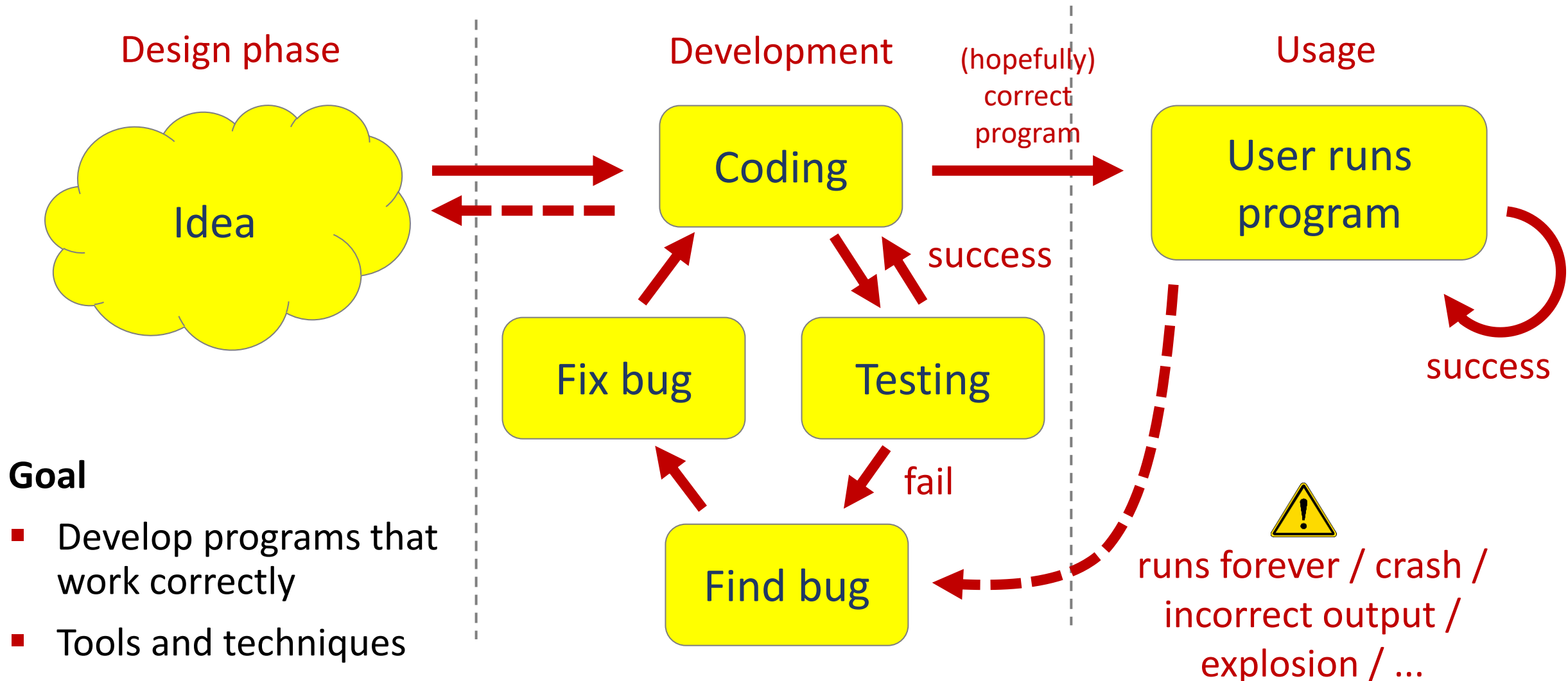


# Documentation, testing and debugging

- docstring
- defensive programming
- assert
- test driven developement
- assertions
- testing
- unittest
- debugger
- coverage
- static type checking (mypy, pyright)

- On average, a developer creates 70 bugs per 1000 lines of code
- 15 bugs per 1,000 lines of code find their way to the customers
- Fixing a bug takes 30 times longer than writing a line of code
- 75% of a developer's time is spent on debugging

# Ensuring good quality code ?



# What is good code ?

- Readability
  - well-structured
  - documentation
  - comments
  - follow some standard structure (easy to recognize, follow [PEP8](#) Style Guide)
- Correctness
  - outputs the correct answer on valid input
  - eventually stops with an answer on valid input (should not go in infinite loop)
- Reusable...

# Why ?

## Documentation

- *specification of functionality*
- docstring
  - *for users of the code*
  - modules
  - methods
  - classes
- comments
  - *for readers of the code*

## Testing

- Correct implementation ?
- Try to predict behavior on unknown input ?
- Performance guarantees ?

## Debugging

- *Where is the #!x\$ bug ?*

# Built-in exceptions (class hierarchy)

```
BaseException
+-- SystemExit
+-- KeyboardInterrupt
+-- GeneratorExit
+-- Exception
    +-- StopIteration
    +-- StopAsyncIteration
    +-- ArithmeticError
    |   +-- FloatingPointError
    |   +-- OverflowError
    |   +-- ZeroDivisionError
    +-- AssertionError
    +-- AttributeError
    +-- BufferError
    +-- EOFError
    +-- ImportError
    |   +-- ModuleNotFoundError
    +-- LookupError
    |   +-- IndexError
    |   +-- KeyError
    +-- MemoryError
    +-- NameError
    |   +-- UnboundLocalError
    +-- TypeError
    +-- ValueError
    |   +-- UnicodeError
    |       +-- UnicodeDecodeError
    |       +-- UnicodeEncodeError
    |       +-- UnicodeTranslateError
```

```
    +-- OSError
    |   +-- BlockingIOError
    |   +-- ChildProcessError
    |   +-- ConnectionError
    |       +-- BrokenPipeError
    |       +-- ConnectionAbortedError
    |       +-- ConnectionRefusedError
    |       +-- ConnectionResetError
    +-- FileNotFoundError
    +-- InterruptedError
    +-- IsADirectoryError
    +-- NotADirectoryError
    +-- PermissionError
    +-- ProcessLookupError
    +-- TimeoutError
+-- ReferenceError
+-- RuntimeError
    +-- NotImplementedError
    +-- RecursionError
+-- SyntaxError
    +-- IndentationError
    +-- TabError
+-- SystemError
+-- Warning
    +-- DeprecationWarning
    +-- PendingDeprecationWarning
    +-- RuntimeWarning
    +-- SyntaxWarning
    +-- UserWarning
    +-- FutureWarning
    +-- ImportWarning
    +-- UnicodeWarning
    +-- BytesWarning
    +-- ResourceWarning
```

# Testing for unexpected behaviour ?

infinite-recursion1.py

```
def f(depth):  
    f(depth + 1)  # infinite recursion  
  
f(0)
```



Python shell

```
| RecursionError: maximum recursion depth exceeded
```

infinite-recursion2.py

```
def f(depth):  
    if depth > 100:  
        print('runaway recursion???)  
        raise SystemExit  # raise built-in exception  
    f(depth + 1)  
  
f(0)
```

Python shell

```
| runaway recursion???
```

infinite-recursion3.py

```
import sys  
  
def f(depth):  
    if depth > 100:  
        print('runaway recursion???)  
        sys.exit()  # system function  
    f(depth + 1)  
  
f(0)
```

raises SystemExit

Python shell

```
| runaway recursion???
```

- let the program eventually fail
- check and raise exceptions
- check and call `sys.exit`

