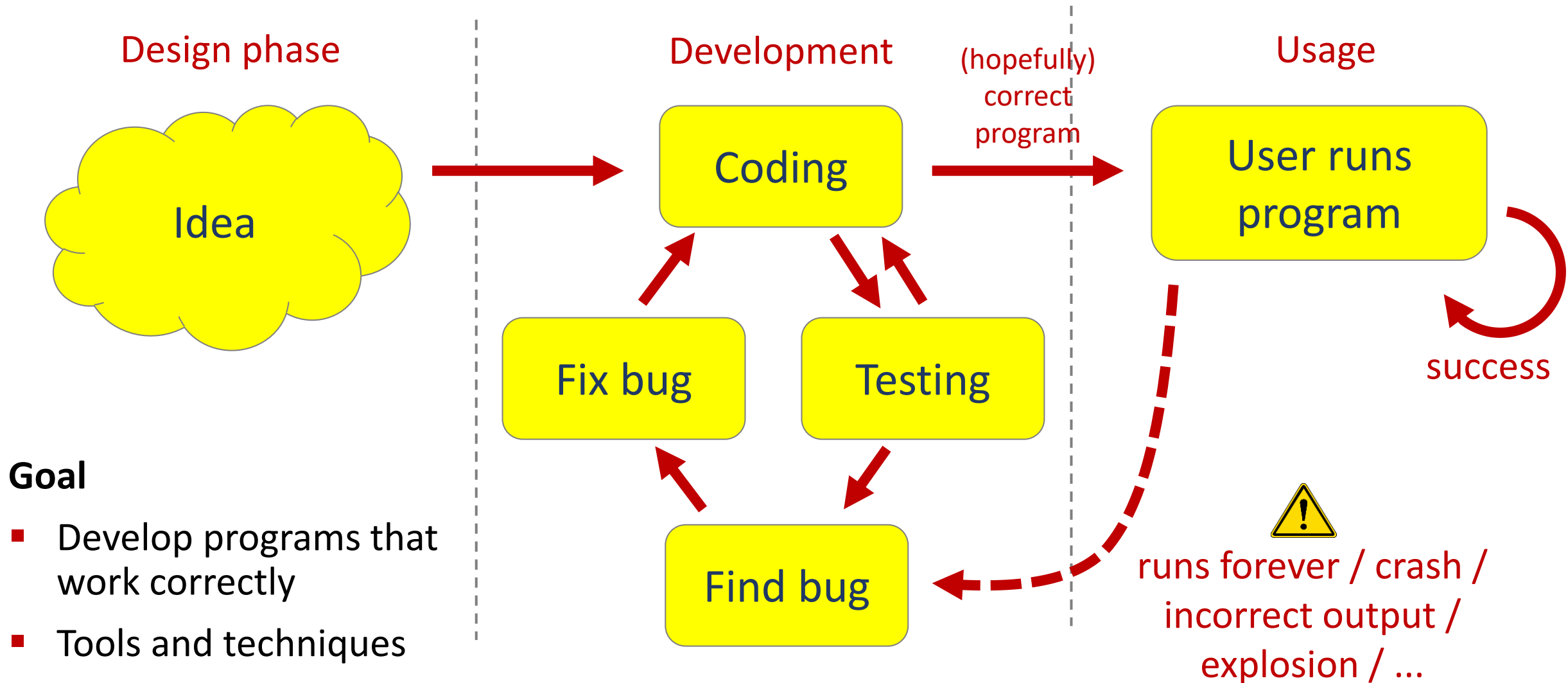


Documentation, testing and debugging

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

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
```

- keyword **`assert`** checks if boolean expression is true, if not, raises exception **`AssertionError`**
- optional second parameter passed to the constructor of the exception

`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???
```

