A Scientist-Friendly Approach to Software Testing

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Introduction

What are we talking about today?

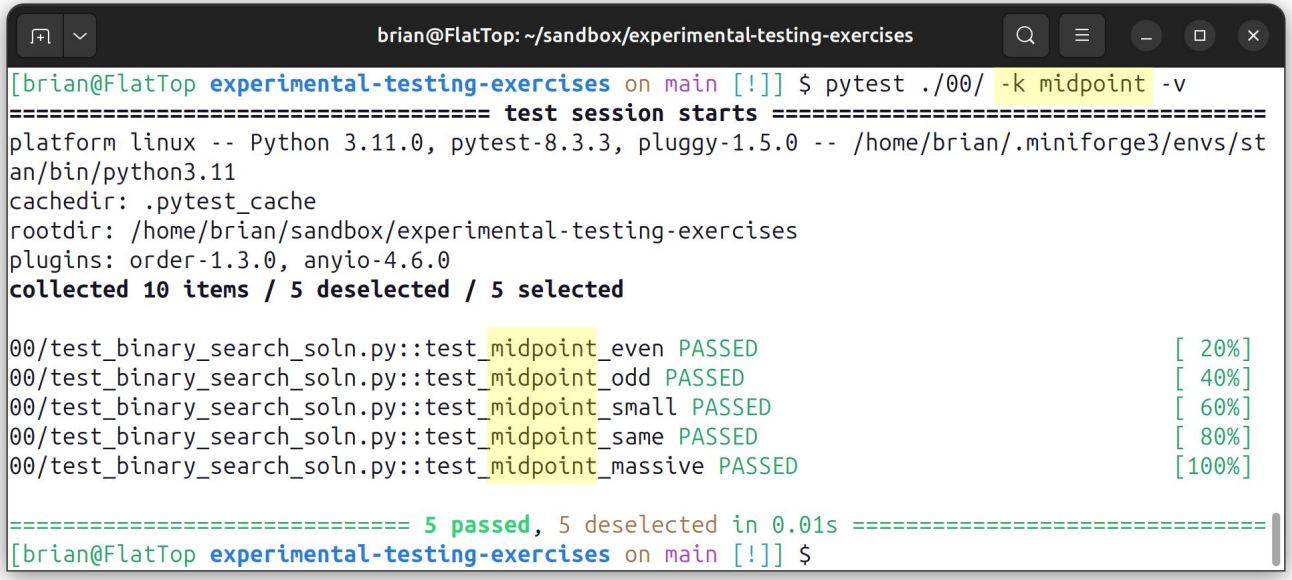
- Automated software tests
  - Regularly re-run (by machine)
  - Evaluated objectively (by machine)
  - Expected to work on all user deployments

    → ANYONE can run & interpret
- Reproducible, deterministic results
  - We do not want a reproducibility crisis in scientific software

STATUS	RUN	COMMIT	BRANCH
✓	441	–	master
✓	1	–	PR-1555
✓	440	cc00c23	master
✓	3	–	PR-1542
✗	2	1e43ad3	PR-1542
✓	439	4156b8e	master
✓	1	–	PR-1553

Automated testing frameworks

- Discovers and runs test functions
- Can help ensure **test isolation**
- Let you **select subsets** of tests to run
- Reporting features (coverage, xml, …)



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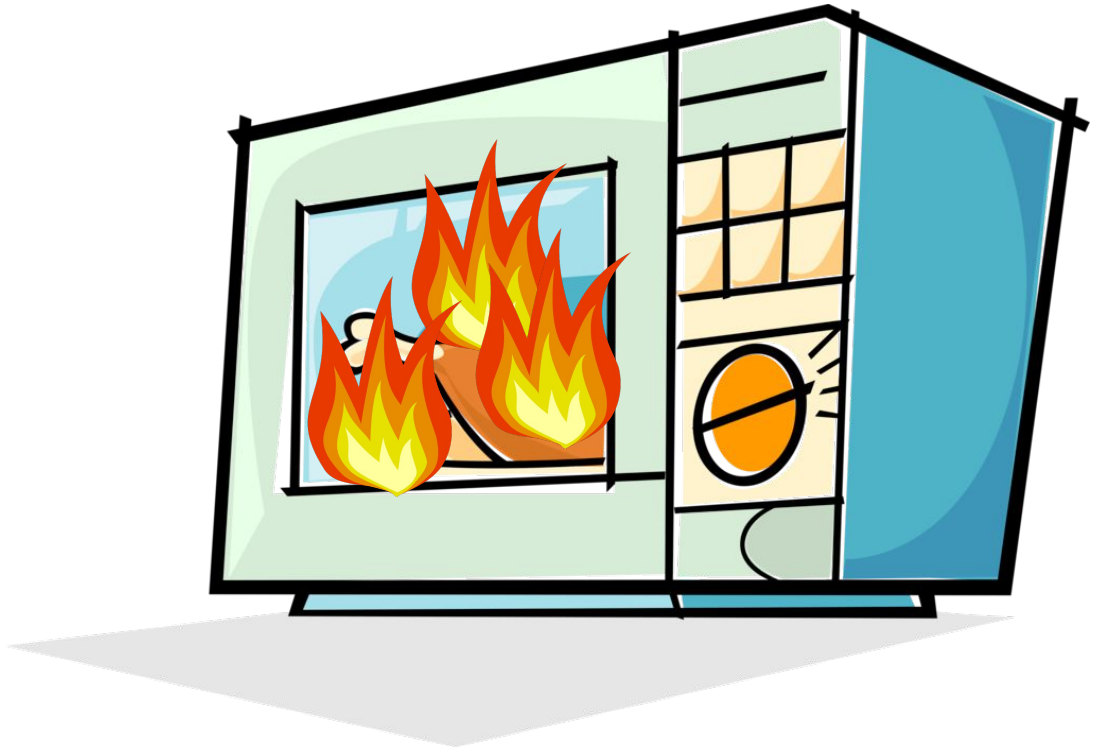
Scientific testing means treating tests as . . .

