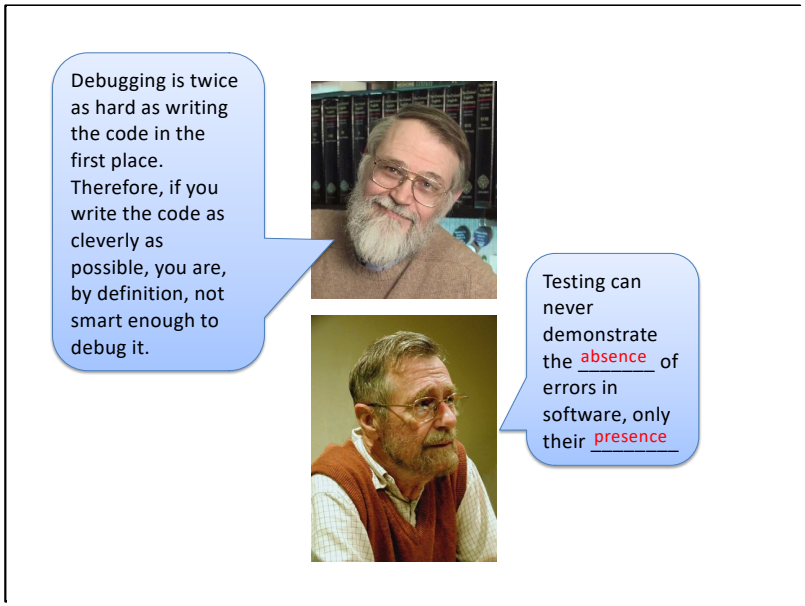


Turing Award winner Brian Kernighan, co-inventor of the C language
Turing Award winner Edsger Dijkstra

The heart of Dijkstra's message is that only formal methods that prove correctness can demonstrate the absence of bugs. But those tools only work in very limited scenarios (that aren't relevant to what we will be working on). Thus, for us, testing can't prove the negative, the absence of bugs, only show the presence of bugs. Thus, we want to try to write tests that are likely to expose possible bugs, i.e., the test both "happy" paths (working code) and "sad" paths (error scenarios), with particular attention to corner cases that are likely to reveal bugs.

Testing in an “agile” workflow

Plan & document (Waterfall, et al.)

- Developers finish code, do some ad-hoc testing
- Toss over the wall to Quality Assurance (QA)
- QA staff responsible for testing

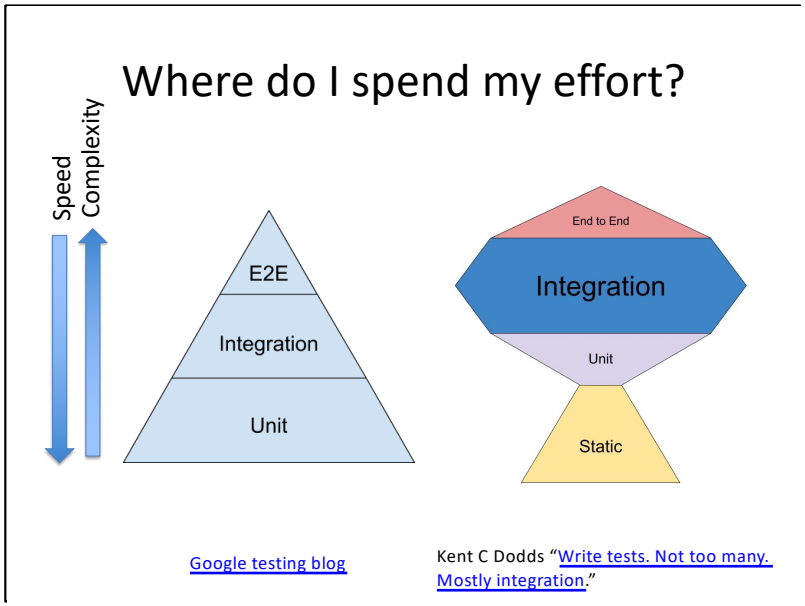
agile

- Testing is part of *every* agile iteration
- Developers test their own code
- Testing tools & processes are highly automated
- QA/testing group improves testability & tools

What do I mean by “ad hoc” testing — it is the kind of testing we all do (myself included!)... You try a couple of examples and when it doesn’t blow up, you declare it working!

Hierarchy of testing (from “high” to “low” level)

- **System (or end-to-end) testing:** Testing the entire application (typically to ensure compliance with the specifications, i.e., "acceptance" testing)
- **Integration testing:** Tests of combinations of units (i.e., integration of multiple units)
- **Unit testing:** Tests for isolated "units", e.g., a single function or object
- **Static testing (analysis):** Compile or build time testing/analysis



What are the advantage of unit tests (in the view of the Google authors)? Fast, Reliable, and Isolates failure (each unit test is focused on a small part of the code). The limitation is that the tests don't simulate a "real user".