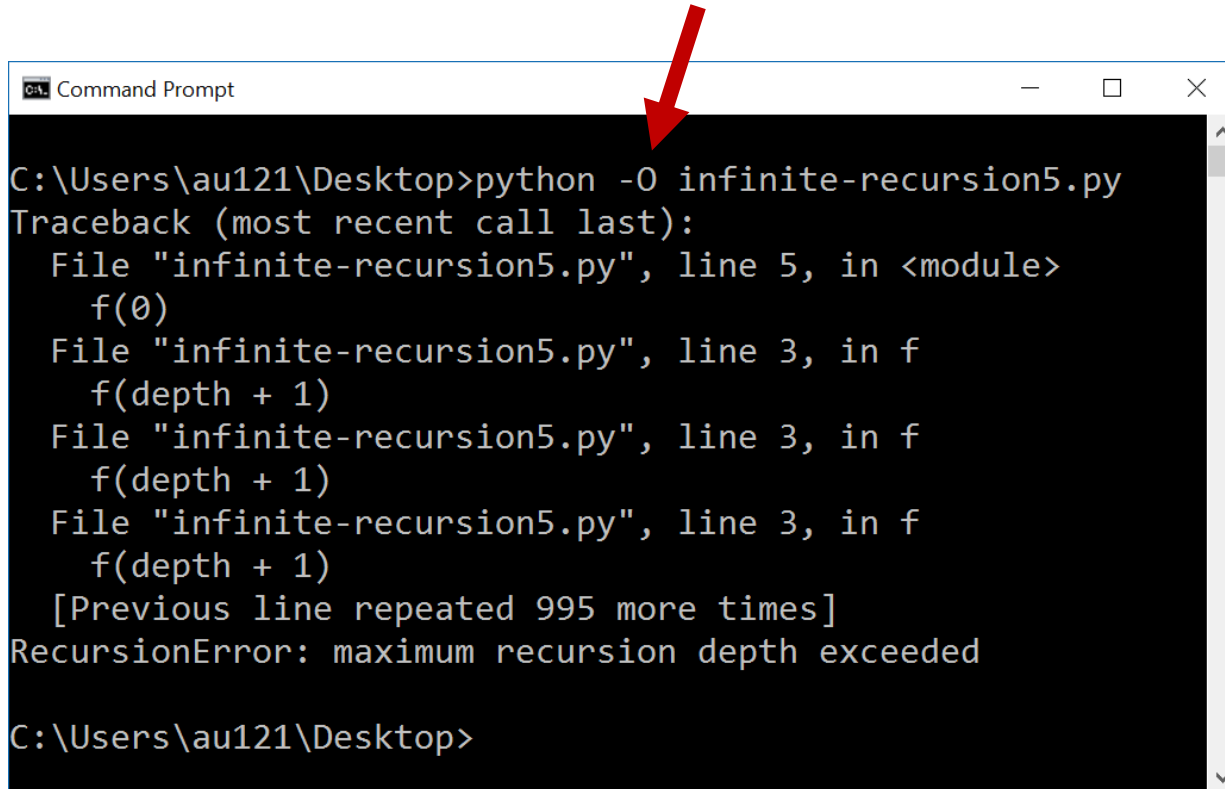
`infinite-recursion6.py`

```
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??
```