# Catching unexpected behaviour – `assert`

## `infinite-recursion4.py`

```
def f(depth):  
    assert depth <= 100 # raise exception if False  
    f(depth + 1)  
  
f(0)
```

## Python shell

```
| File "...\\infinite-recursion4.py", line 2, in f  
|     assert depth <= 100  
| AssertionError
```

## `infinite-recursion5.py`

```
def f(depth):  
    assert depth <= 100, 'runaway recursion???'  
    f(depth + 1)  
  
f(0)
```

## Python shell

```
| File "...\\infinite-recursion5.py", line 2, in f  
|     assert depth <= 100, "runaway recursion???"  
| AssertionError: runaway recursion???
```

- keyword **`assert`** checks if boolean expression is true, if not, raises exception **`AssertionError`**
- optional second parameter passed to the constructor of the exception
- try to fail fast to discover errors early – making debugging easier

## `infinite-recursion6.py`

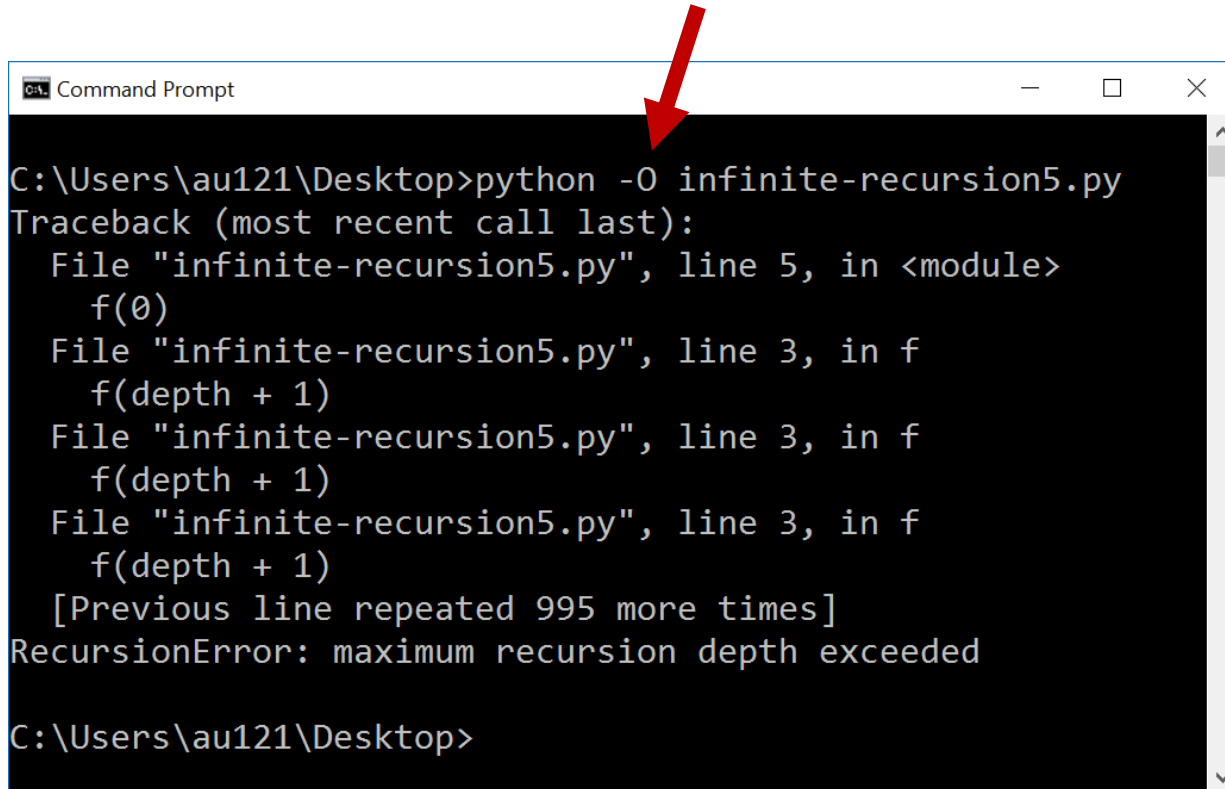
```
def f(depth):  
    if not depth <= 100:  
        raise AssertionError('runaway recursion???)  
    f(depth + 1)  
  
f(0)
```

## Python shell

```
| File "...\\infinite-recursion6.py", line 3, in f  
|     raise AssertionError("runaway recursion???)  
| AssertionError: runaway recursion???
```



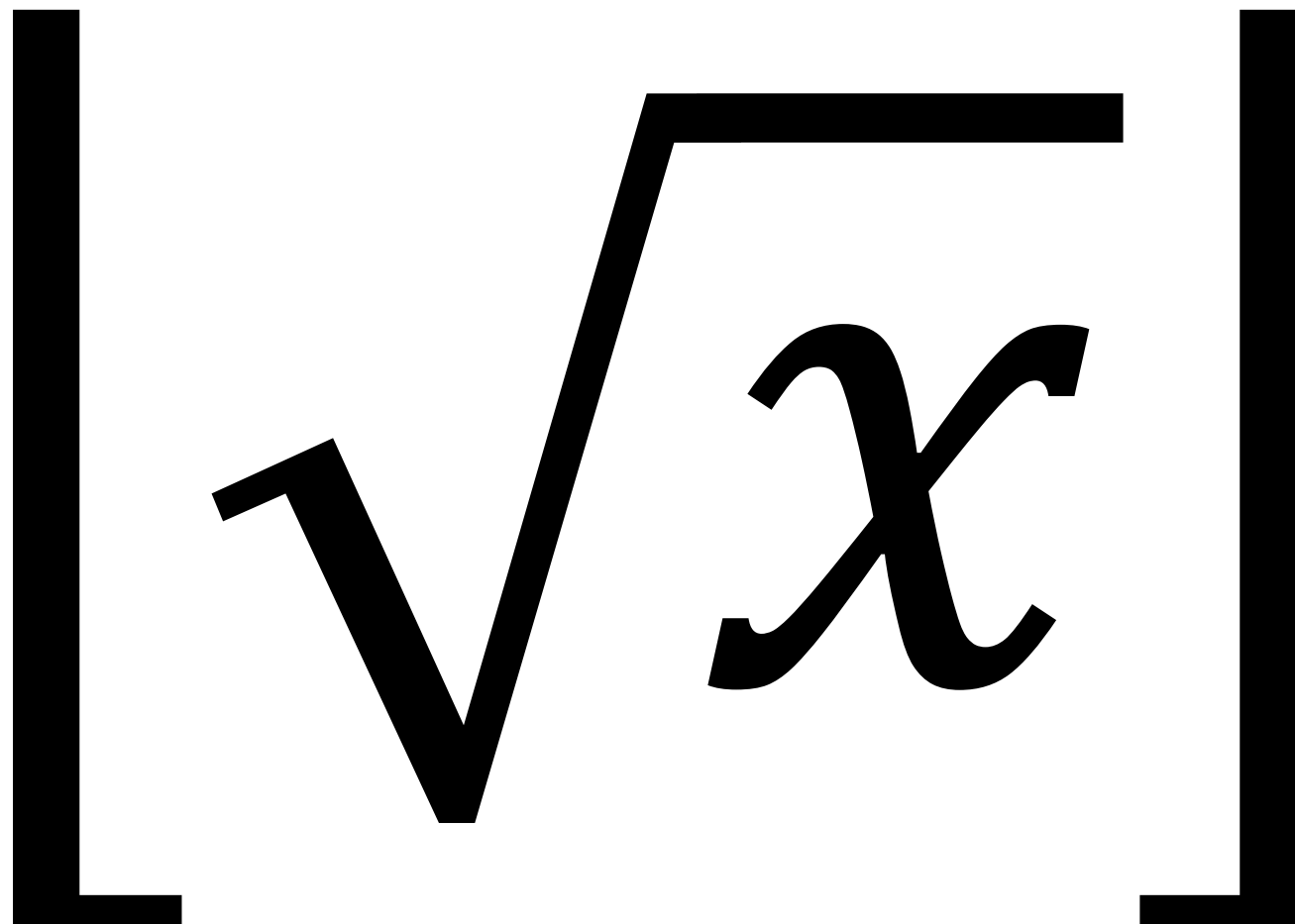
# Disabling `assert` statements



```
Command Prompt
C:\Users\au121\Desktop>python -O infinite-recursion5.py
Traceback (most recent call last):
  File "infinite-recursion5.py", line 5, in <module>
    f(0)
  File "infinite-recursion5.py", line 3, in f
    f(depth + 1)
  File "infinite-recursion5.py", line 3, in f
    f(depth + 1)
  File "infinite-recursion5.py", line 3, in f
    f(depth + 1)
[Previous line repeated 995 more times]
RecursionError: maximum recursion depth exceeded
C:\Users\au121\Desktop>
```

