L1: Advanced Python Functionalities

Modified from Andrea Corradini's slides

Python learned before

- Basics of the language
  - Control flow
- Basic datatypes:
  - Int, float, bool
  - list, dict, set
- Modules:
  - importing and executing
  - Commonly used functions

Next topics

Most slides here are just for your references. You probably do not need to use them at the beginner's stage.

- Function definition
- Positional and keyword arguments of functions
- Functions as objects
- Higher-order functions
- Namespaces and Scopes
- Object Oriented programming in Python
- Inheritance
- Iterators and generators

Functions in Python - Essentials

- Functions are first-class objects
- All functions return some value (possibly **None**)
- Function call creates a new namespace
- Parameters are passed by object reference
- Functions can have optional keyword arguments
- Functions can take a variable number of args and kwargs
- Higher-order functions are supported

Function definition (1)

- Positional/keyword/default parameters

```
def sum(n,m):
    """ adds two values """
    return n+m

>>> sum(3,4)
7
>>> sum(m=5,n=3) # keyword parameters
8

#-----------------------

def sum(n,m=5): # default parameter
    """ adds two values, or increments by 5 """
    return n+m

>>> sum(3)
8
```

Function definition (2)

- Arbitrary number of parameters (varargs)

```
def print_args(*items): # arguments are put in a tuple
    print(type(items))
    return items
>>> print_args(1,"hello",4.5)
<class 'tuple'>
(1, 'hello', 4.5)

def print_kwargs(**items): # args are put in a dict
    print(type(items))
    return items
```

Functions are objects

- As everything in Python, also functions are object, of class **function**

```
def echo(arg): return arg
type(echo)              # <class 'function'>
hex(id(echo))           # 0x1003c2bf8
print(echo)             # <function echo at 0x1003c2bf8>
foo = echo
hex(id(foo))            # '0x1003c2bf8'
print(foo)              # <function echo at 0x1003c2bf8>
isinstance(echo, object)       # => True
```

Function documentation

- The comment after the function header is bound to the **__doc__** special attribute

```
def my_function():
    """Summary line: do nothing, but document it.
    Description: No, really, it doesn't do anything.
    """
    pass


print(my_function.__doc__)
# Summary line: Do nothing, but document it.
#
#     Description: No, really, it doesn't do anything.
```

Higher-order functions

- Functions can be passed as argument and returned as result
- Main combinators (**map**, **filter**) predefined: allow standard functional programming style in Python
- Heavy use of iterators, which support laziness
- Lambdas supported for use with combinators

```
lambda arguments: expression
```

  – The body can only be a single expression

Map

```
>>> print(map.__doc__)   % documentation
map(func, *iterables) --> map object
Make an iterator that computes the function using
arguments from each of the iterables.  Stops when the
shortest iterable is exhausted.
```

```
>>> map(lambda x:x+1, range(4))      % lazyness: returns
<map object at 0x10195b278>          % an iterator
>>> list(map(lambda x:x+1, range(4)))
[1, 2, 3, 4]
>>> list(map(lambda x, y : x+y, range(4), range(10)))
[0, 2, 4, 6]         % map of a binary function
>>> z = 5            % variable capture
>>> list(map(lambda x : x+z, range(4)))
[5, 6, 7, 8]
```

Map and List Comprehension

- **List comprehension** can replace uses of **map**

```
>>> list(map(lambda x:x+1, range(4)))
[1, 2, 3, 4]
>>> [x+1 for x in range(4)]
[1, 2, 3, 4]
>>> list(map(lambda x, y : x+y, range(4), range(10)))
[0, 2, 4, 6]    % map of a binary function
>>> [x+y for x in range(4) for y in range(10)] % multiple `for`
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 1, 2, 3, 4, 5,...  % NO!
>>> [x+y for (x,y) in zip(range(4),range(10))] % OK
[0, 2, 4, 6]
>>> print(zip.__doc__)
zip(iter1 [,iter2 [...]]) --> zip object
Return a zip object whose .__next__() method returns a tuple where
the i-th element comes from the i-th iterable argument. The
.__next__() method continues until the shortest iterable in the
argument sequence is exhausted and then it raises StopIteration.
```

