

The background of the slide is a dark image with a collage of elements. On the left, there are snippets of Python code in various colors (green, yellow, red, blue) on a black background. Overlaid on this is a system of three linear equations in three variables, written in white. The equations are: $5x + 2y + z = 9$, $x - 4y - 3z = 1$, and $3x + 4z = -2$. To the right of these equations is a matrix equation $AX = B$. The matrix A is a 3x3 matrix with rows $[5, 2, 1]$, $[1, -4, -3]$, and $[3, 0, 4]$. The vector X is $\begin{bmatrix} x \\ y \\ z \end{bmatrix}$ and the vector B is $\begin{bmatrix} 9 \\ 1 \\ -2 \end{bmatrix}$. The text 'First, convert the system into equivalent matrix equation' is written in white, slanted text across the middle of the equations. The main title 'Testing software, and building Python packages' is in large, bold, black font on the right side of the slide.

Testing software, and building Python packages

Data Sciences Institute
University of Toronto

Simeon Wong

Previously at the DSI...

- Documenting your code
 - Writing Python docstrings in the numpy style
 - Generating documentation websites with sphinx
- Handling errors in Python
 - try / except
 - Raising your own exceptions
 - Raising exceptions vs. using assertions
 - Writing useful error messages
 - The python logging library

Course overview

1. Configuration files & Environment variables
2. Using and writing Application Programming Interfaces (APIs)
3. Handling errors
- 4. Testing software**
- 5. Building Python packages**
6. Working in software teams using GitHub features

Daily scrum

Write in the chat:

1. How you'll use one thing you've learned so far
2. One thing you're struggling with / wish the course addressed
3. What you're looking forward to in this course

Asking questions

- Zoom chat during class
 - Feel free to post and answer questions at any time
 - I will pause for questions occasionally, and review questions from the chat
- Pre- / Post-class office hours with Tong
- Email
 - simeonm.wong@mail.utoronto.ca
 - tong.su@mail.utoronto.ca

Assessments

- Outcomes-based learning
 - > 75% of course outcomes
- Assessed with both in-class exercises and summative project
- Summative project:
 - The next 4 classes build on each other
 - We will work on the summative project step-by-step through each class

Today's learning outcomes

- I can explain the importance of testing code
- I can write unit tests and integration tests using `pytest`
- I can run `pytest` from the command line and calculate code coverage
- I can write a basic `setup.py` configuration file for `setuptools`
- I can install a package from GitHub using `pip`

Testing software

Why are tests an integral part of coding?

A large-scale study on research code quality and execution

Ana Trisovic,¹ Matthew K. Lau,² Thomas Pasquier,³ and Mercè Crosas¹

► Author information ► Article notes ► Copyright and License information ► [PMC Disclaimer](#)

Associated Data

► Data Citations

► Data Availability Statement

Abstract

This article presents a study on the replication datasets at the Harvard group of scientists and published to and reproducibility. For this study, we define ten questions to address aspects impacting research reproducibility and reuse. First, we retrieve and analyze more than 2000 replication datasets with over 9000 unique R files published from 2010 to 2020. Second, we execute the code in a clean runtime environment to assess its ease of reuse. Common coding errors were identified, and some of them were solved with automatic code cleaning to aid code execution. We find that 74% of R files failed to complete without error in the initial execution, while 56% failed when code cleaning was applied, showing that many errors can be prevented with good coding practices. We also analyze the replication datasets from journals' collections and discuss the impact of the journal policy strictness on the code re-execution rate. Finally, based on our results, we propose a set of recommendations for code dissemination aimed at researchers, journals, and repositories.

