Software Testing

17-313: Foundations of Software Engineering

https://cmu-313.github.io

Michael Hilton and **Josh Sunshine**

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Learning Goals

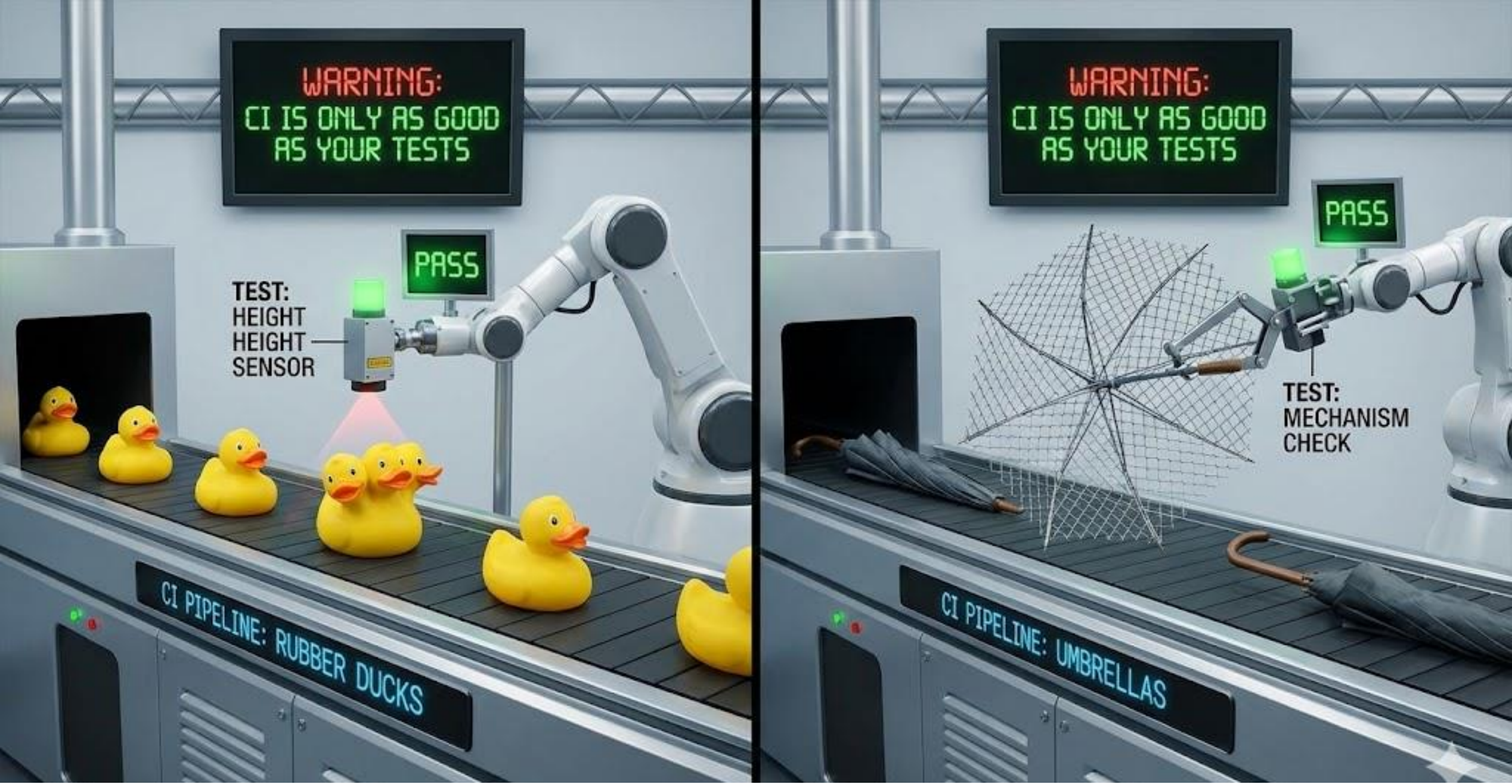
- Distinguish between verification and validation
- Articulate the value of testing
- Evaluate trade-offs in the testing pyramid
- Design and refactor code for testability