Filter (and list comprehension)

```
>>> print(filter.__doc__)  % documentation
filter(function or None, iterable) --> filter object
Return an iterator yielding those items of iterable for
which function(item) is true. If function is None,
return the items that are true.
```

```
>>> filter(lambda x : x % 2 == 0,[1,2,3,4,5,6])
<filter object at 0x102288a58>  % lazyness
>>> list(_)                      % '_' is the last value
[2, 4, 6]
>>> [x for x in [1,2,3,4,5,6] if x % 2 == 0]
[2, 4, 6] % same using list comprehension
% How to say "false" in Python
>>> list(filter(None,
       [1,0,-1,"","Hello",None,[],[1],(),True,False]))
[1, -1, 'Hello', [1], True]
```

More modules for functional programming in Python

- **functools**: Higher-order functions and operations on callable objects, including:
  - reduce(*function*, *iterable*[, *initializer*])
- **itertools**: Functions creating ***iterators*** for efficient looping. Inspired by constructs from APL, Haskell, and SML.
  - count(10) --> 10 11 12 13 14 ...
  - cycle('ABCD') --> A B C D A B C D ...
  - repeat(10, 3) --> 10 10 10
  - takewhile(lambda x: x<5, [1,4,6,4,1]) --> 1 4
  - accumulate([1,2,3,4,5]) --> 1 3 6 10 15

Decorators

- A **decorator** is any callable Python object that is used to modify a **function**, **method** or **class definition**.
- A decorator is passed the original object being defined and returns a modified object, which is then bound to the name in the definition.
- (Function) Decorators exploit Python **higher-order features**:
  - Passing functions as argument
  - Nested definition of functions
  - Returning function
- Widely used in Python (system) programming
- Support several features of meta-programming

Basic idea: wrapping a function

```
def my_decorator(func):        # function as argument
    def wrapper(): # defines an inner function
        print("Something happens before the function.")
        func() # that calls the parameter
        print("Something happens after the function.")
    return wrapper # returns the inner function
```

```
def say_hello():    # a sample function
    print("Hello!")
# 'say_hello' is bound to the result of my_decorator
say_hello = my_decorator(say_hello) # function as arg
>>> say_hello()   # the wrapper is called
Something happens before the function.
Hello!
Something happens after the function.
```

Syntactic sugar: the "pie" syntax

```
def my_decorator(func):         # function as argument
    def wrapper(): # defines an inner function
        ... # as before
    return wrapper # returns the inner function
```

```
def say_hello():           ## HEAVY! 'say_hello' typed 3x
    print("Hello!")
say_hello = my_decorator(say_hello)
```

- Alternative, equivalent syntax

```
@my_decorator
def say_hello():
    print("Hello!")
```

Another decorator: do_twice

```
def do_twice(func):
    def wrapper_do_twice():
        func()       # the wrapper calls the
        func()       #      argument twice
    return wrapper_do_twice
```

```
@do_twice              # decorate the following
def say_hello():       # a sample function
    print("Hello!")
>>> say_hello()        # the wrapper is called
Hello!
Hello!
```

```
@do_twice             # does not work with parameters!!
def echo(str):        # a function with one parameter
    print(str)
>>> echo("Hi...")     # the wrapper is called
TypErr: wrapper_do_twice() takes 0 pos args but 1 was given
>>> echo()
TypErr: echo() missing 1 required positional argument: 'str'
```

do_twice for functions with parameters

- Decorators for functions with parameters can be defined exploiting ***args** and ****kwargs**

```
def do_twice(func):
    def wrapper_do_twice(*args, **kwargs):
        func(*args, **kwargs)
        func(*args, **kwargs)
    return wrapper_do_twice
```

```
@do_twice
def say_hello():
    print("Hello!")
>>> say_hello()
Hello!
Hello!
```

```
@do_twice
def echo(str):
    print(str)
>>> echo("Hi... ")
Hi...
Hi...
```

General structure of a decorator

- Besides passing arguments, the wrapper also forwards the **result** of the decorated function
- Supports introspection redefining **`__name__`** and **`__doc__`**

```
import functools
def decorator(func):
    @functools.wraps(func)     #supports introspection
    def wrapper_decorator(*args, **kwargs):
        # Do something before
        value = func(*args, **kwargs)
        # Do something after
        return value
    return wrapper_decorator
```