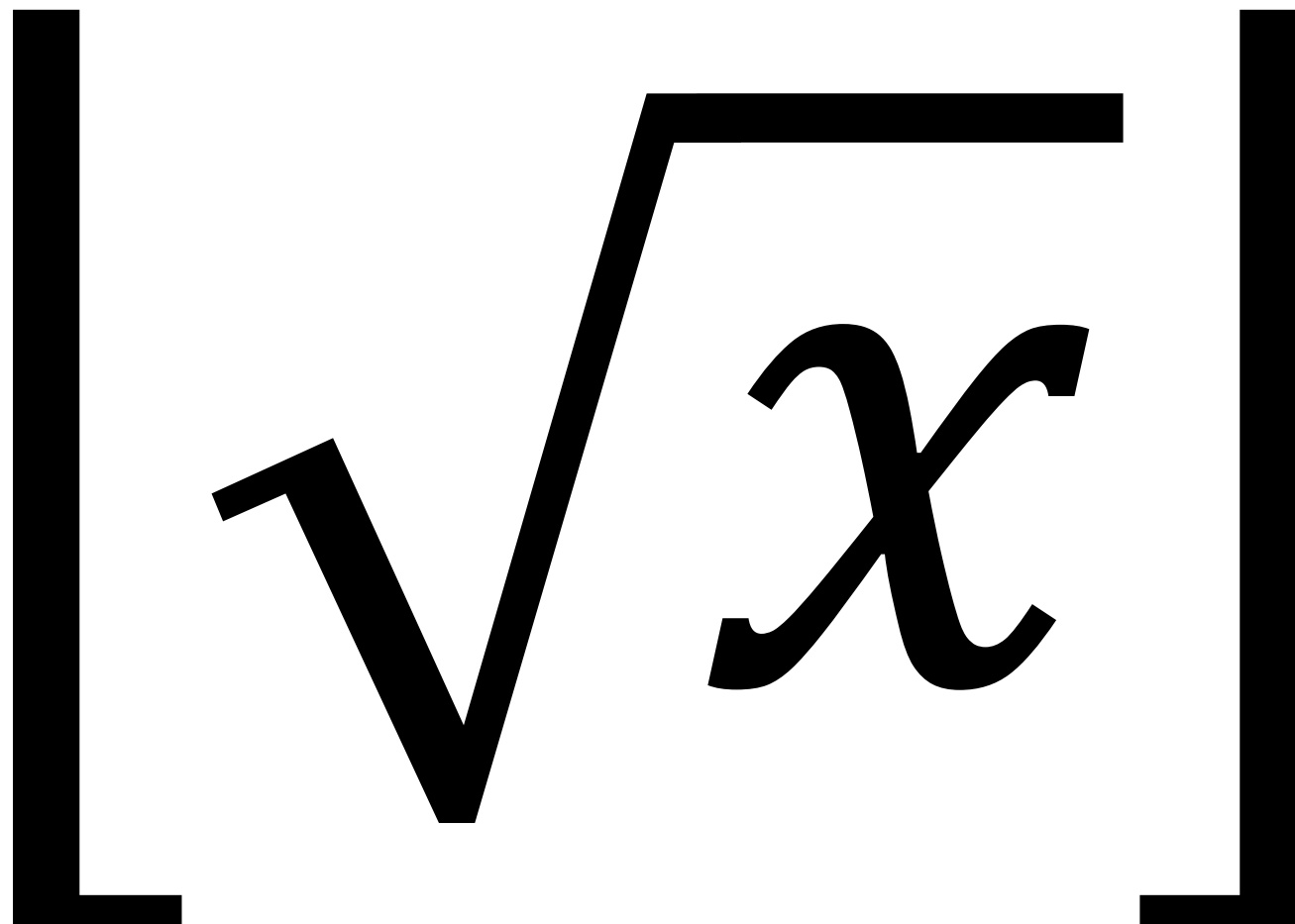
Disabling `assert` statements



```
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.  
    Assumes that x is an integer and x >= 0  
    Returns integer floor(sqrt(x)) """  
    ...
```

docstring {

input requirements → Assumes that x is an integer and x >= 0

output guarantees → Returns integer floor(sqrt(x))

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.  
|     Assumes that x is an integer and x >= 0  
|     Returns 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.  
  
    Assumes that x is an integer and x >= 0  
    Returns 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.  
  