Smoking Section

- Last full row

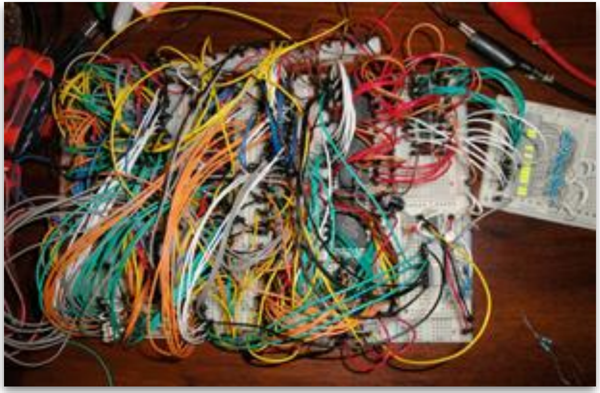
Project 2B and 2C

- Project 2B was due yesterday
  - Many of you didn’t finish your issue
  - That is too be expected, time estimation is hard.
- Project 2C is due February 26.
  - We do expect you to finish your issue in this sprint.
  - New requirement: write tests (today’s topic)


WARNING:
CI IS ONLY AS GOOD AS YOUR TESTS
PASS
TEST:
HEIGHT
HEIGHT
SENSOR
CI PIPELINE: RUBBER DUCKS
WARNING:
CI IS ONLY AS GOOD AS YOUR TESTS
PASS
TEST:
MECHANISM
CHECK
CI PIPELINE: UMBRELLAS

Software Quality

Internal Quality



- Is the code well structured?
- Is the code understandable?
- How well documented?

External Quality

- Does the software crash?
- Does it meet the requirements?
- Is the UI well designed?

