



Lecture 9 – Testing, Unit Tests, Exceptions

<https://cw.fel.cvut.cz/wiki/courses/be5b33prg/start>

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- Including **automated tests** proves invaluable if the project becomes larger or if we have to return to it to make a small change after a long absence
- Tests serve as a form of **documentation** – by reading through test cases we can get an idea of the expected behavior
- Test driven approach – **writing tests first**, thereby creating a **specification** for what the program is supposed to do, and filling in the actual program code **afterwards**

SOURCE: courtesy of Petr Posik BE5b33PR 2016/2017



- Two major approaches: **black-box** or **glass-box** testing
- In **black-box** testing treat tested function like an opaque “black box” – only think about what the function is supposed to do
(*strategies: **equivalence testing, boundary value analysis***)
- In **glass-box** testing choose test cases by analyzing the code inside our function
(*strategies: **path coverage, statement coverage***)



Example: `sum_digits()`

Specifications: In module `tools.py`, create function `sum_digits(string)` which return the sum of all digits in `string`.

Solution: We create the required module as follows:

```
%%writefile tools.py
def sum_digits(string):
    """Return the sum of all digits in the string"""
    sum = 0
    for ch in string:
        if ch in '012346789':
            sum += int(ch)
    return sum
```

Writing `tools.py`

Are we finished? How do we test the code?



Option 1: Try to use it in Python shell

```
>>> from tools import sum_digits
>>> sum_digits('1, 2, 3, dee, dah, dee')
```

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- We have tested a single test case.
- We have to manually check the correctness of the result.
- What if we want to run the test again?

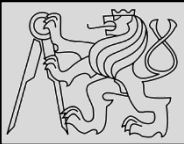


Option 2: Including the test code directly in the module

The code previously written on Python console can be stored directly with the module (or in some other module).

```
%%writefile tools2.py
def sum_digits(string):
    """Return the sum of all digits in the string"""
    sum = 0
    for ch in string:
        if ch in '012346789':
            sum += int(ch)
    return sum

if __name__ == "__main__":
    # All the code below is executed only when the file is run as a script.
    print(sum_digits('1, 2, 3, dee, dah, dee'))
```



```
import tools2 # "Nothing" happens when we import the module (desired), ...
```

```
%run tools2.py # ... but the testing code is executed when we run the module!
```

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- We still test a single test case only.
- We still have to manually check the correctness of the result.
- **But we can run the test easily. As many times as we want!**



Option 3: Check the correctness of the result automatically

Instead of mere printing out the result, we can check its correctness!

```
%%writefile tools3.py
def sum_digits(string):
    """Return the sum of all digits in the string"""
    sum = 0
    for ch in string:
        if ch in '012346789':
            sum += int(ch)
    return sum

if __name__ == "__main__":
    observed = sum_digits('1, 2, 3, dee, dah, dee')
    expected = 6
    if observed == expected:
        print('.')
    else:
        print('Test failed.')
        print('- Expected:', str(expected))
        print('- But got: ', str(observed))
```



```
%run tools3.py
```

- We still test a single test case only.
- **But we do not have to manually check the correctness of the result, we can immediately see if the test passed or not.**
- **And we can run the test easily. As many times as we want!**



Our own module for testing!

The process of checking the correctness of a result may be extracted to a function that will

- allow us to write tests using only a little code,
- be part of a module that can be reused in many projects.

Let's create module `testing` with function `test_equal()` which shall have 3 parameters:

- the `observed` and `expected` values, and
- an optional `name` of the test.

The function shall print

- `" . "` if the test passes, or
- an informative message about the failure, if the test fails.



```
%%writefile testing.py
import sys

def quote(name):
    if name:
        name = "'" + name + "'"
    return name

def test_equal(observed, expected, name=''):
    """Compare the observed and expected results"""
    if observed == expected:
        print('.', end='')
    else:
        lineno = sys._getframe(1).f_lineno # Get the caller's line number.
        print("\nTest {} at line {} FAILED:".format(quote(name), lineno))
        print("- Expected:", str(expected))
        print("- But got: ", str(observed))
```



With the help of our testing module, we can rewrite the `tools` module as follows:

```
%%writefile tools4.py
from testing import test_equal

def sum_digits(string):
    """Return the sum of all digits in the string"""
    sum = 0
    for ch in string:
        if ch in '012346789':
            sum += int(ch)
    return sum

if __name__ == "__main__":
    test_equal(sum_digits('1, 2, 3, dee, dah, dee'), 6, 'Test 1')
```



```
%run tools4.py
```

.

