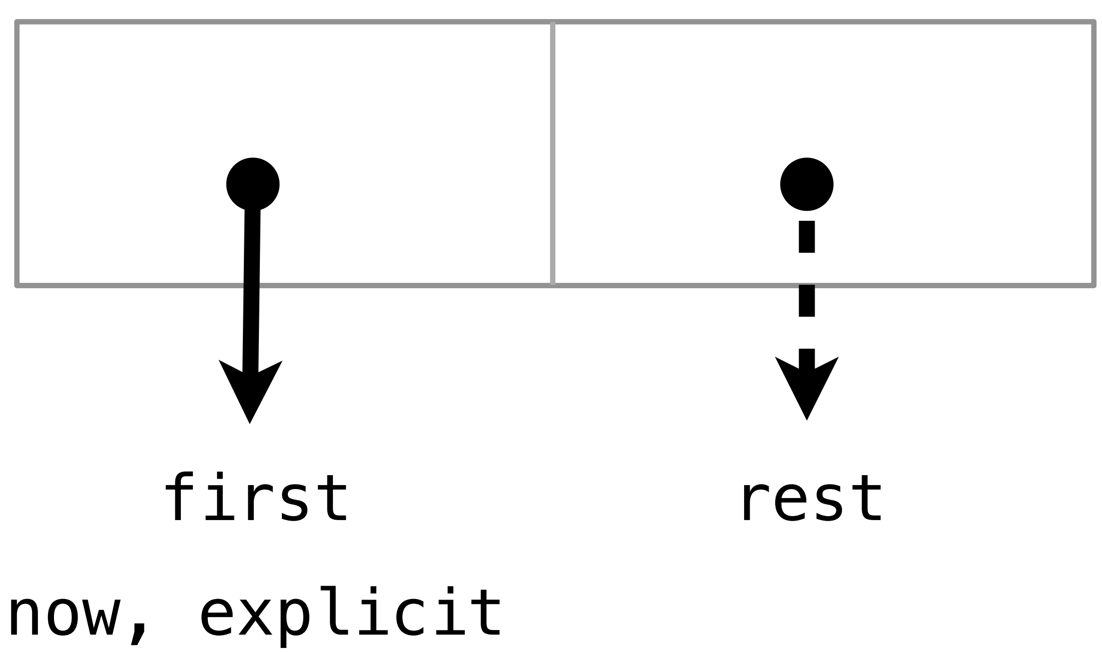


Implementation: nested delayed evaluation

Nested pairs

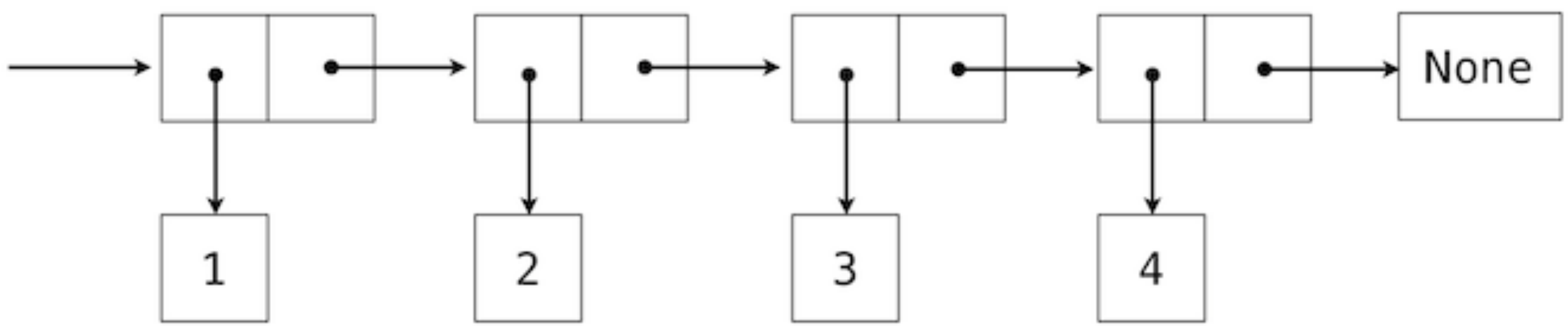


Stream



Implementation: nested delayed evaluation

Nested pairs



Stream

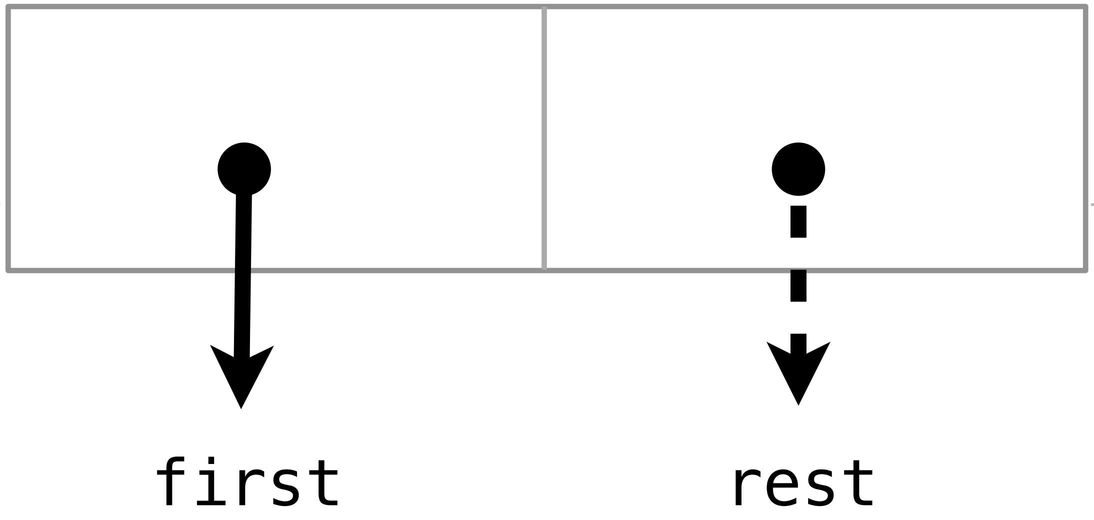
first

now, explicit

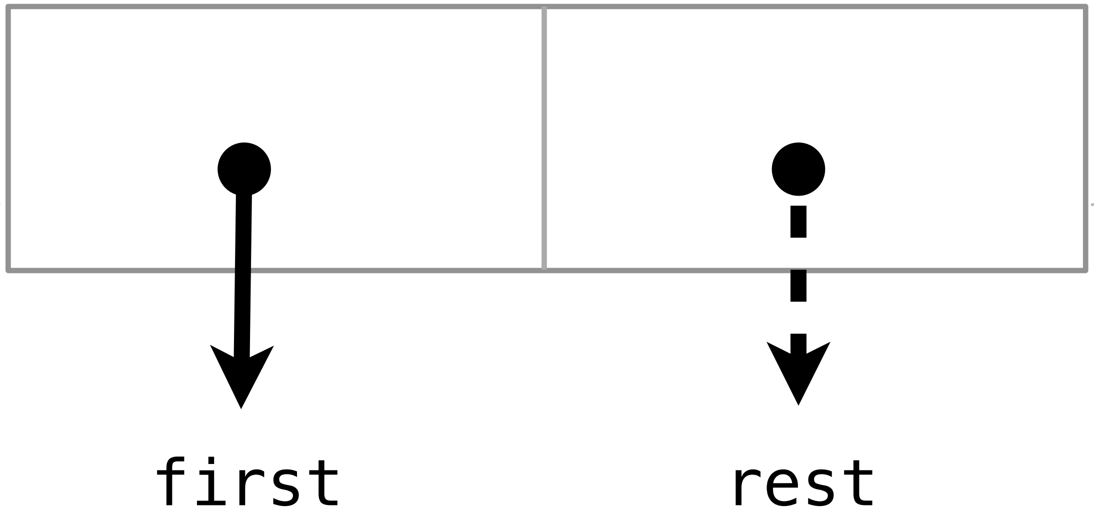
rest

store how to compute it
compute when asked

Streams