    Assumes that x is an integer and x >= 0  
    Returns 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 } check invariant
    mid = (low + high) // 2           for loop
    if mid ** 2 <= x:
        low = mid
    else:
        high = mid
result = low
...
```

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.  
  
    Assumes that x is an integer and x >= 0  
    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,  $-1 \leq i < \text{len}(L)$ , where  $L[i] \leq x < L[i+1]$ ,
    assuming  $L[-1] = -\text{infty}$  and  $L[\text{len}(L)] = +\text{infty}$ """

    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  $-1 \leq \text{result} < \text{len}(L)$  and
            ((result == -1 and (len(L) == 0 or x < L[0])) or
             (result == len(L) - 1 and x >= L[-1]) or
             ( $0 \leq \text{result} < \text{len}(L) - 1$  and  $L[\text{result}] \leq x < L[\text{result} + 1]$ )))
    }

    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

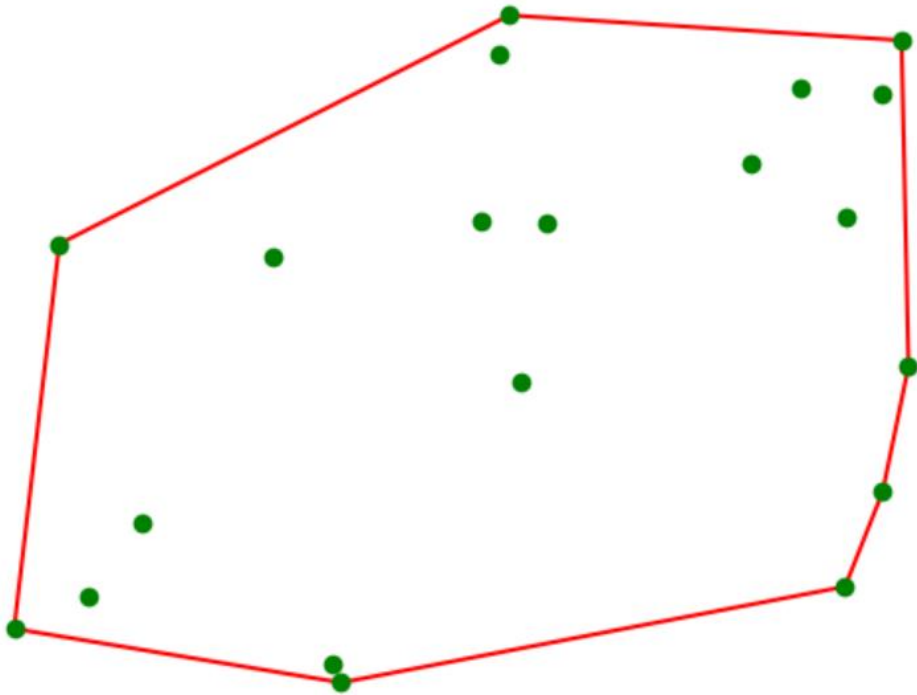
} test cases
```

