Testing Basics

Martin Kellogg

Testing Basics

Today's agenda:

- **Reading Quiz**
- What is testing?
- How to write tests
- Different kinds of tests and how to use them
- Continuous integration
- Test quality
- Test suite quality

Reading Quiz: Testing Basics

Get out a scrap of paper and write your name and UCID. You will have two minutes to answer two questions about the readings. The quiz will be scored out of 4: 2 points for your name/UCID (i.e., attendance) and 1 point for each correct answer.

NOTE: do **not** write a number starting with 31… (i.e., your student ID). You will not receive credit for the quiz if you do. Correctly writing your name looks like this:

Martin Kellogg (mjk76)

Reading Quiz: Testing Basics

Q1: **TRUE** or **FALSE**: test-driven development encourages you to write seemingly-trivial implementations of methods (e.g., a “count()” method that always returns the literal 0) quickly, just to get the tests running

Q2: SQLite maintains which of the following coverage metrics (select all that apply):

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B. 100% branch coverage

C. 100% condition (MC/DC) coverage

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Aside: testing is the canonical example of a ***dynamic analysis***, which is program analysis that requires running the program

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SUT **input** **output** **comparator** **oracle**

Building a test case

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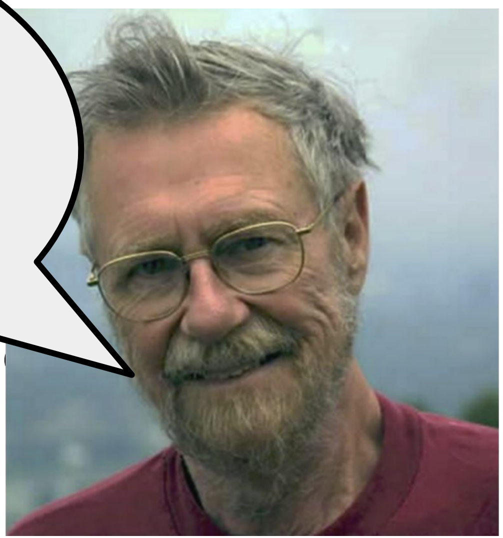
> "Tests can show the presence of bugs, but not their absence"



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We'll talk about these out of order:

- comparators
- oracles
- inputs

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Choosing a comparator is easy for programs that read and write text. For programs that e.g., have a GUI, this can be a very difficult problem.

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Don't do this!
Why not?

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- Choosing an oracle automatically is **very hard**
  - key problem in automated test generation
  - we’ll talk about this in more detail later

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Edge case examples:

- 0, 1, -1
- null
- empty list
- empty file
- etc.

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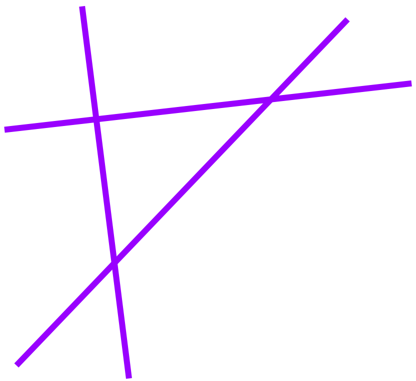

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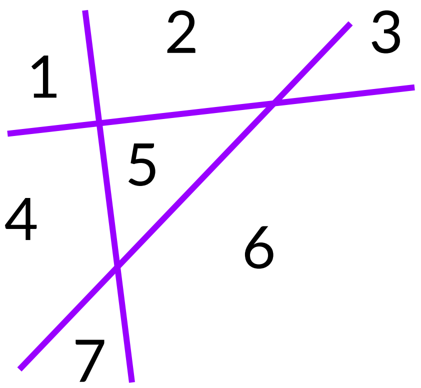

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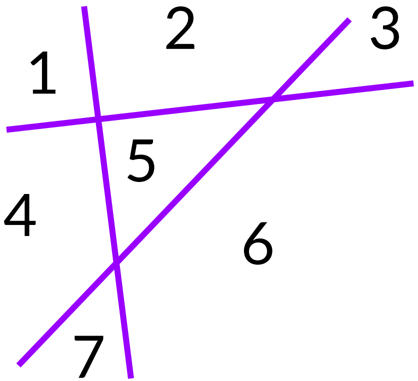

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  - parity (even, odd)
  - positive, negative, zero
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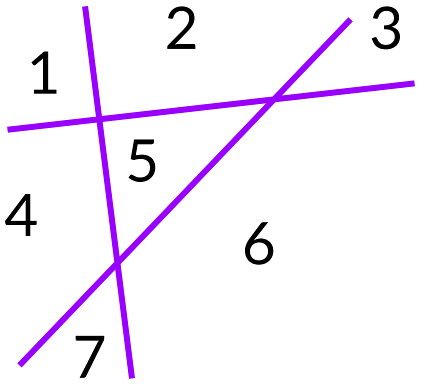
Common technique: split up input space k ways, write 2^k tests



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Disadvantages:

- you have to actually read the code
- easy to accidentally "bias" yourself towards what the code already does

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- key disadvantage vs white-box testing: you can't tell how well you're covering the implementation, only the specification
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- also common in practice: ***grey-box*** testing, which mixes the two styles

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Kinds of tests

Many ways to classify tests:

- by size: **how many resources** do the tests need?
- by scope: **what sort of thing** is the SUT?
- by purpose: **why** are we testing?
- by manner: **how** is testing performed?