- **`assert`** statements are good to help check correctness of program – but can **slow down** program
- invoking Python with option `-O` disables all assertions (by setting `__debug__` to `False`)

Example



First try... (seriously, the bugs were not on purpose)

**intsqrt\_buggy.py**

```
def int_sqrt(x):  
    low = 0  
    high = x  
    while low < high - 1:  
        mid = (low + high) / 2  
        if mid ** 2 <= x:  
            low = mid  
        else:  
            high = mid  
    return low
```

**Python shell**

```
> int_sqrt(10)  
| 3.125 # 3.125 ** 2 = 9.765625  
> int_sqrt(-10)  
| 0 # what should the answer be ?
```

# Let us add a specification...

intsqrt.py

```
def int_sqrt(x):  
    '''Compute the integer square root of an integer x.  
    Requires x >= 0 is an integer. ← input requirements  
    Returns the integer floor(sqrt(x)). ← output guarantees  
    ...  
'''
```

docstring

Python shell

```
> help(int_sqrt)  
| Help on function int_sqrt in module __main__:  
|  
| int_sqrt(x)  
|     Compute the integer square root of an integer x.  
|  
|     Requires x >= 0 is an integer.  
|     Returns the integer floor(sqrt(x)).
```

- all methods, classes, and modules can have a **docstring** (ideally have) as a **specification**
- for methods: summarize purpose in first line, followed by input requirements and output guarantees
- the docstring is assigned to the object's `__doc__` attribute

# Let us check input requirements...

**intsqrt.py**

```
def int_sqrt(x):  
    '''Compute the integer square root of an integer x.  
  
    Requires x >= 0 is an integer.  
    Returns the integer floor(sqrt(x)).'''  
  
    assert isinstance(x, int) } check input  
    assert 0 <= x             } requirements  
    ...
```

**Python shell**

```
> int_sqrt(-10)  
| File "...\\int_sqrt.py", line 7, in int_sqrt  
|     assert 0 <= x  
| AssertionError
```

- doing explicit checks for valid input arguments is part of **defensive programming** and helps spotting errors early

(instead of continuing using likely wrong values... resulting in a final meaningless error)

# Let us check if output correct...

intsqrt.py

```
def int_sqrt(x):  
    '''Compute the integer square root of an integer x.  
  
    Requires x >= 0 is an integer.  
    Returns the integer floor(sqrt(x)).'''  
  
    assert isinstance(x, int)  
    assert 0 <= x  
    ...  
    assert isinstance(result, int)  
    assert result ** 2 <= x < (result + 1) ** 2  
    return result
```

} check  
output

Python shell

```
> int_sqrt(10)  
| File "...\\int_sqrt.py", line 20, in int_sqrt  
|     assert isinstance(result, int)  
| AssertionError
```

- output check identifies the error

mid = (low + high) / 2

- should have been

mid = (low + high) // 2

- The output check helps us to ensure that function specifications are satisfied in applications

# Let us test some input values...

**intsqrt.py**

```
def int_sqrt(x):  
    ...  
  
assert int_sqrt(0) == 0  
assert int_sqrt(1) == 1  
assert int_sqrt(2) == 1  
assert int_sqrt(3) == 1  
assert int_sqrt(4) == 2  
assert int_sqrt(5) == 2  
assert int_sqrt(200) == 14
```

**Python shell**

```
| Traceback (most recent call last):  
|   File "...\\int_sqrt.py", line 28, in <module>  
|     assert int_sqrt(1) == 1  
|   File "...\\int_sqrt.py", line 21, in int_sqrt  
|     assert result ** 2 <= x < (result + 1) ** 2  
| AssertionError
```

- test identifies wrong output for x = 1

# Let us check progress of algorithm...

## intsqrt.py

```
...
low, high = 0, x
while low < high - 1: # low <= floor(sqrt(x)) < high
    assert low ** 2 <= x < high ** 2
    mid = (low + high) // 2
    if mid ** 2 <= x:
        low = mid
    else:
        high = mid
result = low
...
```

} check invariant  
for loop  
 $\lfloor \sqrt{x} \rfloor \in [low, high[$

## Python shell

```
| Traceback (most recent call last):
|   File "... \int_sqrt.py", line 28, in <module>
|     assert int_sqrt(1) == 1
|   File "... \int_sqrt.py", line 21, in int_sqrt
|     assert result ** 2 <= x < (result + 1) ** 2
|   AssertionError
```

- test identifies  
wrong output for  $x = 1$
- but invariant apparently  
correct ???
- problem  
 $low == result == 0$   
 $high == 1$   
implies loop never entered
- output check identifies the  
error  
 $high = x$
- should have been  
 $high = x + 1$



# Final program

We have used **assertions** to:

- Test if **input** arguments / usage is valid (defensive programming)
- Test if computed **result** is correct
- Test if an internal **invariant** in the computation is satisfied
- Perform a **final test** for a set of test cases (should be run whenever we change anything in the implementation)

intsqrt.py

```
def int_sqrt(x):  
    '''Compute the integer square root of an integer x.  
  
    Requires x >= 0 is an integer.  
    Returns the integer floor(sqrt(x)).'''  
  
    assert isinstance(x, int)  
    assert 0 <= x  
  
    low, high = 0, x + 1  
    while low < high - 1: # low <= floor(sqrt(x)) < high  
        assert low ** 2 <= x < high ** 2  
        mid = (low + high) // 2  
        if mid ** 2 <= x:  
            low = mid  
        else:  
            high = mid  
    result = low  
  
    assert isinstance(result, int)  
    assert result ** 2 <= x < (result + 1) ** 2  
  
    return result  
  
assert int_sqrt(0) == 0  
assert int_sqrt(1) == 1  
assert int_sqrt(2) == 1  
assert int_sqrt(3) == 1  
assert int_sqrt(4) == 2  
assert int_sqrt(5) == 2  
assert int_sqrt(200) == 14
```

