15 – Unit testing

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Scientific Programming in Python (2024)

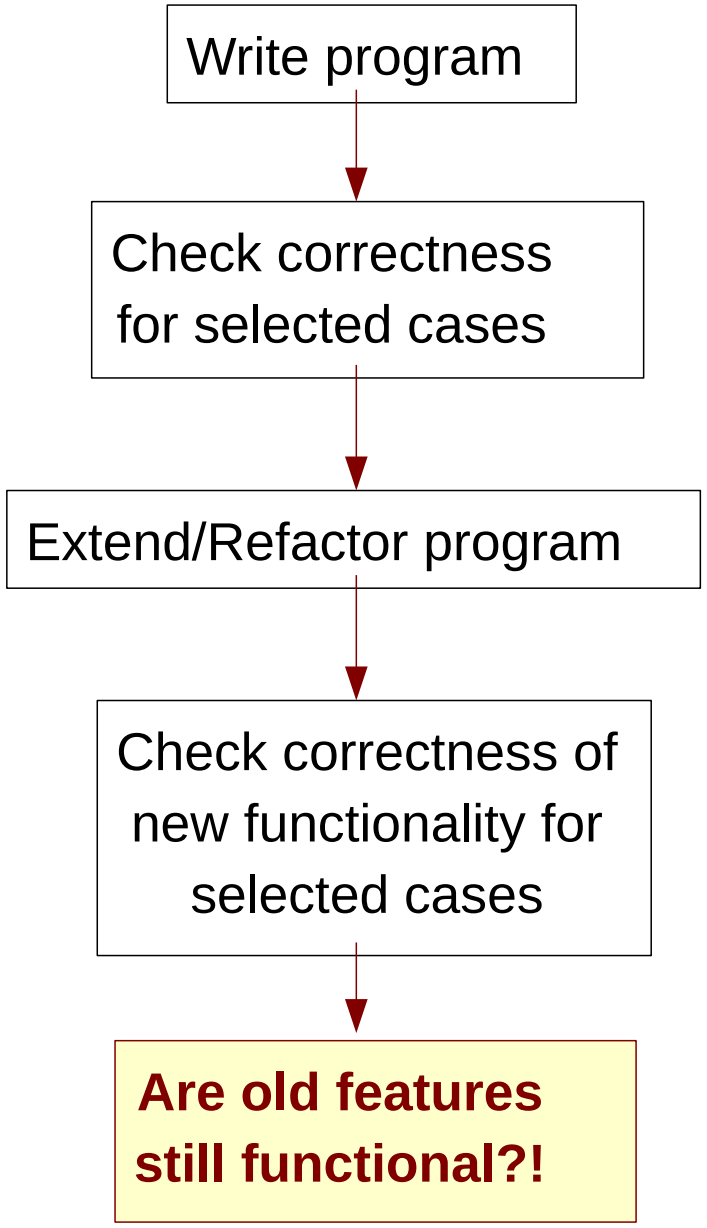
https://atticlectures.net/scipro/python-2024/