- 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

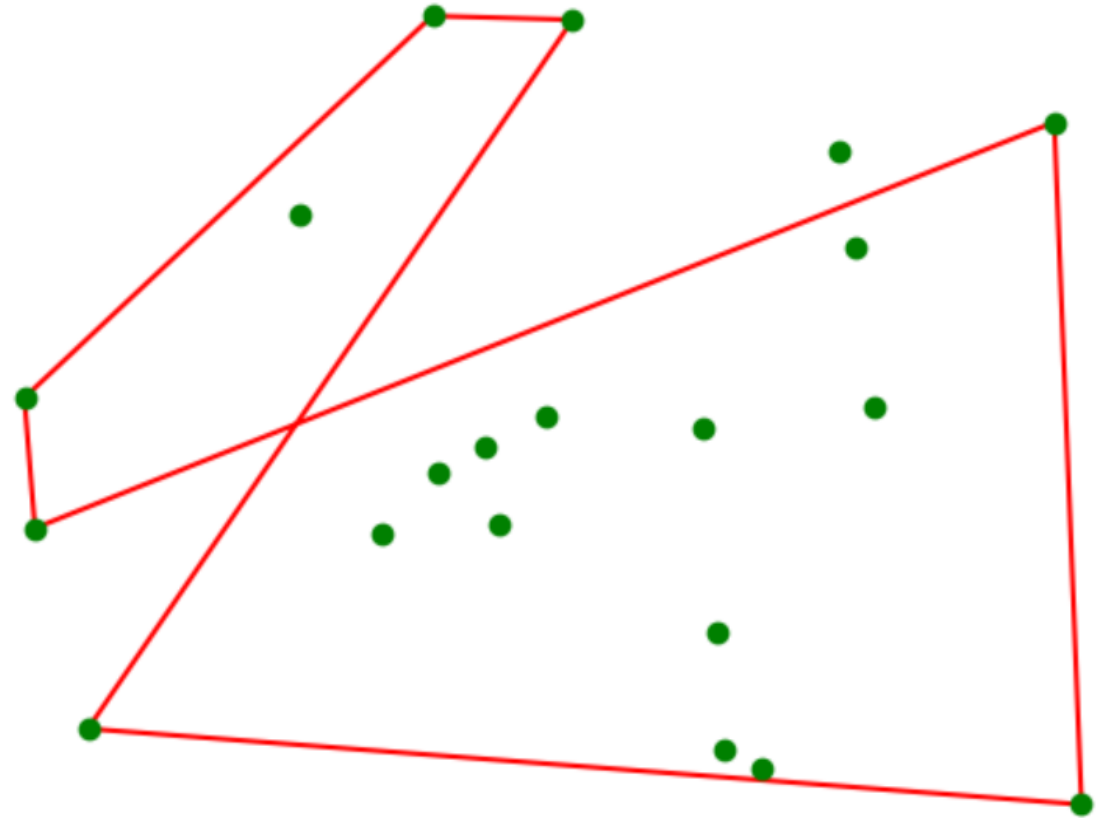
Testing – how ?

- 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	Python shell
<pre>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)</pre>	<pre>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.</pre>

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

binary-search-pytest.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

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

import pytest

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 3.7.2, pytest-4.3.1, ... 0.9.0
| collected 2 items
| binary-search-pytest.py .. [100%]
| ===== 2 passed in 0.06 seconds =====
```

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'])

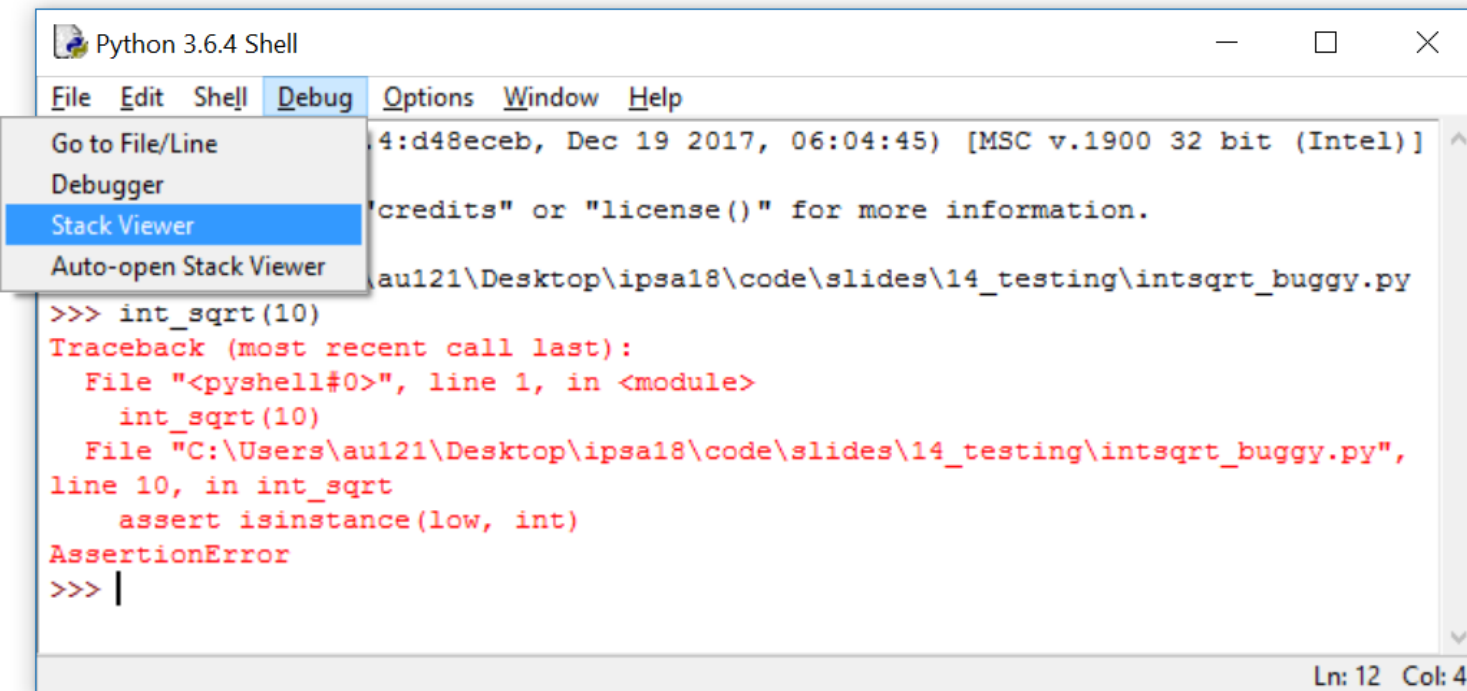
unittest.main(verbosity=2)
```