# Which checks would you add to the below code?

**binary-search.py**

```
def binary_search(x, L):  
    '''Binary search for x in sorted list L.  
  
    Assumes x is an integer, and L a non-decreasing list of integers.  
  
    Returns index i,  $-1 \leq i < \text{len}(L)$ , where  $L[i] \leq x < L[i+1]$ ,  
    assuming  $L[-1] = -\text{infty}$  and  $L[\text{len}(L)] = +\text{infty}$ .'''  
  
    low, high = -1, len(L)  
    while low + 1 < high:  
        mid = (low + high) // 2  
        if x < L[mid]:  
            high = mid  
        else:  
            low = mid  
    result = low  
    return result
```

## binary-search-assertions.py

```
def binary_search(x, L):
    '''Binary search for x in sorted list L.

    Assumes x is an integer, and L a non-decreasing list of integers.

    Returns index i, -1 <= i < len(L), where L[i] <= x < L[i+1],
    assuming L[-1] = -infty and L[len(L)] = +infty.'''

    input {
        assert isinstance(x, int)
        assert isinstance(L, list)
        assert all([isinstance(e, int) for e in L])
        assert all([L[i] <= L[i + 1] for i in range(len(L) - 1)])
    } ① inefficient ⚠

    low, high = -1, len(L)
    while low + 1 < high: # L[low] <= x < L[high]
        input loop {
            assert (low == -1 or L[low] <= x) and (high == len(L) or x < L[high])
            mid = (low + high) // 2
            {
                assert isinstance(L[mid], int)
                assert (low == -1 or L[low] <= L[mid]) and (high == len(L) or L[mid] <= L[high])
            } ②
            if x < L[mid]:
                high = mid
            else:
                low = mid
        }
    result = low

    output {
        assert (isinstance(result, int) and -1 <= result < len(L) and
            ((result == -1 and (len(L) == 0 or x < L[0])) or
             (result == len(L) - 1 and x >= L[-1]) or
             (0 <= result < len(L) - 1 and L[result] <= x < L[result + 1])))
    }

    return result

assert binary_search(42, []) == -1
assert binary_search(42, [7]) == 0
assert binary_search(7, [42]) == -1
assert binary_search(7, [42, 42, 42]) == -1
assert binary_search(42, [7, 7, 7]) == 2
assert binary_search(42, [7, 7, 7, 56, 81]) == 2
assert binary_search(8, [1, 3, 5, 7, 9]) == 3
} test cases
```

- ① Verifying if L is a sorted list of integers can slow down the program significantly
- ② Alternative is to only verify if the part of L visited is a sorted subsequence

# Test driven development / Stress tests / Random testing

## ■ Test driven development

Write the tests before functionality  
– only write code needed by tests

## ■ The challenge – what tests to do?

Can you manually find all relevant cases? In particular all edge cases?

## ■ Automate the testing?

- Write method that can verify the output (possibly slower than the method)
- Systematically try *all* possible inputs (if range is small)
- Try a large random subset of inputs (if many possible inputs)

### intsqrt\_automatic\_testing.py

```
import random

def int_sqrt(x):
    return 42 # Dummy code - write test code first

def test_int_sqrt(x):
    print('.', end='', flush=True) # Show progress
    assert x >= 0 # Verify input
    answer = int_sqrt(x)
    # Verify output
    assert answer ** 2 <= x < (answer + 1) ** 2

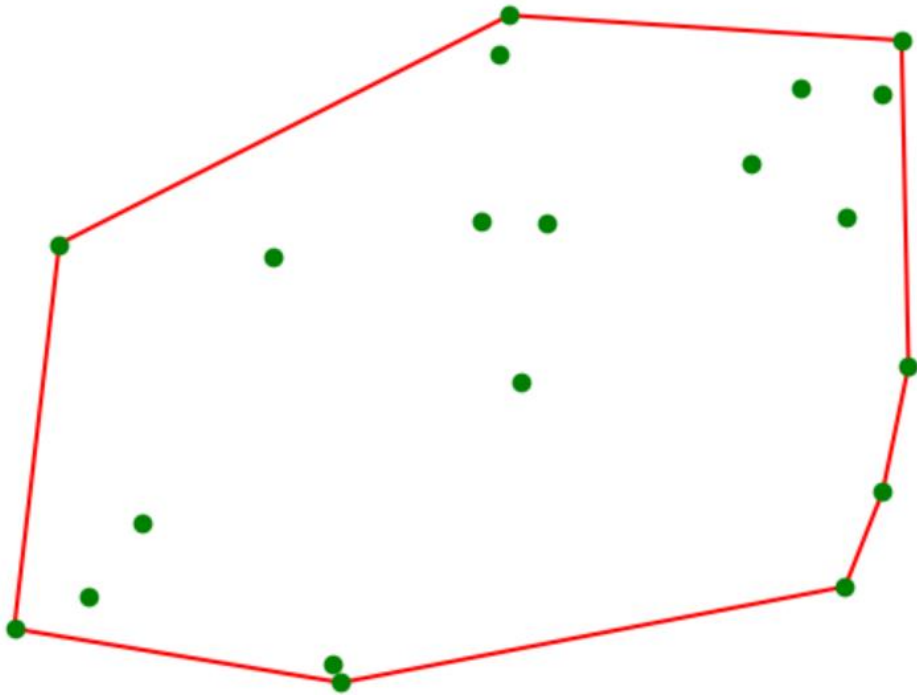
# Test small inputs
for x in range(0, 100):
    test_int_sqrt(x)

# Test increasing sized inputs
for d in range(3, 30):
    for _ in range(100): # Repeat for each size
        test_int_sqrt(random.randint(1, 10 ** d))
```