Example: Measuring running time

```
import functools, time

def timer(func):
    """Print the runtime of the decorated function"""
    @functools.wraps(func)
    def wrapper_timer(*args, **kwargs):
        start_time = time.perf_counter()
        value = func(*args, **kwargs)
        end_time = time.perf_counter()
        run_time = end_time - start_time
        print(f"Finished {func.__name__!r} in {run_time:.4f} secs")
        return value
    return wrapper_timer


@timer
def waste_some_time(num_times):
    for _ in range(num_times):
        sum([i**2 for i in range(10000)])

print(waste_some_time.__name__) # prints ‘waste_some_time’
print(waste_some_time.__doc__)  #
```

Other uses of decorators

- Debugging: prints argument list and result of calls to decorated function
- Registering plugins: adds a reference to the decorated function, without changing it
- In a web application, can wrap some code to check that the user is logged in
- @staticmethod and @classmethod make a function invocable on the class name or on an object of the class
- More: decorators can be nested, can have arguments, can be defined as classes…

Example: Caching Return Values

```
import functools
from decorators import count_calls

def cache(func):
    """Keep a cache of previous function calls"""
    @functools.wraps(func)
    def wrapper_cache(*args, **kwargs):
        cache_key = args + tuple(kwargs.items())
        if cache_key not in wrapper_cache.cache:
            wrapper_cache.cache[cache_key] = func(*args, **kwargs)
        return wrapper_cache.cache[cache_key]
    wrapper_cache.cache = dict()
    return wrapper_cache

@cache
@count_calls   # decorator that counts the invocations
def fibonacci(num):
    if num < 2:
        return num
    return fibonacci(num - 1) + fibonacci(num - 2)
```

OOP in Python

- Typical ingredients of the Object Oriented Paradigm:
  - **<u>Encapsulation</u>**: dividing the code into a public **interface**, and a private **implementation** of that interface;
  - **<u>Inheritance</u>**: the ability to create **subclasses** that contain specializations of their parent classes.
  - **<u>Polymorphism</u>**: The ability to **override** methods of a Class by extending it with a subclass (inheritance) with a more specific implementation (**inclusion polymorphism**)

From https://docs.python.org/3/tutorial/classes.html:

- *"Python classes provide all the standard features of Object Oriented Programming: the class inheritance mechanism allows multiple base classes, a derived class can override any methods of its base class or classes, and a method can call the method of a base class with the same name. Objects can contain arbitrary amounts and kinds of data. As is true for modules, classes partake of the dynamic nature of Python: they are created at runtime, and can be modified further after creation*."

Defining a class (object)

- A class is a blueprint for a new data type with specific internal ***attributes*** (like a struct in C) and internal functions (***methods***).
- To declare a class in Python the syntax is the following:

```
class className:
    <statement-1>
    …
    <statement-n>
```

- `statements` are assignments or function definitions
- A new namespace is created, where all names introduced in the statements will go.
- When the class definition is left, a ***class object*** is created, bound to **className**, on which two operations are defined: ***attribute reference*** and ***class instantiation***.
- *Attribute reference* allows to access the names in the namespace in the usual way

