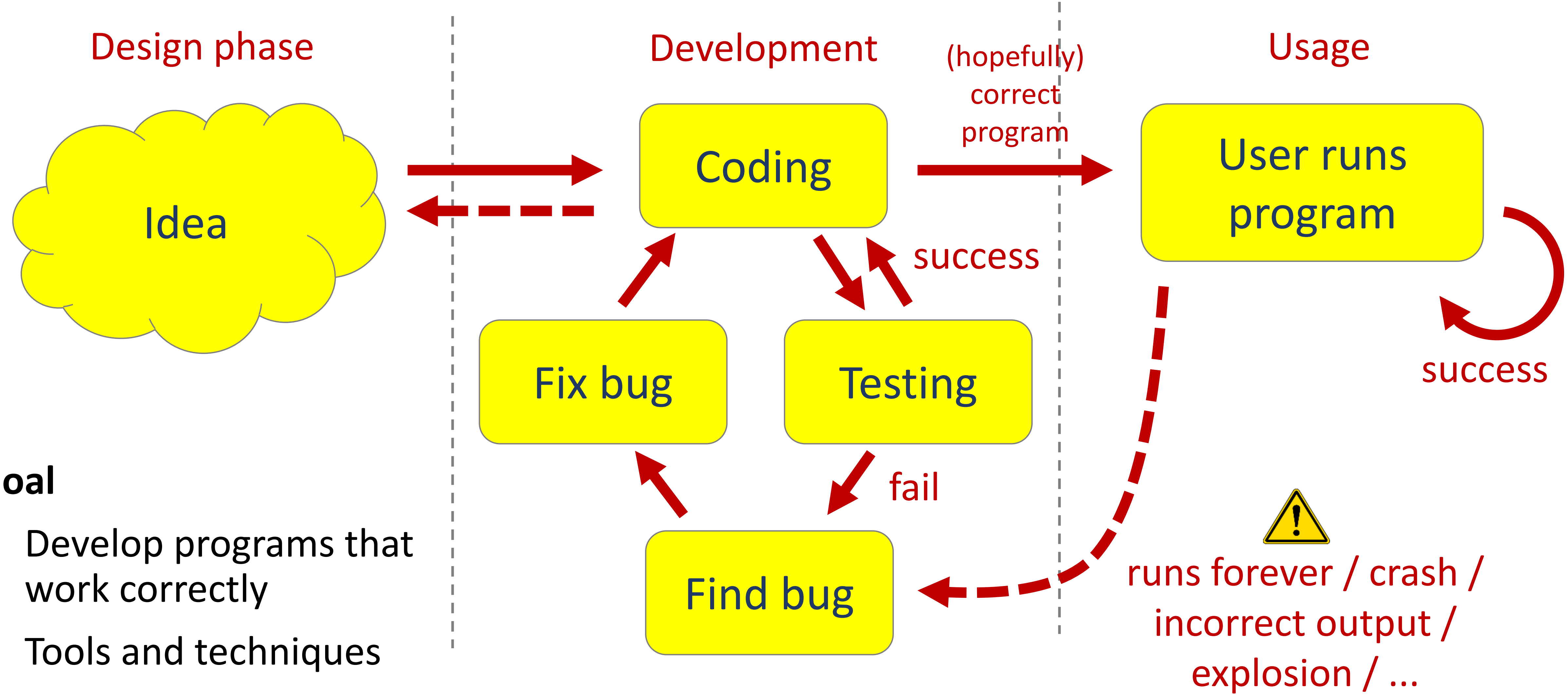
Documentation, testing and debugging

- 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 ?



Design phase

Idea

Development

Coding

success

Fix bug

Testing

fail

Find bug

(hopefully) correct program

Usage

User runs program

success

runs forever / crash / incorrect output / explosion / ...