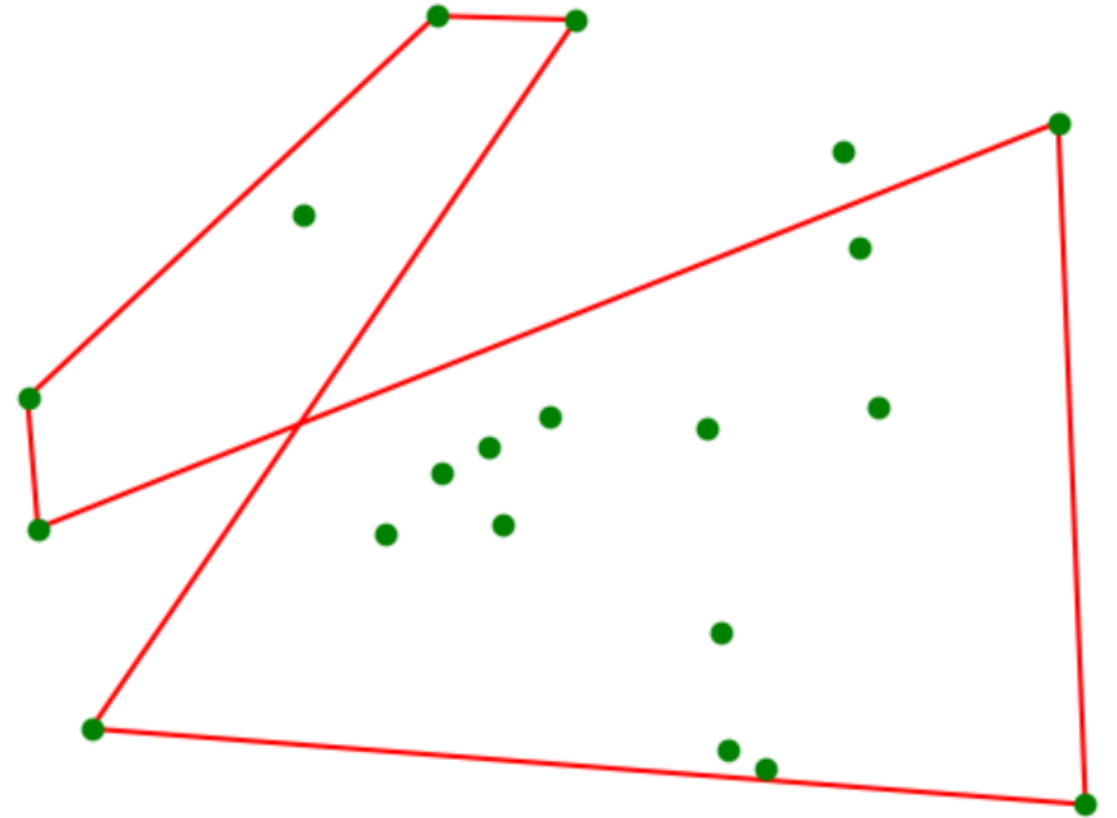
# Testing – how ?

- Run set of test cases
  - test all cases in input/output specification (**black box testing**)
  - test all special cases (**black box testing**)
  - set of tests should force all lines of code to be tested (**glass box testing**)
- Visual test
- Automatic testing
  - Systematically / randomly generate input instances
  - Create function to **validate** if output is correct (hopefully easier than finding the solution)
- Formal verification
  - Use computer programs to do formal proofs of correctness, like using Coq

# Visual testing – Convex hull computation



**Correct**



**Bug !  
(not convex)**

# doctest

- Python module
- Test instances (pairs of input and corresponding output) are written in the doc strings, formatted as in an interactive Python session

## binary-search-doctest.py

```
def binary_search(x, L):
    '''Binary search for x in sorted list L.

    Examples:
    >>> binary_search(42, [])
    -1
    >>> binary_search(42, [7])
    0
    >>> binary_search(42, [7,7,7,56,81])
    2
    >>> binary_search(8, [1,3,5,7,9])
    3
    '''

    low, high = -1, len(L)
    while low + 1 < high:
        mid = (low + high) // 2
        if x < L[mid]:
            high = mid
        else:
            low = mid
    return low

import doctest
doctest.testmod(verbose=True)
```

## Python shell

```
Trying:
    binary_search(42, [])
Expecting:
    -1
ok
Trying:
    binary_search(42, [7])
Expecting:
    0
ok
Trying:
    binary_search(42, [7,7,7,56,81])
Expecting:
    2
ok
Trying:
    binary_search(8, [1,3,5,7,9])
Expecting:
    3
ok
1 items had no tests:
    __main__
1 items passed all tests:
   4 tests in __main__.binary_search
4 tests in 2 items.
4 passed and 0 failed.
Test passed.
```

# pytest

- Run all tests stored in functions prefixed by `test_` or `test_` prefixed test methods inside `Test` prefixed test classes
- `pip install pytest`
- Run the `pytest` program from a shell

[pytest.org](https://pytest.org)

## binary-search-pytest.py

```
import pytest

def binary_search(x, L):
    '''Binary search for x in sorted list L.'''
    low, high = -1, len(L)
    while low + 1 < high:
        mid = (low + high) // 2
        if x < L[mid]:
            high = mid
        else:
            low = mid
    return low

def test_binary_search():
    assert binary_search(42, []) == -1
    assert binary_search(42, [7]) == 0
    assert binary_search(42, [7,7,7,56,81]) == 2
    assert binary_search(8, [1,3,5,7,9]) == 3

def test_types():
    with pytest.raises(TypeError):
        _ = binary_search(5, ['a', 'b', 'c'])
```

## Shell

```
> pytest binary-search-pytest.py
| ===== test session starts =====
| platform win32 -- Python 3.11.2, pytest-7.2.1, pluggy-1.0.0
| plugins: anyio-3.6.2
| collected 2 items
|
| binary-search-pytest.py .. [100%]
| ===== 2 passed in 0.05s =====
```



# unittest

- Python module
- A comprehensive **object-oriented test framework**, inspired by the corresponding JUnit test framework for Java

## binary-search-unittest.py

```
def binary_search(x, L):
    '''Binary search for x in sorted list L.'''

    low, high = -1, len(L)
    while low + 1 < high:
        mid = (low + high) // 2
        if x < L[mid]:
            high = mid
        else:
            low = mid
    return low

import unittest

class TestBinarySearch(unittest.TestCase):
    def test_search(self):
        self.assertEqual(binary_search(42, []), -1)
        self.assertEqual(binary_search(42, [7]), 0)
        self.assertEqual(binary_search(42, [7,7,7,56,81]), 2)
        self.assertEqual(binary_search(8, [1,3,5,7,9]), 3)

    def test_types(self):
        self.assertRaises(TypeError, binary_search, 5, ['a', 'b', 'c'])

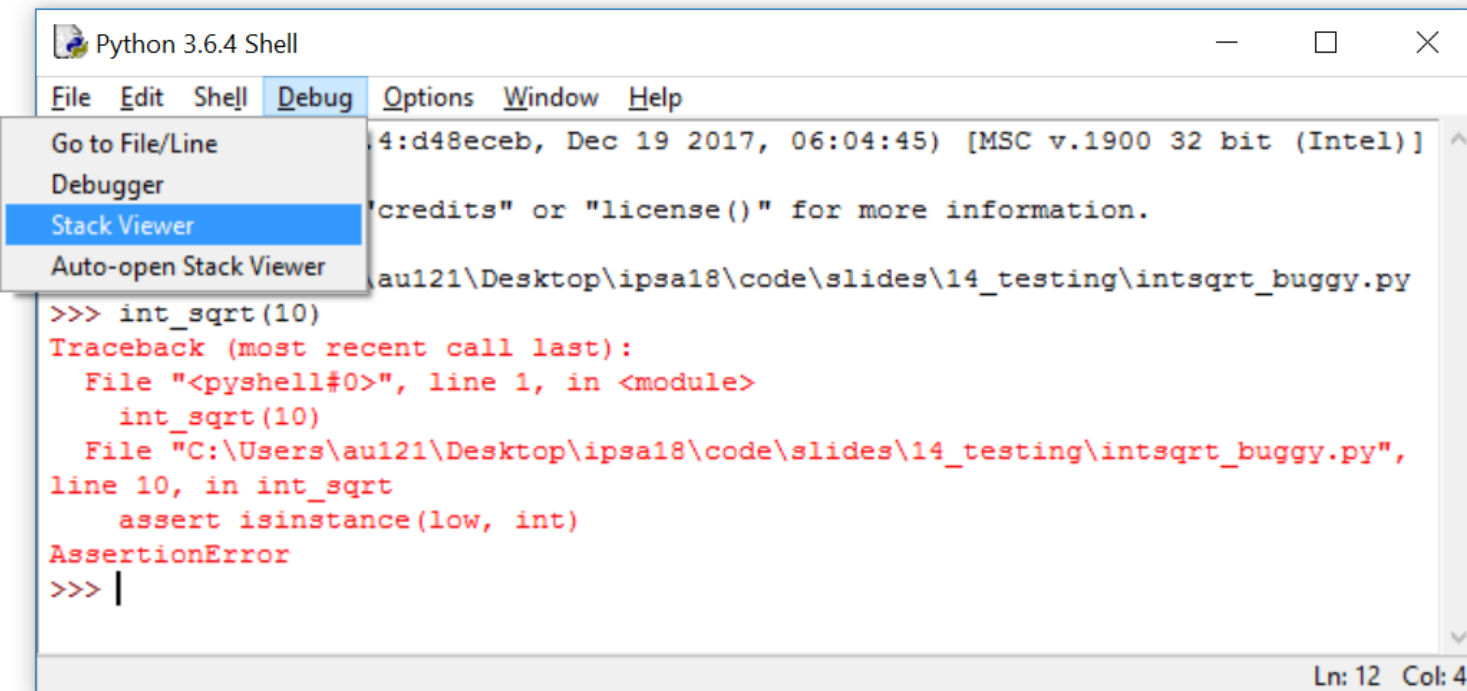
unittest.main(verbosity=2)
```

