

Generators, iterators

- `__iter__`, `__next__`
- `yield`
- generator expression
- measuring memory usage

Iterable & Iterator

Python shell

```
> L = ['a', 'b', 'c']
> type(L)
| <class 'list'>
> it = L.__iter__()
> type(it)
| <class 'list_iterator'>
> it.__next__()
| 'a'
> it.__next__()
| 'b'
> it.__next__()
| 'c'
> it.__next__()
| StopIteration # Exception
```

Python shell

```
> L = ['a', 'b', 'c']
> it = iter(L) # calls L.__iter__()
> next(it)    # calls it.__next__()
| 'a'
> next(it)
| 'b'
> next(it)
| 'c'
> next(it)
| StopIteration
```

iterator ≈ pointer into list
↓
['a', 'b', 'c']

- Lists are **iterable** (must support `__iter__`)
- `iter` returns an **iterator** (must support `__next__`)

Some iterables in Python: string, list, set, tuple, dict, range, enumerate, zip, map, reversed

Iterator

- `next(iterator_object)` returns the next element from the iterator, by calling the `iterator_object.__next__()`. If no more elements to report, raises exception `StopIteration`
- `next(iterator_object, default)` returns `default` when no more elements are available (no exception is raised)
- for-loops and list comprehensions require iterable objects
`for x in range(5): and [2**x for x in range(5)]`
- The iterator concept is also central to Java and C++

for loop

Python shell

```
> for x in ['a', 'b', 'c']:
    print(x)
```

| a
| b
| c

result of next
on iterator

iterable object
(can call iter on it to
generate an iterator)

=

Python shell

```
> L = ['a', 'b', 'c']
> it = iter(L)
> while True:
    try:
        x = next(it)
    except StopIteration:
        break
    print(x)
```

| a
| b
| c

8.3. The `for` statement

The `for` statement is used to iterate over the elements of a sequence (such as a string, tuple or list) or other iterable object:

```
for_stmt ::= "for" target_list "in" expression_list ":" suite
           ["else" ":" suite]
```

The expression list is evaluated once; it should yield an iterable object. An iterator is created for the result of the `expression_list`. The suite is then executed once for each item provided by the iterator, in the order returned by the iterator. Each item in turn is assigned to the target list using the standard rules for assignments (see [Assignment statements](#)), and then the suite is executed. When the items are exhausted (which is immediately when the sequence is empty or an iterator raises a `StopIteration` exception), the suite in the `else` clause, if present, is executed, and the loop terminates.

for loop over changing iterable



Changing (extending) the list while scanning
The iterator over a list is just an index into the list

Python shell

```
> L = [1, 2]
> for x in L:
    print(x, L)
    L.append(x + 2)
| 1 [1, 2]
| 2 [1, 2, 3]
| 3 [1, 2, 3, 4]
| 4 [1, 2, 3, 4, 5]
| 5 [1, 2, 3, 4, 5, 6]
...

```

Python shell

```
> L = [1, 2]
> for x in L:
    print(x, L)
    L[:0] = [L[0] - 2, L[0] - 1]
| 1 [1, 2]
| 0 [-1, 0, 1, 2]
| -1 [-3, -2, -1, 0, 1, 2]
| -2 [-5, -4, -3, -2, -1, 0, 1, 2]
| -3 [-7, -6, -5, -4, -3, -2, -1, 0, 1, 2]
...

```

range

Python shell

```
> r = range(1, 6) # 1,2,3,4,5
> type(r)
| <class 'range'>
> it = iter(r)
> type(it)
| <class 'range_iterator'>
> next(it)
| 1
> next(it)
| 2
> for x in it:
    print(x)
| 3
| 4
| 5
> list(r)
| [1, 2, 3, 4, 5]
```

iterable expected
but got iterator ?

create list from iterable

Python shell

```
> it
| <range_iterator object at 0x03E7FFC8>
> iter(it)
| <range_iterator object at 0x03E7FFC8>
> it is iter(it)
| True
```