Subject terms: Research data, Software, Information technology

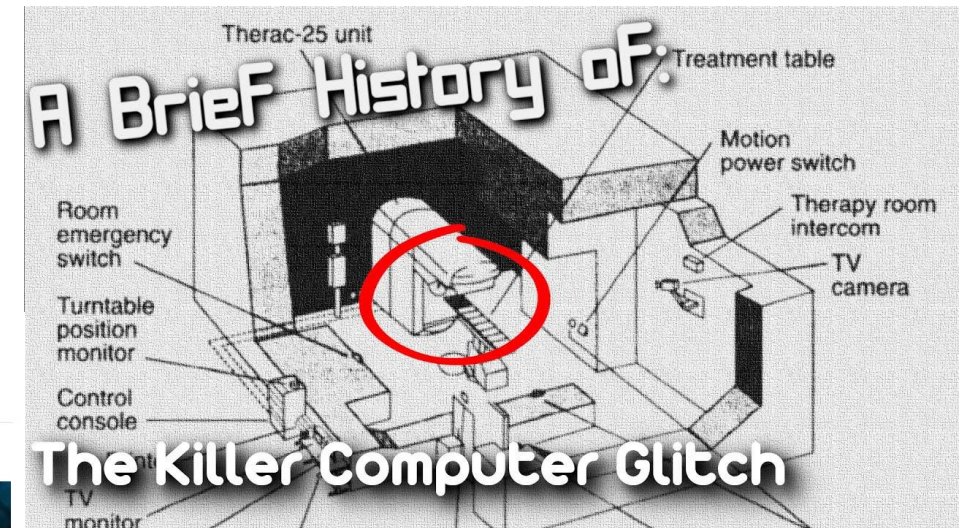
Introduction

Go to: ►

Knight Capital Says Trading Glitch Cost It \$440 Million

BY NATHANIEL POPPER AUGUST 2, 2012 9:07 AM 356

Runaway Trades Spread Turmoil Across Wall St.



Plainly Difficult

The New York Times

Boeing Starliner Flight's Flaws Show 'Fundamental Problem,' NASA Says

A software glitch that could have destroyed the capsule was fixed in orbit, during an uncrewed December test flight that had already gone awry.

Why are tests an integral part of coding?

- We should **always consider** how the code needs to be tested when writing it
 - Impact and risk (code authority) vs. cost of testing
 - When using `rm *.txt`, it's easy to double-check for typos and run `ls *.txt` first
 - It's probably not worth writing an entire testing program with SOPs
 - Using `ls *.txt` is very low risk, so might decide to run first and check that way
 - Which parts of the code need more focus?
 - What are edge/unexpected cases that the code might need to handle?
 - Testing the code's ability to gracefully and accurately handle errors

Testing software

Testing as part of coding process

Two common paradigms for testing

1. Test-driven development
2. Checking-driven development

Test-driven development

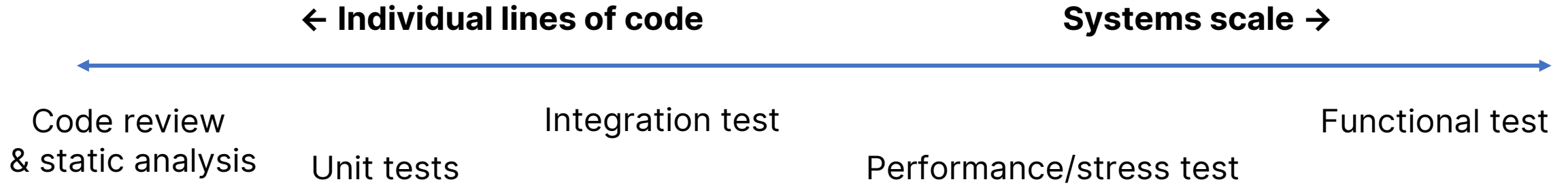
- Rather than writing code and then writing tests, we write tests first and then write just enough code to make them pass
- Advocates claim that it leads to better code because:
 - Writing tests clarifies what the code is supposed to do.
 - It eliminates confirmation bias.
 - If someone has just written a function, they are predisposed to want it to be right, so they will bias their tests towards proving that it is correct instead of trying to uncover errors.
 - Writing tests first ensures that they get written.