Why the difference between the Google blog post and Dodds? Unit testing doesn't verify components work together. In a UI setting, for example, unit tests often verify that framework works as documented (click invokes handler) not that your application does the right thing in that handler.

"It doesn't matter if your button component calls the onClick handler if that handler doesn't make the right request with the right data! So, while having some unit tests to verify these pieces work in isolation isn't a bad thing, *it doesn't do you any good if you don't **also** verify that they work together."* -Kent Dodds

Test-driven development (TDD)

- Think about one thing the code *should* do
- Capture that thought in a test, which fails
- Write the simplest possible code that lets the test pass
- Refactor: DRY out commonality w/other tests
- Continue with next thing code should do

Red – Green – Refactor

Aim to "always have working code"

Recall our focus is on agile development methods, which are all about short development cycles that improve working (but not yet complete) code. To that end we will practice test-driven development in which we write the tests first, then implement the code that passes those tests (I suspect this is very different from the way you typically work...). We can think of this as a series of very short test-develop-refactor cycles.

How much testing is enough?

- Bad: “Until time to ship”
- A bit better: *X%* of coverage, i.e., 95% of code is exercised by tests
- Even better?

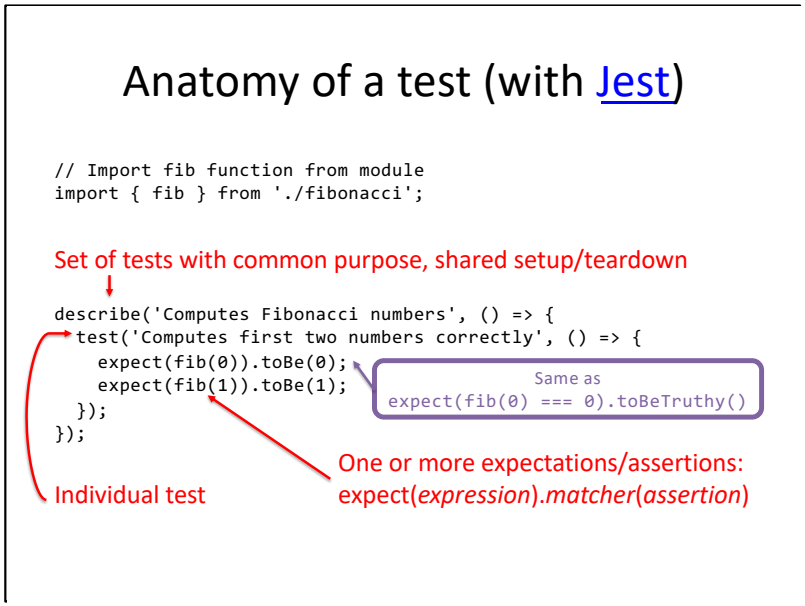
  “You rarely get bugs that escape into production, [and] you are rarely hesitant to change some code for fear it will cause production bugs.”

  –Martin Fowler

Coverage alone is limited measure of test quality. A high-quality test suite will likely have high coverage, but a high coverage test suite does not guarantee high quality. A key use for code coverage can be to help you find the portions of the code base that are not being tested. Testing is really about confidence, specifically building your confidence that the code works as intended and you didn't break anything as you made changes. Enough testing is the amount that creates that confidence for you.

Moderation in all things

- ✗ "I kicked the tires, it works"
- ✗ "Don't ship until 100% covered & green"
- ☑ Use coverage to identify untested or undertested parts of code
- ✗ "Focus on unit tests, they're more thorough"
- ✗ "Focus on integration tests, they're more realistic"
- ☑ Each finds bugs the other misses



In class we will use the Jest test tool (runner/assertions). This is one those one choice among many… Much like many programming languages have different syntax, but similar semantics (functions, conditionals), test frameworks tend to have similar features. We will try to highlight those aspects as we talk about Jest.

<click> Describe <click> containing individual tests <click> with one or more assertions

Note that this just the start of the tools available within Jest. Check out its documentation, with a particular eye to the many different matchers it provides. In general, we want to use the most specific matcher possible, i.e., expect(fib(0)).toBe(0) is preferred over expect((fib(0) === 0).toBeTruthy(). Why? The test is clearer (and thus easier to maintain) and we will get more informative error messages, i.e., that we didn't get the return value expected as opposed we didn't get the Boolean value we expected.

