Lecture Notes
September 24, 2020

Working in a team: *finding bugs*

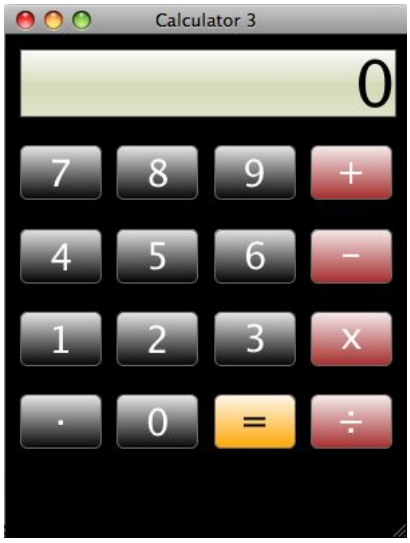
A large portion of this course is concerned with preventing, finding and fixing bugs, and defending against those you haven't yet found/fixed (security and reliability).

"Assignment I2"
https://courseworks2.columbia.edu/courses/104335/assignments/482608
focuses on finding bugs in your tic-tac-toe game, using both unit testing (JUnit) and a static analysis bug finder (SpotBugs). Both tools help find bugs in your code.

Bugs are not always in code. A bug could be in:

- Requirements
- Design
- Tests
- Documentation
- Configuration
- Environment
- User

Consider the following "bugs" in a simple calculator:



The tester enters a number, presses +, enters another number, presses =

- Nothing happens
- Computes the wrong answer

Calculator works correctly for some period of time or some number of computations, and then does nothing

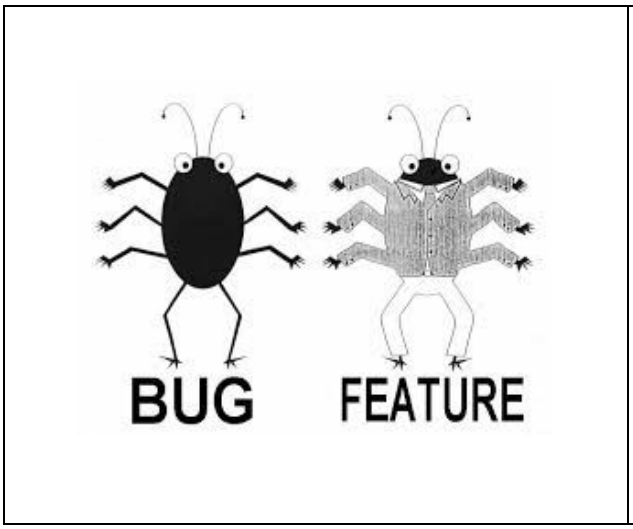
Calculator displays all 0’s and won’t do anything else

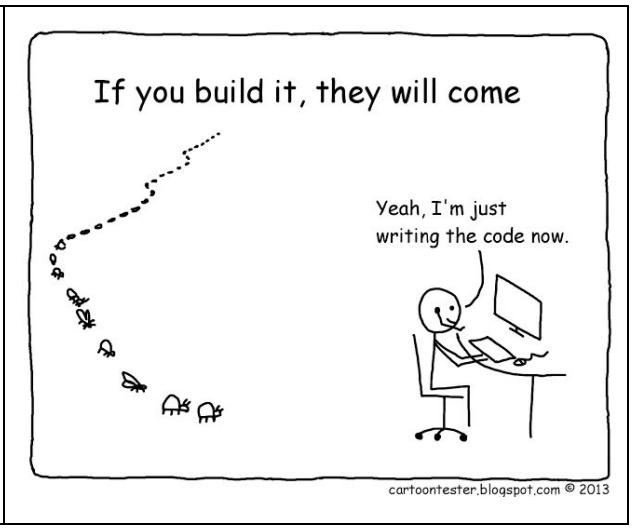
The calculator correctly adds, subtracts, multiplies and divides, but the tester found that if two operators are held down simultaneously, it appears to do square root

The calculator’s buttons are too small, the = key is in an odd place, the display is hard to read, ...

Broad concept of what is a bug:

- Software doesn’t do something requirements say it should do
- Software does something requirements say it shouldn’t do
- Software does something that requirements don’t mention
- Software doesn’t do something that requirements don’t mention but should
- Software is difficult to understand, hard to use, slow, etc. - users will consider this a bug





Many bugs can be found by *static analysis*, which examines the code to find “generic” bugs and suspicious code patterns that appear in many programs. The static analysis tool does not know what your program is supposed to do, so cannot tell if it’s doing it right.