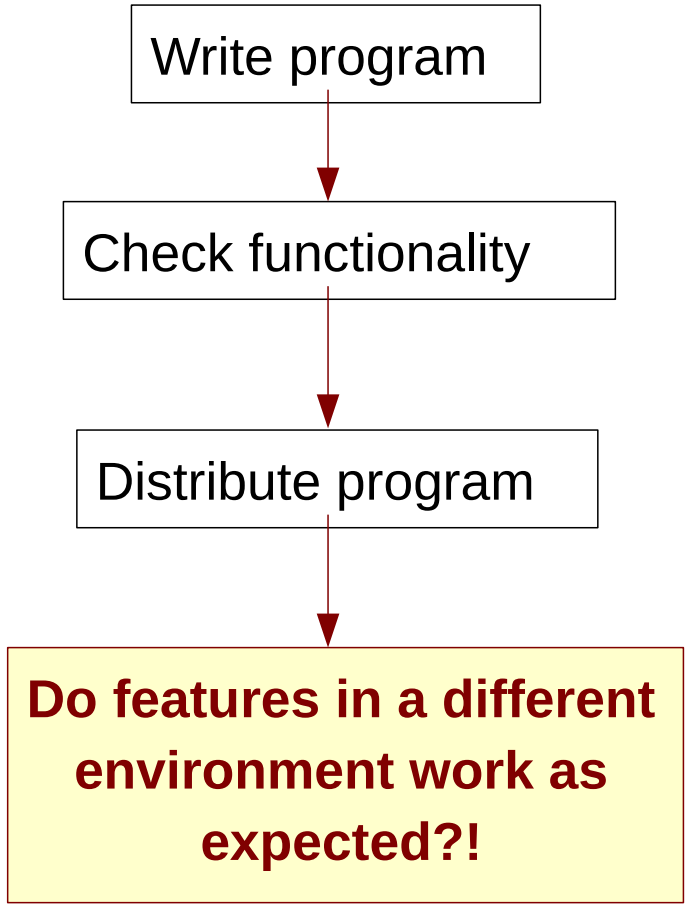
Prerequisites

- pytest
- coverage (with pytest binding)

```
conda install pytest coverage pytest-cov
```

Program testing





Program testing

When to test?

- Package functionality/integrity must be tested after each (relevant) change
- Package functionality/integrity must be tested whenever it is used in a different environment

How to test?

Effort needed to carry out tests must be as low as possible

- It should be possible to run all (or seleted tests) with one command
- Tests should be reasonably fast
- Correctness of the results should be checked automatically

Automated testing (with test protocol) is an essential part of the development

Testing during development

Unit tests – white box testing

- Each program unit (e.g. function) is tested independently
- Check whether for given input the right output is returned

Regression tests – black box testing

- Testing the package functionality as whole
- Tesintg whether for given input (e.g. user supplied data) expected output is generated
- Often includes stress-tests or scaling tests

Test driven development (e.g. agile programming)

- **First** write the tests for a given functionality, **then** implement the functionality
- If a bug is found, add it as test first (improve **coverage**) and then fix it so that it passes the test

Automatic Python testing frameworks

Unittest package in Python

- Comes as package with the standard Python 3 distribution (out of the box)
- Powerful with a lot of features
- Requires object-oriented approach to define tests

[Unittest documentation]

Pytest package

- Third party package (extra dependency, although quite standard)
- Extremly powerful and versatile, actively developed with large community
- Works both, with procedure and object oriented approach
- Simple tests can be set up with a few lines of code

[Pytest documentation]

Writing simple tests in pytest

mymath.py

```
"""Demo mathematical routines"""

def factorial(nn: int) -> int:
    """Calculates the factorial of a number

    Args:
        nn: Number to calculate the factorial of.

    Returns:
        Factorial of the argument.
    """
    res = 1
    for ii in range(2, nn + 1):
      res *= ii
    return res
```

Writing simple tests in Pytest

1. Write functions for testing given procedures / functionality
2. Function should indicate test result (success / failure) using **assert**

test_mymath.py

```
"""Testing routines for mymath module"""

import mymath

def test_factorial_5():
    "Test 5!"
    result = mymath.factorial(5)
    assert result == 120

def test_factorial_0():
    "Test 0!"
    result = mymath.factorial(0)
    assert result == 1
```

The name of the test functions must start with **“test”**

assert: If expression evaluates to **False,** code execution is stopped (an exception is raised to signalize failure) otherwise execution is continued

Running the tests from the shell

- Go to directory with the test file
- Start Python and import the pytest module

```
python3 -m pytest
```