Checking-driven development

- Writing just a few lines of code and testing it before moving on rather than writing several pages of code and then spending hours on testing
- For example: every time we add a step to our pipeline
 - Look at its output
 - Write a test or check of some kind to the pipeline
 - Ensure that what we are checking remains true if it were run on other data or if the pipeline evolves

Testing software

Some types of software testing



Other types of testing:

- Security tests
- Usability tests
- Acceptance tests

Tests get more expensive when hardware / systems / humans are in-the-loop

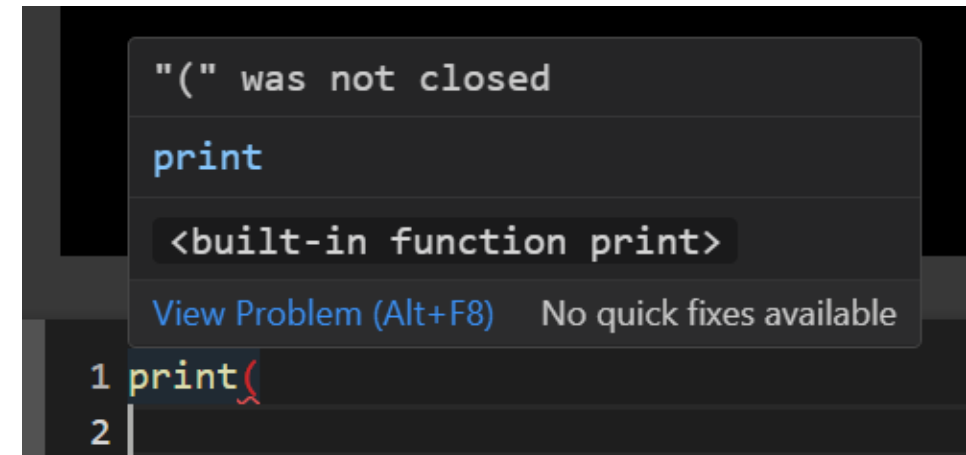
All these tests are part of a comprehensive quality strategy

What questions do we have?

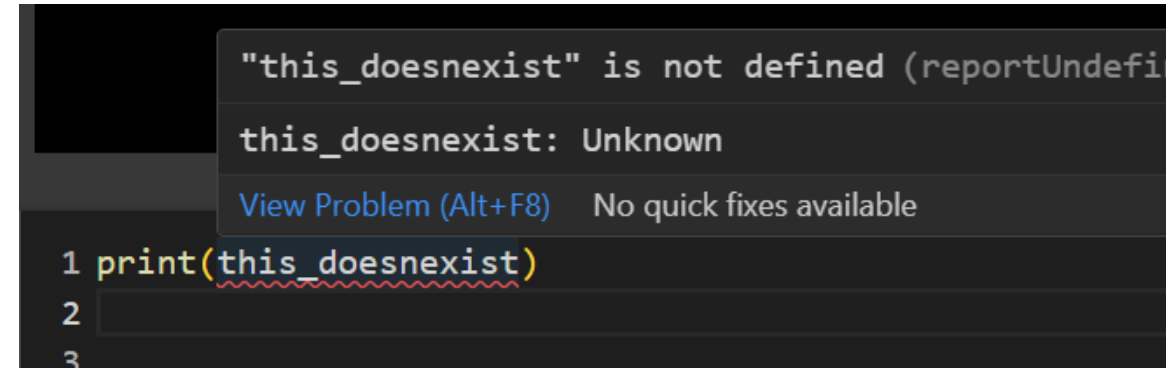
Testing software

Static analysis

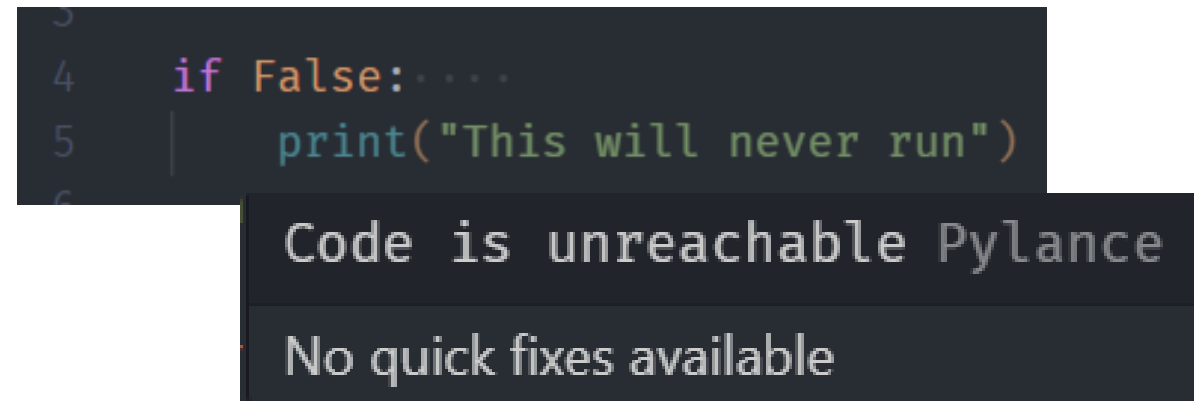
- Like spell check, but for code
- Catches some common mistakes
 - Use before declare
 - Variable type issues
 - Syntax errors
- Common analysis engines:
 - Python: pylance, pyflake
 - Bash: shellcheck



```
(" was not closed  
print  
<built-in function print>  
View Problem (Alt+F8) No quick fixes available  
1 print(  
2 |
```



```
"this_doesnexist" is not defined (reportUndefinedVariable)  
this_doesnexist: Unknown  
View Problem (Alt+F8) No quick fixes available  
1 print(this_doesnexist)  
2  
3
```



```
4 if False: 5 | print("This will never run") 6  
Code is unreachable Pylance  
No quick fixes available
```