Tests should be F.I.R.S.T.

- **F**ast: Tests need to be fast since you will run them frequently
- **I**ndependent: No test should depend on another so any subset can run in any order
- **R**epeatable: Test should produce the same results every time, i.e., be deterministic
- **S**elf-checking: Test can automatically detect if passed, i.e., no manual inspection
- **T**imely: Test and code developed currently (or in TDD, test developed first)

Which of the following kinds of code can be tested *Repeatedly* and *Independently* (without additional tools)?

1. Code that relies on randomness (e.g., shuffling a deck of cards)
2. Code that relies on the time of day (e.g., run backups every Sunday at midnight)

A. Only 1

B. Only 2

C. Both

D. Neither

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Answer: D

Both kinds of code are not repeatable, since the random shuffle could be different each time and the backup test would depend on the current day of the week when testing. Both would require some form of mocking (replacing code during testing) to make the random number generator deterministic and control the "current" day of the week.

How would you test this function?

```
const isBirthday = function(birthday){
    const today = new Date();
    return today.getDate() === birthday.getDate()
        && today.getMonth() === birthday.getMonth();
}

test("Test if this works on the birthday",()=>{
    const birthday = new Date('August 15 1999');
    const today = new Date('2022-08-15T12:00:00');
    jest.spyOn(global, 'Date')
        .mockImplementation(()=> today);
    expect(isBirthday(birthday)).toBeTruthy();
    jest.restoreAllMocks();
});
```

Jest "spies on" the global `Date` object's constructor and replaces it with our preset date.

What is tricky here? Repeatability. We would could get different results on the different days. How could make it repeatable? Try to work "relatively", i.e., define the inputs in terms of today. But limits how we can construct our tests and could be trick in its own right!. Alternately, we can control today's date by replacing Date with a mock implementation with a known, repeatable, value. <click>

Mock functions allow us to control the return value (and assert it was called with specific arguments, etc.)

Does just creating the mock make our tests F.I.R.S.T.? No, it gets us part of the way there. The mock makes the test repeatable, while invoking `restoreAllMocks`, which resets spies, like the Date constructor, back to their original value, make his test independent (or more precisely other tests independent of this one).

What is missing from this test suite? Tests for days that aren't the birthday, i.e., when the function should return false.

An example of *seams*

Seam: A place where you can change an application's *behavior* without changing its *source code*.

- Useful for testing: *isolate* behavior of code from that of other code it depends on
- Here we use JS's flexible objects to create a seam for `Date()`
- Make sure to reset all mocks, etc. to ensure tests are **I**ndependent

Definition of seam from Michael Feathers in *Working Effectively With Legacy Code*

What is the **primary** benefit of mocking an external service (such as an API accessed via the Internet)?

A. Keeps each test “Independent” (from other tests)
B. Keeps tests “Fast” and “Repeatable”
C. Tests can be written before the code
D. Tests can be “Self checking”

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Answer: B (although A is arguable)

The primary benefit is to keep tests Fast and Repeatable. Fast because they are not actually accessing the Internet and Repeatable because the tests are not dependent on the current state of an external service (that may not be under your control). Simply creating mocks does not automatically make tests independent. As we saw before, you need to make sure the mocks are created in a way (e.g., initialized for each test and ”cleaned up” afterwards) that ensures tests are independent.

Seams, not just after-the-fact

Development is an iterative process

- Work from the “outside in” to identify code “collaborators”
- Implement “the code you wish you had” at seam
- Efficiently test out the desired interface

One of the roles for seams is to decouple development of different portions of the application.

Example, what if we wanted search functionality…

- Who would collaborate to provide that search (mock a search function on a server)
- Test the “happy path” with search results, and the “sad path” without

Suite lifecycle methods for independence, repeatability…

```
describe('My test suite', () => {
  beforeAll(() => {
    // Run once before all tests
  });
  afterAll(() => {
    // Run once after all tests
  });
  beforeEach(() => {
    // Run before each test
  });
  afterEach(() =>
    // Run after each test
  });
  describe('Nested test suite', () => {
    // Nested lifecycle methods
  });
});
```

"One-time" setup & teardown

"Repeating" setup & teardown

Within a test suite Jest provides methods for different types of setup and teardown. How might you use these? If you find yourself performing the same setup in multiple tests, that is a sign to pull it out to a shared setup/teardown function. For example, you might use beforeEach and afterEach to configure and reset mocks used in the tests. When we start using databases, we will frequently use beforeAll to initialize the database (since it only needs to happen once) and beforeEach to set/reset the data therein to a known state.

The suites execute setup/teardown in nested order, i.e., you can nest these functions.