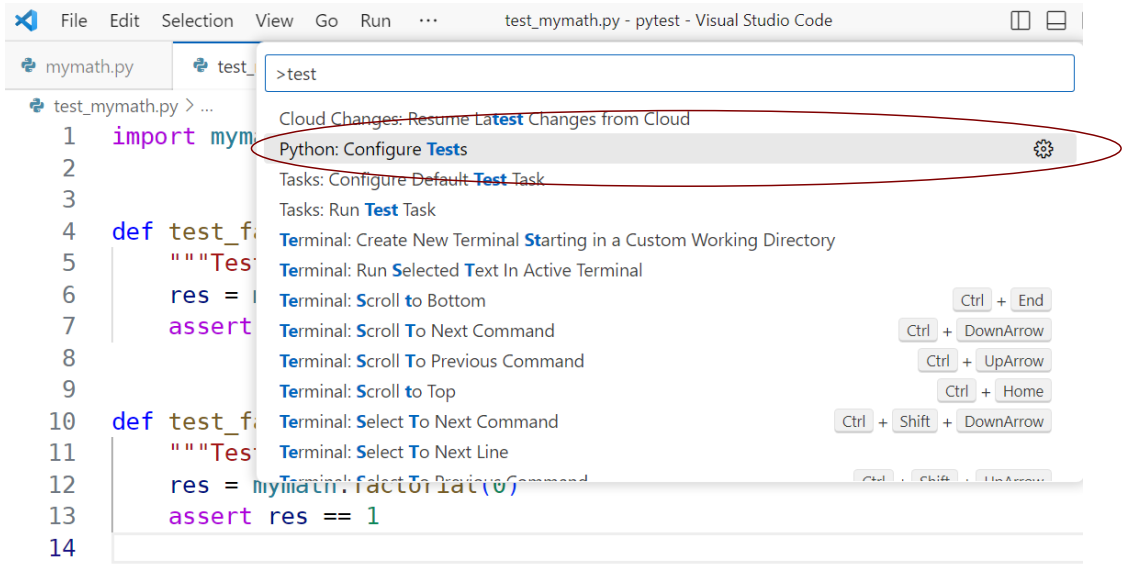
```
python -m pytest
```

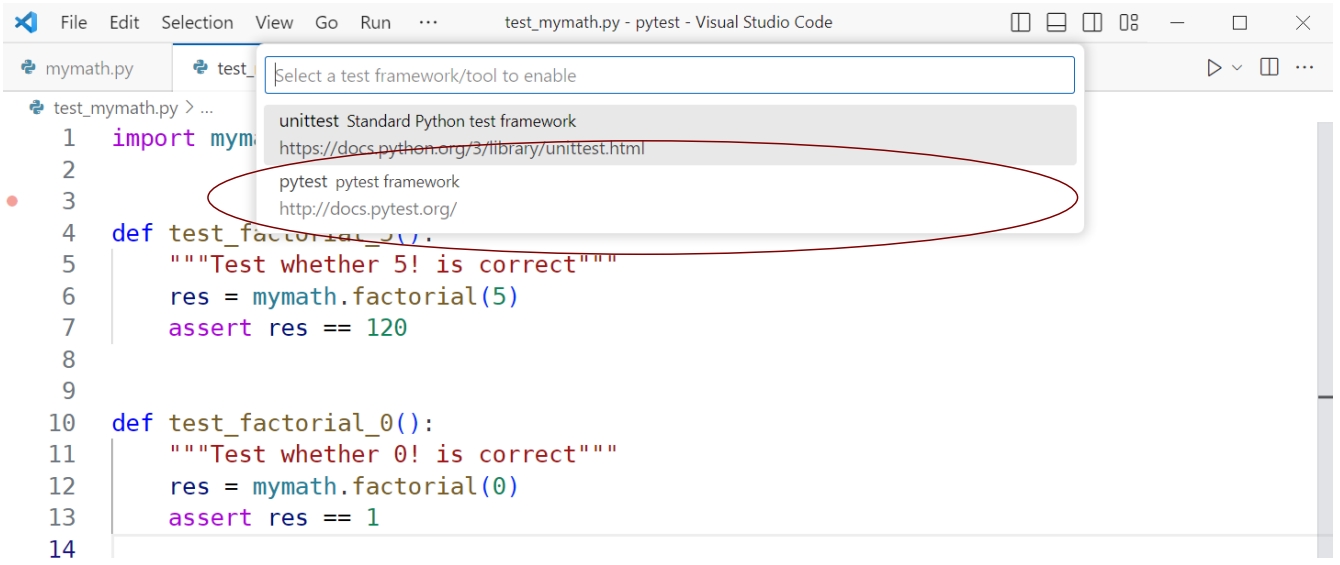
- When pytest is imported in an executable, it will automatically start **test-discovery**
- It will scan all Python source files in the given directory for test functions and execute all tests found (all functions with names prefixed by “test”)