Static analysis sometimes produces *false positives*, reporting bugs that could never happen during actual execution because it considers all paths through the program - which may not all be feasible at runtime

Is this a false positive or a real bug?

```
function foo (int x) {
    if (x<0) { do something buggy }
    else { do something not buggy }
}

function bar (int y) {
    if (y<0) return;
    foo(y)
}
```

There are also “generic” *dynamic* analyzers that don’t know what your code is supposed to do but can still find some bugs - particularly crashing bugs

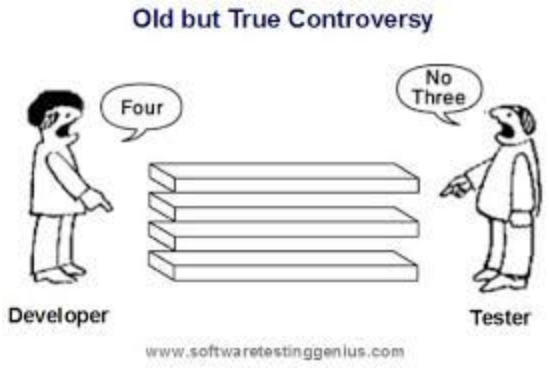
For example, fuzzing takes existing test cases and “fuzzes” the inputs with semi-random changes, seeking to produce inputs that are:

- structurally invalid
- structurally valid but semantically invalid

Both should be rejected by the application, via “input gatekeeper” code, but are often accepted (in itself a bug) and processed, which can trigger other bugs

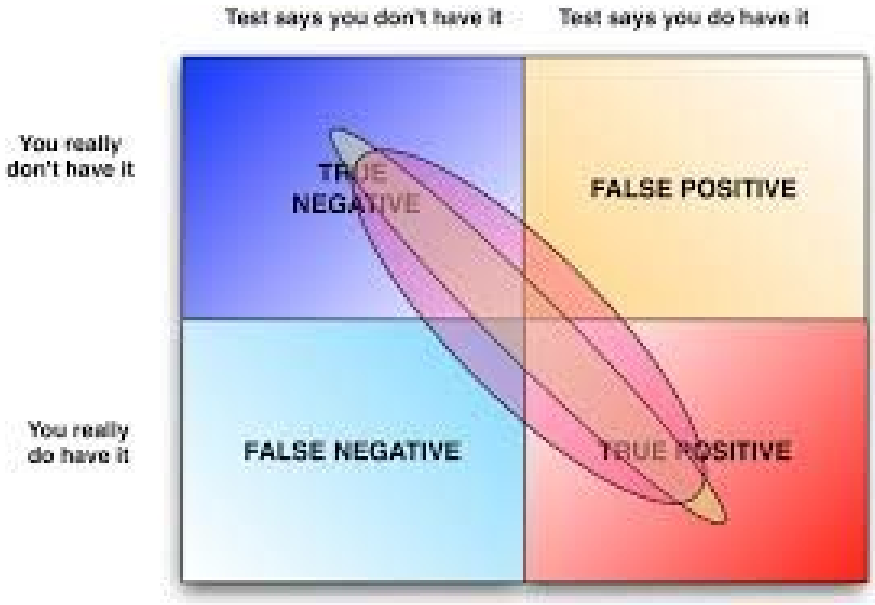
It is sometimes argued that the second case consists of false positives, because the invalid input would never have reached the internal code, beyond the gatekeeper, if it were not for the gatekeeper bug (*missing* code is a bug!)

To find application-specific bugs in your program, you also need to check the features, another form of dynamic analysis usually referred to as *software testing*



Bugs found during full program testing using valid inputs are never false positives, because not only *could* they happen during actual execution, they *did* happen