More generally this an example of functionality that (most) every testing tool has. The naming, etc. might be slightly different, but should be able to expect similar capabilities.

Student advice: TDD & Testing

- "TDD is hard at first, but it gets easier"
- "Was great for quickly noticing bugs [regression] and made them easy to fix"
- "Helped me organize my thoughts as well as my code" [the code you wish you had]
- "Wish we had committed to it earlier & more aggressively"
- "We didn't always test before pushing, and it caused a lot of pain"

Adapted from Berkeley CS169

Student advice: Test coverage, code quality

- "Good coverage gave us confidence we weren't breaking stuff when we deployed new code"
- "Felt great to get high grade from [coverage estimator]"
- "Pull-request model for constant code reviews made our code quality high"
- "Wish we had committed to TDD + coverage measurement earlier"

Adapted from Berkeley CS169

Despite good testing, debugging happens

To minimize the time to solution, take a "scientific" approach to debugging:

1. What did you expect to happen (be as specific as possible)?
2. What actually happened (again as specific as possible)?
3. Develop a hypothesis that could explain the discrepancy
4. Test your specific hypothesis (e.g., with `console.log`, the debugger)

1 & 2 aren't that different than writing tests!

One of the things I find most challenging about software development, generally, is the indeterminate time required for debugging. No amount of experience suddenly makes debugging predictable. You will have to spend the time (and often an unknown amount of time). But I want to distinguish between good time and bad time. This type of "scientific debugging" represents good time. You have a specific hypothesis of the problem and tests that you can use to confirm/falsify that hypothesis. When you no longer have a specific idea, when you are just making changes randomly, that is "bad time" where you have stopped being productive. That is a good moment to pause, do something else to clear your head and seek out help (in our case, Ed discussion board, drop-in hours, office hours, your classmates). Our assignments are not intended to be trivial, but they are also not intended to be slogs. Before you start, set an expected amount of time for yourself. When that time has elapsed evaluate if you are spending good time or bad time.

Another way of thinking about debugging: 9 rules…

1. Understand the system
2. Make it fail
3. Quit thinking and look
4. Divide and conquer
5. Change one thing at a time
6. Keep an audit trail
7. Check the plug
8. Get a fresh view
9. If you didn't fix it, it ain't fixed

debuggingrules.com

This has some overlap with our previous example, but steps "back" to offer a more general process. Some of these steps occur before we actually have, or more accurately actually find, bugs.

These are from the book "Debugging" by Dave Agans. He wrote: "You need a working knowledge of what the system is supposed to do, how it's designed, and, in some cases, why it was designed that way. If you don't understand some part of the system, that always seems to be where the problem is. (This is not just Murphy's Law; if you don't understand it when you design it, you're more likely to mess up.)" … "The essence of "Understand the System" is, "Read the manual." Contrary to my dad's comment, read it first—before all else fails."

That is start by looking at the documentation for the system, library, function, etc. you are going to use before you start using it. By doing so we can avoid bugs, and already have a mental checklist of potential causes before we start debugging.

A key step to debugging is making the problem appear repeatedly. Only by doing so can you observe the problem, identify the true cause and be confident you actually fixed the problem. #3 is a reminder to actually "visualize" the failure, e.g., via print statements, debugger, not just attempt to intuit the issue. In this sense this argues for a slightly different approach than implied before.

Agans, David J.. Debugging: The 9 Indispensable Rules for Finding Even the Most Elusive Software and Hardware Problems. HarperCollins Christian Publishing. Kindle Edition.

The R.A.S.P. method

- **R**ead the error message (*really* read it).
- **A**sk a colleague an *informed* question, not just "Why doesn't it work?".
- **S**earch using keywords from error, specific SW versions, etc..
- **P**ost on StackOverflow, Ed, etc. Everyone is busy, you will get better answers if you provide a Minimal, Complete and Verifiable example

When you fix a bug, make a test!

Or in keeping with TDD, once you identify the bug, make a test that exercises the bug (and thus fails), fix the bug and then verify that your test now passes.

You found a bug, what to do next?

"In-class" has a reminder feature. But it didn't work when I tried to post a multi-sentence reminder but did when I just use "test" as the message.

1. Hypothesis: There is an unintended limit on the string length
2. Build understanding: Reviewing documentation reveals string types have a default length of 255.
3. Create test to demonstrate error, e.g.,:

```
"This is a long description".repeat(100)
```

4. Visualize error: Observe saving a long reminder generates a "string too long" error
5. Revise types to allow variable length strings
6. Ensure tests are now passing!

What do you hypothesize the problem is, and how would you approach finding and fixing it?