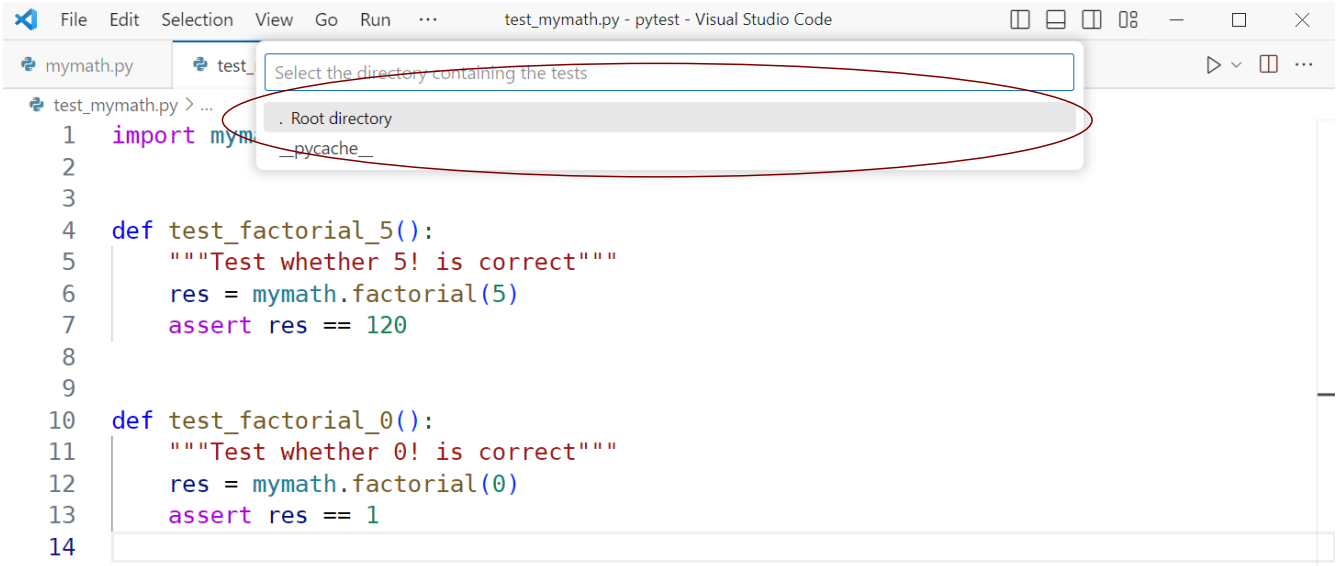
```
======== test session starts ========
test_mymath.py ...

====== 2 passed in 0.13 seconds ====
```