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All valid ways to classify tests!

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We'll discuss the following important kinds of tests:

- **unit** tests
- **integration** tests
  - with a discussion of **mocking**
- **regression** tests

Kinds of tests: unit tests

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Collectively referred to as **xUnit** frameworks

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- Each test is run in a “fresh” environment
  - A **test fixture** specifies which code to run before/after the test case to setup/teardown the right environment

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- **Goal**: answer the question "Does our application work from start to finish?"
- Typically **combined with unit testing**: unit test individual components, then test that they integrate together properly

Kinds of tests: integration tests vs unit tests

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Answer: perspective!

Remember, all of computer science is based on **abstractions**. An integration test for layer *n* of a software stack might be a unit test for layer *n+1*

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This also promotes a modular, decoupled design

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Testing SUTs that are hard to test

What if we want to write unit or integration tests for some SUT, but the SUT has **expensive dependencies**?

Exercise: take two minutes and, in pairs, generate three examples of things that are hard to test because of their dependencies or other expense factors.

Mocking

Definition: ***Mock objects*** are simulated objects that mimic the behavior of real objects in controlled ways.

In testing, **mocking** uses a mock object to test the behavior of some other object.

- analogy: use a crash test dummy instead of real human to test automobiles

Mocking example: Web API Dependency

- Suppose we're writing a single-page web app
- The API we'll use (e.g., Speech to Text) hasn't been implemented yet or costs money to use
- We want to be able to write our frontend (website) code without waiting on the serverside developers to implement the API and without spending money each time
- What should we do?

Mocking example: Web API Dependency

- Solution: make our own “fake” (“mock”) implementation of the API
- For each method the API exposes, write a substitute for it that just returns some hardcoded data (or any other approximation)
    - Why does this work?

Mocking example: Error Handling

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- We'd like to apply the same strategy: write a fake version of the function ...
  - But that sounds difficult to do manually, because many functions would be impacted
  - Example: many functions use the disk

Mocking example: Error Handling

- Strategy one: **static** (= “before running the program”) mocking
  - Move all disk access to a wrapper API, use mocking there at that one point (coin flip fake error)
  - Combines modularity/encapsulation with mocking

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  - Combines modularity/encapsulation with mocking
- Strategy two: **dynamic** (= “while running the program”) mocking
  - While the program is executing, have it **rewrite itself** and replace its existing code with fake or mocked versions
  - this approach is common but has serious downsides, so let’s explore it in a little more detail

Dynamic mocking

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  - For one test, we could use a mocking library to force another line of code inside our target function to throw an exception when reached
- This feature is available in modern dynamic languages with reflection (Python, Java, etc.)
  - the Jest library used by Covey.Town supports this

Dynamic mocking library uses

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    - How would you do this with dynamic mocking?

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  - Exceptions are considered a side effect by mocking libraries
- Test locking in multithreaded code
  - e.g., force a thread to stall after acquiring a lock

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- Dynamic mocking **requires good integration tests**
    - If we mock dependencies, we need to be extra careful that our data structures play nicely together
- Dynamic mocking libraries have a **learning curve**
    - Many language-specific caveats, based on the implementation of the library
    - Error messages are often cryptic (modified program)

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- theory: **monotonically increasing** software quality
- **best practice**: when you fix a bug, add a test that specifically exposes that bug
  - that test is a regression test

How to use tests

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  - ***regression testing***
- as a **gatekeeper** to prevent breaking changes to the system
  - ***continuous integration***

Test driven development

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- **key idea**: using TDD **guarantees** that you have a test for each line of code that you write
- research shows that TDD **dramatically improves** software quality (as measured by defect density)
    - implication: **always use TDD** if possible

Test driven development: steps

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- “run your entire suite of tests and watch the new test fail”
- what if your new test ***doesn’t*** fail?
  - actually a very common problem!
  - when reporting a bug, this is why you should try to provide a failing test case

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1. “think of a test that will **force** you to add the next few lines of production code”
2. write the test and **observe** the test failure

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Common mistake: don't actually run the tests, just assume that your test will fail

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Don't worry too much about elegance - goal in step 3 is to get back to **working code**

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6. go back to step 1

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- edit the code
- test to make sure it works
- debug why it doesn't

Research shows that having a fast edit-test-debug cycle is critical for programmer productivity.