Calling `iter` on a `range_iterator` just returns the iterator itself, i.e. can use the iterator wherever an iterable is expected

str

Python shell

```
> s = 'abcde'
> list(s) # create list from iterable
| ['a', 'b', 'c', 'd', 'e']
> type(s)
| <class 'str'>
> it = iter(s)
> type(it)
| <class 'str_ascii_iterator'>
> next(it)
| 'a'
> next(it)
| 'b'
> list(it) # iter(it) is it
| ['c', 'd', 'e']
```


Creating an iterable class

names.py

```
class Names:
    def __init__(self, *arg):
        self.people = arg

    def __iter__(self):
        return Names_iterator(self)

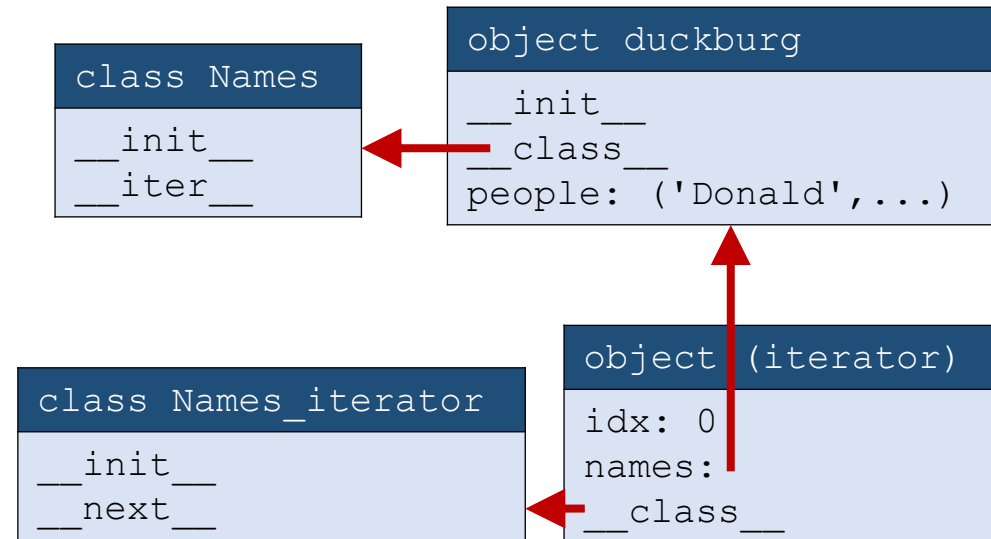
class Names_iterator:
    def __init__(self, names):
        self.idx = 0
        self.names = names

    def __next__(self):
        if self.idx >= len(self.names.people):
            raise StopIteration
        self.idx += 1
        return self.names.people[self.idx - 1]

duckburg = Names('Donald', 'Goofy', 'Mickey', 'Minnie')
for name in duckburg:
    print(name)
```

Python shell

```
| Donald
| Goofy
| Mickey
| Minnie
```



An infinite iterable

infinite_range.py

```
class infinite_range:
    def __init__(self, start=0, step=1):
        self.start = start
        self.step = step

    def __iter__(self):
        return infinite_range_iterator(self)

class infinite_range_iterator:
    def __init__(self, inf_range):
        self.range = inf_range
        self.current = self.range.start

    def __next__(self):
        value = self.current
        self.current += self.range.step
        return value

    def __iter__(self):  # make iterator iterable
        return self
```

Python shell

```
> r = infinite_range(42, -3)
> it = iter(r)
> for idx, value in zip(range(5), it):
    print(idx, value)
| 0 42
| 1 39
| 2 36
| 3 33
| 4 30
> for idx, value in zip(range(5), it):
    print(idx, value)
| 0 27
| 1 24
| 2 21
| 3 18
| 4 15
> print(sum(r))  # don't do this
| (runs forever)
```



sum and zip take iterables
(zip stops when shortest iterable is exhausted)