Python shell

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

Debugger (IDLE)

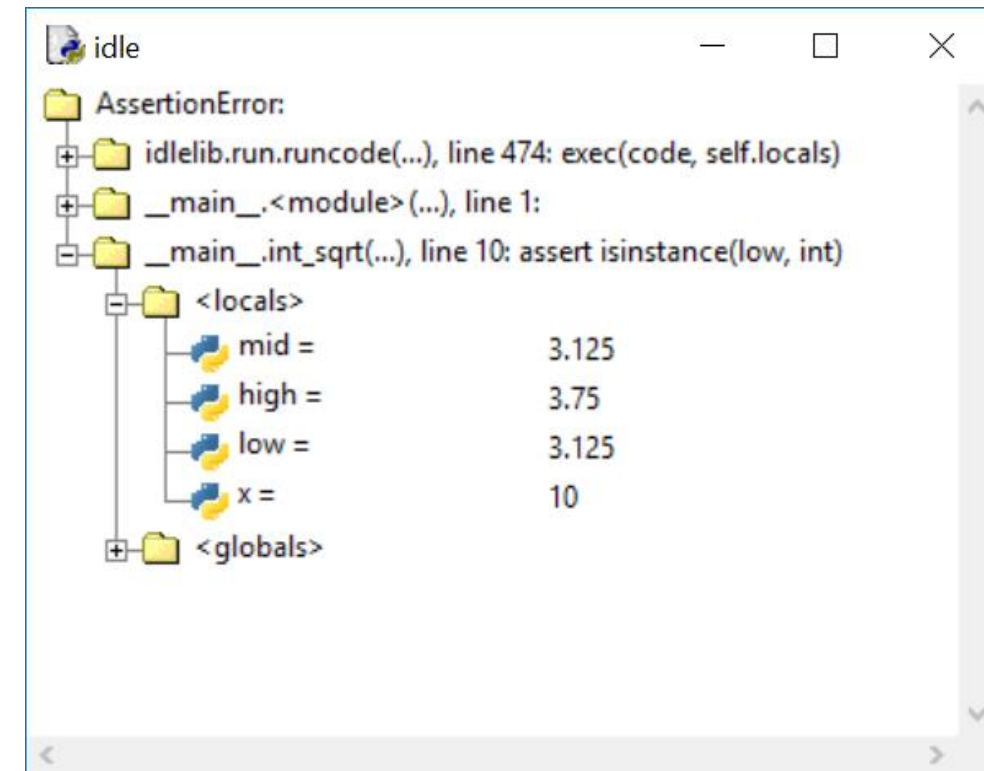
- When an exception has stopped the program, you can examine the state of the variables using **Debug > Stack Viewer** in the Python shell