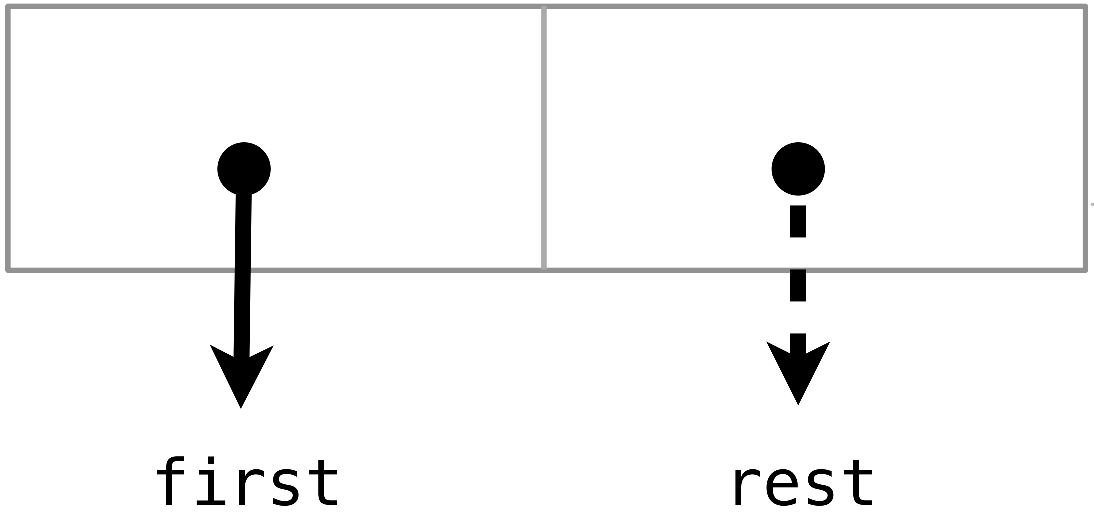


Streams




```
class Stream(object):
```

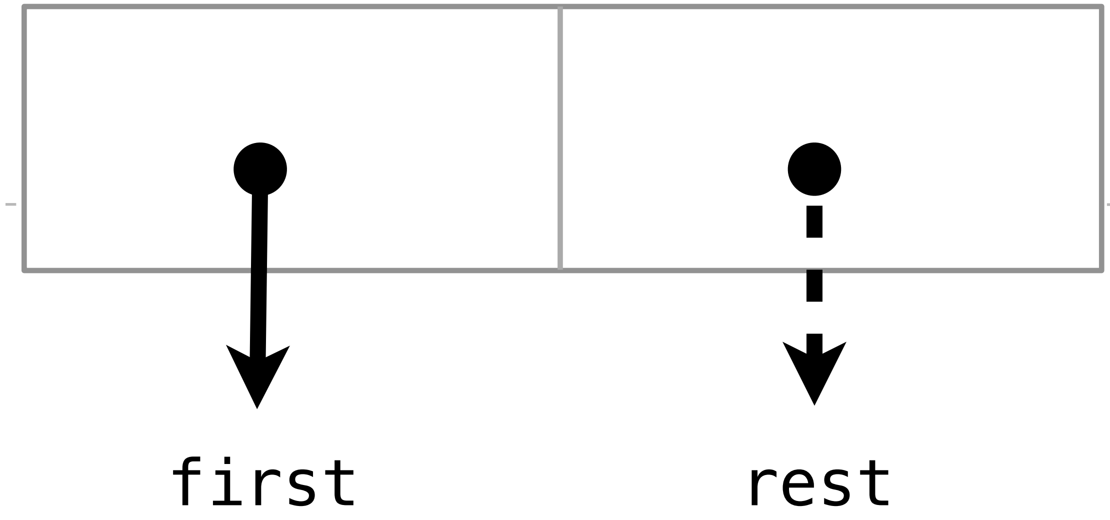
Streams




```
class Stream(object):

    def __init__(self, first, compute_rest, empty= False):
```

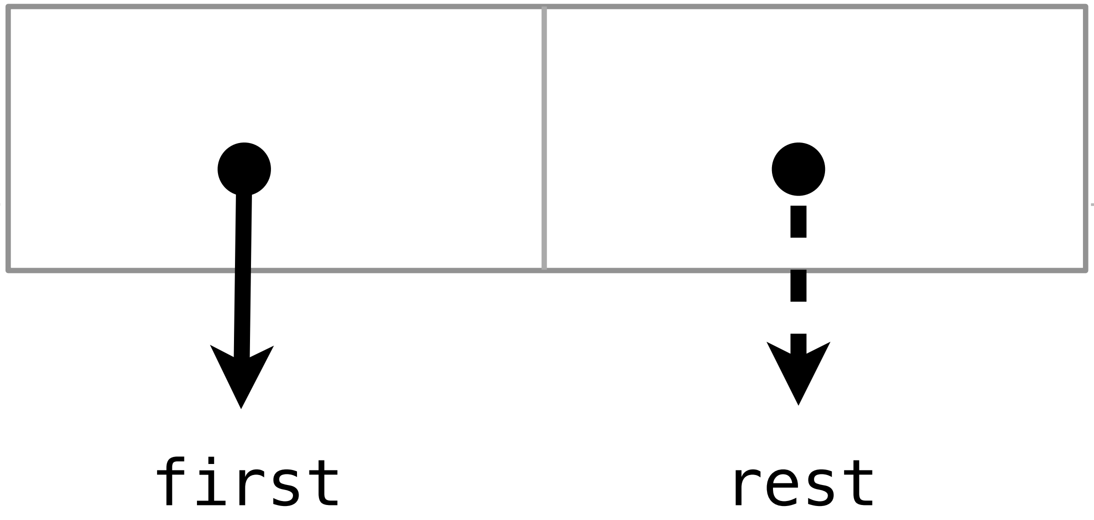
Streams




```
class Stream(object):

    def __init__(self, first, compute_rest, empty= False):
        self.first = first
```

