

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 result of next  
| c 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)      iterable expected
| 2              but got iterator ?
> for x in it:
|     print(x)
|
| 3
| 4
| 5
> list(r)        create list from iterable
| [1, 2, 3, 4, 5]
```

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']
```

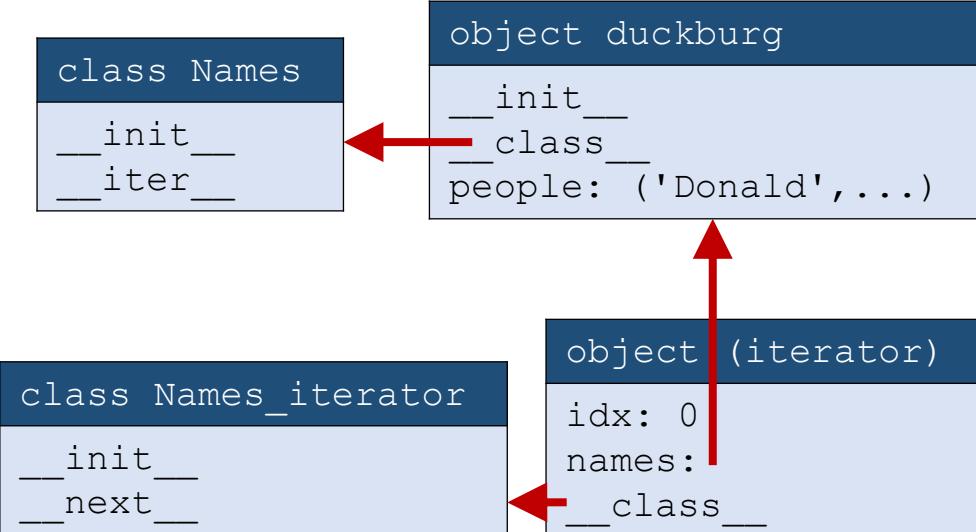
Creating an iterable class

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 object acts both as an iterable and an iterator
- This e.g. also applies to `zip` objects
- Can only iterate over a `my_range` once A yellow triangular warning sign with a black exclamation mark inside.

This is a reminiscence from Python 1 – now rarely used

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
```

odds.__contains__ does not exist

```
> 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
```

- 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

Inifinite sequence: start, stat + step, ...

Infinite repeats of the elements from seq

Infinite repeats of value or times repeats

Concatenate sequences

func (*seq[0]), func (*seq[1]), ...

Genereate 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

$$f(\dots \text{ for } x \text{ in } \dots) \quad \equiv \quad f(\textcolor{red}{(\dots \text{ for } x \text{ in } \dots)})$$

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
| 1999999500000003333333333330000000
> sum((x ** 2) ** 2 for x in range(100000000))  # generator expression
| 19999995000000033333333333330000000
> 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** ≈ **for x in exp: yield x**

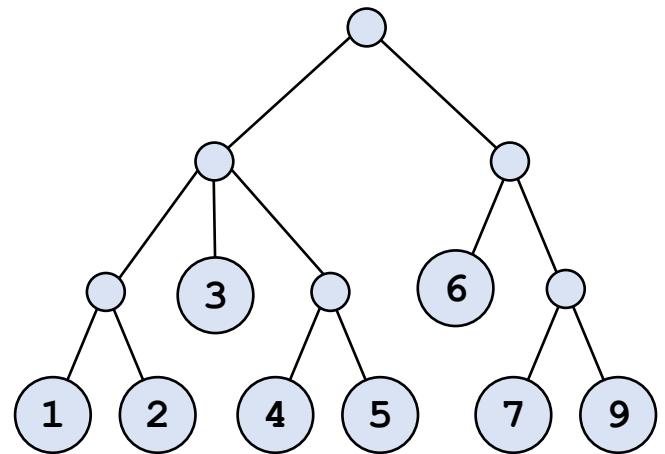
Recursive yield from

without **yield from**