Example: Attribute reference on a class object

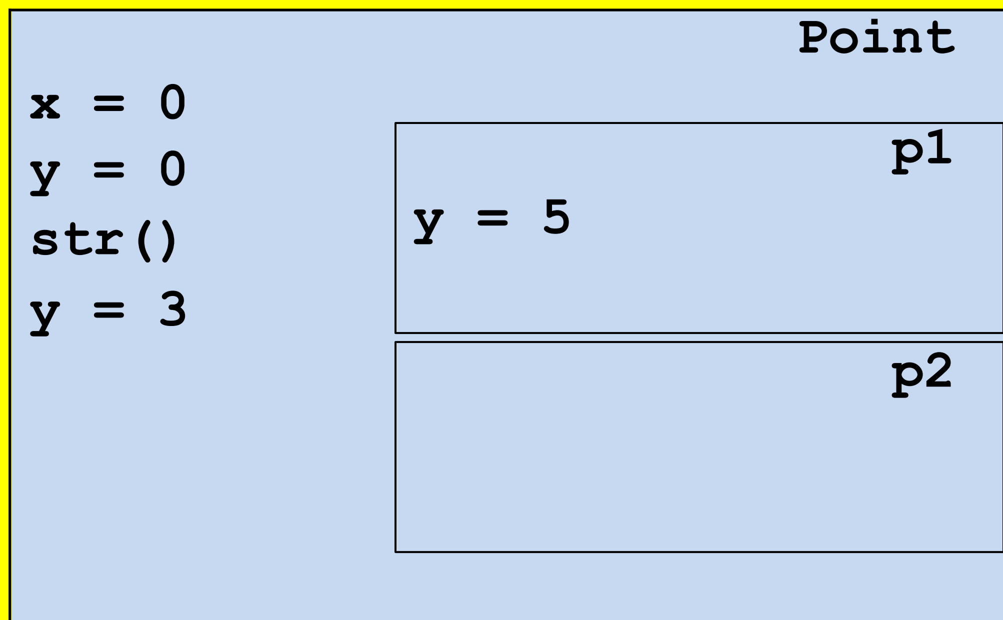
```
class Point:
  x = 0
  y = 0
  def str(): # no closure: needs qualified names to refer to x and y
      return  "x = " + (str) (Point.x) + ", y = " + (str) (Point.y)
#--------
import ...
>>> Point.x
0
>>> Point.y = 3
>>> Point.z = 5 # adding new name
>>> Point.z
5
>>> def add(m,n):
      return m+n
>>> Point.sum = add # adding new function
>>> Point.sum(3,4)
7
```

```
Point
x = 0
y = 0
str()
y = 3
z = 5
sum = add(m,n)
```

Creating a class instance

- A **class instance** introduces a **new namespace** ***nested in the class namespace***: by visibility rules all names of the class are visible
- If no *constructor* is present, the syntax of class instantiation is **className()**: the new namespace is empty

```
class Point:
  x = 0
  y = 0
  def str():
      return  "x = " + str(Point.x) + ", y = " + str(Point.y)
#--------
>>> p1 = Point()
>>> p2 = Point()
>>> p1.y
0
>>> Point.y = 3
>>> print(p1.y, p2.y)
3 3
>>> p1.y = 5
>>> print(p1.y, p2.y)
5 3
```



Instance methods

- A class can define a set of ***instance methods***, which are just functions:

```
def methodname(self, parameter1, ..., parametern):
         statements
```

- The first argument, usually called **self**, represents the ***implicit parameter*** (`this` in Java)
- A method ***must*** access the object's attributes through the `self` reference (eg. **self.x**) and the class attributes using **className.<attrName>** (or **self.__class__.<attrName>**)
- The first parameter must not be passed when the method is called. It is bound to the target object. Syntax:

```
obj.methodname(arg1, ..., argn):
```

- But it can be passed explicitly. Alternative syntax:

```
className.methodname(obj, arg1, ..., argn):
```

"Instance methods"

- Any function ***with at least one parameter*** defined in a class can be invoked on an instance of the class with the dot notation.

```
class Foo
    def fun(par-0, par-1, ..., par-n):
          statements
#---
>>>obj = Foo()
>>>obj.fun(arg-1,...,arg-n)
# is syntactic sugar for
>>>obj.__class__.fun(obj,arg-1,...,arg-n)
```

- Since the instance **`obj`** is bound to the first parameter, **`par-0`** is usually called **`self`**.

- A name **`x`** defined in the (namespace of the) instance is accessed as **`par-0.x`** (i.e., usually **`self.x`**)

- A name **`x`** defined in the class is accessed as **`className.x`** (or **`self.__class__.x`**)

Constructors

- A constructor is a **special instance method** with name `__init__`.

Syntax:

```
def __init__(self, parameter_1, ..., parameter_n):
        statements
```

- Invocation: `obj = className(arg_1, ..., arg_n)`
- The first parameter `self` is bound to the new object.
- `statements` typically initialize (thus create) "instance variables", i.e. names in the new object namespace.
- Note: at most ONE constructor (**no overloading in Python**!)

```
class Point:
   instances = []
   def __init__(self, x, y):
      self.x = x
      self.y = y
      Point.instances.append(self)
#--------
>>> p1 = Point(3,4)
```

Point instances = [<Point object at …>]

P1

x = 3

y = 4

String representation

- It is often useful to have a textual representation of an object with the values of its attributes. This is possible with the following instance method:

```
 def __str__(self) :
          return <string>
```

- This is equivalent to Java's **toString** (converts object to a string) and it is invoked automatically when **str** or **print** is called.