- We still test a single test case only.
- **But we do not have to manually check the correctness of the result, we can immediately see if the test passed or failed.**
- **And we do not need to write much code to test a single case!**
- **And we can run the tests easilly. As many times as we want!**



Adding more tests

When we have more test cases, we can add them either

- to the `if __name__=="__main__"` section of the main file, or
- to a separate testing module.

Let's create a separate testing module.

```
: %%writefile test_tools.py
from testing import test_equal
from tools4 import *

def test_sum_digits():
    test_equal(sum_digits(''), 0, 'Test empty string')
    test_equal(sum_digits('0'), 0, 'Test 0')
    test_equal(sum_digits('1'), 1, 'Test 1')
    test_equal(sum_digits('2'), 2, 'Test 2')
    test_equal(sum_digits('3'), 3, 'Test 3')
    test_equal(sum_digits('4'), 4, 'Test 4')
    test_equal(sum_digits('5'), 5, 'Test 5')
    test_equal(sum_digits('6'), 6, 'Test 6')
    test_equal(sum_digits('7'), 7, 'Test 7')
    test_equal(sum_digits('8'), 8, 'Test 8')
    test_equal(sum_digits('9'), 9, 'Test 9')
    test_equal(sum_digits('1, 2, 3, dee, dah, dee'), 6, 'Non trivial test')

# Run the test suite
test_sum_digits()
```

SOURCE: courtesy of Petr Posik BE5b33PR 2016/2017



```
%run test_tools.py
```

```
.....  
Test 'Test 5' at line 11 FAILED:  
- Expected: 5  
- But got: 0  
.....
```

Ha! We have an error in our code! Can you find it?

With the help of a testing framework:

- We can easily build comprehensive test suites.
- We do not have to manually check the correctness of the result, we can immediately see if the test passed or failed.
- We do not need to write much code to test a single case!
- We can run the test suite easily. As many times as we want.

Other testing frameworks

Our module `testing` is not an original idea. Python has several popular testing frameworks, e.g. modules

- `doctest` and
- `unittest`.

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Testing the code using doctest

- Create the habit to include examples of the functions' usage in their docstrings (see below).
- Module `doctest` allows you to easily execute the examples from the docstrings:

```
%%writefile modulewithdoctests.py
def average(x,y):
    """Return the average of 2 numbers.

    >>> average(10,20)
    15.0
    >>> average(1.5, 2.0)
    1.75
    """
    return (x + y) / 2

if __name__ == "__main__":
    import doctest
    doctest.testmod(verbose=True)
```

Writing `modulewithdoctests.py`



Then, if you run the module, the tests are executed automatically and compared with their expected results:

```
%run modulewithdoctests.py
```

```
Trying:
    average(10,20)
Expecting:
    15.0
ok
Trying:
    average(1.5, 2.0)
Expecting:
    1.75
ok
1 items had no tests:
    __main__
1 items passed all tests:
    2 tests in __main__.average
2 tests in 2 items.
2 passed and 0 failed.
Test passed.
```



Summary

- Testing your own code is **extremely important!**
- You should learn several ways how to test your code.
- Using a **testing framework**, from simple ones (like our `testing`) to comprehensive ones (like `unittest`), gives you an considerable **advantage!**
- Testing frameworks like `unittest` are common to many other languages. If you learn it for one language, you will profit from it also in the other languages.



```
ourprog/  
  ourprog/  
    __init__.py  
    db.py  
    gui.py  
    rules.py  
    test/  
      __init__.py  
      test_db.py  
      test_gui.py  
      test_rules.py  
  setup.py
```

- Advanced framework for testing – python **unittest** module
- All tests in a file hierarchy **separated** from main the program (directory *test/*)
- Create a **test module for each program module** and put them all in a **separate test directory**



```
if __name__ == '__main__':  
    unittest.main()
```

```
# these commands will try to find all our tests  
python -m unittest  
python -m unittest discover  
  
# but we can be more specific  
python -m unittest ourprog.test.test_rules  
python -m unittest ourprog.test.test_rules.TestPerson  
python -m unittest ourprog.test.test_rules.TestPerson.test_fullname  
  
# we can also turn on verbose output with -v  
python -m unittest -v test_rules
```

- *Many ways of running tests!* (test automation frameworks)
- Run all the tests from a single file by adding **unittest.main()** at the bottom of *test_rules.py* and **execute as a script**
- Execute the unittest module on the **commandline** and use it to import and run some or all of our tests



```
def suite():  
    suite = unittest.TestSuite()  
    suite.addTest(TestPerson)  
    return suite
```

- The **unittest** package allows to **group some or all of our tests into suites**
- This way many related tests can be executed at once
- **EXAMPLE:**
One way to add all the tests from the **TestPerson** class to a suite is to add for example **suite()** function to the **test_rules.py** file



The `unittest` module provides a rich set of tools for constructing and running tests. This section demonstrates that a small subset of the tools suffice to meet the needs of most users.