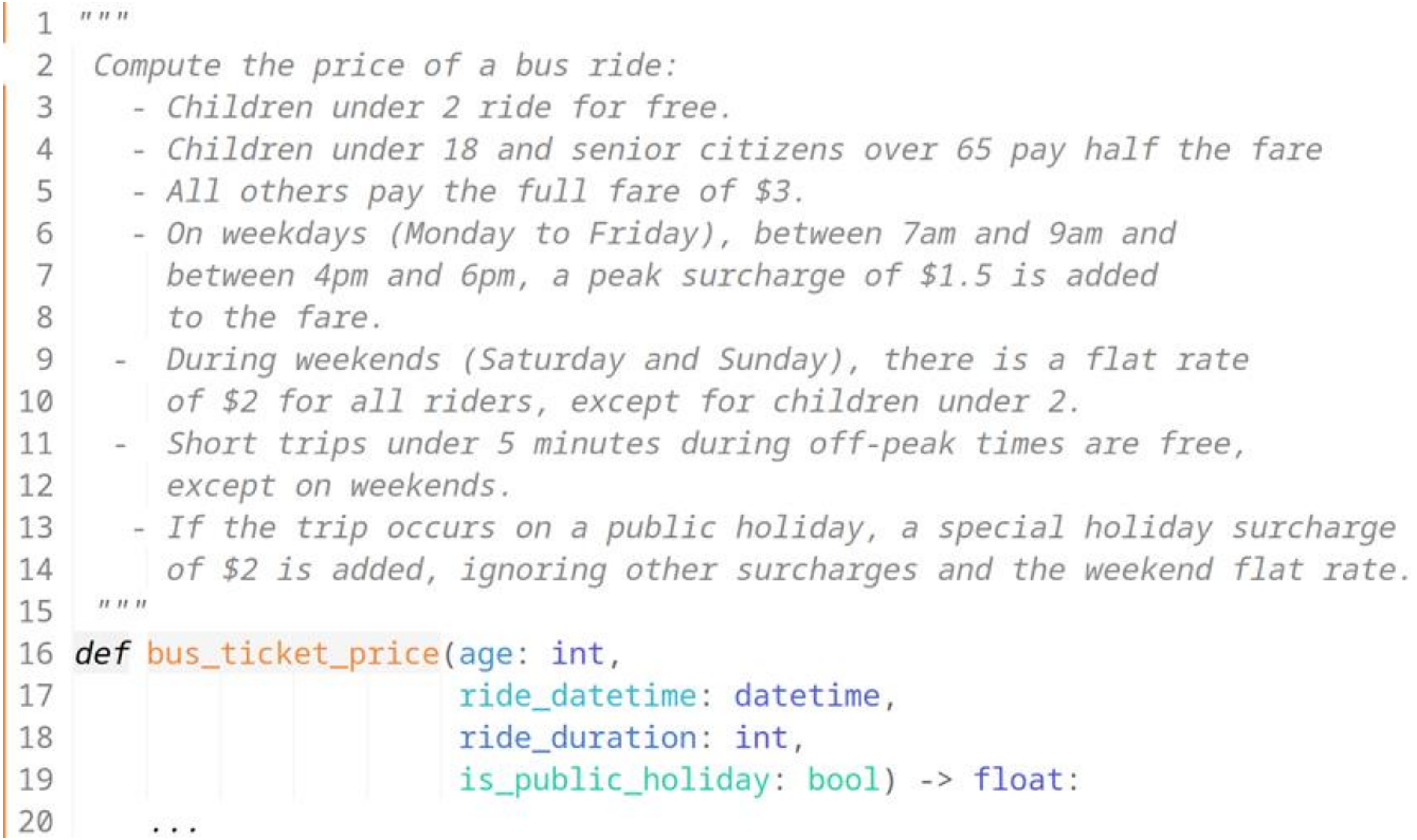
Testing Focuses on External Quality

Specification Testing

Tests are based on the specification

Advantages:

- Avoids implementation bias
- Robust to changes in the implementation
- Tests don’t require familiarity with the code
- Tests can be developed before the implementation



```python
"""
 Compute the price of a bus ride:
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def bus_ticket_price(age: int,
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    ...
```
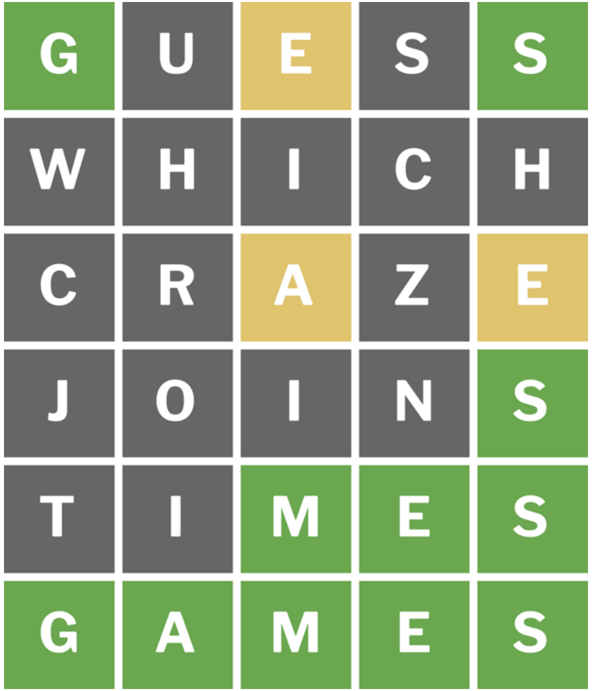

Testing Pyramid

- **Unit Testing**: Testing the smallest testable parts (e.g. functions, objects, modules, or services) in isolation.
- **Integration Testing**: Verifying that different units work together correctly.
- **System/End-to-End (E2E) Testing**: Testing the fully integrated application from the user's perspective.
- **The Pyramid Trade-off:** We want many unit tests (fast, cheap, specific) and fewer E2E tests (slow, expensive, brittle).