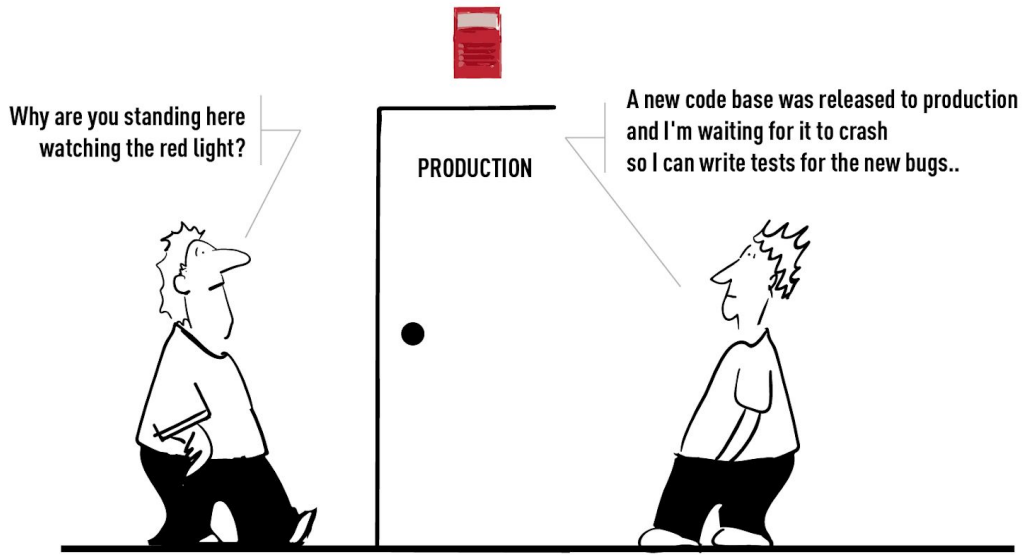
Both static and dynamic analysis exhibit *false negatives*, failing to report all bugs - there is no technique that can be guaranteed to find *all* bugs in a non-trivial program written in a conventional programming language. (Although it may be possible to prove certain properties.)



Test-to-pass: initial testing makes sure the software minimally works (“smoke test”)

Test-to-fail: most testing is trying to find bugs, so they can be fixed before deployment.

Much more expensive to fix a bug found by a user than to fix it before the user gets a chance to encounter it.



Functional testing: Checks that the code does what it is supposed to do - often divided into unit, integration, system testing

Non-functional testing: compatibility testing, performance testing, penetration and other security testing, fault injection, UI/UX testing, etc.

Unit testing - tests that individual methods, classes, modules, packages or other “units” do what they are supposed to do to fulfill their role in the design.

Unit tests aim to test a method or class *in isolation from the rest of the program*. They call the method, or a series of methods in the same class, from a test harness, not from the other code in the rest of the program.

When a unit itself would normally call other code or otherwise interact with the environment outside the unit, it instead calls stubs (state verification) or mocks (behavior verification). We will cover unit testing and stubs/mocks later in course.

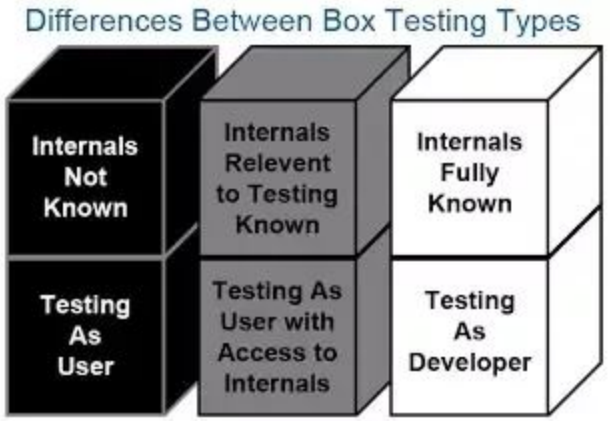
Integration testing - tests boundaries between “units”, to check that the units do what they are supposed to do to fulfill their role in the design. Usually integrate only two, or a few, units at a time. So now when a unit would normally call other code, it indeed calls code in the selected other unit(s), but still uses stubs or mocks for all other code.