Here is a short script to test three string methods:

```
import unittest

class TestStringMethods(unittest.TestCase):

    def test_upper(self):
        self.assertEqual('foo'.upper(), 'FOO')

    def test_isupper(self):
        self.assertTrue('FOO'.isupper())
        self.assertFalse('Foo'.isupper())

    def test_split(self):
        s = 'hello world'
        self.assertEqual(s.split(), ['hello', 'world'])
        # check that s.split fails when the separator is not a string
        with self.assertRaises(TypeError):
            s.split(2)

if __name__ == '__main__':
    unittest.main()
```

SOURCE <https://docs.python.org/3.7/library/unittest.html>



A testcase is created by subclassing `unittest.TestCase`. The three individual tests are defined with methods whose names start with the letters `test`. This naming convention informs the test runner about which methods represent tests.

The crux of each test is a call to `assertEqual()` to check for an expected result; `assertTrue()` or `assertFalse()` to verify a condition; or `assertRaises()` to verify that a specific exception gets raised. These methods are used instead of the `assert` statement so the test runner can accumulate all test results and produce a report.

The `setUp()` and `tearDown()` methods allow you to define instructions that will be executed before and after each test method. They are covered in more detail in the section [Organizing test code](#).

The final block shows a simple way to run the tests. `unittest.main()` provides a command-line interface to the test script. When run from the command line, the above script produces an output that looks like this:

```
...  
-----  
Ran 3 tests in 0.000s  
  
OK
```

SOURCE <https://docs.python.org/3.7/library/unittest.html>



Passing the `-v` option to your test script will instruct `unittest.main()` to enable a higher level of verbosity, and produce the following output:

```
test_isupper (__main__.TestStringMethods) ... ok
test_split (__main__.TestStringMethods) ... ok
test_upper (__main__.TestStringMethods) ... ok
```

```
-----
Ran 3 tests in 0.001s
```

```
OK
```

The above examples show the most commonly used `unittest` features which are sufficient to meet many everyday testing needs. The remainder of the documentation explores the full feature set from first principles.

- Verbosity for the tests can be defined using `-v`



The unittest module can be used from the command line to run tests from modules, classes or even individual test methods:

```
python -m unittest test_module1 test_module2
python -m unittest test_module.TestClass
python -m unittest test_module.TestClass.test_method
```

You can pass in a list with any combination of module names, and fully qualified class or method names.

Test modules can be specified by file path as well:

```
python -m unittest tests/test_something.py
```

- Unit tests can be executed for specified **modules**, **classes**, or **methods**; path to a python file can be used as well



- Whenever **runtime error** occurs, it creates an *exception object*
- The **program stops running** at this point and Python prints out the *traceback*, which ends with an **error message** describing the exception that occurred
- **Exception** – An error that occurs at runtime
- **Handle an exception** – To prevent an exception from causing our program to *crash*, by wrapping the block of code in a **try ... except** construct
- **Raise** – To create a deliberate exception by using the raise statement



```
>>> print(55/0)
Traceback (most recent call last):
  File "<interactive input>", line 1, in <module>
ZeroDivisionError: integer division or modulo by zero
```

```
>>> a = []
>>> print(a[5])
Traceback (most recent call last):
  File "<interactive input>", line 1, in <module>
IndexError: list index out of range
```

```
>>> tup = ("a", "b", "d", "d")
>>> tup[2] = "c"
Traceback (most recent call last):
  File "<interactive input>", line 1, in <module>
TypeError: 'tuple' object does not support item assignment
```

- The **error message** on the last line has two parts:
 - the **type of error** before the colon,
 - and **specifics** about the error after the colon



```
1 filename = input("Enter a file name: ")
2 try:
3     f = open(filename, "r")
4 except:
5     print("There is no file named", filename)
```

- **TASK:** To execute an operation that might **cause an exception** but **does not stop** the program
- **SOLUTION:** Handle the exception using the **try-except** statement to “wrap” a region of code
- **EXAMPLE:** *Prompt the user for the name of a file and then try to open it. If the file does not exist, we do not want the program to crash*



```
1 def exists(filename):  
2     try:  
3         f = open(filename)  
4         f.close()  
5         return True  
6     except:  
7         return False
```

- The **try statement** has three separate clauses, or parts, introduced by the keywords **try ... except ... else ... finally**
- The **except**, **else** or the **finally** clauses can be omitted
- The try statement executes and **monitors the statements** in the first block and *if no exceptions occur, it skips the block under the except clause*
- If any *exception occurs, it executes the statements in the except clause* and then continues



```
>>> while True:
...     try:
...         x = int(input("Please enter a number: "))
...         break
...     except ValueError:
...         print("Oops! That was no valid number. Try again...")
... 
```

The `try` statement works as follows.

