Testing (Part 1/3)

Martin Kellogg

Testing (part 1)

Today's agenda:

- **Reading Quiz**
- What is testing?
- How to write tests
- Different kinds of tests and how to use them
- Continuous integration (or: why most of your tests should be automated)

Reading Quiz: testing (1)

Q1: **TRUE** or **FALSE**: The basic workflow of test-driven development (TDD) is to design your entire class first, then write all of its test methods, then write the code.

Q2: IP1 is based on a variant of TicTacToe originally proposed in a…

A. movie
B. TikTok video
C. blog post
D. webcomic

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Announcements:

- Make sure you can access Gradescope (easiest via Canvas)
- TA OH today in GITC 4403:
  - Nathan, 1:30-2:30pm
  - Tiffany, 5:30-6:30pm
- My OH cancelled this week (travel)
  - Make-up OH on 9/22, 9-10am

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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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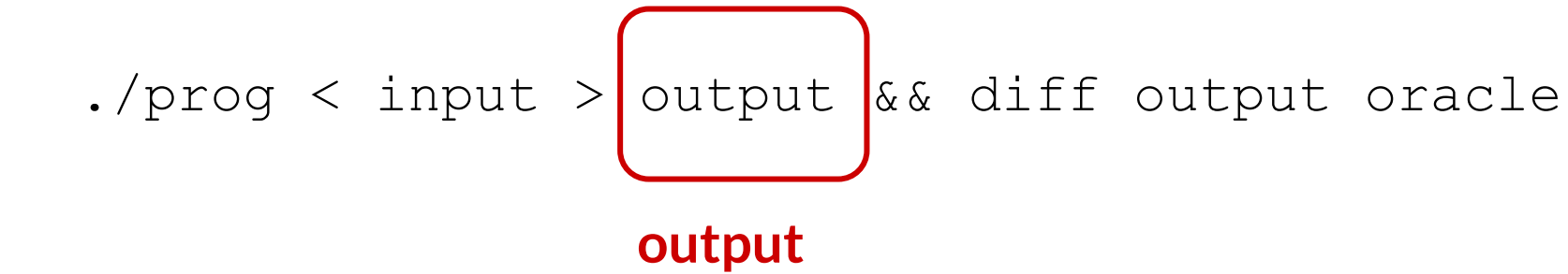

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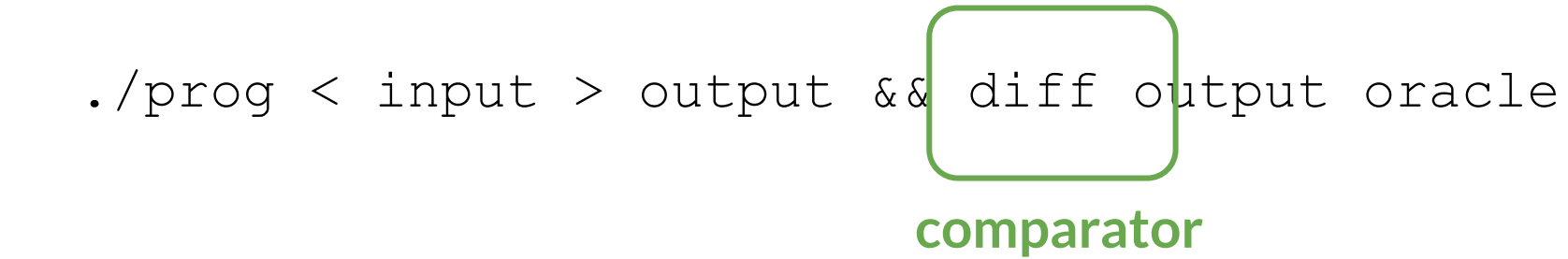

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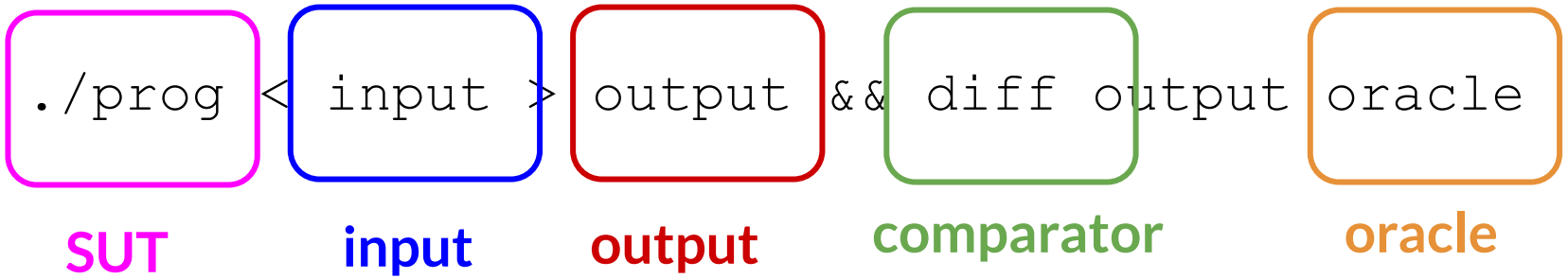

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- You usually know the SUT

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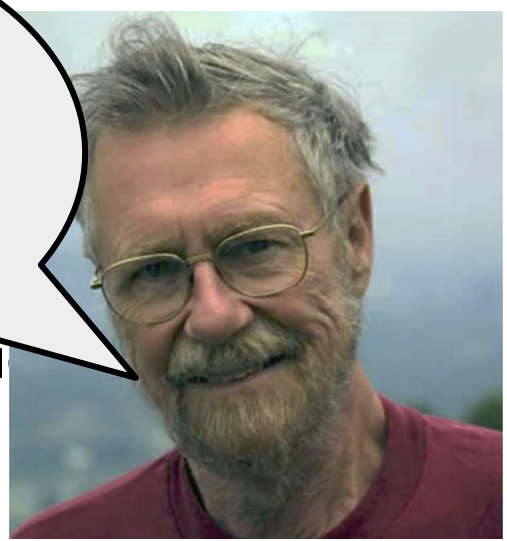

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We'll talk about these out of order:

- 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!