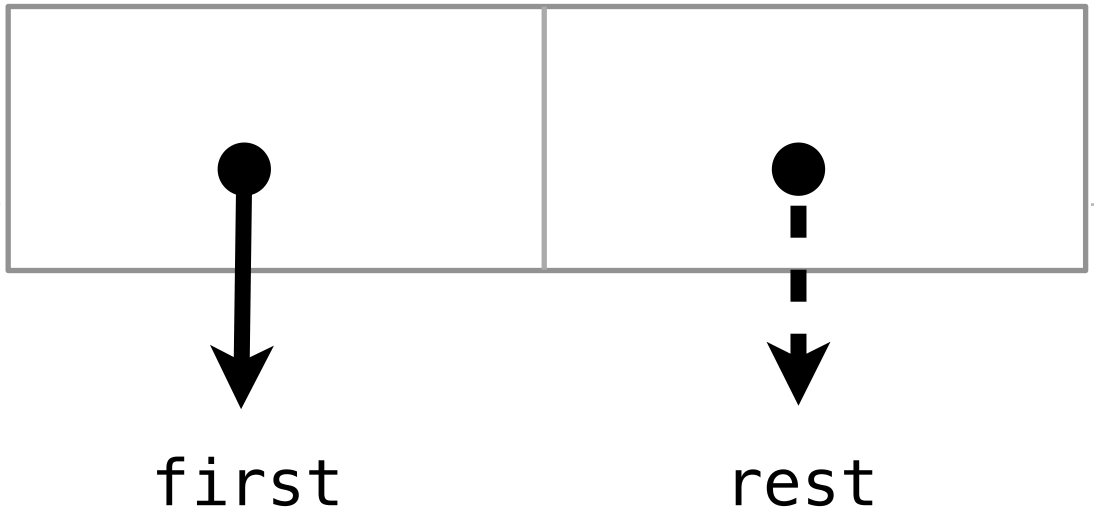
Streams




```
class Stream(object):

    def __init__(self, first, compute_rest, empty= False):
        self.first = first
        self._compute_rest = compute_rest
```

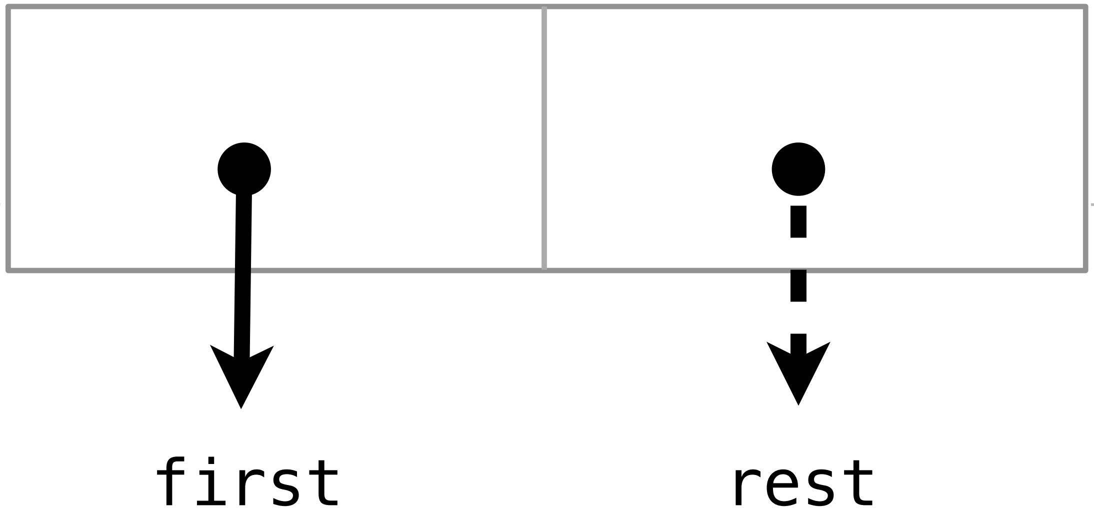
Streams




```
class Stream(object):

    def __init__(self, first, compute_rest, empty= False):
        self.first = first
        self._compute_rest = compute_rest
        self.empty = empty
```

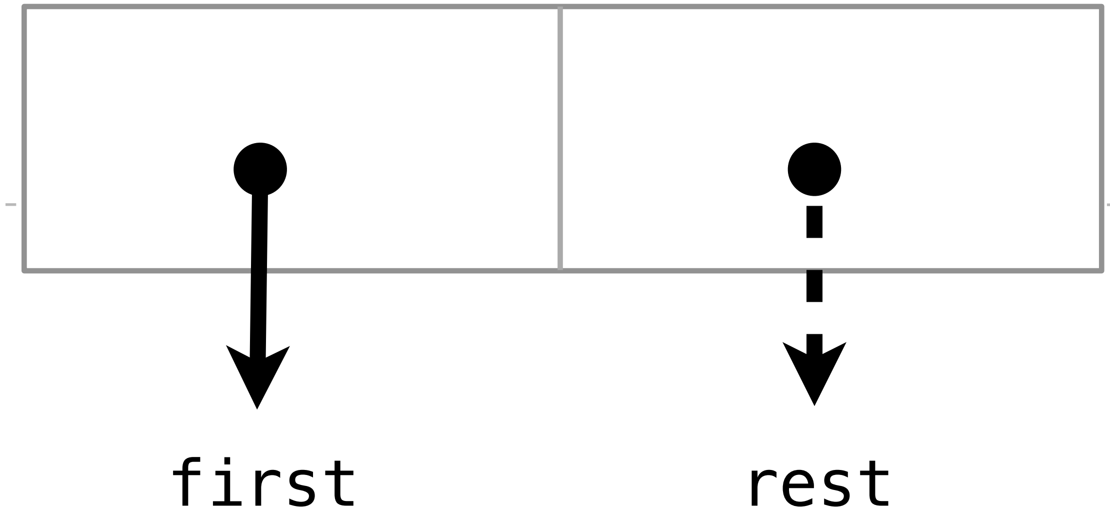
Streams




```
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
```