Goal

- Develop programs that work correctly
- Tools and techniques

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 #!¤$ bug ?*

”Program testing can be used to show the presence of bugs, but never to show their absence” – Edsger W. Dijkstra

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
      |    +-- FileExistsError
      |    +-- 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
```

docs.python.org/3/library/exceptions.html

Testing for unexpected behaviour ?

infinite-recursion1.py

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

f(0)
```

Python shell

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

infinite-recursion2.py

```python
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

```python
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

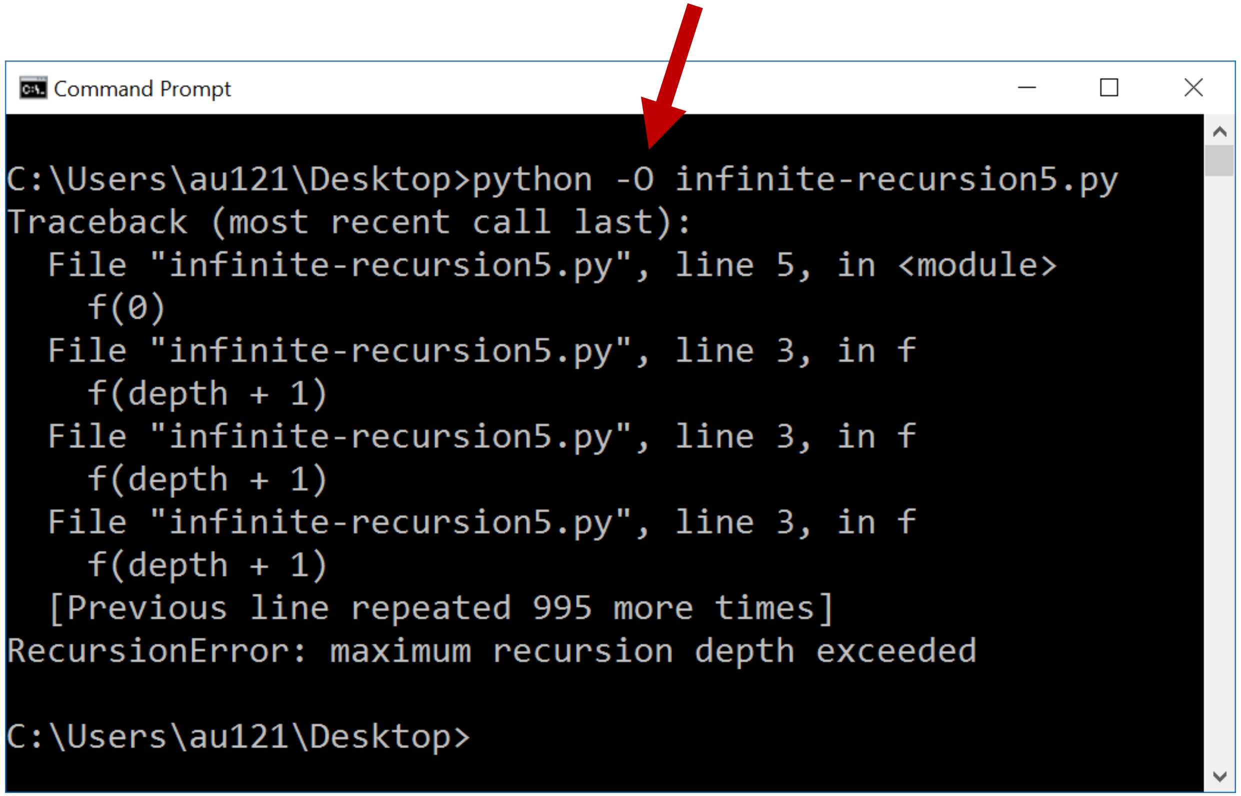
infinite-recursion6.py

```
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



```
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`)

docs.python.org/3/reference/simple_stmts.html#assert

Example

$$\left\lfloor \sqrt{x} \right\rfloor$$

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.
    Returns the integer floor(sqrt(x)).'''

    ...
```

docstring

input requirements

output guarantees

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 ouput guarantees
- the docstring is assigned to the object's `__doc__` attribute

PEP 257 -- Docstring Conventions
www.python.org/dev/peps/pep-0257/

Let us check input requirements...

intsqrt.py

```python
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
    ...
```

check input 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

```python
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

$\lfloor\sqrt{x}\rfloor \in [\mathrm{low},\mathrm{high}[$

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

```python
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

```python
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.'''