## Python shell

```
| test_search (__main__.TestBinarySearch) ... ok
| test_types (__main__.TestBinarySearch) ... ok
| -----
| Ran 2 tests in 0.051s
| OK
```

# Debugger (IDLE)

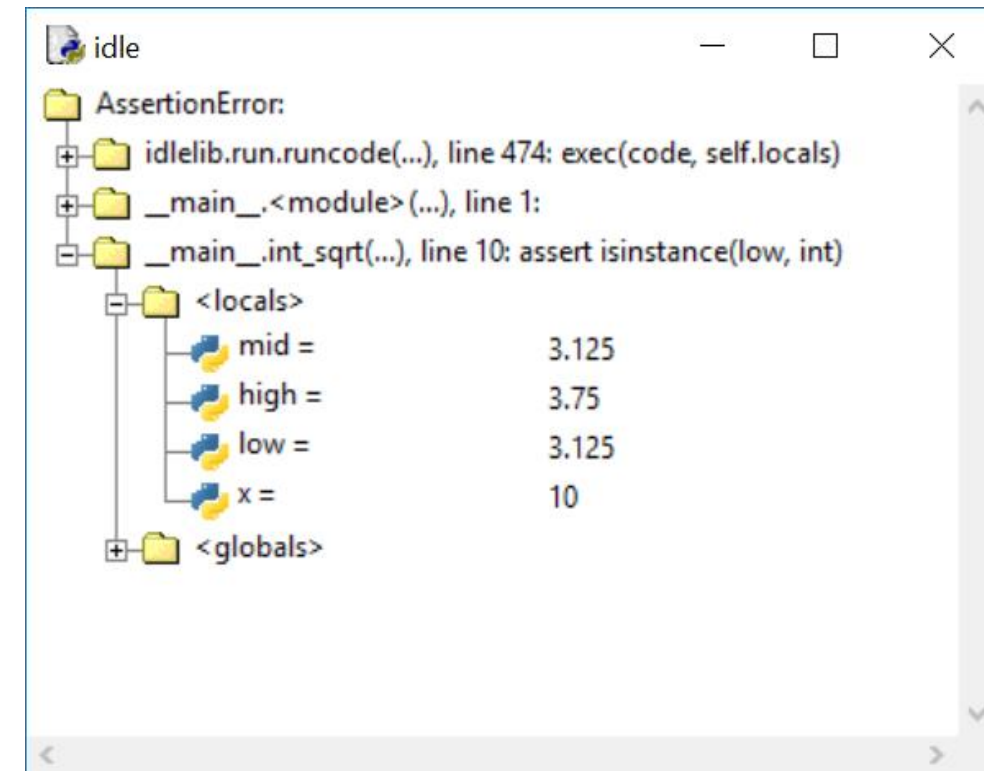
- When an exception has stopped the program, you can examine the state of the variables using **Debug > Stack Viewer** in the Python shell



The screenshot shows the Python 3.6.4 Shell window. The 'Debug' menu is open, with 'Stack Viewer' highlighted. The shell displays a traceback for an `AssertionError` that occurred in `intsqrt_buggy.py` at line 10. The code being executed is `int_sqrt(10)`.

```
Python 3.6.4 Shell
File Edit Shell Debug Options Window Help
Go to File/Line
Debugger
Stack Viewer
Auto-open Stack Viewer
4:d48eceb, Dec 19 2017, 06:04:45) [MSC v.1900 32 bit (Intel)]
credits" or "license()" for more information.
au121\Desktop\ipsa18\code\slides\14_testing\intsqrt_buggy.py
>>> int_sqrt(10)
Traceback (most recent call last):
  File "<pyshell#0>", line 1, in <module>
    int_sqrt(10)
  File "C:\Users\au121\Desktop\ipsa18\code\slides\14_testing\intsqrt_buggy.py",
line 10, in int_sqrt
    assert isinstance(low, int)
AssertionError
>>> |
```

Ln: 12 Col: 4

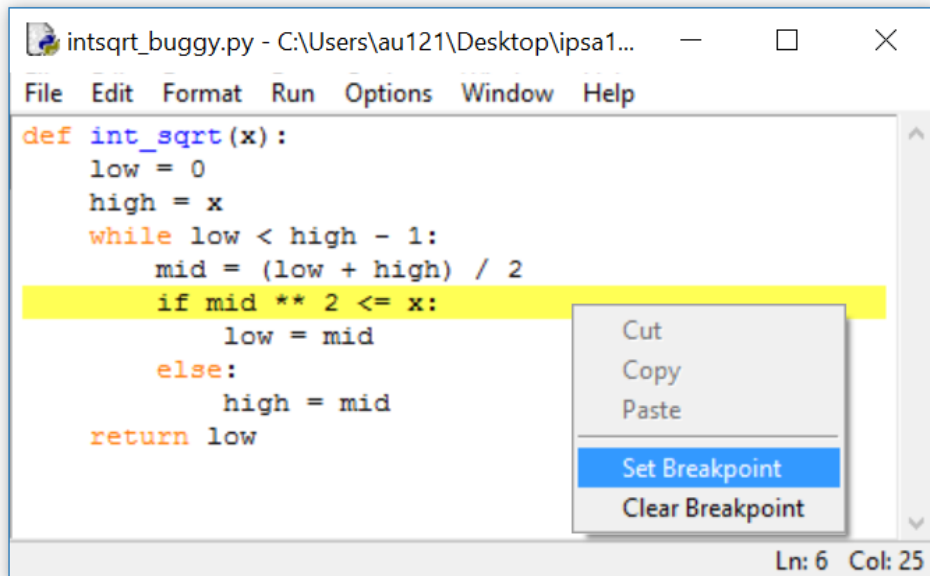


The screenshot shows the Stack Viewer window in IDLE. It displays the call stack for the `AssertionError`. The stack includes the `idlelib.run.runcode(...)` call, the `_main_.<module>(...)` call, and the `_main_.int_sqrt(...)` call. The `<locals>` section shows the current state of variables: `mid = 3.125`, `high = 3.75`, `low = 3.125`, and `x = 10`.