Creating an iterable class (iterable = iterator)

my_range.py

```
class my_range:
    def __init__(self, start, end, step):
        self.start = start
        self.end = end
        self.step = step
        self.x = start

    def __iter__(self):
        return self # self also iterator


    def __next__(self):
        if self.x >= self.end:
            raise StopIteration
        answer = self.x
        self.x += self.step
        return answer

r = my_range(1.5, 2.0, 0.1)
```

Python shell

```
> list(r)
| [1.5, 1.6,
  1.7000000000000002,
  1.8000000000000003,
  1.9000000000000004]
> list(r)
| []
```



- Note that objects act both as an iterable and an iterator
- This e.g. also applies to `zip` objects
- Can only iterate over a `my_range` once 

The old sequence iteration protocol

Python shell

```
> class Odd_numbers:
    def __getitem__(self, idx):
        print('getting item', idx)
        if not 0 <= idx < 10:
            raise IndexError
        return 2 * idx + 1

> odds = Odd_numbers()
> odds[3]
> getting item 3
| 7
> it = iter(odds)
> it
| <iterator object at ...>
> print(next(it), next(it), next(it))
| getting item 0
| getting item 1
| getting item 2
| 1 3 5
```

```
> 5 in odds
| getting item 0
| getting item 1
| getting item 2
| True
> 6 in odds
| getting item 0
| getting item 1
| getting item 2
| getting item 3
| getting item 4
| getting item 5
| getting item 6
| getting item 7
| getting item 8
| getting item 9
| getting item 10
| False
```

odds.__contains__ does not exist

- Class with no `__iter__` method but supporting index lookup with `__getitem__`
- Python automatically creates iterator looking up `obj[0]`, `obj[1]`, `obj[2]`, ... until `IndexError` raised
- Keyword `in` falls back to iteration if no method `__contains__`

itertools

Function

`count(start, step)`
`cycle(seq)`
`repeat(value[, times])`
`chain(seq0, ..., seqk)`
`starmap(func, seq)`
`permutations(seq)`
`islice(seq, start, stop, step)`
...

Description

Infinite sequence: `start, start + step, ...`
Infinite repeats of the elements from `seq`
Infinite repeats of `value` or `times` repeats
Concatenate sequences
`func(*seq[0]), func(*seq[1]), ...`
Generate all possible permutations of `seq`
Create a slice of `seq`
...

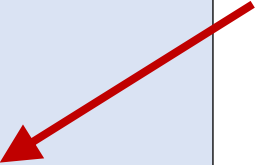
Example : Java iterators

vector-iterator.java

```
import java.util.Vector;
import java.util.Iterator;

class IteratorTest {
    public static void main(String[] args) {
        Vector<Integer> a = new Vector<Integer>();
        a.add(7);
        a.add(42);
        // "C" for-loop & get method
        for (int i=0; i<a.size(); i++)
            System.out.println(a.get(i));
        // iterator
        for (Iterator it = a.iterator(); it.hasNext(); )
            System.out.println(it.next());
        // for-each loop - syntax sugar since Java 5
        for (Integer e : a)
            System.out.println(e);
    }
}
```

In Java iteration does not stop using exceptions, but instead the iterator can be tested if it is at the end of the iterable



Example : C++ iterators

vector-iterator.cpp

```
#include <iostream>
#include <vector>
int main() {
    // Vector is part of STL (Standard Template Library)
    std::vector<int> A = {20, 23, 26};
    // "C" indexing - since C++98
    for (int i = 0; i < A.size(); i++)
        std::cout << A[i] << std::endl;
    // iterator - since C++98
    for (std::vector<int>::iterator it = A.begin(); it != A.end(); ++it)
        std::cout << *it << std::endl;
    // "auto" iterator - since C++11
    for (auto it = A.begin(); it != A.end(); ++it)
        std::cout << *it << std::endl;
    // Range-based for-loop - since C++11
    for (auto e : A)
        std::cout << e << std::endl;
}
```