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 `int_sqrt(10)`. The traceback shows the call stack starting from the shell, through the module, and into the `int_sqrt` function at line 10, where the assertion `assert isinstance(low, int)` failed.

```
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 current exception. The stack frames are:

- `idlelib.run.runcode(...), line 474: exec(code, self.locals)`
- `_main_.<module>(...), line 1:`
- `_main_.int_sqrt(...), line 10: assert isinstance(low, int)`

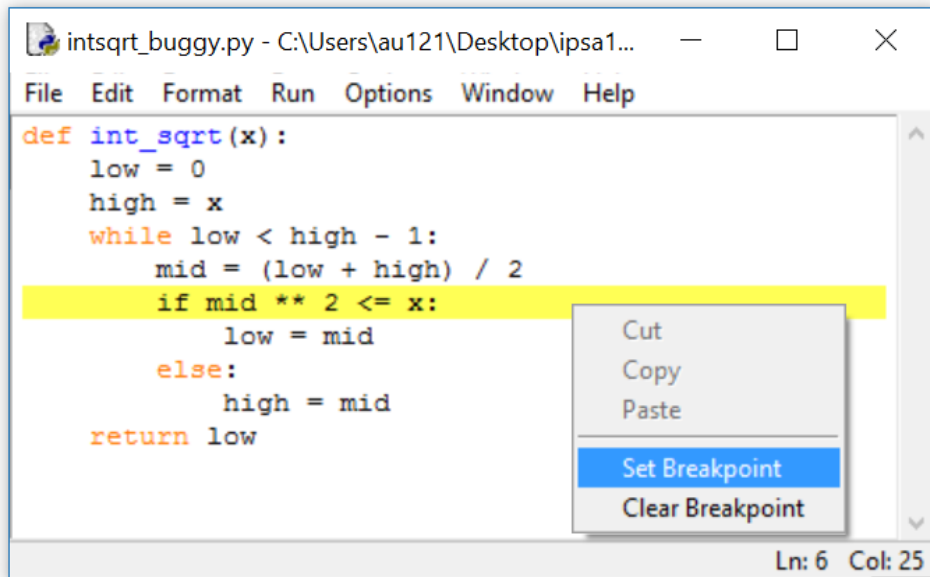
The current frame is `_main_.int_sqrt(...)`. It shows the local variables:

Variable	Value
<code>mid</code>	<code>3.125</code>
<code>high</code>	<code>3.75</code>
<code>low</code>	<code>3.125</code>
<code>x</code>	<code>10</code>

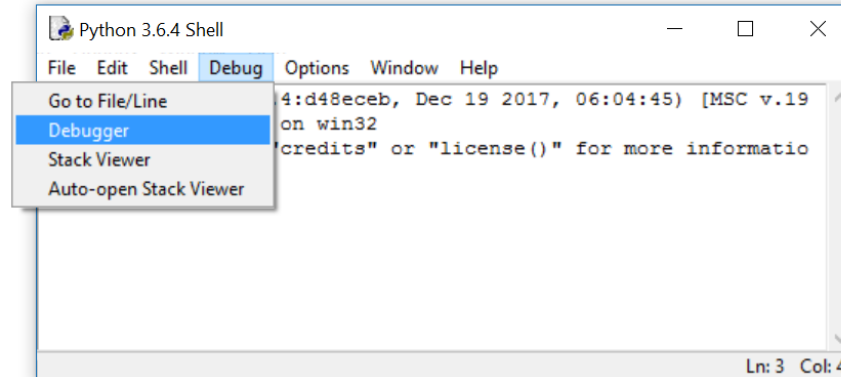
The global variables section is also visible, showing `<globals>`.

Stepping through a program (IDLE debugger)

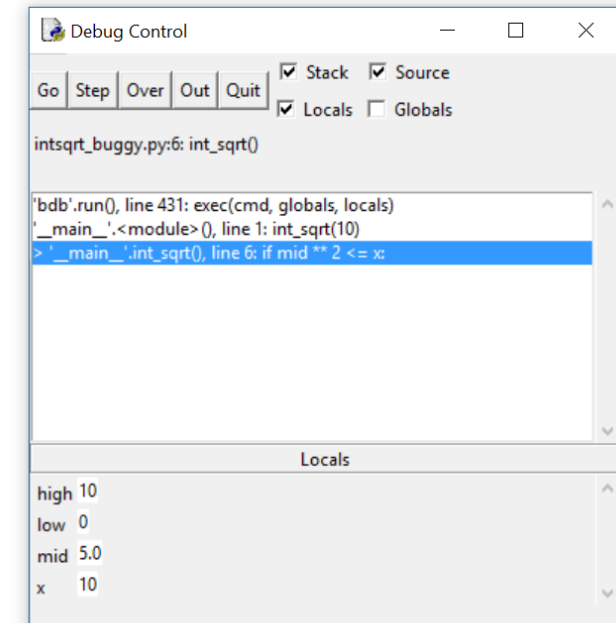
- **Debug > Debugger** in the Python shell opens Debug Control window
- **Right click** on a code line in editor to set a “breakpoint” in your code
- **Debug Control:** Go → run until next breakpoint is encountered;
Step → execute one line of code; Over → run function call without details;
Out → finish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

[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

« prev

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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)
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, 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")
```