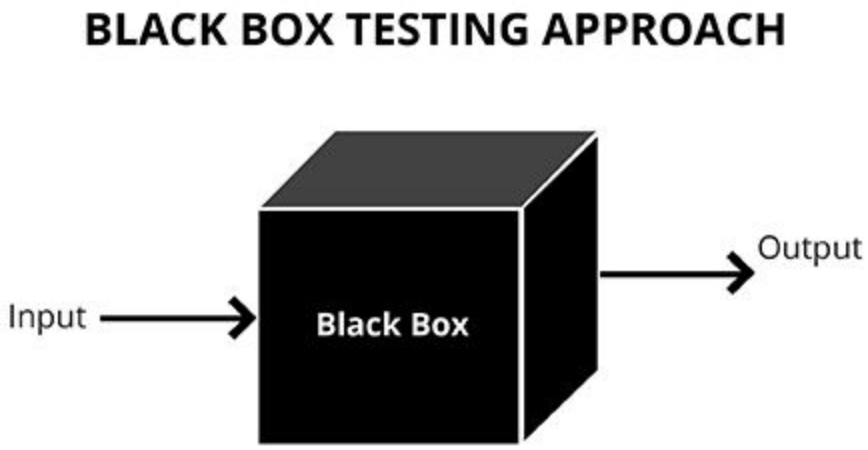
Integration testing may also refer to testing the full program’s interfaces to external libraries, systems, databases, etc.

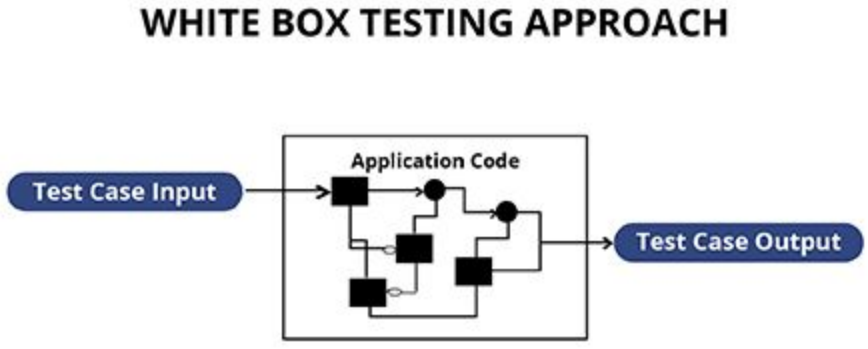
System testing - aka end-to-end testing, tests the full system from external user-visible entry points, to check that the code fulfills the customer’s requirements - often done by independent testers, not the developers.

Acceptance testing and beta testing are special cases of system testing.

Functional and some non-functional testing divided into black box vs. white box testing, often also grey box







Black box - tester considers what the box is supposed to do, not how it does it, doesn't look inside the box

For example, for unit testing, the box might be a method. The tester provides input parameters and checks the outputs - the method might contain one line of code or might invoke a complicated graph of method calls, doesn't matter for black box testing.

For integration testing, the tester considers two or more boxes and the possible communication paths between them - providing inputs and checking outputs on those paths

For system testing, the box is the full program. The tester provides external inputs and checks the externally visible outputs.

External inputs include error messages. Error messages (or lack thereof) are typically the last thing developers think about but the first thing users notice when software does not work as users expected.

White box - tester leverages full knowledge of what is inside the box.

Unit testing is often implicitly white box, since typically done by the same developers who coded the box.

White box is necessary to achieve *coverage* - track what code has and has not already been exercised by previous tests, then construct additional test inputs specifically to force execution of previously unexercised code

➢Coverage cannot detect *missing* code

Gray box (or grey box) - tester looks at intermediate products between boxes (e.g., network I/O) and leftover side-effects after box is done executing (e.g., temporary files, database connections left open)

For all blackbox and whitebox test cases, check any error status, exceptions, logs, etc. produced by one box that are visible to other boxes or to human users (or administrators) and external systems.

All these forms of testing will be discussed more deeply later in course.

“Assignment I2”
https://courseworks2.columbia.edu/courses/104335/assignments/482608
Assignment 2 builds on Assignment 1. Please make sure you have completed Assignment 1 before starting this assignment. In addition to using unit testing (JUnit), coverage tracking (Emma), and a static analysis bug finder (SpotBugs) to identify bugs in your application, you need to fix the bugs!

Shirish will now give a second Eclipse tutorial, focused on what you need to do for Assignment 2.

There will be one more assignment for this individual project, to add persistent storage of an in-progress game, with one more corresponding tutorial.

“Assignment T0”: https://courseworks2.columbia.edu/courses/104335/assignments/486855 This is the initial team assignment, to form a team and choose which programming language your team will use (C/C++, Java, Javascript, Python).

It’s not due until October 15, after the individual project and first assessment, but you should start forming teams.

There is a “search for teammates” thread in piazza that you can use to look for teammates https://courseworks2.columbia.edu/courses/104335/external_tools/1456