In C++ iterators can be tested if they reach the end of the iterable



move iterator to next element

Generators

Generator expressions

Python shell

```
> [x ** 2 for x in range(5)] # list comprehension
| [0, 1, 4, 9, 16] # list
> (x ** 2 for x in range(3)) # generator expression
| <generator object <genexpr> at 0x03D9F8A0>
> o = (x ** 2 for x in range(3))
> next(o) # use generator expression as iterator
| 0
> next(o)
| 1
> next(o)
| 4
> next(o)
| StopIteration
```

- A generator expression (... for x in ...) looks like a list comprehension, except square brackets are replaced by parenthesis
- Is an iterable and iterator, that uses less memory than a list comprehension
- computation is done *lazily*, i.e. first when needed

Nested generator expressions

Python shell

```
> squares = (x ** 2 for x in range(1, 6)) # generator expression
> ratios = (1 / y for y in squares) # generator expression
> ratios
| <generator object <genexpr> at 0x031FC230>
> next(ratios)
| 1.0
> next(ratios)
| 0.25
> list(ratios)
| [0.1111111111111111, 0.0625, 0.04] # remaining 3
```

- Each fraction is first computed when requested by `next(ratios)` (implicitly called repeatedly in `list(ratios)`)
- The next value of `squares` is first computed when needed by `ratios`

Generator expressions as function arguments

Python shell

```
> doubles = (x * 2 for x in range(1, 6))
> sum(doubles)    # sum takes an iterable
| 30
> sum((x * 2 for x in range(1, 6)))
| 30
> sum(x * 2 for x in range(1, 6))    # one pair of parenthesis omitted
| 30
```

- Python allows to omit a pair of parenthesis when a generator expression is the only argument to a function

`f(... for x in ...)` \equiv `f((... for x in ...))`

Generator functions

two.py

```
def two():  
    yield 1  
    yield 2
```

Python shell

```
> two()  
| <generator object two at 0x03629510>  
> t = two()  
> next(t)  
| 1  
> next(t)  
| 2  
> next(t)  
| StopIteration
```

- A *generator function* contains one or more `yield` statements
- Python automatically makes a call to a generator function into an iterable and iterator (provides `__iter__` and `__next__`)
- Calling a generator function returns a *generator object*
- Whenever `next` is called on a generator object, the executing of the function continues until the next `yield exp` and the value of `exp` is returned as a result of `next`
- Reaching the end of the function or a return statement, will raise `StopIteration`
- Once consumed, can't be reused

Generator functions (II)

my_generator.py

```
def my_generator(n):  
    yield 'Start'  
    for i in range(n):  
        yield chr(ord('A') + i)  
    yield 'Done'
```

Python shell

```
> g = my_generator(3)  
> print(g)  
| <generator object my_generator at 0x03E2F6F0>  
> print(list(g))  
| ['Start', 'A', 'B', 'C', 'Done']  
> print(list(g)) # generator object g exhausted  
| []  
> print(*my_generator(5)) # * takes an iterable (PEP 448)  
| Start A B C D E Done
```

Generator functions (III)

```
my_range_generator.py
```

```
def my_range(start, end, step):  
    x = start  
    while x < end:  
        yield x  
        x += step
```

```
Python shell
```

```
> list(my_range(1.5, 2.0, 0.1))  
| [1.5, 1.6, 1.7000000000000002, 1.8000000000000003, 1.9000000000000004]
```

- Generator functions are often easier to write than creating an iterable class and the accompanying iterator class

Pipelining generators

Python shell

```
> def squares(seq):      # seq should be an iterable object
    for x in seq:        # use iterator to run through seq
        yield x ** 2     # generator

> list(squares(range(5)))
| [0, 1, 4, 9, 16]

> list(squares(squares(range(5))))    # pipelining generators
| [0, 1, 16, 81, 256]

> sum(squares(squares(range(100000000))))    # pipelining generators
| 199999995000000003333333333333333333330000000

> sum((x ** 2) ** 2 for x in range(100000000))    # generator expression
| 199999995000000003333333333333333333330000000

> sum([(x ** 2) ** 2 for x in range(100000000)])    # list comprehension
| MemoryError    # when using a 32-bit version of Python, limited to 2 GB
```

yield vs yield from

Python shell

```
> def g():  
    yield 1  
    yield [2, 3, 4]  
    yield 5  
  
> list(g())  
| [1, [2, 3, 4], 5]
```