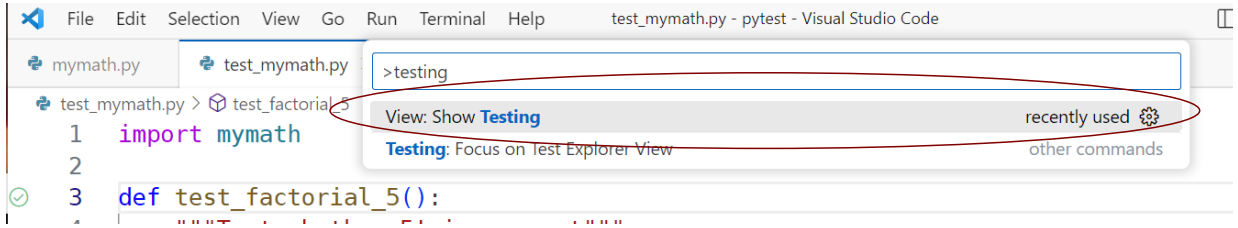
Running tests from VSCode

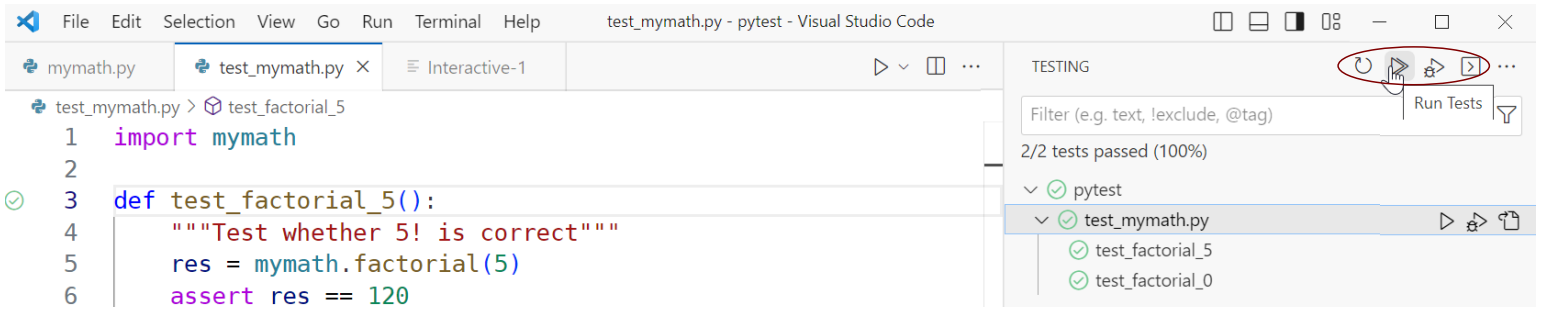






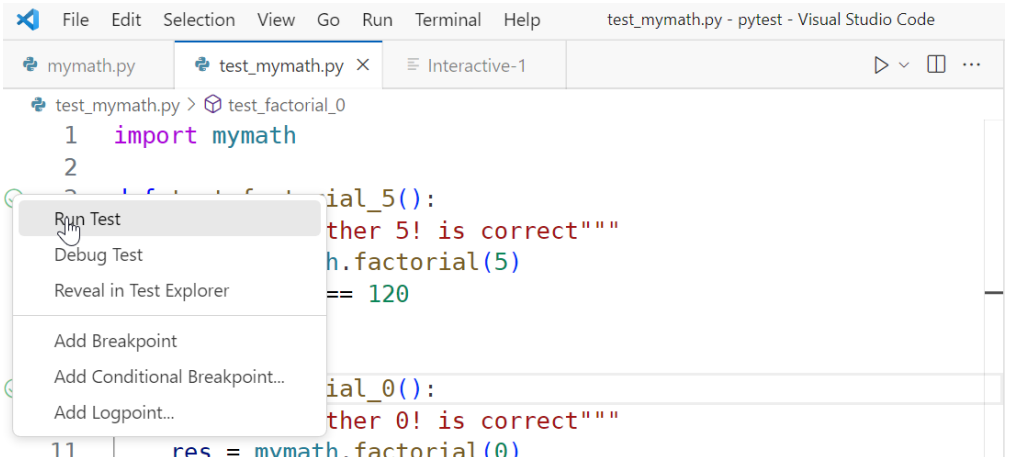
Running tests from VSCode





Run all tests

Run individual test (right click)



Putting tests in a separate directory

- In most projects tests are separated from actual code
- **Convention:** tests are placed in a **test/** subdirectory
- Pytest can still **discover** them, when invoked **from** the **root project folder**

```
python3 -m pytest
```

```
python -m pytest
```

```
======== test session starts =======
test/test_mymath.py ...

====== 2 passed in 0.13 seconds ====
```

- Some IDEs (e.g. Visual Studio Code) need an **empty package initialization file** (`__init__.py`) in the **test/** folder to discover tests properly

```
.gitignore
README.txt
solvers.py
test/
    __init__.py
    test_solver.py
```

Empty file (make sure to add to repository)

Parametrized tests

- When same test should be run several times with different input data
- **pytest.mark.parametrize** decorator executes test function for various tests by running over a list of parameters and passing one parameter at a time to the test function

```
import pytest
import mymath


factorials = [(0, 1), (1, 1), (2, 2), (3, 6), (4, 24), (8, 40320)]


@pytest.mark.parametrize("factorial", factorials)
def test_factorials(factorial):
    """Tests explicit factorial results"""
    num, result = factorial
    assert mymath.factorial(num) == result
```

Decorator (note @!) must be placed **immediately before the function definition**