- First, the *try clause* (the statement(s) between the `try` and `except` keywords) is executed.
- If no exception occurs, the *except clause* is skipped and execution of the `try` statement is finished.
- If an exception occurs during execution of the `try` clause, the rest of the clause is skipped. Then if its type matches the exception named after the `except` keyword, the `except` clause is executed, and then execution continues after the `try` statement.
- If an exception occurs which does not match the exception named in the `except` clause, it is passed on to outer `try` statements; if no handler is found, it is an *unhandled exception* and execution stops with a message as shown above.

```
... except (RuntimeError, TypeError, NameError):
...     pass
```



```
>>> def divide(x, y):
...     try:
...         result = x / y
...     except ZeroDivisionError:
...         print("division by zero!")
...     else:
...         print("result is", result)
...     finally:
...         print("executing finally clause")
...
>>> divide(2, 1)
result is 2.0
executing finally clause
>>> divide(2, 0)
division by zero!
executing finally clause
>>> divide("2", "1")
executing finally clause
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<stdin>", line 3, in divide
TypeError: unsupported operand type(s) for /: 'str' and 'str'
```

- The **finally** clause is *always executed before leaving the try statement* whether the exception has occurred or not
- When an exception is *not handled by corresponding except clause* (or is raised in the *except* or the *else* clause), it is re-raised after the finally (see the example for division of strings)



```
for arg in sys.argv[1:]:
    try:
        f = open(arg, 'r')
    except OSError:
        print('cannot open', arg)
    else:
        print(arg, 'has', len(f.readlines()), 'lines')
        f.close()
```

The use of the `else` clause is better than adding additional code to the `try` clause because it avoids accidentally catching an exception that wasn't raised by the code being protected by the `try ... except` statement.

- Optional **else** clause that must follow all **except** clauses
- Useful for code that must be executed if the **try** clause *does not raise* an exception



```
1 def get_age():
2     age = int(input("Please enter your age: "))
3     if age < 0:
4         # Create a new instance of an exception
5         my_error = ValueError("{0} is not a valid age".format(age))
6         raise my_error
7     return age
```

```
>>> get_age()
Please enter your age: 42
42
>>> get_age()
Please enter your age: -2
Traceback (most recent call last):
  File "<interactive input>", line 1, in <module>
  File "learn_exceptions.py", line 4, in get_age
    raise ValueError("{0} is not a valid age".format(age))
ValueError: -2 is not a valid age
```

- If the program detects an error condition, an exception can be **raised manually**.
- **EXAMPLE:** take input from the user and check that the number is non-negative



- **Line 5** creates an **exception object**, the **ValueError object**, that encapsulates specific information about the error
- **EXAMPLE:** Assume that in this case function A called B which called C which called D which called `get_age()`:
 - *The raise statement on line 6 carries this object out as a kind of “return value”, and immediately exits from `get_age()` to its caller D*
 - *Then D again exits to its caller C, and C exits to B and so on, each returning the exception object to their caller, until it encounters a try ... except that can handle the exception*



```
1 raise ValueError("{0} is not a valid age".format(age))
```

- It is often the case that lines 5 and 6 (**creating the exception** object, then **raising the exception**) are combined into a single statement
- Those are **two different and independent things**, so it makes sense to keep the two steps separate
- **ERRORS** – multiple except clauses to handle different kinds of exceptions <https://docs.python.org/3/tutorial/errors.html>



This lecture re-uses selected parts of the **OPEN BOOK PROJECT**
Learning with Python 3 (RLE)

<http://openbookproject.net/thinkcs/python/english3e/index.html>
available under [GNU Free Documentation License Version 1.3](#))

- Version date: October 2012
- by Peter Wentworth, Jeffrey Elkner, Allen B. Downey, and Chris Meyers (based on 2nd edition by Jeffrey Elkner, Allen B. Downey, and Chris Meyers)
- Source repository is at <https://code.launchpad.net/~thinkcspy-rle-team/thinkcspy/thinkcspy3-rle>
- For offline use, download a zip file of the html or a pdf version from <http://www.ict.ru.ac.za/Resources/cspw/thinkcspy3/>

This lecture re-uses selected parts of the **PYTHON TEXTBOOK**
Object-Oriented Programming in Python

[http://python-textbok.readthedocs.io/en/1.0/Packaging and Testing.html#testing](http://python-textbok.readthedocs.io/en/1.0/Packaging_and_Testing.html#testing)
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