Testing

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Testing

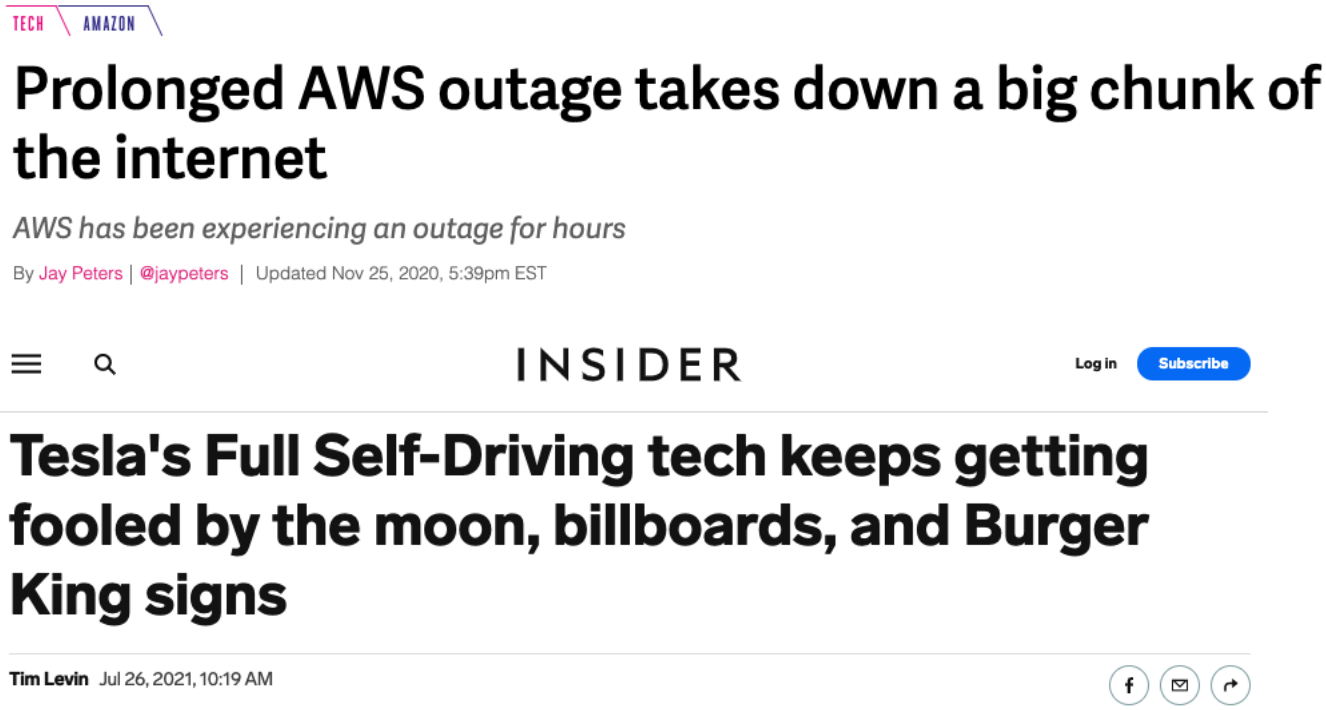
- Programming to analyze data is powerful
- It's useless (or worse!) if the results are not correct
- **Correctness is far more important than speed**

Famous examples

- Ariane 5 rocket (1996)
  - fault in the software in the inertial navigation system (link)

- Therac-25 radiation therapy machine (1986/1987)
  - Fatal overdose due to software bugs and no external controls (link)

More recent examples



TECH | AMAZON

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AWS has been experiencing an outage for hours

By Jay Peters | @jaypeters | Updated Nov 25, 2020, 5:39pm EST

INSIDER

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Tim Levin Jul 26, 2021, 10:19 AM

Forbes

EDITORS' PICK | Oct 5, 2021, 09:09pm EDT | 3,285 views

Facebook Says A Bug In A Software Audit Tool Triggered Yesterday's Mega Outage

Testing does not *prove* correctness

> *"Program testing can be used to show the presence of bugs, but never to show their absence!"*
>
> - Edsger Dijkstra

- Testing can only increase our confidence in program correctness.
- Exhaustive testing (e.g. testing all possible inputs) is generally not possible
- Instead we have to be smart about testing

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 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, HW3 & HW4 with small data sets

Testing parts of your program

- Often called “unit testing”
- Testing that the output of individual functions is correct.

How to write a test

- An example test for **`sum`**:

```
assert sum([1, 2, 3]) == 6
```

Call the function

How to write a test

- An example test for **`sum`**:

```
assert sum([1, 2, 3]) == 6
```

Input (sometimes called “test data”)

- Input should be simple, easy to calculate the expected output by hand

How to write a test

- An example test for **`sum`**:

```
assert sum([1, 2, 3]) == 6
```

Expected output

How to write a test

- An example test for **`sum`**:

```
assert sum([1, 2, 3]) == 6
```

Ask Python to do
the check for us

- **`assert True`** does nothing
- **`assert False`** crashes the program
  - and prints a message

How to write a test

- An example test for **`sqrt`**:

```
assert sqrt(2) == 1.41421356237…
```

- Is this a proper way to test this function?

