Testing

• Programming to analyze data is powerful
• It’s useless (or worse!) if the results are not correct
• Correctness is far more important than speed
Famous examples

- Ariane 5 rocket
- Therac-25 radiation therapy machine
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 can only increase our confidence in program correctness.
Testing your program

• 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 the expected output by hand
  – We did this in HW2 and HW3 with small data sets
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
Testing parts of your program

• Often called “unit testing”
• Testing that the output of individual functions is correct.
What is a test?

- A test consists of:
  - an **input** (sometimes called “test data”)
  - expected output

- Example test for **sum**:
  - input:  [1, 2, 3]
  - expected output: result is 6
  - write the test as: `sum([1, 2, 3]) == 6`

- Example test for **sqrt**:
  - input: 3.14
  - expected output: result is within 0.00001 of 1.772
  - ways to write the test:
    - `sqrt(3.14) - 1.772 < 0.00001` and `sqrt(3.14) - 1.772 > -0.00001`
    - `-0.00001 < sqrt(3.14) - 1.772 < 0.00001`
    - `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:
  
  ```python
  assert sum([1, 2, 3]) == 6
  assert math.abs(sqrt(3.14) - 1.772) < 0.00001
  ```

• 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):
      ... body of hypotenuse ...
  assert hypotenuse(3, 4) == 5  # (As in HW 4)
  assert hypotenuse(5, 12) == 13
  ```

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

  (As in HW 3 and HW5)
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., in local variable, or 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 of expected type/size/value/shape?
  – 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 need to 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
• It’s best to write tests first

• If you write the code first, you remember the implementation while writing the tests
  – You are likely to make the same mistakes that you made in the implementation (e.g. assuming that negative values would never be present)
• 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, some special case of input that you would have forgotten to handle
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 expected output – BAD!!

• You didn’t write a full test: only half of a test!
  – Created the tests inputs, but not the expected output

• 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
Tests outside of function body are for behavior described in the specification

def roots(a, b, c):
    """Returns a list of the two roots of ax**2 + bx + c."""

What is wrong with this test?

assert roots(1, 0, -1) == [-1, 1]

• Does the **specification** imply that this should be the **order** these two roots are returned?
• Assertions **inside** a routine can be used for implementation-specific behavior
Tests prevent you from introducing errors when you modify a function body

- **Abstraction**: the implementation details do not matter
- As long as the specification of the function remains the same, tests of the external behavior of the function should still apply.
- Preventing introducing errors when you make a change is called “regression testing”
Coming up with good test cases

• Think about and test “corner cases”
  – \( \text{abs}(\text{val}) \)
  – \( \text{find\_max}(\text{lst}) \)
Testing Approaches

• **Black box testing** - Choose test data *without* looking at implementation, just test behavior mentioned in the specification.

• **Glass box (white box, clear box) testing** - Choose test data *with* knowledge of implementation (e.g. test that all paths through your code are exercised and correct).
def isBigger(x, y):
    """ Assumes x and y are ints.
    Returns True if x is greater than y,
    and False otherwise.
    """

What to test?
Tests might not reveal an error

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, 2.1, 3.2]) == 2.1

This implementation is elegant, but wrong!

mean([1, 2, 3, 4])
Don’t write meaningless tests

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:
mean([1, 2, "hello"])
mean("hello")
mean([])
def isPrime(x):
    """Assumes x is a nonnegative int
    Returns True if x is prime; False otherwise"
    if x <= 2:
        return False
    for i in range(2, x):
        if x % i == 0:
            return False
    return True