Special methods

- **Method overloading**: you can define special instance methods so that Python's built-in operators can be used with your class.

Binary Operators

Operator	Class Method
-	`__sub__(self, other)`
+	`__add__(self, other)`
*	`__mul__(self, other)`
/	`__truediv__(self, other)`

Operator	Class Method
==	`__eq__(self, other)`
!=	`__ne__(self, other)`
<	`__lt__(self, other)`
>	`__gt__(self, other)`
<=	`__le__(self, other)`
>=	`__ge__(self, other)`

Unary Operators

-	`__neg__(self)`
+	`__pos__(self)`

- Analogous to C++ overloading mechanism:
  - Pros: very compact syntax
  - Cons: may be more difficult to read if not used with care

(Multiple) Inheritance, in one slide

- A class can be defined as a *derived class*

```
class derived(baseClass):
    statements
    statements
```

- No need of additional mechanisms: the namespace of **derived** is nested in the namespace of **baseClass**, and uses it as the next non-local scope to resolve names
- All instance methods are automatically virtual: lookup starts from the instance (namespace) where they are invoked
- Python supports **multiple inheritance**

```
class derived(base1,..., basen):
    statements
    statements
```

- **Method resolution order** (**MRO**) determines how to resolve a method (or an attribute) during multiple inherence
- Python 3: depth first, left-to-right order. C.f., https://www.geeksforgeeks.org/method-resolution-order-in-python-inheritance/

Encapsulation (and "name mangling")

- **Private** instance variables (not accessible except from inside an object) **don't exist in Python.**

- **Convention:** a **name prefixed with underscore** (e.g. `_spam`) is treated as ***non-public part of the API*** (function, method or data member). It should be considered an implementation detail and subject to change without notice.

Name mangling

- Sometimes class-private members are needed to avoid clashes with names defined by subclasses. Limited support for such a mechanism, called *name mangling.*

- Any **name with at least two leading underscores and at most one trailing underscore** like e.g. `__spam` is textually replaced with `_class__spam`, where `class` is the current class name.

Example for name mangling

- Name mangling is helpful for letting subclasses override methods without breaking intraclass method calls.

```
class Mapping:
    def __init__(self, iterable):
        self.items_list = []
        self.__update(iterable)

    def update(self, iterable):
        for item in iterable:
            self.items_list.append(item)

    __update = update # private copy of update() method

class MappingSubclass(Mapping):

    def update(self, keys, values):
        # provides new signature for update()
        # but does not break __init__()
        for item in zip(keys, values):
            self.items_list.append(item)
```

Static methods and class methods

- **Static methods** are simple functions defined in a class with no `self` argument, preceded by the **@staticmethod** decorator
- They are defined inside a class but they cannot access instance attributes and methods
- They can be called through both the class and any instance of that class!
- **Benefits of static methods**: they allow subclasses to customize the static methods with inheritance. Classes can inherit static methods without redefining them.
- Class methods are similar to static methods but they have a first parameter which is the class name.
- Definition must be preceded by the **@classmethod** decorator
- Can be invoked on the class or on an instance.

Iterators

- An **iterator** is an object which allows a programmer to traverse through all the elements of a collection (**iterable** object), regardless of its specific implementation. In Python they are used implicitly by the **FOR** loop construct.

- Python iterator objects required to support two methods:
  - **`__iter__`** returns the iterator object itself. This is used in **FOR** and **IN** statements.
  - The **`next`** method returns the next value from the iterator. If there is no more items to return then it should raise a **`StopIteration`** exception.

- Remember that an iterator object can be used only once. It means after it raises **`StopIteration`** once, it will keep raising the same exception.

- Example:

```
for element in [1, 2, 3]:
      print(element)
```

```
>>> list = [1,2,3]
>>> it = iter(list )
>>> it
<listiterator object at 0x00A1DB50>
>>> it.next()
1
>>> it.next()
2
>>> it.next()
3
>>> it.next() -> raises StopIteration
```

Generators and coroutines

- **Generators** are a simple and powerful tool for creating iterators.
- They are written like **regular functions** but use the `yield` statement whenever they want to return data.
- Each time the `next()` is called, the generator resumes where it left-off (it remembers all the data values and which statement was last executed).
- ***Anything that can be done with generators can also be done with class based iterators (not vice-versa).***
- What makes generators so compact is that the `__iter__()` and `next()` methods are created automatically.
- Another key feature is that the local variables and execution state are **automatically saved** between calls.