Parameter list

Variable containing the actual parameter value

Parametrized tests

Example

- Prepare input and expected result (e.g. loading from files)
- Calculate result using prepared input, compare result with prepared result

```
import pytest
import solvers
TESTNAMES = ['elimination_3', 'pivot_3']


@pytest.mark.parametrize("testname", TESTNAMES)
def test_successful_elimination(testname):
    """Tests successful elimination."""
    aa, bb = _get_test_input(testname)
    xx_expected = _get_test_output(testname)
    xx_gauss = solvers.gaussian_eliminate(aa, bb)
    assert np.allclose(xx_gauss, xx_expected, rtol=1e-10, atol=1e-10)
```

Decorator must be placed **immediately before function definition**

Test coverage

- Indicates which **amount of the total code lines** have been **executed** at least ones during the tests.
- Desirable: 100%
- Note: 100% coverage does not mean bug free code!
  It only means, that each line has been reached at least once during some tests. The code still can misbehave, if given line is executed with different (non-tested) data.

Collect coverage data

- **coverage** can collect coverage data while running a Python application
- It can be used together with Pytest to collect coverage info during testing (provided the coverage plugin for Pytest is installed)

Run python application and collect coverage information

Only look for coverage of source files in current folder (otherwise coverage of 3rd party modules is also collected)

Import pytest module on start-up

(starts automatic test discovery and testing)

```
coverage run --source=. -m pytest
```

```
============================= test session starts ...
platform linux -- Python 3.5.2, ...
rootdir: /home/aradi/pyprojects/linsolver, inifile:
plugins: cov-2.2.1
collected 10 items

test_mymath.py ..........
```

Visualize coverage data

Short summary on the console

```
coverage report -m
```

```
Name                Stmts   Miss  Cover   Missing
-------------------------------------------------
mymath.py               6      0   100%
test_mymath.py         27      0   100%
-------------------------------------------------
TOTAL                  33      0   100%
```

Line number of line(s) not executed during any test (missing)

Number of statements (executable code lines)

Coverage in percentage of code lines (statements)