    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

```python
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

```python
    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

```python
    low, high = -1, len(L)
    while low + 1 < high:  # L[low] <= x < L[high]
```

loop

```python
        assert (low == -1 or L[low] <= x) and (high == len(L) or x < L[high])
        mid = (low + high) // 2
```

input ②

```python
        assert isinstance(L[mid], int)
        assert (low == -1 or L[low] <= L[mid]) and (high == len(L) or L[mid] <= L[high])
        if x < L[mid]:
            high = mid
        else:
            low = mid
    result = low
```

output

```python
    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
```

test cases

```python
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
```

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)

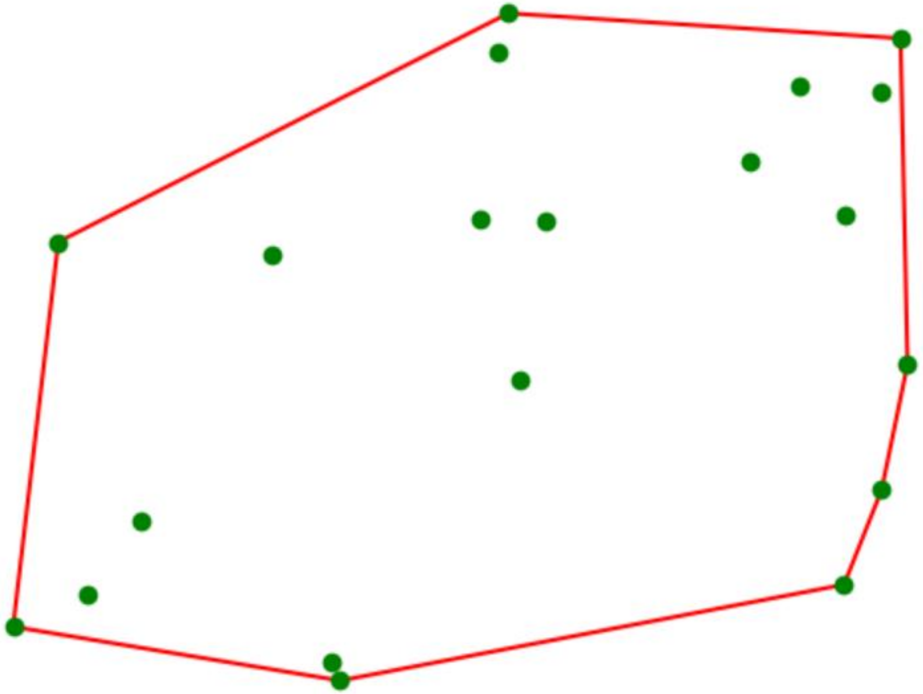
intsqrt_automatic_testing.py

```
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))
```

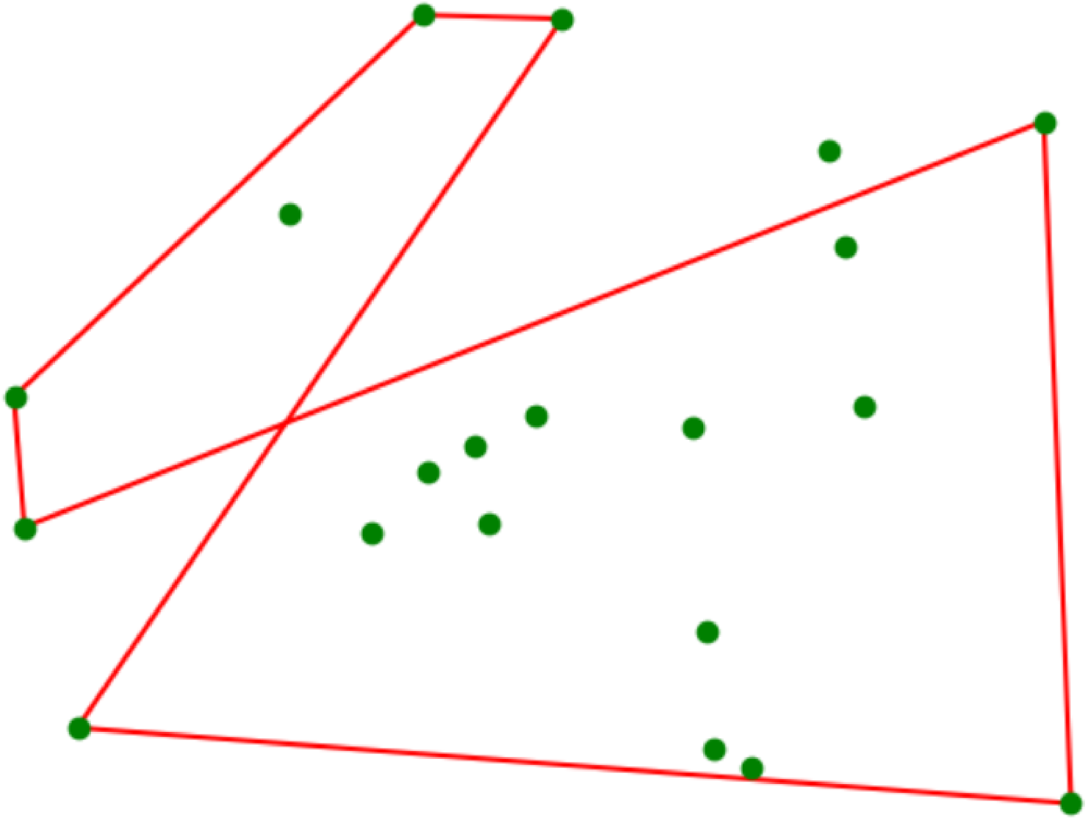
Testing – how ?