Generators (2)

- In addition to automatic method creation and saving program state, when generators terminate, they automatically raise **`StopIteration`**.

- In combination, these features make it easy to create iterators with no more effort than writing a regular function.

```
def reverse(data):
    for index in range(len(data)-1, -1, -1):
        yield data[index]

#-----------

>>> for char in reverse('golf'):
...     print(char)
...
f
l
o
g
```

Typing in Python

- Dynamic, strong duck typing
- Code can be annotated with types

```
def greetings(name: str) -> str:
    return 'Hello ' + name.
```

- Module **typing** provides runtime support for type hints
- Type hints can be checked statically by external tools, like **mypy**
- They are ignored by CPython

Duck Typing

- "If it walks like a duck, and it quacks like a duck, then it must be a duck."
- The type or the class of an object is less important than the methods it defines. When you use duck typing, you do not check types at all. Instead, you check for the presence of a given method or attribute.

```
>>> class TheHobbit:
...     def __len__(self):
...         return 95022
...
...
>>> the_hobbit = TheHobbit()

>>> the_hobbit
<__main__.TheHobbit object at 0x108deeef0>

>>> len(the_hobbit)
95022
```

Dynamic Adding Methods

```python
class User:
    pass

# Add instance attributes dynamically
jane = User()
jane.name = "Jane Doe"
jane.job = "Data Engineer"
jane.__dict__  # {'name': 'Jane Doe', 'job': 'Data Engineer'}
```

```
{'name': 'Jane Doe', 'job': 'Data Engineer'}
```

```python
# Add methods dynamically
def __init__(self, name, job):
    self.name = name
    self.job = job

User.__init__ = __init__
User.__dict__  # mappingproxy({'__init__': <function __init__ at 0x1036ccae0>})
```

```
mappingproxy({'__module__': '__main__',
              '__dict__': <attribute '__dict__' of 'User' objects>,
              '__weakref__': <attribute '__weakref__' of 'User' objects>,
              '__doc__': None,
              '__init__': <function __main__.__init__(self, name, job)>})
```

```python
linda = User("Linda Smith", "Team Lead")
linda.__dict__  # {'name': 'Linda Smith', 'job': 'Team Lead'}
```

```
{'name': 'Linda Smith', 'job': 'Team Lead'}
```

Miscellaneous

- Overloading: forbidden, but not necessary
- Overriding: ok, thanks to namespaces
- Generics: type hints support generics

Criticisms to Python: syntax of tuples

```
>>> type((1,2,3))
<class 'tuple'>
>>> type(())
<class 'tuple'>
>>> type((1))
<class 'int'>
>>> type((1,))
<class 'tuple'>
```

- Tuples are made by the commas, not by ( )
- With the exception of the empty tuple…

Criticisms to Python: indentation

- Lack of brackets makes the syntax "weaker" than in other languages: accidental changes of indentation may change the semantics, leaving the program syntactically correct.

```
def foo(x):
    if x == 0:
        bar()
        baz()
    else:
        qux(x)
        foo(x - 1)
```

```
def foo(x):
    if x == 0:
        bar()
        baz()
    else:
        qux(x)
    foo(x - 1)
```

- Mixed use of tabs and blanks may cause bugs almost impossible to detect

Criticisms to Python: indentation

- Lack of brackets makes it harder to refactor the code or insert new one
- "When I want to refactor a bulk of code in Python, I need to be very careful. Because if lost, I'm not sure what I'm editing belongs to which part of the code. Python depends on indentation, so if I have mistakenly removed some indentation, I totally have no idea whether the correct code should belong to that **if** clause or this **while** clause."
- Will Python change in the future?

```
>>> from __future__ import braces
  File "<stdin>", line 1
SyntaxError: not a chance
>>>
```

Builtins & Libraries

- The Python ecosystem is extremely rich and in fast evolution
- For available functions, classes and modules browse:
  - **Builtin Functions**
    - https://docs.python.org/3.8/library/functions.html
  - **Standard library**
    - https://docs.python.org/3.8/tutorial/stdlib.html
- There are dozens of other libraries, mainly for scientific computing, machine learning, computational biology, data manipulation and analysis, natural language processing, statistics, symbolic computation, etc.