Advice: Try to avoid "test" steps of > 30 seconds.

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Advice: Try to **avoid** "test" steps of **> 10 seconds**.

Why does TDD improve code quality?

- every behavior has a **regression test** immediately
- fast **edit-test-debug cycle**
- code is **working most of the time** (TDD and Agile are closely related: almost all Agile methodologies advocate for TDD)

Testing Basics

Today’s agenda:

- Reading Quiz
- What is testing?
- How to write tests
- Different kinds of tests and how to use them
- **Continuous integration**
- Test quality
- Test suite quality

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A few slides ago, I mentioned that it's a good idea to avoid edit-test-debug cycles with > 10 second "test" steps

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- but what if your tests **take longer** than that to run?
- answer: move them from the developer's machine to a **continuous integration** server

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- use of CI is **practically mandatory** in industry
- **best practices**:
  - use CI for every project, even very small ones
  - all changes to a project should be gated by CI tests passing
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Advice: be very concerned about any project that:

- doesn’t have a CI setup
- doesn’t run all tests in CI
- lets CI builds regularly fail for long periods of time
  - a failing CI build is an **emergency**

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Aside: emergencies

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Why is a failing CI build considered an **emergency**?

- CI should block merging new code, so failing CI = no new code

Testing Basics

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- Reading Quiz
- What is testing?
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- Different kinds of tests and how to use them
- Continuous integration
- **Test quality**
- Test suite quality

Test quality: what makes a test good or bad?

Good	Bad

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Good	Bad

In-class exercise: with a partner, spend ~2 minutes making a list of factors that make a test "good" or "bad".

Test quality: what makes a test good or bad?

Good	Bad
• isolated (only tests one thing)	• brittle
• runs quickly	• slow
• strong oracle	• weak oracle
• hermetic	• redundant
• easy to understand	• hard to understand (“mystery”)
• deterministic	• non-deterministic (“flaky”)
• etc.	• etc.

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- avoid dependencies on the environment (e.g., software installed on the machine, environment variables, contents of other files, operating system behaviors, etc.)
- being hermetic is also important for builds generally (we’ll discuss more in our lecture on build systems later this semester)

Brittle tests

Definition: a ***brittle*** test fails for reasons unrelated to what it ostensibly tests

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- common causes:
  - not being hermetic
  - testing too much at once
  - comparator or oracle is too specific

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- commonly **co-occurs with brittleness**: test is brittle because it is too complicated, and when it fails it's not clear why
  - especially common for very large, end-to-end tests
- **best practice**: tests should give as much information as possible when they fail
  - **implication**: when writing tests, think about why they might fail in the future and document that in the test itself

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- are a **major problem in practice**
  - difficult to debug, so waste a lot of developer time
  - detecting them is an active research area

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Question: what makes one test suite **better or worse** than another?

- not just the sum of the "goodness" of all the individual tests!

Test suite quality: who cares?

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- sometimes, we may not even have enough resources to run all tests

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  - leads to ***mutation testing***, which we'll cover later this semester

Lens of Logic: a brief introduction to coverage

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- **Key Logical Observation**: If we **never test** line X then testing **cannot rule out** the presence of a bug on line X
- Example: if our test executes lines 1 and 2, but there is a bug on line 3, there is **no way** that our test will find the bug!

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foo(a):
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Test Suite { `foo(7), foo(4)` } has 100% line coverage and 100% branch coverage.

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- Statement and branch coverage are all you need for this week's homework assignment
  - but we will cover both in a lot more detail next week
- Next week we will also cover:
  - how to compute coverage
  - other kinds of coverage (e.g., path coverage)
  - advantages/disadvantages of various kinds of coverage

Using test suite quality metrics

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- This is especially true when using automated test generation tools
  - Which many produce many tests but **lower-quality** ones than humans would produce
  - A **big cost problem**!

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- **question**: how **hard** are these problems?
  - theory strikes again!
  - answer: it's "hard" (similar "traditional" problem that you might consider a reduction to: **knapsack**)

Aside: reductions

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Your CS education is incomplete until you have **reduced** one problem to another

- examples: reducing something to the halting problem to show that it is not computable; reducing something to satisfiability or knapsack to show that it is NP-hard
- should be covered in a theory of computation class (likely near the end of the semester)

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Reduction is a **powerful tool** for thinking about problems: it lets you solve difficult problems indirectly by re-using solutions for other, related problems.

Today’s in-class exercise

- That’s all we’ll cover today
- Our in-class exercise today will ask you to achieve high (statement and branch) coverage on a small program
  - I expect you to write tests by hand to do this
- You are welcome to work with a partner
- This assignment should be relatively easy
  - later assignments are harder!