Type hints (PEP 484)

- Python allows type hints in programs
- They are **ignored** at run-time by Python, but useful for static type analysis (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) -> str: return str(x) + " " + units def g(x, units: str) -> 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>> python mypy-function.py 3 cm one meter 3 cm one meter {'x': <class 'int'>, 'units': <class 'str'>, 'return': <class 'str'>} > mypy mypy-function.py mypy-function.py:8: error: Argument 1 to "f" has incompatible type "str"; expected "int"</pre>

- Note: for functions and methods `function.__annotations__` is a dictionary with the annotation

Type hints – objects

mypy-classes.py

```
class A:
    pass

class B(A):
    pass

class C:
    pass

a : A
b : B
c : C

a = A()
a = B() # valid, B subclass of A
a = C() # error
b = A() # error
b = B()
b = C() # error
c = A() # error
c = B() # error
c = C()
```

Shell

```
> mypy mypy-classes.py
| mypy-classes.py:15: error: Incompatible types in assignment (expression has type "C", variable has type "A")
| mypy-classes.py:16: error: Incompatible types in assignment (expression has type "A", variable has type "B")
| mypy-classes.py:18: error: Incompatible types in assignment (expression has type "C", variable has type "B")
| mypy-classes.py:19: error: Incompatible types in assignment (expression has type "A", variable has type "C")
| mypy-classes.py:20: error: Incompatible types in assignment (expression has type "B", variable has type "C")
```


More type hints... 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] # list can only contain int and str
L2 : List[Optional[str]] = ['abc', None, 42] # 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]       # list can only contain int and str
L2 : list[str | None] = ['abc', None, 42]   # 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]"
```

[PEP 585 - Type Hinting Generics In Standard Collections](#) (Python 3.9)

[PEP 604 – Allow writing union types as X | Y](#) (Python 3.10)