Python shell

```
> def g():  
    yield 1  
    yield from [2, 3, 4]  
    yield 5  
  
> list(g())  
| [1, 2, 3, 4, 5]
```

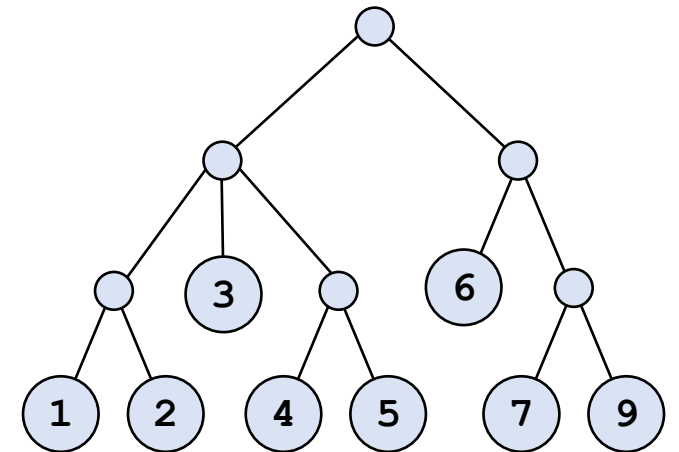
- `yield from` available since Python 3.3
- `yield from exp` \approx `for x in exp: yield x`

Recursive yield from

Python shell

```
> def traverse(T): # recursive generator
    if isinstance(T, tuple):
        for child in T:
            yield from traverse(child)
    else:
        yield T

> T = (((1, 2), 3, (4, 5)), (6, (7, 9)))
> traverse(T)
| <generator object traverse at 0x03279F30>
> list(traverse(T))
| [1, 2, 3, 4, 5, 6, 7, 9]
```



Making objects iterable using `yield`

vector2D.py

```
class vector2D:
    def __init__(self, x_value, y_value):
        self.x = x_value
        self.y = y_value

    def __iter__(self): # generator
        yield self.x
        yield self.y

    def __iter__(self): # alternative generator
        yield from (self.x, self.y)

v = vector2D(5, 7)
print(list(v))
print(tuple(v))
print(set(v))
```

Python shell

```
| [5, 7]
| (5, 7)
| {5, 7}
```

Generators vs iterables

- Iterables can often be reused (like lists, tuples, strings)
- Generators cannot be reused (only if a new generator object is created, starting over again)
- David Beazley's tutorial on *"Generators: The Final Frontier"*, PyCon 2014 (3:50:54)
Throughout advanced discussion of generators, e.g. how to use `.send` method to implement coroutines
<https://www.youtube.com/watch?v=D1tw9kLmYg>

Measuring memory usage

Measuring memory usage (memory profiling)

- Macro level:

Task Manager (Windows)
Activity Monitor (Mac)
top (Linux)

- Variable level:

`getsizeof` from `sys` module

- Detailed overview:

Module `memory_profiler`

Allows detailed space usage of the code line-by-line (using `@profile` function decorator) or a plot of total space usage over time

`pip install memory-profiler`

Python shell

```
> import sys
> sys.getsizeof(42)
| 28 # size of the integer 42 is 28 bytes
> sys.getsizeof(42 ** 42)
| 56 # the size increases with value
> sys.getsizeof('42')
| 51 # size of a string
> import numpy as np
> sys.getsizeof(np.array(range(100), dtype='int32'))
| 512 # also works on Numpy arrays
> squares = [x ** 2 for x in range(1000000)]
> sys.getsizeof(squares)
| 8448728
> g = (x ** 2 for x in range(1000000))
> sys.getsizeof(g)
| 208
```