- **controlled experiments** that
- each **confirm one specific property** or **invariant** of
- the **code artifact** you are publishing

Test result must depend on **your code – a small part of your code – and nothing but your code**

Test your oven with a thermometer, not a turkey.

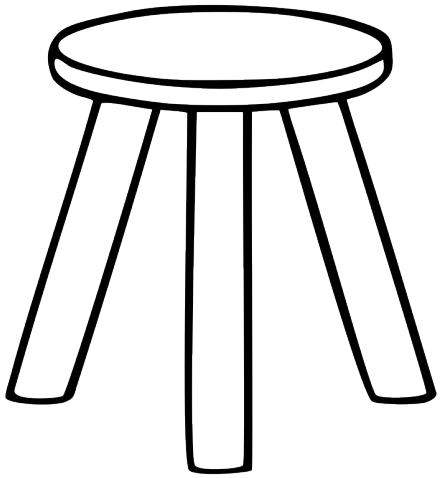


Scientific testing can

- Show **correctness** of our implementation
- **Localize** sources of error
- Increase confidence during **future code changes**
- **Document** code expectations/design choices

Three pillars of test suites

- Fast
- Trustworthy
- Specific



Honorable mention: maintainable
Implicit requirement: independent

What you need to follow along today

- https://github.com/flatironinstitute/sciware/tree/main/42_ScientificTesting
- If you're using Python, we recommend installing pytest
- If you want to use C++, we will provide links to the Compiler Explorer

Anatomy of a test

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What makes a test?

To do a test, you must:

- Set up the preconditions for the behavior you're testing
- Call the code whose behavior you're testing
- Compare the actual result with the expected result

Mnemonic is "arrange, act, assert"

…but the greatest of these is **assert**

Assertion libraries

```
1  #include <gtest/gtest.h>
2
3  TEST(fp, equality) {
4      EXPECT_EQ(0.1 + 0.2, 0.3);
5  }
6
7  TEST(fp, better_equality){
8      EXPECT_FLOAT_EQ(0.1 + 0.2, 0.3);
9  }
```

- You've only tested what you've **asserted**
- Good tools help you **zero in on discrepancies**
  - Expressive comparisons, error handlers, etc. let you make more precise assertions
- **Hypothesis testing tools** can help turn invariants into assertions automatically
- Gold/expect/`cram` testing can help ensure reliable output (but may be brittle)

```
[----------] 2 tests from fp
[ RUN      ] fp.equality
/app/example.cpp:4: Failure
Expected equality of these values:
  0.1 + 0.2
    Which is: 0.30000000000000004
  0.3

[  FAILED  ] fp.equality (0 ms)
[ RUN      ] fp.better_equality
[       OK ] fp.better_equality (0 ms)
```

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Let’s look at some tests

Follow along at
https://github.com/flatironinstitute/sciware/tree/main/42_ScientificTesting

Folder ‘`binary_search`’

Goals for tests

One test, one property

- Every test should test a specific, explicitly stated property of the code
- It should pass if, and only if, that property holds

Yes, this will lead to lots of tests!

This is not a problem so long as you keep them all fast.

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Controlled experiments

- Success or failure should depend **only** on the property under test
- Any **other** factors should be set to known values
- Systems not under test should be **omitted**
  - by use of fakes/stubs/mocks, monkey-patching, etc.