Program Under Test: Wordle

- Guessing game
- User guesses a 5-letter English word
- After each guess, the tiles change color to show how close guesser is to secret word



G U E S S

W H I C H

C R A Z E

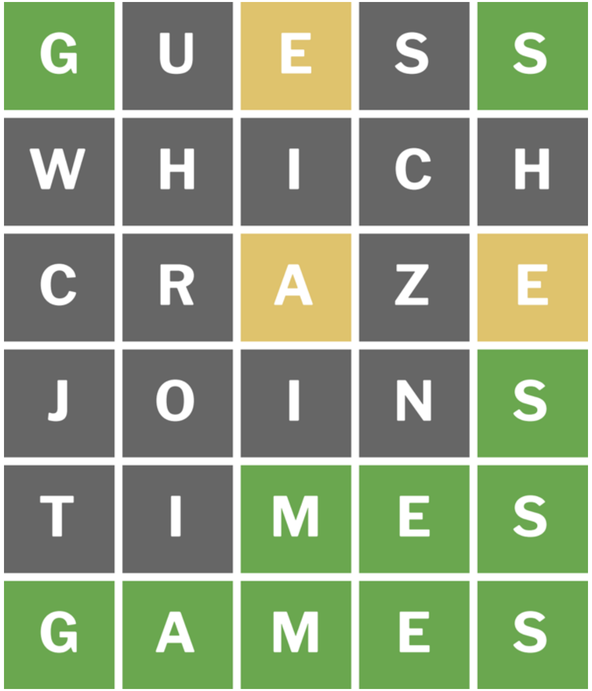
J O I N S

T I M E S

G A M E S

Program Under Test: Wordle

- **Green:** The letter is in the word and in the **correct spot.**
- **Yellow:** The letter is in the word but in the **wrong spot**.
- **Black:** The letter is **not in the word** in any spot.



🟩 G	⬛ U	🟨 E	⬛ S	🟩 S
⬛ W	⬛ H	⬛ I	⬛ C	⬛ H
⬛ C	⬛ R	🟨 A	⬛ Z	🟨 E
⬛ J	⬛ O	⬛ I	⬛ N	🟩 S
⬛ T	⬛ I	🟩 M	🟩 E	🟩 S
🟩 G	🟩 A	🟩 M	🟩 E	🟩 S

Activity: Write Wordle Examples

- Your job is to create unit tests for the `mark_guess` function.
- `mark_guess` takes two arguments: `guess_word` and `secret_word`.
- `mark_guess` returns either a tuple 5 “colors” (G for green, Y for Yellow, and B for Black) or `Error`

Key rules:

- **Green:** The letter is in the word and in the **correct spot.**
- **Yellow:** The letter is in the word but in the **wrong spot**.
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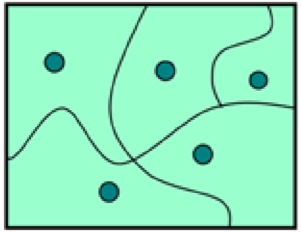
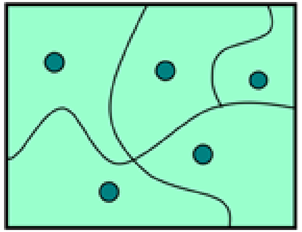
What makes a test good?