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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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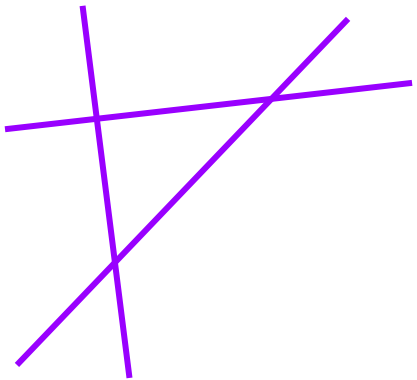

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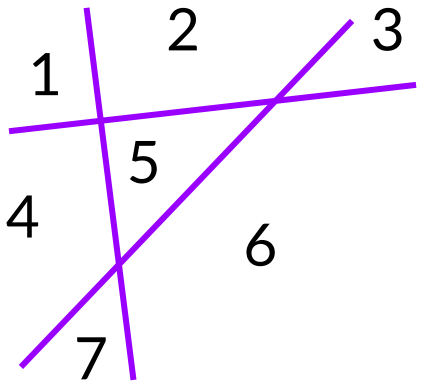

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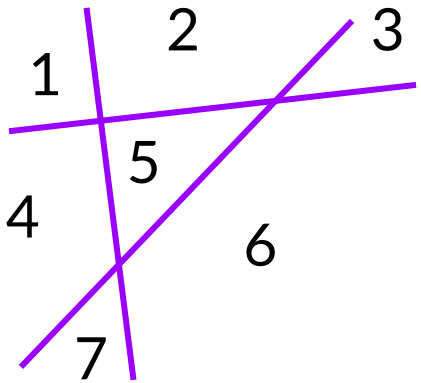

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  - positive, negative, zero
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  - correctly-formatted input vs incorrectly-formatted input

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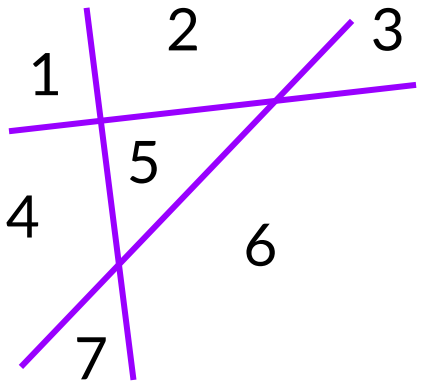
Common technique: split up input space k ways, write 2^k tests



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- 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

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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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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

Testing SUTs that are hard to test

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

Exercise: take one minute 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, an LLM, etc.) 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 server-side 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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- Suppose we're writing some code where certain kinds of errors will occur **sporadically once deployed**, but “never” in development
  - Out of memory, disk full, network down, etc.
- 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

Mocking example: Error Handling

- Strategy one: **static** (= “before running the program”) mocking
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- 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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- Some languages provide **dynamic mocking libraries** that allow you to substitute objects and functions at runtime
  - 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

- Track how many times a function was called and/or with what arguments (“***spying***”)
  - How would you do this with dynamic mocking?

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- 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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- prevents old bugs from being **reintroduced**
  - by you or someone else
- 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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- to **prevent** the recurrence of **past mistakes**
  - ***regression testing***
- as a **gatekeeper** to prevent breaking changes to the system
  - ***continuous integration***

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- research shows that TDD **dramatically improves** software quality (as measured by defect density)
  - implication: **always use TDD** if possible

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- research shows that T… quality (as measured b…
  - implication: **always use TDD** if possible

Analogy: TDD is like **double-entry bookkeeping** for software engineers, because everything is written down twice in two different ways.

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- “run your entire suite of tests and watch the new test fail”
- what if your new test ***doesn’t*** fail?

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requirement: the test must **fail** when first written!

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

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- code is **working most of the time** (TDD and Agile are closely related: almost all Agile methodologies advocate for TDD)

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  - we'll come back to this in the "Process" lecture

Testing (part 1)

Today's agenda:

- Reading Quiz
- What is testing?
- How to write tests
- Different kinds of tests and how to use them
- **Continuous integration** (or: why most of your tests should be automated)

Continuous integration

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

- but what if your tests **take longer** than that to run?

Continuous integration

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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

Continuous integration

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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
  - run all tests (and other quality checks) automatically in CI

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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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Takeaways

- A test is an input + a comparator + an oracle
- Use strategies like partition testing when writing test cases by hand
- Different kinds of tests serve different purposes
  - understand the difference between unit, integration tests
  - regression testing prevents bugs (especially when combined with TDD + CI)
- Use TDD + CI to improve software quality
- Next time: test suite quality and mutation testing