Streams




```
class Stream(object):

    def __init__(self, first, compute_rest, empty= False):
        self.first = first
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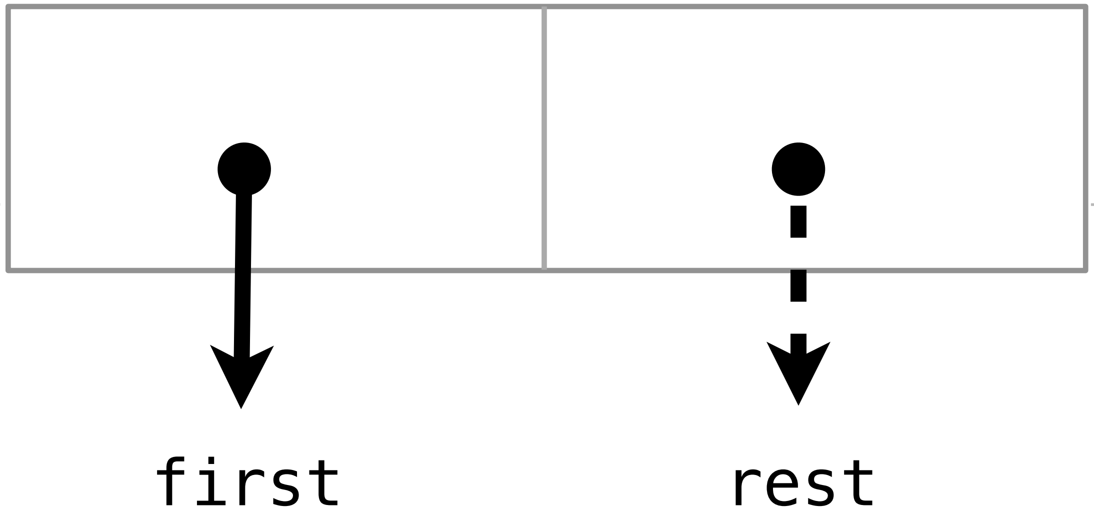
```

Streams

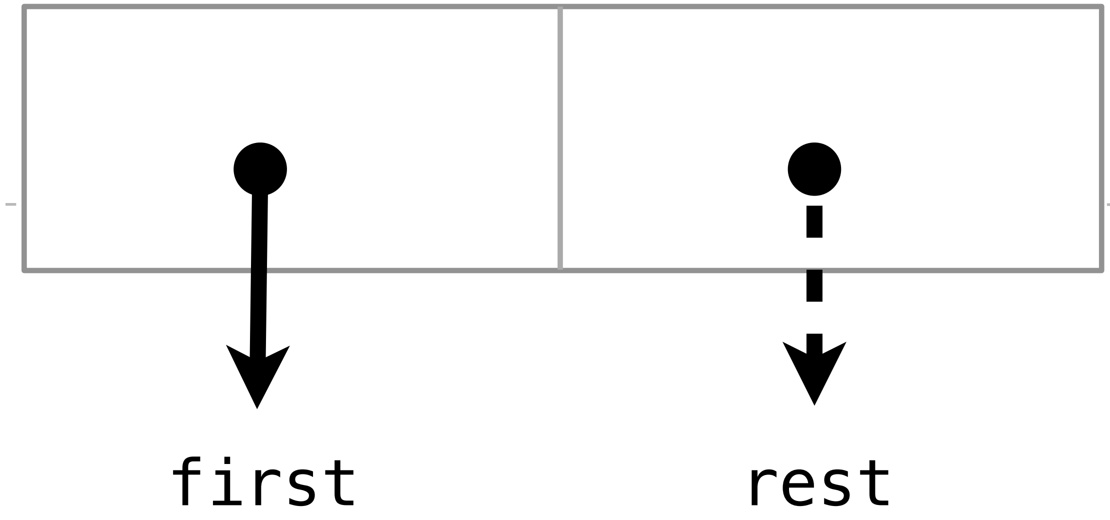



```
class Stream(object):

    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
```

Streams




```
class Stream(object):

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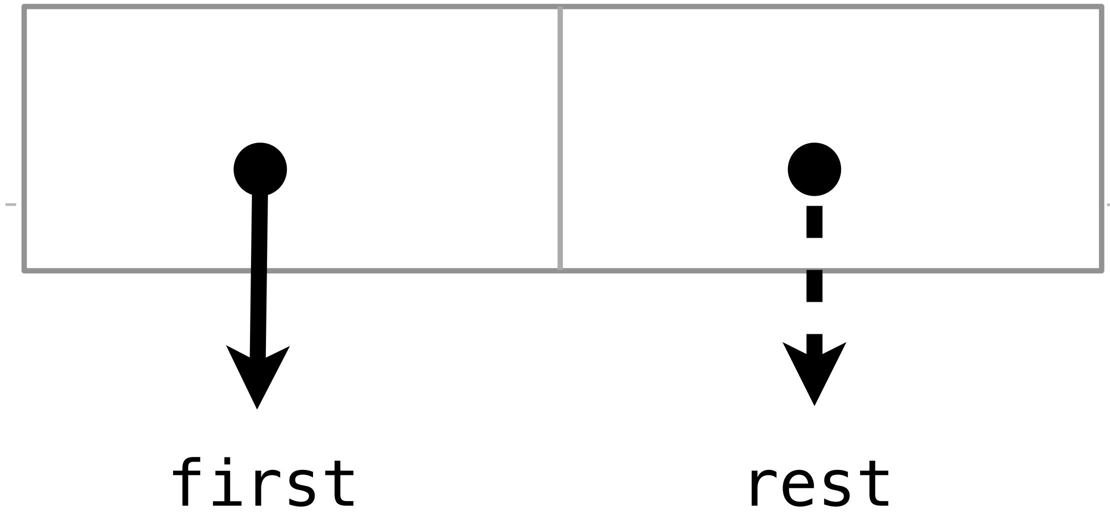
        self._rest = None
        self._computed = False

    @property
    def rest(self):
```

Streams




```
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        self._rest = None
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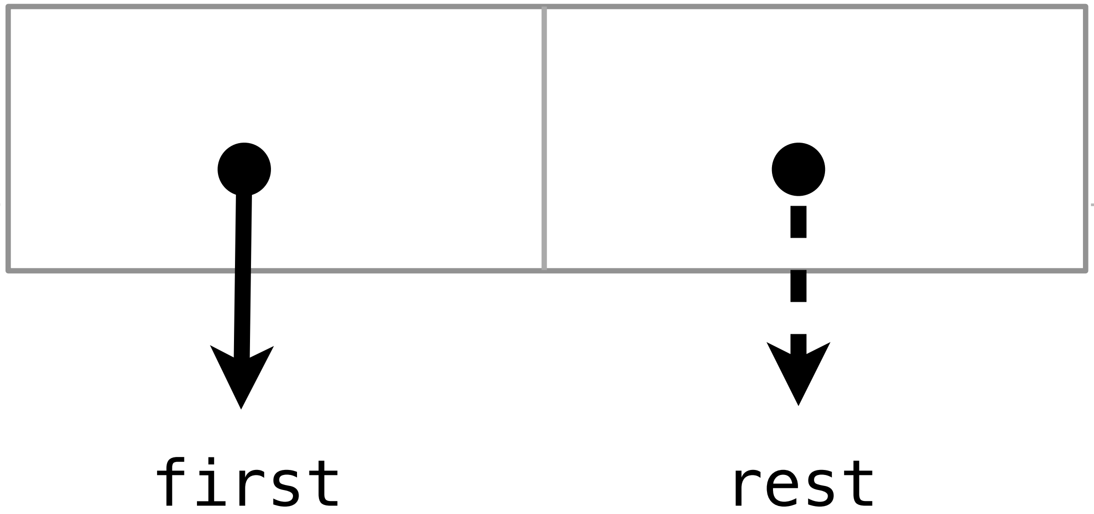
    @property
    def rest(self):
        assert not self.empty, 'Empty streams have no rest.'
```