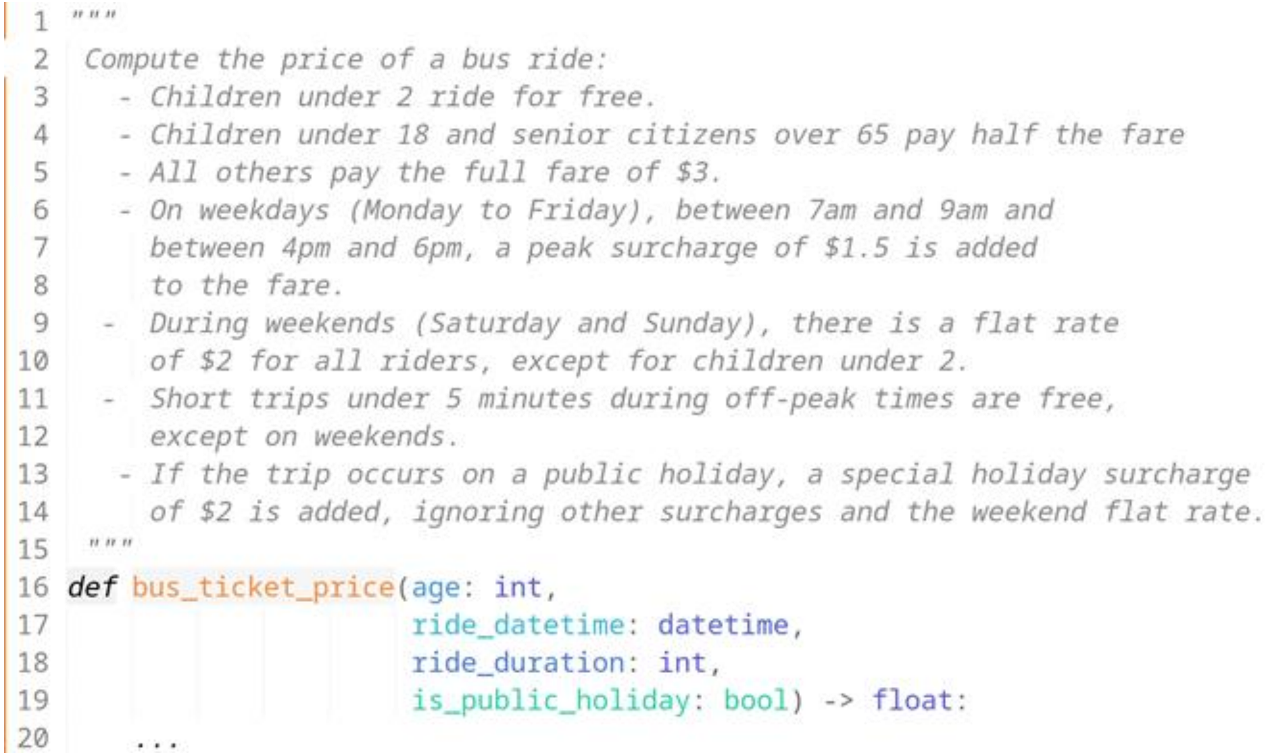
Equivalence Partitioning



- Identify sets with same behavior (**equivalence class**)
- Try one input from each set
- Equivalence classes derived from specifications (e.g., cases, input ranges, error conditions, fault models)
- Requires domain-knowledge

Example: Equivalence Classes?





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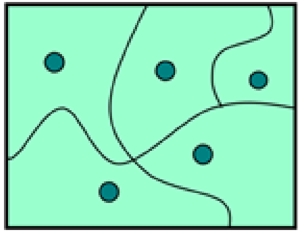
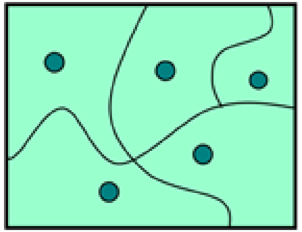
Boundary-value analysis