- 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.
```

docs.python.org/3/library/doctest.html

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

```
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

```python
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)
```

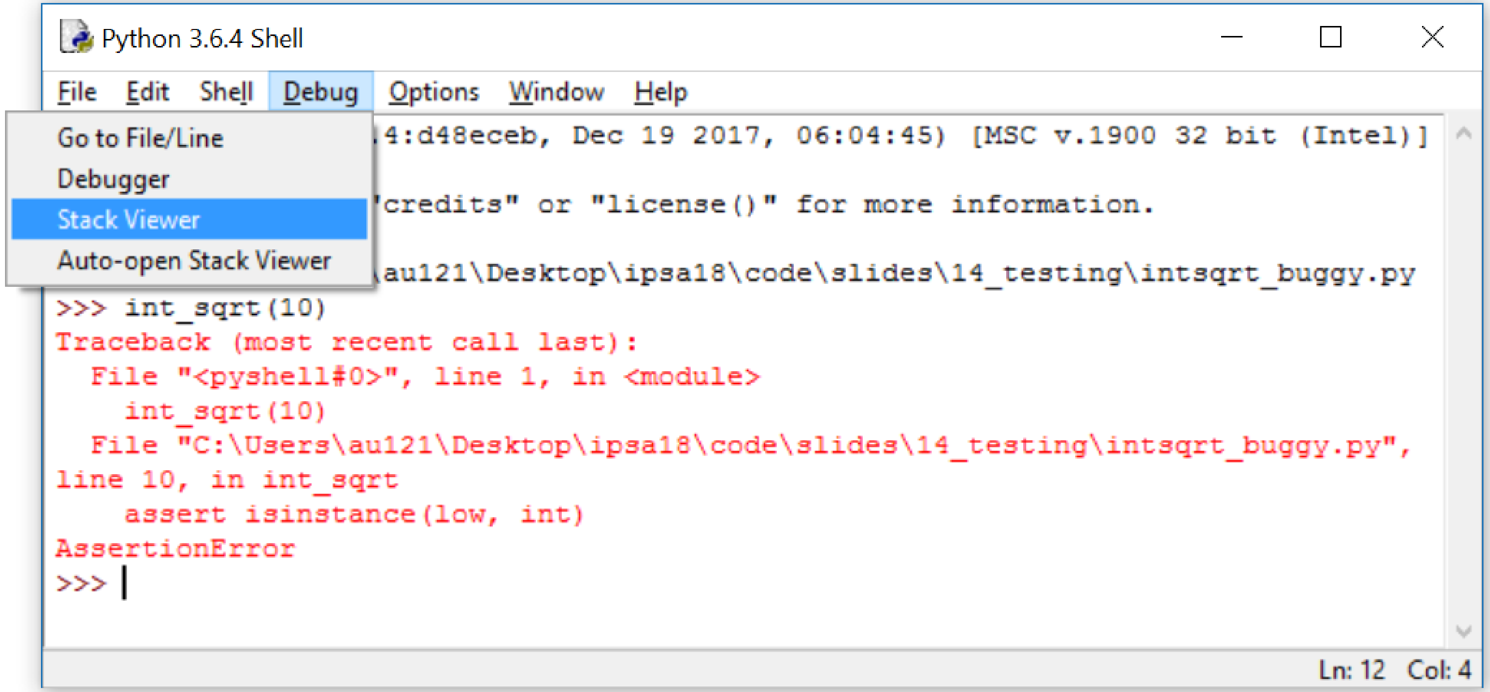
Python shell