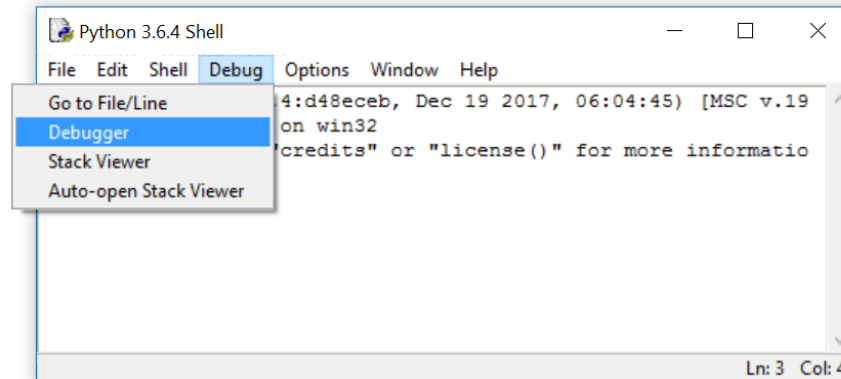
```
idle
AssertionError:
+ idlelib.run.runcode(...), line 474: exec(code, self.locals)
+ _main_.<module>(...), line 1:
- _main_.int_sqrt(...), line 10: assert isinstance(low, int)
  - <locals>
    mid = 3.125
    high = 3.75
    low = 3.125
    x = 10
  + <globals>
```

# Stepping through a program (IDLE debugger)

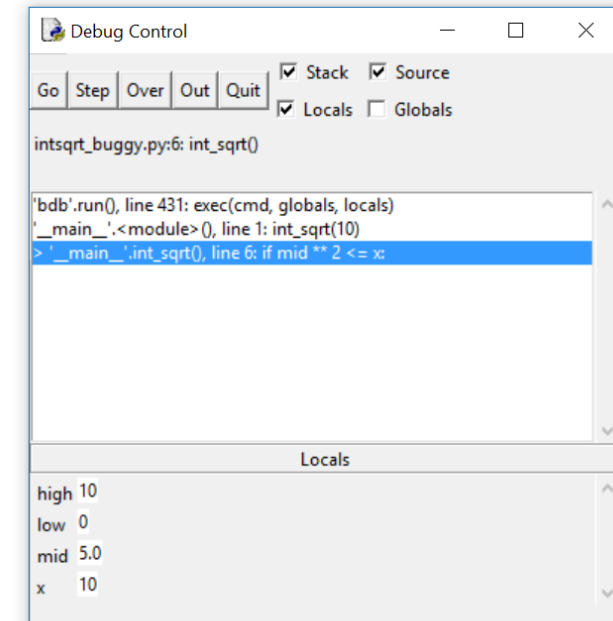
- **Debug > Debugger** in the Python shell opens Debug Control window
- **Right click** on a code line in editor to set a “breakpoint” in your code
- **Debug Control:** Go → run until next breakpoint is encountered;  
Step → execute one line of code; Over → run function call without details;  
Out → finish current function call; Quit → Stop program;



```
def int_sqrt(x):  
    low = 0  
    high = x  
    while low < high - 1:  
        mid = (low + high) / 2  
        if mid ** 2 <= x:  
            low = mid  
        else:  
            high = mid  
    return low
```



```
Python 3.6.4 Shell  
File Edit Shell Debug Options Window Help  
4:d48eceb, Dec 19 2017, 06:04:45) [MSC v.19  
on win32  
credits" or "license()" for more informatio
```



Debug Control

Go Step Over Out Quit

☒ Stack ☒ Source  
☒ Locals ☐ Globals

intsqrt\_buggy.py:6: int\_sqrt()

'bdb'.run(), line 431: exec(cmd, globals, locals)  
['\_main\_'.<module> 0], line 1: int\_sqrt(10)  
> '.\_main\_'.int\_sqrt(), line 6: if mid \*\* 2 <= x:

Locals

high 10  
low 0  
mid 5.0  
x 10

# Coverage

- Ensure that your tests cover the whole code and all possible branches are taken
- The module `coverage` can monitor running your code and report which lines and branches were not executed
- `pip install coverage`
- **Note** 100% coverage does not guarantee that there are no errors... just fewer

goldbach.py

```
1 def odd(x):
2     return x % 2 == 1

3 def sum_of_three_primes(n):
4     assert odd(n) and n > 5
5     primes = (set(range(2, n + 1)) -
6               set(x for f in range(2, n + 1)
7                   for x in range(2 * f, n + 1, f)))
8     for x in primes:
9         for y in primes:
10            for z in primes:
11                if n == x + y + z:
12                    print(n, 'is the sum of three primes', x, y, z)
13            return
14    print(n, 'is not the sum of three primes')

15 for n in range(7, 1000, 2):
16     sum_of_three_primes(n)
```

Shell

```
> coverage run --branch goldbach.py
7 is the sum of three primes 2 2 3
9 is the sum of three primes 2 2 5
...
999 is the sum of three primes 3 5 991
> coverage report -m goldbach.py
```

Name	Stmts	Miss	Branch	BrPart	Cover	Missing
goldbach.py	14	1	12	1	92%	14
TOTAL	14	1	12	1	92%	

[pypi.org/project/coverage](https://pypi.org/project/coverage)

[en.wikipedia.org/wiki/Goldbach's weak conjecture](https://en.wikipedia.org/wiki/Goldbach's_weak_conjecture)

# coverage html

Coverage for **goldbach.py**: 92%

14 statements

13 run

1 missing

0 excluded

1 partial

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coverage.py v6.5.0, created at 2022-10-05 17:23 +0200

```
1 def odd(x):
2     return x % 2 == 1
3 def sum_of_three_primes(n):
4     assert odd(n) and n > 5
5     primes = (set(range(2, n + 1)) -
6               set(x for f in range(2, n + 1)
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10            for z in primes:
11                if n == x + y + z:
12                    print(n, 'is the sum of three primes', x, y, z)
13                return
14     print(n, 'is not the sum of three primes')
15 for n in range(7, 1001, 2):
16     sum_of_three_primes(n)
```

8 ↔ 14

line 8 didn't jump to line 14, because the loop on line 8 didn't complete

# Concluding remarks

- Simple debugging: add print statements
- **Test driven development** → Strategy for code development, where tests are written before the code
- **Defensive programming** → add tests (assertions) to check if input/arguments are valid according to specification
- When designing tests, ensure **coverage**  
(the set of test cases should make sure all code lines get executed)
- **Python testing frameworks: doctest, unittest, pytest, ...**

# Mypy – a static type checker for Python

Experimental 

- **Static type checking** tries to analyze a program for potential type errors **without** executing the program
- Installing:  

```
pip install mypy
```
- Running Python will cause an error during execution, whereas using **mypy** the error will be found without executing the program
- Standard (and required) in statically typed languages like Java, C, C++