size values depend on the Python version, e.g., 32 vs 64 bit

Module

memory-profiler

pypi.org/project/memory-profiler/

memory_usage.py

```
from memory_profiler import profile

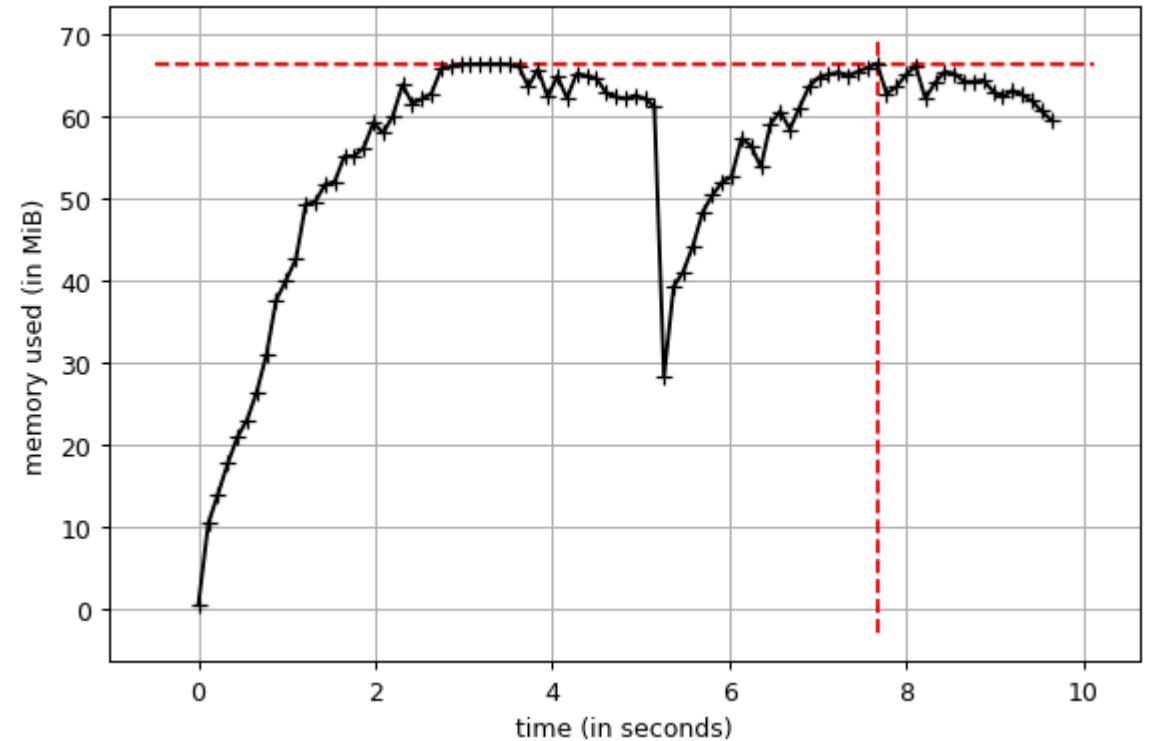
@profile # prints new statistics for each call
def use_memory():
    s = 0
    x = list(range(20_000_000))
    s += sum(x)
    y = list(range(10_000_000))
    s += sum(x)

use_memory()
```

Python Shell

Filename: C:/.../memory_usage.py

Line #	Mem usage	Increment	Line Contents
3	32.0 MiB	32.0 MiB	@profile
4			def use_memory():
5	32.0 MiB	0.0 MiB	s = 0
6	415.9 MiB	383.9 MiB	x = list(range(20_000_000))
7	415.9 MiB	0.0 MiB	s += sum(x)
8	607.8 MiB	191.9 MiB	y = list(range(10_000_000))
9	607.8 MiB	0.0 MiB	s += sum(x)



memory_sin_usage.py

```
from math import sin, pi

for a in range(1000):
    x = list(range(int(1000000 * sin(pi * a / 250))))
```

Windows Shell

```
> pip install memory-profiler
> mprof run memory_sin_usage.py
| mprof: Sampling memory every 0.1s
| running as a Python program...
> mprof plot
```