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

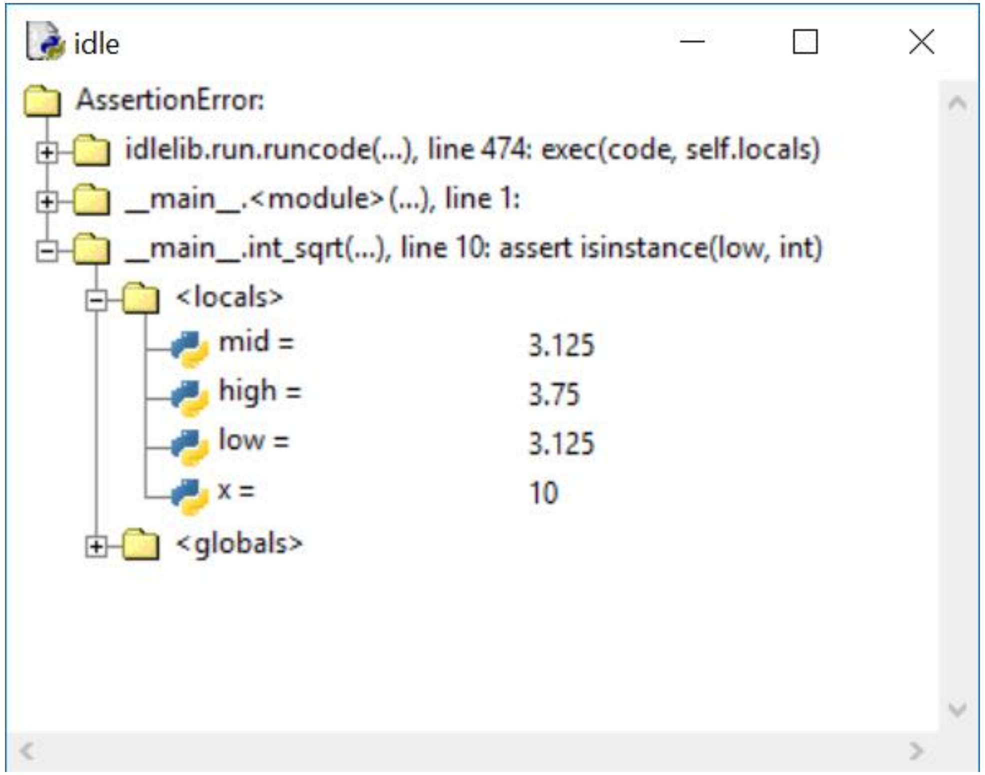
docs.python.org/3/library/unittest.html

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



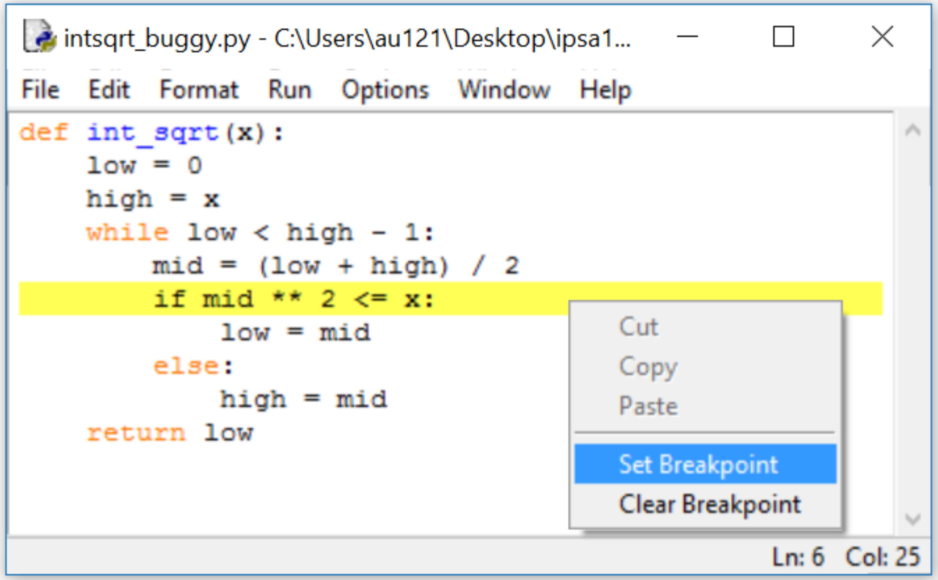
```
4:d48eceb, Dec 19 2017, 06:04:45) [MSC v.1900 32 bit (Intel)]

'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
>>> |
```