Streams




```
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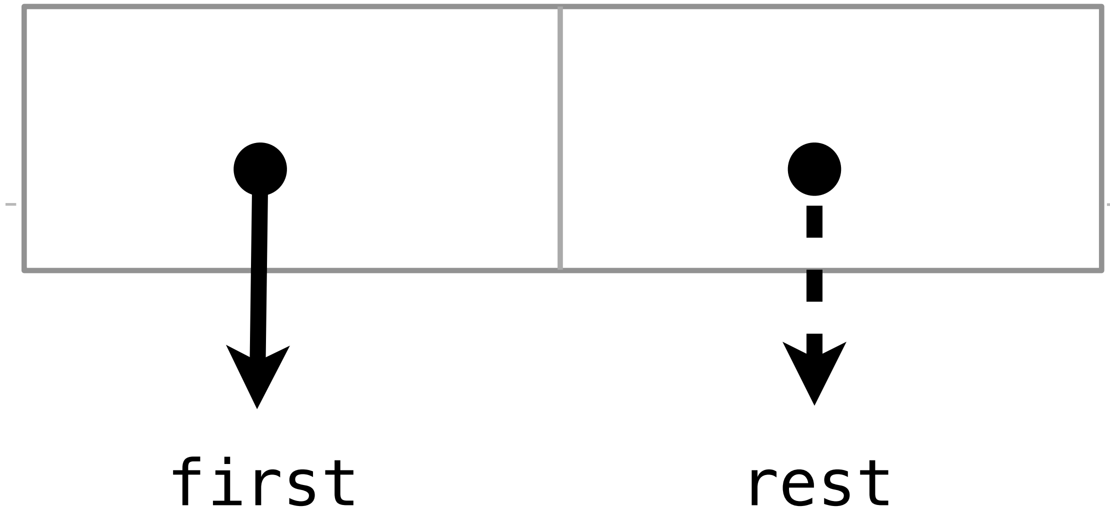
        self.empty = empty
        self._rest = None
        self._computed = False

    @property
    def rest(self):
        assert not self.empty, 'Empty streams have no rest.'
        if not self._computed:
```

Streams




```
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        self.empty = empty
        self._rest = None
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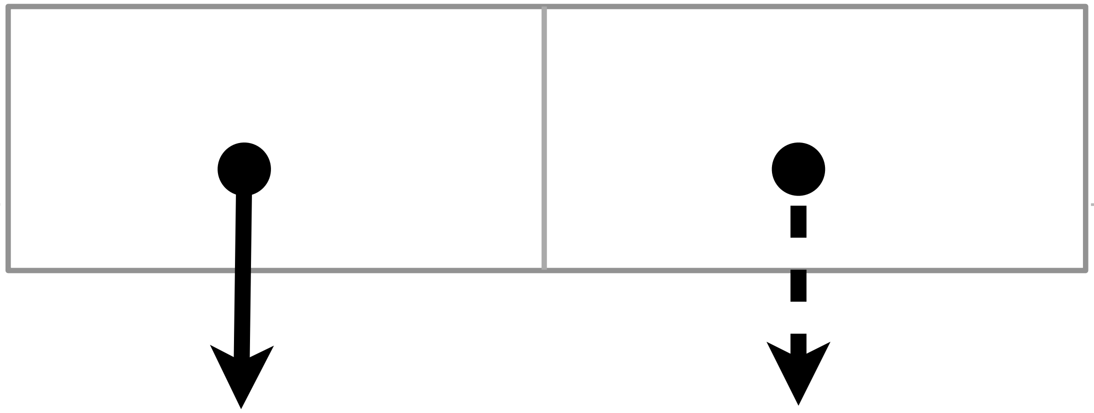
    @property
    def rest(self):
        assert not self.empty, 'Empty streams have no rest.'
        if not self._computed:
            self._rest = self._compute_rest()
```

Streams

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        self._compute_rest = compute_rest
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    def rest(self):
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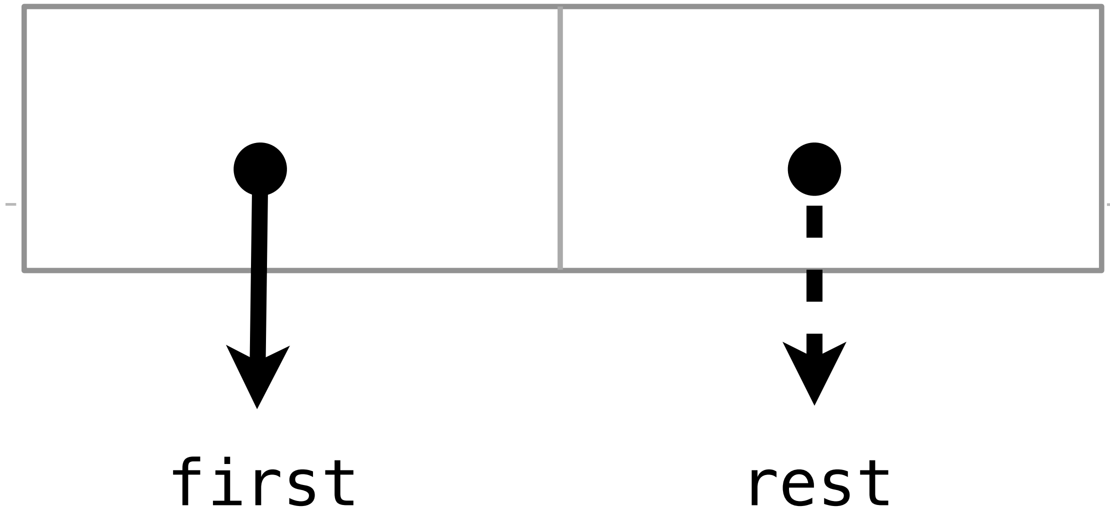
            self._computed = True
```

Streams

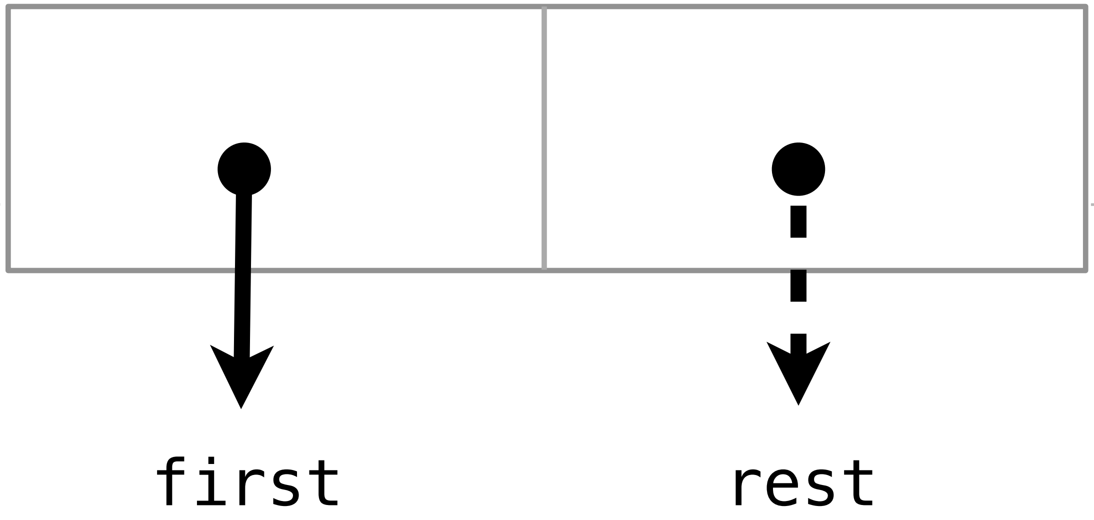



