Testing

BBM 101 - Introduction to Programming I
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Testing

• Programming to analyze data is powerful
• It is useless if the results are not correct
• Correctness is far more important than speed

Famous Examples

• Ariane 5 rocket
  – On June 4, 1996, the maiden flight of the European Ariane 5 launcher crashed about 40 seconds after takeoff.
  – Media reports indicated that the amount lost was half a billion dollars
  – The explosion was the result of a software error

• Therac-25 radiation therapy machine
  – In 1985 a Canadian-built radiation-treatment device began blasting holes through patients' bodies.

Testing does not Prove Correctness

• Edsger Dijkstra: “Program testing can be used to show the presence of bugs, but never to show their absence!”
Testing = Double-Checking Results

• How do you know your program is right?
  – Compare its output to a correct output

• How do you know a correct output?
  – Real data is big
  – You wrote a computer program because it is not convenient to compute it by hand

• Use small inputs so you can compute by hand

• Example: standard deviation
  – What are good tests for std_dev?
  \[ \sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2}, \]

Testing ≠ Debugging

• Testing: Determining whether your program is correct
  – Doesn’t say where or how your program is incorrect

• Debugging: Locating the specific defect in your program, and fixing it
  2 key ideas:
  – divide and conquer
  – the scientific method

What is a Test?

• A test consists of:
  – an input (sometimes called “test data”)
  – an oracle (a predicate (boolean expression) of the output)

• Example test for sum:
  – input: [1, 2, 3]
  – oracle: result is 6
  – write the test as: sum([1, 2, 3]) == 6

• Example test for sqrt:
  – input: 3.14
  – oracle: result is within 0.00001 of 1.772
  – ways to write the test:
    • assert(sqrt(3.14) - 1.772 < 0.00001)
    • assert(sqrt(3.14) - 1.772 > -0.00001)
    • assert(0.00001 < sqrt(3.14) - 1.772 < 0.00001)
    • assert(math.abs(sqrt(3.14) - 1.772) < 0.00001)

Test Results

• The test passes if the boolean expression evaluates to True

• The test fails if the boolean expression evaluates to False

• Use the assert statement:
  – assert sum([1, 2, 3]) == 6
  – assert True does nothing
  – assert False crashes the program and prints a message
Where to Write Test Cases

- At the **top level**: is run every time you load your program
  ```python
def hypotenuse(a, b):
    ...
    assert hypotenuse(3, 4) == 5
    assert hypotenuse(5, 12) == 13
  ```

- In a **test function**: is run when you invoke the function
  ```python
def hypotenuse(a, b):
    ...
    def test_hypotenuse():
        assert hypotenuse(3, 4) == 5
        assert hypotenuse(5, 12) == 13
  ```

Assertions are not Just for Test Cases

- Use assertions throughout your code
- Documents what you think is true about your algorithm
- Lets you know immediately when something goes wrong
  - The longer between a code mistake and the programmer noticing, the harder it is to debug

Assertions Make Debugging Easier

- Common, but unfortunate, course of events:
  - Code contains a mistake (incorrect assumption or algorithm)
  - Intermediate value (e.g., result of a function call) is incorrect
  - That value is used in other computations, or copied into other variables
  - Eventually, the user notices that the overall program produces a wrong result
  - Where is the mistake in the program? It could be anywhere.

- Suppose you had 10 assertions evenly distributed in your code
  - When one fails, you can localize the mistake to 1/10 of your code (the part between the last assertion that passes and the first one that fails)

Where to Write Assertions

- Function entry: Are arguments legal?
  - Place blame on the caller before the function fails
- Function exit: Is result correct?
- Places with tricky or interesting code
- Assertions are ordinary statements; e.g., can appear within a loop:
  ```python
  for n in myNumbers:
      assert type(n) == int or type(n) == float
  ```
Where *not* to Write Assertions

- Don’t clutter the code
  - Same rule as for comments

- Don’t write assertions that are certain to succeed
  - The existence of an assertion tells a programmer that it might possibly fail

- Don’t write an assertion if the following code would fail informatively
  
  ```python
  assert type(name) == str
  print("Hello, " + name)
  ```

- Write assertions where they may be useful for debugging

What to Write Assertions About

- Results of computations

- Correctly-formed data structures
  
  ```python
  assert 0 <= index < len(mylist)
  assert len(list1) == len(list2)
  ```

When to Write Tests

- Two possibilities:
  - Write code first, then write tests
  - Write tests first, then write code

- If you write the code first, you remember the implementation while writing the tests
  - You are likely to make the same mistakes in the implementation

- If you write the tests first, you will think more about the functionality than about a particular implementation
  - You might notice some aspect of behavior that you would have made a mistake about
  - This is the better choice

Write the Whole Test

- A common mistake:
  1. Write the function
  2. Make up test inputs
  3. Run the function
  4. Use the result as the oracle

- You didn’t write a test, but only half of a test
  - Created the tests inputs, but not the oracle

- The test does not determine whether the function is correct
  - Only determines that it continues to be as correct (or incorrect) as it was before
Testing Approaches

• **Black box testing** - Choose test data *without* looking at implementation

• **Glass box** (white box, clear box) testing - Choose test data *with* knowledge of implementation

Inside Knowledge might be Nice

• Assume the code below:

```python
c = a + b
if c > 100
    print("Tested")
    print("Passed")
```

• Creating a test case with a=40 and b=70 is not enough
  – Although every line of the code will be executed

• Another test case with a=40 and b=30 would complete the test

Tests might not Reveal an Error Sometimes

```python
def mean(numbers):
    """Returns the average of the argument list.
    The argument must be a non-empty list of numbers.""
    return sum(numbers)//len(numbers)

# Tests
assert mean([1, 2, 3, 4, 5]) == 3
assert mean([1, 2, 3]) == 2
```

This implementation is elegant, but *wrong*!

```python
mean([1,2,3,4]) → would return 2.5!!!
```

Last but not Least, Don’t Write Meaningless Tests

```python
def mean(numbers):
    """Returns the average of the argument list.
    The argument must be a non-empty list of numbers.""
    return sum(numbers)//len(numbers)
```

Unnecessary tests. *Don’t write these:*

```python
mean([1, 2, "hello"])
mean("hello")
mean([])
```