Testing software

Unit tests

- A **unit test** checks of the correctness of a single unit of software.
 - What constitutes a “unit” is subjective, but typically it means the behavior of a single function in one situation.
- A unit test will typically have:
 - a **fixture**, which is the thing being tested (e.g., an array of numbers);
 - an **actual result**, which is what the code produces when given the fixture; and
 - an **expected result** that the actual result is compared to
- Easy to automate!

The pytest framework

- **pytest** is a testing framework that simplifies the creation, organization, and execution of tests.
 - Tests are put in files whose names begin with `test_`.
 - Each test is a function whose name also begins with `test_`.
 - These functions use `assert` to check results.
- To add more tests, we simply write more `test_` functions in this `py` file!

Testing software

The pytest framework

- The pytest library can be used from the command-line.
- When we run it with no options, it searches for all files in the working directory whose names match the pattern `test_*.py`

```
$ pytest
```

```
===== test session starts =====  
platform darwin -- Python 3.7.6, pytest-6.2.0, py-1.10.0,  
pluggy-0.13.1  
rootdir: /Users/amira  
collected 1 item  
  
bin/test_zipfs.py . [100%]  
  
===== 1 passed in 0.02s =====
```

\$> Interactive live coding

- Write function to calculate the area of a square:

```
calc_area_square(side_length:float) -> float
```

- Write a unit test for this function

The pytest framework

- pytest includes functions to write tests for special circumstances:
 - approx – for floating point calculations where some tolerance is expected
 - raises – for checking if an error is raised given erroneous input

\$> Interactive live coding

- Write function to calculate the area of a circle:

```
calc_area_circle(radius:float) -> float
```

- Write a unit test for this function
- Add a test of whether the input is a valid number
- Write a unit test for this error

Integration testing

- Integration testing is a test that checks whether the parts of a system work properly **when put together**.
- Integration tests are structured the same way as unit tests:
 - a **fixture** is used to produce an **actual result** that is compared against the **expected result**.
 - However, creating the fixture and running the code can be considerably more complicated

Testing software

Example

- Testing a function that reads a list of radii from a text file and calculates the corresponding areas:

```
def test_load_and_calculate():  
    ##### Generate test case #####  
    # save list of radii  
    np.array([5.2, 1.1, 9.3, 11.4, 19.2]).savetxt('radii.txt')  
  
    ##### Run function #####  
    # load list of radii  
    radii_list = load_from_file('radii.txt')  
  
    # calculate area  
    area_list = calc_area_circle(radii_list)  
  
    ##### Test result #####  
    assert area_list == approx([84.95, 3.8, 271.7, 408.3, 1158.1])
```

Testing software

Regression tests

- When we don't know the answer, we can use regression tests to compare today's answer with a previous one.
- This doesn't guarantee that the answer is right
 - if the original answer is wrong, we could carry that mistake forward indefinitely
 - draw attention to any changes (or “**regressions**”)
- Especially useful for large projects:
 - When dependencies are updated
 - When code is re-used in multiple places for different contexts