```
class Stream(object):

    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
```

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

Sequential data: nested streams

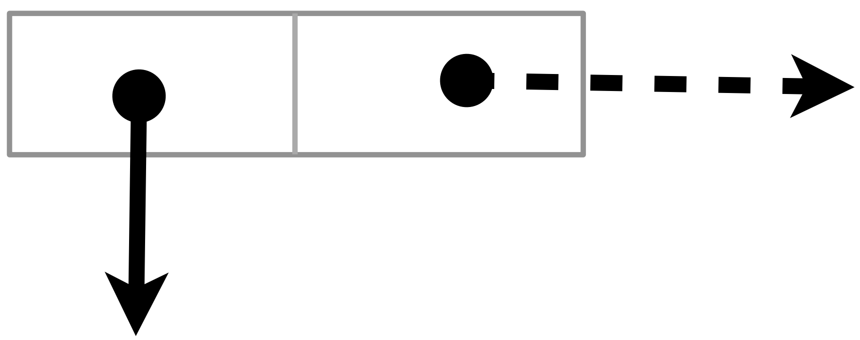
```
Nest streams inside each other
```

Sequential data: nested streams

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

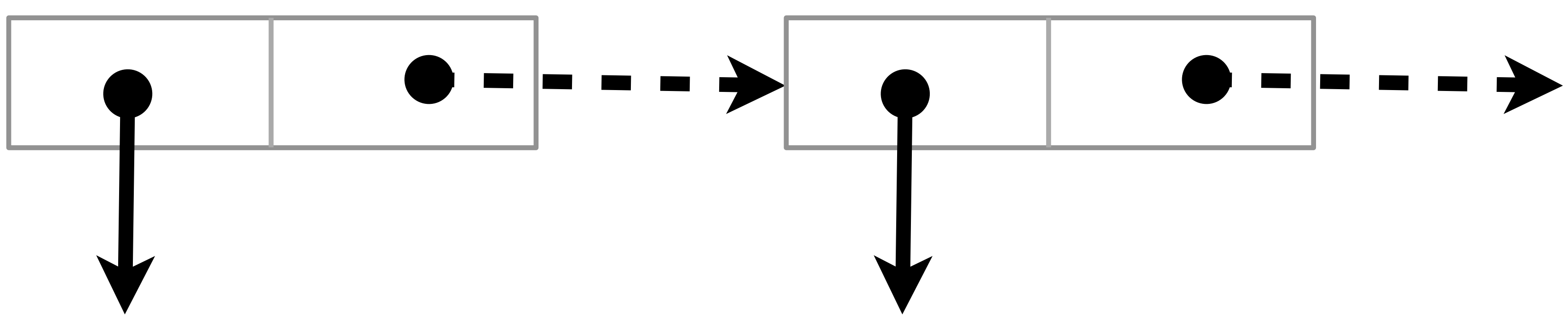
Sequential data: nested streams

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



Sequential data: nested streams

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



Sequential data: nested streams

```
Nest streams inside each other
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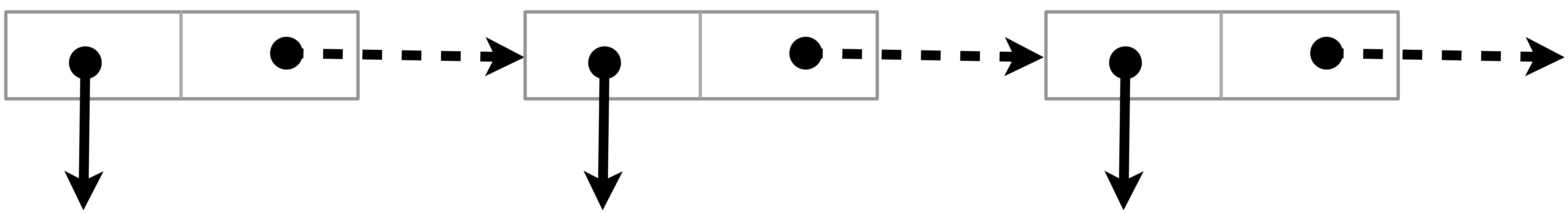
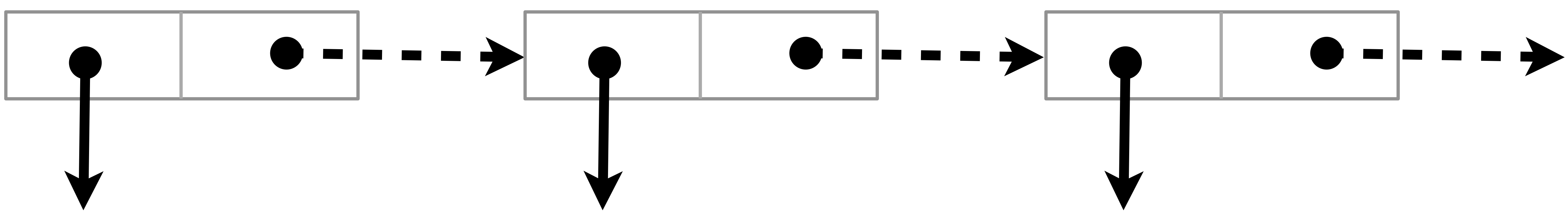