**mypy-simple.py**

```
print('start')
print(42 + 'abc') # error
print('end')
```

**Shell**


```
> python mypy-simple.py
| start
| TypeError: unsupported operand type(s)
| for +: 'int' and 'str'
> mypy mypy-simple.py
| mypy-simple.py:2: error: Unsupported
| operand types for + ("int" and "str")
| [operator]
```

# mypy does not spot all errors...

**mypy-add.py**

```
def add(x, y):  
    return x + y  # bug: x int and y string  
print(add(42, 'abc'))
```

**Shell**

```
> python add.py  
| TypeError: unsupported operand type(s) for +: 'int' and 'str'  
> mypy add.py  
| Success: no issues found in 1 source file 
```



# Type hints (PEP 484)

- Python allows type hints in programs
- Type hints are **ignored** at run-time by Python, but useful for static type analysis (e.g. mypy)
- Syntax

*variable* : *type*

*variable* : *type* = value

## mypy-basic-types.py

```
x : int # type hint
x = 42
x = 'abc' # type error
y : int = 42 # type hint
y = 'abc' # type error
z = 42
z = 'abc' # type changed from int to str
print(x, y, z)
```

## Shell

```
> python mypy-basic-types.py
| abc abc abc
> mypy mypy-basic-types.py
| mypy-basic-types.py:3: error: Incompatible
| types in assignment (expression has type
| "str", variable has type "int")
| mypy-basic-types.py:5: error: ...
| mypy-basic-types.py:7: error: ...
```

# Type hints – functions

`def name(variable : type, ...) -> return type:`

mypy-function.py	Shell
<pre>def f(x: int, units: str) -&gt; str:     return str(x) + ' ' + units  def g(x, units: str) -&gt; str:     return str(x) + ' ' + units  print(f(3, 'cm')) print(f('one', 'meter'))  print(g(3, 'cm')) print(g('one', 'meter'))  print(f.__annotations__)</pre>	<pre>&gt; python mypy-function.py   3 cm   one meter   3 cm   one meter   {'x': &lt;class 'int'&gt;, 'units': &lt;class 'str'&gt;,   'return': &lt;class 'str'&gt;} &gt; mypy mypy-function.py   mypy-function.py:8: error: Argument 1 to "f"   has incompatible type "str"; expected "int"</pre>

- For functions and methods `function.__annotations__` is a dictionary with the annotation
- The types become part of the documentation

# More type hints in Python 3.9

## ...see PEP 484 for even more...

mypy-typing.py

```
from typing import Mapping, Set, List, Tuple, Union, Optional

S : Set = {}                                # error {} dictionary
S2 : Set[int] = {1, 2, 'abc'}               # error 'abc' is not int
D : Mapping[int, int] = {1: 42, 'a': 1}     # error 'a' is not int
T : Tuple[int, str] = (42, 7)               # error 7 is not str
L : List[Union[int, str]] = [42, 'a', None] # error list can only contain int and str
L2 : List[Optional[str]] = ['abc', None, 42] # error list can only contain str og None
```

Shell

```
> mypy mypy-typing.py
| mypy-typing.py:3: error: Incompatible types in assignment (expression has type "Dict[<nothing>, <nothing>]", variable has type "Set[Any]")
| mypy-typing.py:4: error: Argument 3 to <set> has incompatible type "str"; expected "int"
| mypy-typing.py:5: error: Dict entry 1 has incompatible type "str": "int"; expected "int": "int"
| mypy-typing.py:6: error: Incompatible types in assignment (expression has type "Tuple[int, int]", variable has type "Tuple[int, str]")
| mypy-typing.py:7: error: List item 2 has incompatible type "None"; expected "Union[int, str]"
| mypy-typing.py:8: error: List item 2 has incompatible type "int"; expected "Optional[str]"
```

# ... the same in Python 3.10

## mypy-typing-new.py

```
# deprecated: from typing import Mapping, Set, List, Tuple, Union, Optional

S : set = {}                                # error {} dictionary
S2 : set[int] = {1, 2, 'abc'}               # error 'abc' is not int
D : dict[int, int] = {1: 42, 'a': 1}         # error 'a' is not int
T : tuple[int, str] = (42, 7)               # error 7 is not str
L : list[int | str] = [42, 'a', None]       # error list can only contain int and str
L2 : list[str | None] = ['abc', None, 42]   # error list can only contain str og None
```

## Shell

```
> mypy mypy-typing-new.py
| mypy-typing-new.py:3: error: Incompatible types in assignment (expression has type "Dict[<nothing>, <nothing>]", variable has type "Set[Any]")
| mypy-typing-new.py:4: error: Argument 3 to <set> has incompatible type "str"; expected "int"
| mypy-typing-new.py:5: error: Dict entry 1 has incompatible type "str": "int"; expected "int": "int"
| mypy-typing-new.py:6: error: Incompatible types in assignment (expression has type "Tuple[int, int]", variable has type "Tuple[int, str]")
| mypy-typing-new.py:7: error: List item 2 has incompatible type "None"; expected "Union[int, str]"
| mypy-typing-new.py:8: error: List item 2 has incompatible type "int"; expected "Optional[str]"
```

# Specific values

mypy-literal.py

```
from typing import Literal

def calc(cmd: Literal['add', 'sub'], x: int, y: int) -> int:
    match cmd:
        case 'add': return x + y
        case 'sub': return x - y
        case _: raise ValueError(f"Unknown command '{cmd}'")

print(f"{calc('add', 5, 8) = }")
print(f"{calc('sub', 5, 8) = }")
print(f"{calc('mul', 5, 8) = }") # error
```

Shell

```
> python.exe mypy-literal.py
| calc('add', 5, 8) = 13
| calc('sub', 5, 8) = -3
| ValueError: Unknown command 'mul'
> mypy.exe .\mypy-literal.py
| mypy-literal.py:11: error: Argument 1 to "calc" has incompatible type "Literal['mul']";
|   expected "Literal['add', 'sub']" [arg-type]
| Found 1 error in 1 file (checked 1 source file)
```

# Type hints for methods with multiple signatures

printing1.py

```
class MyClass:
    def print(self, value: int | str) -> None:
        if isinstance(value, int):
            print('An integer', value)
        elif isinstance(value, str):
            print('A string', value)
```

- The right solution is useful for functions/methods with more complex overloaded type signatures
- `...` is the Python Ellipsis object
- `@overload` is a Python *decorator*

printing2.py

```
from typing import overload

class MyClass:
    # type definition of usages
    @overload
    def print(self, value: int) -> None: ...

    @overload
    def print(self, value: str) -> None: ...

    # actual implementation
    def print(self, value):
        if isinstance(value, int):
            print('An integer', value)
        elif isinstance(value, str):
            print('A string', value)
```

# Type hints for class inheritance

```
abstract.py

from typing import override, final

class A():
    @final # prevent subclasses to override f (since Python 3.8)
    def f(self):
        print('f')
        self.g()

    def g(self):
        raise NotImplementedError

class B(A):
    @override # check if parent class contains g (since Python 3.12)
    def g(self):
        print('g')
```

- Use **pyright** (`pip install pyright`) to check the above, a static type checking tool from Microsoft
- mypy does not check it (mypy 1.8.0)