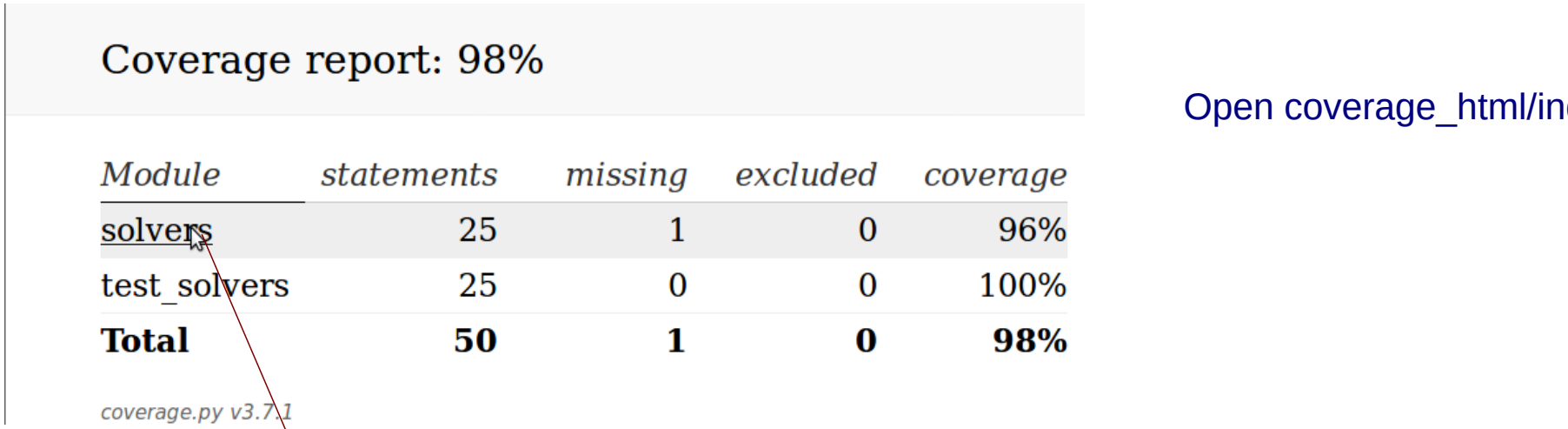
Visualize coverage data

Detailed coverage information in HTML

```
coverage html -d coverage_html
```

Directory where HTML pages should be stored

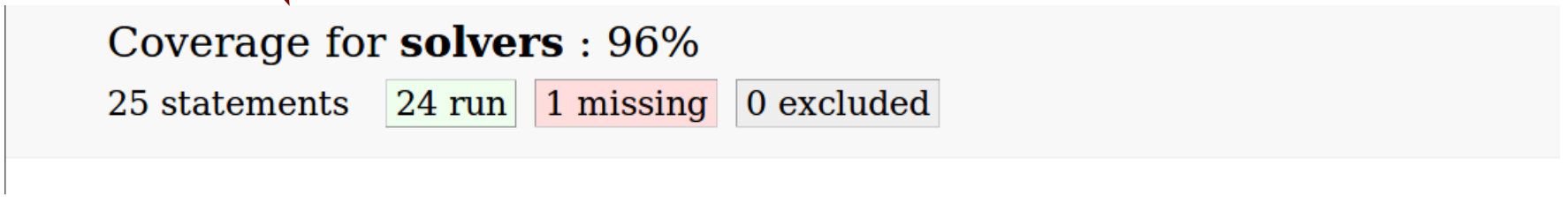
Open coverage_html/index.html in a browser



Coverage report: 98%

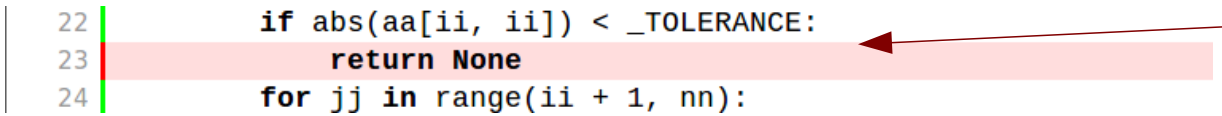
Module	statements	missing	excluded	coverage
solvers	25	1	0	96%
test_solvers	25	0	0	100%
Total	**50**	**1**	**0**	**98%**

coverage.py v3.7.1



Coverage for **solvers** : 96%

25 statements | 24 run | 1 missing | 0 excluded



```
22          if abs(aa[ii, ii]) < _TOLERANCE:
23              return None
24          for jj in range(ii + 1, nn):
```

Apparently none of the tests contained a linearly dependent system of equations …

Useful functions when comparing arrays

- When two arrays (or an array and an integer) are compared, the comparison is made elementwise
- Result: array of logicals with the results of each elementwise comparison

```
aa = np.array([1, -2, 9])
aa < 0
```

→ `[False  True False]`

np.any() Checks whether any elements of an array evaluate to **True**

```
np.any(aa < 0)
```

→ `True`

np.all() Checks whether all elements of an array evaluate to **True**

```
np.all(aa < 0)
```

→ `False`

np.where() Returns elementwise 2nd or 3rd argument depending on logical values in 1st

```
np.where(aa < 0, 0, aa)
```

→ `[1, 0, 9]`

Comparing floating point values (scalars / arrays)

Floating point values **must not** be compared with the "**==**" operator

Floating point values **must** be **compared with tolerances**

- Floating point representation is **not exact** (e.g. 0.1 requires infinite binary digits)
- **Numerical errors** occur during operations

```
6 * 0.1 == 0.1 + 0.1 + 0.1
         + 0.1 + 0.1 + 0.1
```

→ **False**

Scalars

```
np.abs(x - y) < ABS_TOL
```

absolute error

```
np.abs((x – y) / y) < REL_TOL
```

relative error

```
np.isclose(
    x, y, rtol=REL_TOL, atol=ABS_TOL
)
```

"combined" error

Arrays

```
np.all(np.abs(x - y) < ABS_TOL)
```

```
np.all(
    np.abs((x – y) / y) < REL_TOL
)
```

```
np.allclose(
    x, y, rtol=REL_TOL, atol=ABS_TOL
)
```