Sequential data: nested streams

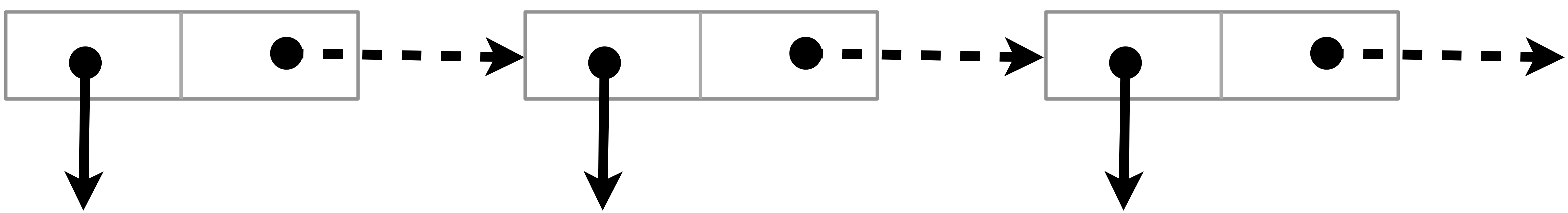
Nest streams inside each other
Only compute one element of a sequence at a time



```
def make_integer_stream(first=1):
```

Sequential data: nested streams

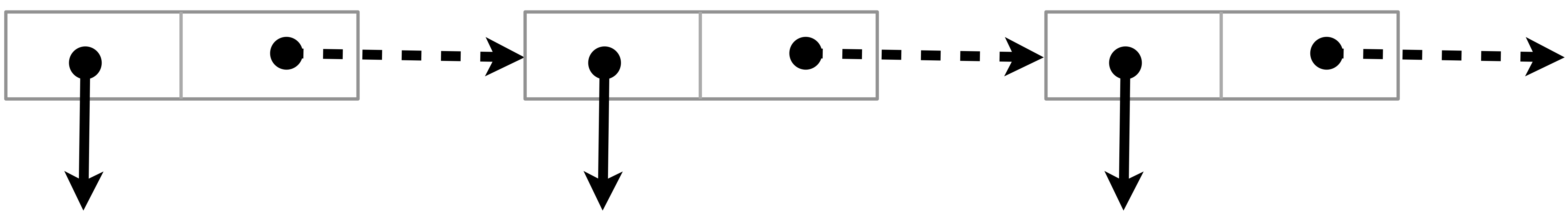
```
Nest streams inside each other
Only compute one element of a sequence at a time
```



```
def make_integer_stream(first=1):
        def compute_rest():
```

Sequential data: nested streams

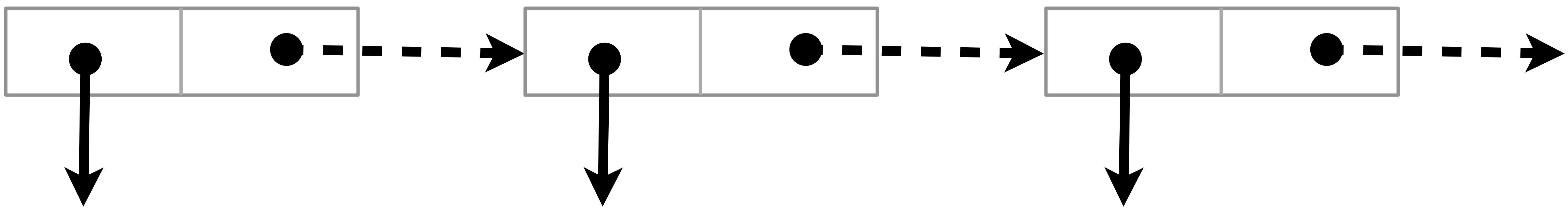
Nest streams inside each other
Only compute one element of a sequence at a time



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

Sequential data: nested streams

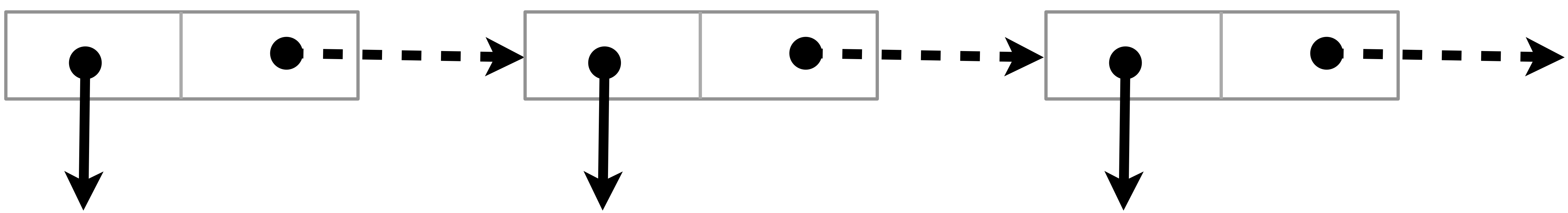
Nest streams inside each other
Only compute one element of a sequence at a time



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

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

Prime numbers with nested streams

```
def filter_stream(filter_func, stream):
```

Prime numbers with nested streams

```
def filter_stream(filter_func, stream):
    def make_filtered_rest():
```

Prime numbers with nested streams

```
def filter_stream(filter_func, stream):
    def make_filtered_rest():
        return filter_stream(filter_func, stream.rest)
```

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:
```

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
```

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):
```

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)
```

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:
```

Prime numbers with nested streams

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

Prime numbers with nested streams

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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:
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def primes(positive_ints):
```

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:
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    else:
        return filter_stream(filter_funct, stream.rest)


def primes(positive_ints):
    def not_divible(x):
```

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
```

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():
```

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))
```

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

Prime numbers with nested streams

```
def primes(positive_ints):
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Prime numbers with nested streams

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def primes(positive_ints):
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        return primes(filter_stream(not_divible, positive_ints.rest
```

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Prime numbers with nested streams

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def primes(positive_ints):
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        return primes(filter_stream(not_divible, positive_ints.rest
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```

```
>>> p = primes(make_integer_stream(5))
```

Prime numbers with nested streams

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def primes(positive_ints):
    def not_divible(x):
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        return primes(filter_stream(not_divible, positive_ints.rest
    return Stream(pos_stream.first, sieve)
```

```
>>> p = primes(make_integer_stream(5))
>>> p.first
```

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)
```

```
Stream(pos_stream.first, sieve)
```

```
>>> p = primes(make_integer_stream(5))
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Prime numbers with nested streams

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def primes(positive_ints):
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        return primes(filter_stream(not_divible, positive_ints.rest
    return Stream(pos_stream.first, sieve)
```

```
>>> p = primes(make_integer_stream(5))
>>> p.first
5
```

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
```

Prime numbers with nested streams

```
def primes(positive_ints):
    def not_divible(x):
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```

```
>>> p = primes(make_integer_stream(5))
>>> p.first
5
>>> p.rest
```