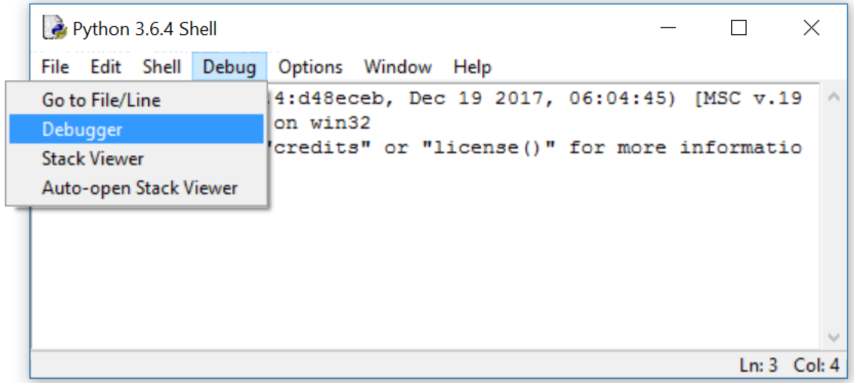
```
AssertionError:
  idlelib.run.runcode(...), line 474: exec(code, self.locals)
  __main__.<module>(...), line 1:
  __main__.int_sqrt(...), line 10: assert isinstance(low, int)
    <locals>
      mid =     3.125
      high =    3.75
      low =     3.125
      x =       10
    <globals>
```

Stepping through a program (IDLE debugger)

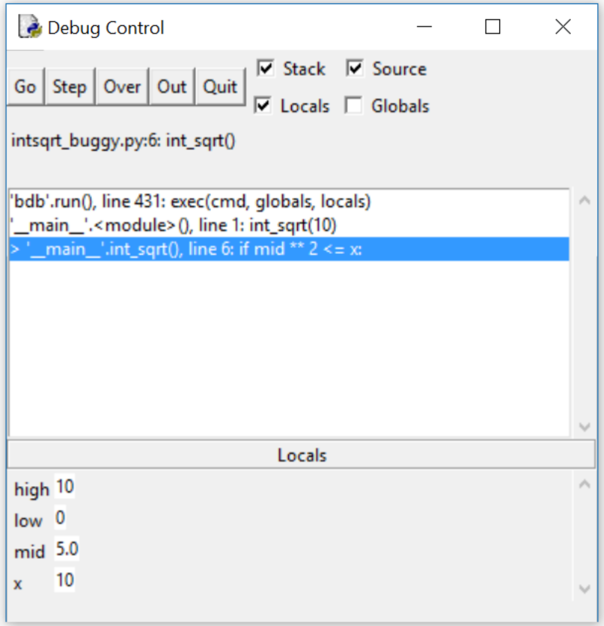
- **Debug > Debugger** in the Python shell opens Debug Control window
- **Right click** on a code line in editor to set a “breakpoint” in your code
- **Debug Control:** Go → run until next breakpoint is encountered;
  Step → execute one line of code; Over → run function call without details;
  Out →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



```
4:d48eceb, Dec 19 2017, 06:04:45) [MSC v.19
on win32
credits" or "license()" for more informatio
```



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:
```

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)
```