Testing software

Test coverage

- How much of our code do we have unit and integration tests for?
- We can use the **coverage** library to get the percentage of lines of code that have been tested.

```
$ coverage run -m pytest
```

```
===== test session starts =====
platform darwin -- Python 3.7.6, pytest-6.2.0, py-1.10.0,
pluggy-0.13.1
rootdir: /Users/amira
collected 4 items

bin/test_zipfs.py .... [100%]

===== 4 passed in 0.72s =====
```

```
$ coverage report -m
```

bin/countwords.py	20	7	65%	25-26, 30-38
bin/plotcounts.py	58	37	36%	48-55, 75-77, 82-83, 88-118, 122-140
bin/test_zipfs.py	31	0	100%	
bin/utilities.py	8	5	38%	18-22

TOTAL	117	49	58%	

What questions do we have?

Testing programs

Continuous integration

- Automatically run all tests whenever a change is made
 - Visibility into which changes resulted in errors
 - Integration tests help catch errors affecting other parts of the code, or errors resulting from operating system or system interactions
- GitHub Actions is a built-in way to do CI
 - Usually configured to run on every single push
 - Can run pretty much any command (e.g. pytest) on the code

Testing programs

GitHub Actions

- Defined in a YAML file placed in `.github/workflows`

```
name: Run unit tests
on: [push]
jobs:
  my_pytest:
    runs-on: ubuntu-latest
    steps:
      - ...
```

Name of your workflow

When should this run?

What should happen when it runs?

Base system to run this action on

What steps?

Testing software

\$> Interactive live coding

- Create a GitHub repository for our circle code with unit tests
- Try `pytest` locally
- Write a GitHub Actions file to run `pytest` on push

What questions do we have?

Course overview

1. Configuration files & Environment variables
2. Using and writing Application Programming Interfaces (APIs)
3. Handling errors
- 4. Testing software**
- 5. Building Python packages**
6. Working in software teams using GitHub features

Creating a Python package

- A generic package folder hierarchy has:
 - a top-level directory with the package name
 - ↳ that contains a directory that is also named after the package
 - ↳ that contains the package's source files
- Modules can contain functions and classes


```
pkg_name
├── pkg_name
│   ├── module1.py
│   └── module2.py
├── README.md
└── setup.py
```

Python packages

setuptools

- Using setuptools allows everyone, regardless of Python distribution, to use our package
- setuptools attempts to install package requirements automatically
- The setup.py file defines some properties of our package

```
pkg_name
├── pkg_name
│   ├── module1.py
│   └── module2.py
├── README.md
└── setup.py
```



```
from setuptools import setup

setup(
    name='pyzipf',
    version='0.1.0',
    author='Amira Khan',
    packages=['pyzipf'])
```

Testing packages

- Install the package
 - in a fresh Python installation (to make sure it's compatible with everyone)
 - in editable mode (for easy debugging)

```
pip install -e /path/to/package
```

- After installation, the code can be imported

```
from my_package import my_module
```

Distributing packages

- Python has a default repository: the Python Package Index (PyPI)
 - Packages are publicly and freely available to everyone
 - When you run `pip install`, it usually downloads from there
 - Beware of installing packages indiscriminately.
 - Anybody can contribute a package to PyPI
 - Although eventually delisted, there have been malicious packages
- Companies and research groups will often have private repositories, or keep packages in a private GitHub Organization for internal use

Python packages

\$> Interactive live coding

- Create a simple Python package
- Install using `pip`
- Upload to GitHub
- Install using `pip` in another instance

Today's learning outcomes

- I can explain the importance of testing code
- I can write unit tests and integration tests using `pytest`
- I can run `pytest` from the command line and calculate code coverage
- I can write a basic `setup.py` configuration file for `setuptools`
- I can install a package from GitHub using `pip`

Exercise + Homework

- Turn your GitHub API code into a Python package
- Write one or more unit test for your API code
- Commit and push your changes to the same repository
- *Optional:* Use GitHub Actions to automatically run your unit tests

References

- Research Software Engineering with Python by Damien Irving, Kate Hertweck, Luke Johnston, Joel Ostblom, Charlotte Wickham, and Greg Wilson (<https://merely-useful.tech/py-rse/config.html>)