Prime numbers with nested streams

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

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

Prime numbers with nested streams

```
def primes(positive_ints):
    def not_divible(x):
        return (x % positive_integers.first) != 0
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```

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

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

Native python iterators

```
Python natively supports iterators
```

Native python iterators

Python natively supports iterators

The Iterator interface in python:

Native python iterators

```
Python natively supports iterators

The Iterator interface in python:
```

- `__iter__`

Native python iterators

Python natively supports iterators

The Iterator interface in python:

- `__iter__`
  - should return an iterator object

Native python iterators

Python natively supports iterators

The Iterator interface in python:

- `__iter__`
  - should return an iterator object
- `__next__`

Native python iterators

Python natively supports iterators

The Iterator interface in python:

- __iter__
  - should return an iterator object
- __next__
  - should return a value OR

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

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

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

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```
class Letters(object):
```

Native python iterators: example

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

Native python iterators: example

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

Native python iterators: example

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

Native python iterators: example

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

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:
```

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class Letters(object):
    def __init__(self, start, finish):
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    def __next__(self):
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        self.current = chr(ord(result)+1)
```

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```

```
>>> letters = Letters('a', 'd')
```

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```
>>> letters = Letters('a', 'd')
>>> letters.__next__()
```

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```
>>> letters = Letters('a', 'd')
>>> letters.__next__()
'a'
```

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>>> letters = Letters('a', 'd')
>>> letters.__next__()
'a'
>>> letters.__next__()
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Native python iterators: example

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```python
>>> letters = Letters('a', 'd')
>>> letters.__next__()
'a'
>>> letters.__next__()
'b'
```

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'a'
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```

Native python iterators: example

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>>> letters = Letters('a', 'd')
>>> letters.__next__()
'a'
>>> letters.__next__()
'b'
>>> letters.__next__()
'c'
```

Native python iterators: example

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class Letters(object):
    def __init__(self, start, finish):
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>>> letters = Letters('a', 'd')
>>> letters.__next__()
'a'
>>> letters.__next__()
'b'
>>> letters.__next__()
'c'
>>> letters.__next__()
```

Native python iterators: example

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>>> letters.__next__()
'a'
>>> letters.__next__()
'b'
>>> letters.__next__()
'c'
>>> letters.__next__()
'd'
```

Native python iterators: example

```
class Letters(object):
    def __init__(self, start, finish):
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>>> letters = Letters('a', 'd')
>>> letters.__next__()
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Native python iterators: example

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    def __init__(self, start, finish):
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        return result

    def __iter__(self):
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```

```
>>> 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

From a native python iterator to a nested stream

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

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def iterator_to_stream(iterator):
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```
empty_stream = Stream(None, None, True)

def iterator_to_stream(iterator):
    def streamify():
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From a native python iterator to a nested stream

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empty_stream = Stream(None, None, True)

def iterator_to_stream(iterator):
    def streamify():
        try:
```

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__()
```

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)
```

From a native python iterator to a nested stream

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empty_stream = Stream(None, None, True)

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

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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()
```

From a native python iterator to a nested stream

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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()
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```

More support: for loops!

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```
for item in obj:
  do stuff
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“for” loops use iterators

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"for" loops use iterators

- Step 1: get an iterator

More support: for loops!

```
for item in obj:
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```

“for” loops use iterators

- Step 1: get an iterator
  - `iterator = obj.__iter__()`

More support: for loops!

```
for item in obj:
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```

"for" loops use iterators

- Step 1: get an iterator
  - iterator = obj.__iter__()
- Step 2:

More support: for loops!

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“for” loops use iterators

- Step 1: get an iterator
  - iterator = obj.__iter__()
- Step 2:
  - try iterator.__next__()

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“for” loops use iterators

- Step 1: get an iterator
  - iterator = obj.__iter__()
- Step 2:
  - try iterator.__next__()
  - assign value to “item”

More support: for loops!

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“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

More support: for loops!

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“for” loops use iterators

- Step 1: get an iterator
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  - until StopIteration is raised

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```
def for_each(sequence, function):
```

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```
def for_each(sequence, function):
    iterator = sequence.__iter__()
    try:
```

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```python
def for_each(sequence, function):
    iterator = sequence.__iter__()
    try:
        while True :
```

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```
def for_each(sequence, function):
    iterator = sequence.__iter__()
    try:
        while True :
            element = iterator.__next__()
```

More support: for loops!

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  - iterator = obj.__iter__()
- Step 2:
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  - 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)
```

More support: for loops!

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for item in obj:
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“for” loops use iterators

- Step 1: get an iterator
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```
def for_each(sequence, function):
    iterator = sequence.__iter__()
    try:
        while True :
            element = iterator.__next__()
            function(element)
    except StopIteration as e:
```

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"for" loops use iterators

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

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“for” loops use iterators

- Step 1: get an iterator
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```

live example

Even more support: generator functions

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```
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
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Even more support: generator functions

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Generator version

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        self.current = chr(ord(result)+1)
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    def __iter__(self):
        return self
```

Generator version

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

Even more support: generator functions

```
class Letters(object):
    def __init__(self, start, finish):
        self.current = start
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def letters(start, finish):
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Even more support: generator functions

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        self.current = chr(ord(result)+1)
        return result

    def __iter__(self):
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```

Generator version

```
def letters(start, finish):
    current = start
    while current <= finish:
        yield current
```

Even more support: generator functions

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class Letters(object):
    def __init__(self, start, finish):
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        result = self.current
        self.current = chr(ord(result)+1)
        return result

    def __iter__(self):
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```

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
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Generator function.

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Generator function.
When called, creates a
Generator object

Yield: a built-in flow-control statement

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   while current <= finish:
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```

Generator function.
When called, creates a
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```
>>> l = letters('a', 'd')
```

Yield: a built-in flow-control statement

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def letters(start, finish):
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```
Generator function.
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>>> l
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Yield: a built-in flow-control statement

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def letters(start, finish):
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Generator function.
When called, creates a
Generator object

>>> l = letters('a', 'd')
>>> l
<generator instance at..>
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    while current <= finish:
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        current = chr(ord(current)+1)
```

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When called, creates a
Generator object

```
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>>> l
<generator instance at..>
```

Automatically creates:

`l.__iter__()`

Yield: a built-in flow-control statement

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def letters(start, finish):
   current = start
   while current <= finish:
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       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__()
```

Yield: a built-in flow-control statement

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

Does nothing at first

```
Generator function.
When called, creates a
Generator object

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

Automatically creates:

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

Yield: a built-in flow-control statement

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def letters(start, finish):
   current = start
   while current <= finish:
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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

Yield: a built-in flow-control statement

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

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Generator function.
When called, creates a
Generator object
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```
>>> 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

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

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
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Iterators get used up

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The Iterator interface in python:

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    def __init__(self, start, finish):
        self.current = start
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class LetterSequence(object):
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Any questions?

Processing pipelines for sequential data

Next time