```
for value in traverse(child):
    yield value
```

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]
```



Generator .close()

random_integers.py

```
def random_integers(n):
    seen = set() # integers generated so far
    while len(seen) < n:
        value = random.randint(1, n)
        if value in seen:
            continue # skip duplicates
        seen.add(value)
        yield value
```

- A generator can be forced to terminate by calling **.close()**
- Technically, the generator continues with a **GeneratorExit** exception raised, so that it can clean up before returning
- Useful to release resources from generators, e.g. infinite generators

Python shell

```
> r = random_integers(10)
> next(r)
| 9
> next(r)
| 3
> next(r)
| 5
> r.close()
> next(r)
| StopIteration

> r = random_integers(1_000_000_000)
> next(r)
| 191907382           # memory usage ~ 10 MB
> sum(next(r) for _ in range(10_000_000))
| 4998986626629771   # memory usage ~ 550 MB
> r.close()           # memory usage ~ 10 MB
> next(r)
| StopIteration
```

releases the **seen** set containing 10.000.001 elements for garbage collection

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=D1twn9kLmYg>

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)

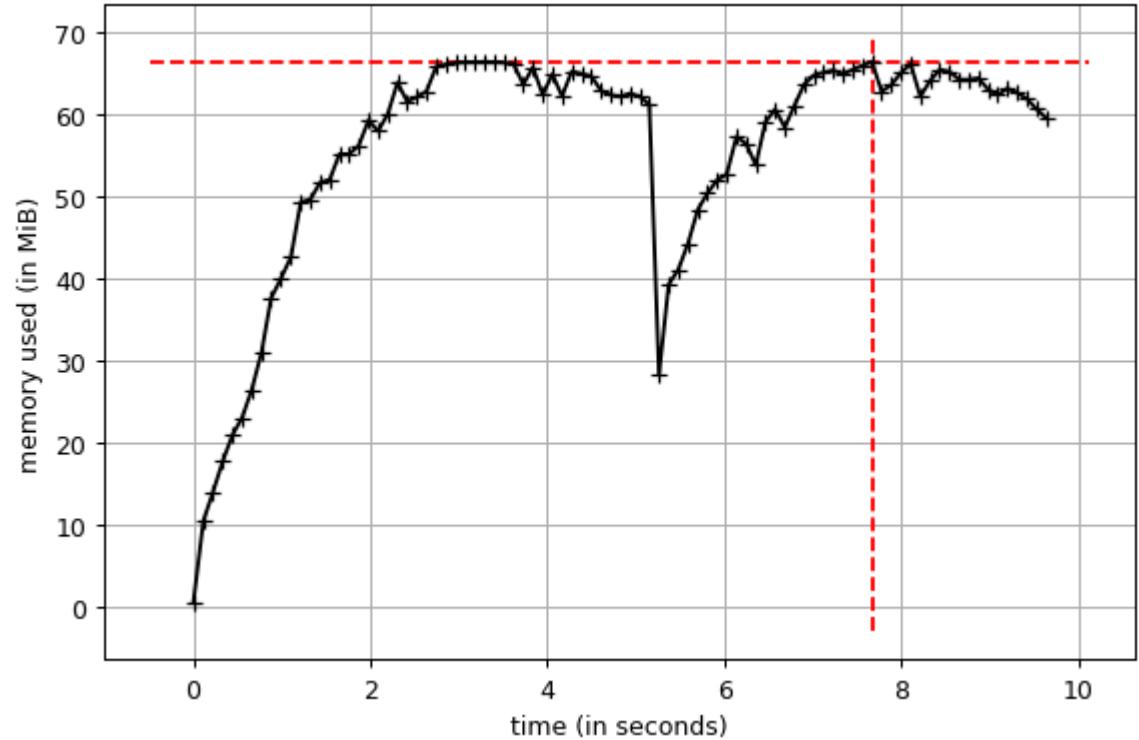
use_memory()
```

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
```