How to write a test

- An example test for **`sqrt`**:

```
assert sqrt(2) == 1.41421356237…
```

```
assert math.abs(sqrt(2) - 1.414) < 0.001
```

- Be careful about floating point comparison!
  - See example from lecture

How to write a good test suite

- Test suite: a collection of test cases used to test a program
- Property:
  - Good coverage of **input space**
  - Good coverage of **code execution** (do not always know what the code is beforehand)
  - Address **boundary cases**

Example (input space coverage)

```
def abs(x):
    """
    Takes in an integer x and returns the absolute
    value of that integer.
    """
        if x > 0:
                return x
        else:
                return -x
```

What are the possible categories of values **x** can take?

x > 0, x < 0, or x = 0

Example (code coverage)

```
def abs(x):
    """
    Takes in an integer x and returns the absolute
    value of that integer.
    """
        if x > 0:
                return x
        else:
                return -x
```

What are the possible paths to go through this function?

Example (code coverage)

```
def abs(x):
    """
    Takes in an integer x and returns the absolute
    value of that integer.
    """
        if x > 0:
                return x
        else:
                return -x

assert abs(5) == 5
```

Example (code coverage)

```
def abs(x):
    """
    Takes in an integer x and returns the absolute
    value of that integer.
    """
        if x > 0:
                return x
        else:
                return -x

assert abs(-2) == 2
```

Example (code coverage)

```
def abs(x):
    """
    Takes in an integer x and returns the absolute
    value of that integer.
    """
        if x > 0:
                return x
        else:
                return -x

assert abs(5) == 5
assert abs(-2) == 2
```

Example (code coverage)

```
def abs(x):
    """
    Takes in an integer x and returns the absolute
    value of that integer.
    """
        if x > 1:
            return x
        else:
            return -x
```


```
assert abs(5) == 5  # pass
assert abs(-2) == 2  # pass
```

100% code coverage, but **`abs(1)`** won't produce the right output!

Example (boundary cases)

```
def abs(x):
    """
    Takes in an integer x and returns the absolute
    value of that integer.
    """
        if x > 0:
                return x
        else:
                return -x
```

What are the possible boundary cases to test?

```
assert abs(0) == 0
```

Coming up with good test cases

- Think about and test “corner cases”
  - Numbers:
    - int vs. float values (remember not to test for equality with floats)
    - Zero
    - Negative values
  - Lists:
    - Empty list
    - Lists containing duplicate values (including all the same value)
    - Lists in ascending order/descending order
    - Mix of types in list (if specification does not rule out)

How to write a good test suite

- Test suite: a collection of test cases used to test a program
- Property:
  - Good coverage of **input space**
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Another example (discussion)

```
def find_max(lst):
    """
    Takes in a list of integers lst and
    returns the maximum value in the list. If
    the list is empty, return None.
    """
```

Testing approaches

- **Black box testing** - Choose test data ***without*** looking at the implementation, just test behavior mentioned in the specification (or doc-string)

- **Glass box** (white box, clear box) **testing** -Choose test data ***with*** knowledge of the implementation. Test that all paths through your code are exercised and correct. Examples:
  - If statement with several elifs, make sure your test cases will execute all branches
  - For loop, test if it is executed never, once, >1, max times

Tests prevent you from introducing errors when you modify a function body

- Regression testing
  - Whenever you find a bug (not from an existing test)
    - Add a new test case with the input that exposes the bug and the expected output to the test suite
    - Verify that the test suite fails
    - Fix the bug
    - Verify the fix
  - Do NOT remove tests - protects against reintroducing the same bug later

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 (confirmation bias!)
  - You are likely to make the same mistakes that you made in the implementation (e.g. assuming that negative values would never be present in a list of numbers)
- 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

Where to write test cases

- At the **top level**: is run every time you load your program

```
def hypotenuse(a, b):
    … body of hypotenuse …
assert hypotenuse(3, 4) == 5
assert hypotenuse(5, 12) == 13
```

(As in HW 2)

- In a **test function**: is run when you invoke the function

```
def hypotenuse(a, b):
    … body of hypotenuse …
def test_hypotenuse():
    assert hypotenuse(3, 4) == 5
    assert hypotenuse(5, 12) == 13
# test_hypotenuse()
```

(As in HW 3 & 4)

What not to test

- Input types not described in the specification

```
def abs(a):
    """
    Takes in an integer and returns the absolute value
    of that integer.
    """
```

Example of unnecessary tests:

```
abs(0.01)
abs('hi')
abs([])
```

What not to test

- Function behaviors not described in the specification

```
def roots(a, b, c):
    """
    Returns a list of the two roots of ax**2 + bx + c = 0.
    """
```

What is wrong with this test?

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

The **specification** did not imply that this should be the *order* these two roots are returned.

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

It's HARD to write good tests!

- Requires:
  - Good understanding of specification and function behavior with different inputs
  - Overcoming confirmation bias (especially if you have already written the code)
    - Adopt an adversarial mindset

Assertions are not just for test cases

- Use assertions throughout your code
- Documents what you think is true about your algorithm
  - E.g., `assert 0 <= index < len(my_list)`
- 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:

```
for n in my_numbers:
  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

```
a = 5
assert a == 5  # Not needed!
```

- Don't need to write an assertion if the following code would fail informatively:

```
assert type(name) == str
print("Hello, " + name)
```

- Write assertions where they may be useful for debugging

Conclusion

- Testing doesn't prove correctness, only increase confidence in program correctness
- Writing a good test suite is hard, but can use heuristics including:
  - Good coverage of **input space**
  - Good coverage of **code execution** (not always known beforehand)
  - Address **boundary cases**
- Write tests before you write the code!
- Good tests help with debugging

Next step ☺

- Try adding more tests for your homework!
  - Only after you make sure you know what the function behavior should be, of course…
- Add more tests for the final exam!
  - Our provided tests won't cover all cases - up to you to read the specification carefully and add more tests!