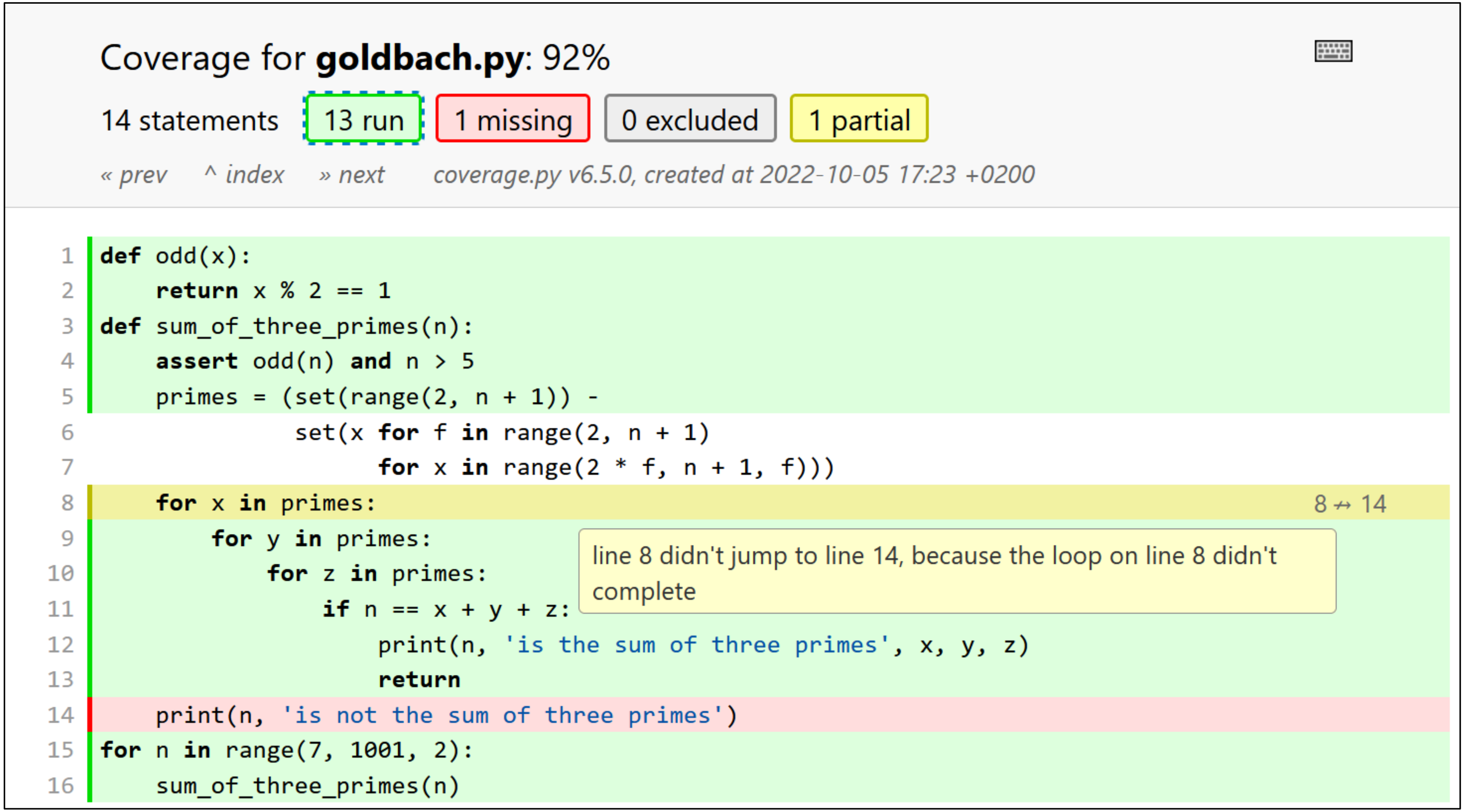
Shell

```
> 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

coverage html



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

14 statements 13 run 1 missing 0 excluded 1 partial

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:                                          8 ↛ 14
 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)
```

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

```python
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-lang.org

PEP 484 - Type Hints

`mypy` does not spot all errors...

mypy-add.py

```python
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

```python
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

```
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__)
```

Shell

```
> 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"
```

- 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]"
```

PEP 484 - Type Hints

… the same in Python 3.10

mypy-typing-new.py

```python
# 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]"
```

PEP 585 - Type Hinting Generics In Standard Collections (Python 3.9)
PEP 604 – Allow writing union types as X | Y (Python 3.10)

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)
```

PEP 586 - Literal Types (since Python 3.8)

Type hints for methods with multiple signatures

printing1.py

```python
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)
```

printing2.py

```python
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)
```

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

docs.python.org/3/library/typing.html

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)