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Only test your code

- A useful test must **call the implementation**
  - It's common to write a slow/naive version of an algorithm for testing, but make sure you're comparing that to the *real* one at some point!
- There's little point to testing library code

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Three varieties of bad tests

Those that…

- Never fail (tautological, or fail to assert anything)
- Never pass (or: fail if you breathe on them)
- Might fail or pass on the same inputs

Also fishy: tests that take a huge amount of work to achieve control

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Assumptions and invariants

What to assert?

Universal invariants: confirming expectations

- Results of a (deterministic) computation
- Correct logical branch was taken
- Error states are handled appropriately
- Does your code ‘do nothing’ correctly?

By making assumptions **explicit,** tests act as a kind of documentation

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What to assert?

System invariants: interactions with external systems

- Did the file actually get written?
- Database call was correct?
- Handled unexpected response from system?

Requires **experimental control** (e.g. through fakes) and **test isolation**

What to assert?

Scientific invariants: domain-specific results

- Is energy conserved?
- Are results properly normalized?
- Do lists have the right length/shape, loops have right iterations, etc

Consider using **unrealistic inputs**

Test implementation, not methods

Implementation correctness is orthogonal to scientific correctness.

- Right result ≠ correct code
  - evaluated by summary statistic?
  - error tolerance too loose?
- Wrong result ≠ incorrect code
  - Newtonian simulator, relativistic problem

This is exactly why you need controls!

More code examples

https://github.com/flatironinstitute/sciware/tree/main/42_ScientificTesting
Folder ‘`file_writer`’

Gaining control

What is a control?

Removing influence of variables not under investigation

- In software tests, avoiding calls to code not under test
- Interpreted languages (Python): *mocking libraries*
- Compiled languages (C++): need to use *dependency injection*

Replace calls to outside libraries/expensive functions with observable substitutes

Why use controls?

- External resources (e.g. data downloads)
  - Unreliable (in uninteresting ways)
  - Costly to use for repeated testing
- Other parts of your code (e.g. file writing, computations)
  - Introduce stochasticity
  - Require cleanup
  - Slow
- Generating errors/rare states reliably

Consider: should it actually be user-facing?

Mocking in Python

`unittest.mock`

- `Mock` object
  - Replaces any functions or objects with minimal config
  - Can set function return values, side effects, errors thrown etc.
  - Tracks any calls made & what values were passed
- `patch` function
  - Replaces arbitrary code with `Mock` object
  - works as function decorator or context manager
  - syntax is idiosyncratic

Fakes in C++

Compiled: can’t replace code arbitrarily

- Dependency injection
  - Replace hard-coded calls with function parameters or templates
  - Use a controlled implementation for testing
  - Exposes flexibility for actual users of code too
- This can get messy if taken too far, it’s common to provide an overload with defaults for the user

These techniques can also be applied in interpreted languages!

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Experimenting on a *world you shape*

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The envy of every experimentalist

- You create the very world you experiment upon!
- Reshape interfaces to something more convenient
- Or keep the interface but update the implementation
- Use testability as a guide to writing better code

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Tests: beyond pass and fail

Code that's difficult to test is often also difficult to…

- Understand and reason about
- Explain and document
- Maintain & extend
- Actually use

Listen to your pain.

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Signs that things need to change

- Lots of setup/fakes/mocks needed to achieve experimental control
- Cleanup required after calling ordinary functions
- Tests need a lot of logic to match the right case
- Difficult to state the expected result of an operation
- Things work with fakes but not with real values

Responding to common issues

- *Control is hard* → the units are too big/too ambitious
- *Frequent cleanup* → isolate code with external effects
- *Test contains logic* → separate control-flow and operational code
- *Hard to describe results* → code unit is too ambitious
- *Test passes with fakes only* → Poor interface documentation; ought to have many more tests

Final code examples

https://github.com/flatironinstitute/sciware/tree/main/42_ScientificTesting
Folders ‘`histogram`’ and ‘`obfuscated`’

Conclusion

Tests are experiments

They should be:

- Controlled
- Focused
- Repeatable

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You have an advantage

- You usually control the system you're experimenting on
- Testability is highly correlated with other measures of code quality

Thank you

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Appendix: Helpful tools

Tools to help with testing

Coverage reporting

- Visual tool to see what definitely hasn't been tested
- Cannot say what you **meaningfully asserted**, only what you called
- **Not** a progress bar (despite appearances)
- Particularly useful for checking conditional branches

```
102
103 const loadSamplingOptsFromString = (
104   data: ProjectDataModel,
105   json: string,
106   clearExisting: boolean = false,
107 ): ProjectDataModel => {
108   const newSampling = parseSamplingOpts(json);
109   const newSamplingOptsMember = clearExisting
110     ? { ...newSampling }
111     : { ...data.samplingOpts, ...newSampling };
112   return { ...data, samplingOpts: newSamplingOptsMember };
113 };
```