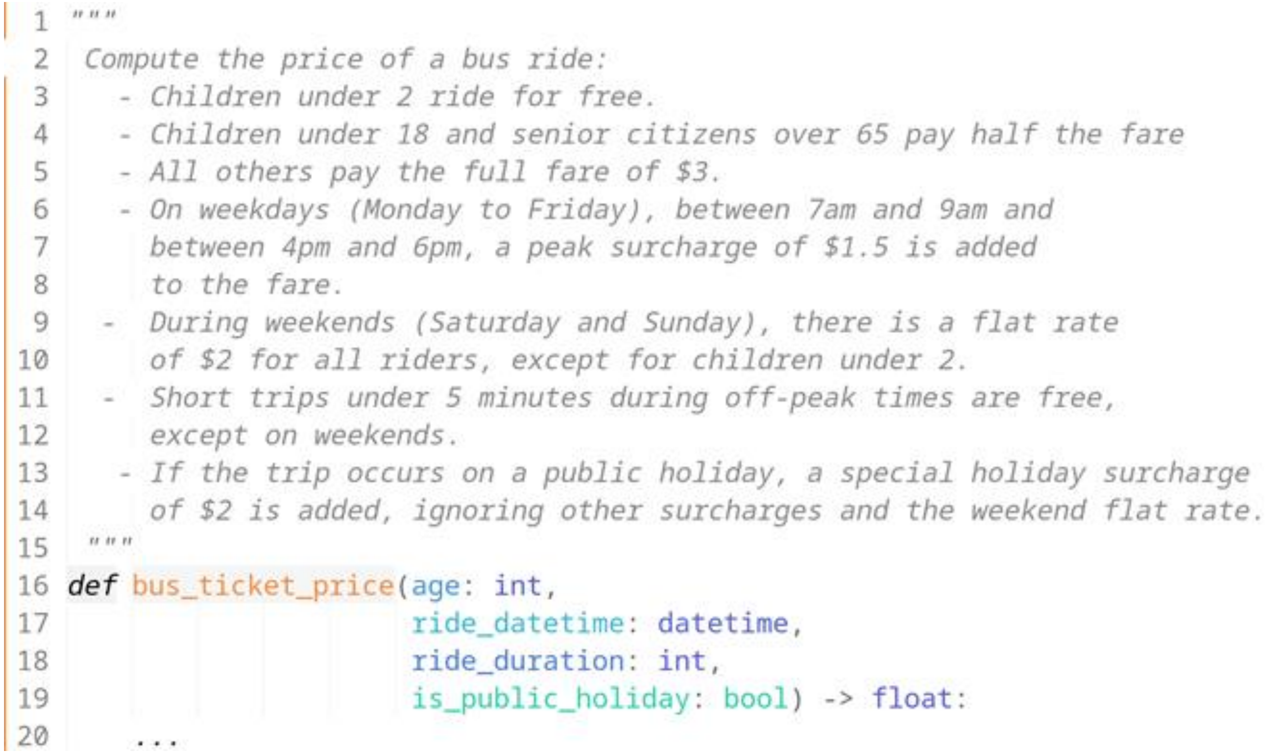


Key Insight: Errors often occur at the boundaries of a variable value

- For each variable, select:
  - minimum,
  - min+1,
  - medium,
  - max-1,
  - maximum;
  - possibly also invalid values min-1, max+1

Boundary-value analysis





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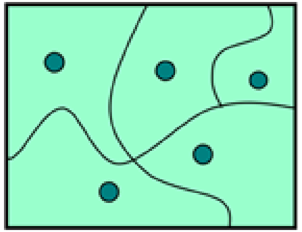
Variable	Domains
age	<2, [2,17], [18,65], >65
ride_datetime	weekdays peak and off-peak, weekends peak and off-peak …
ride_duration	<5, >=5
is_public_holiday	F, T

Pairwise testing



Key Insight: some problems only occur as the result of an interaction between parameters/components

- Examples of interactions:
  - The bug occurs for senior citizens traveling on weekends (pairwise interaction)
  - The bug occurs for senior citizens traveling on weekends during peak hours (3-way interaction)
  - The bug occurs for adults traveling long trips during public holidays that are weekends. (4-way interaction)
- **Claim: Considering pairwise interactions finds about 50% to 90% of defects**

Test Driven Development

Tests first!

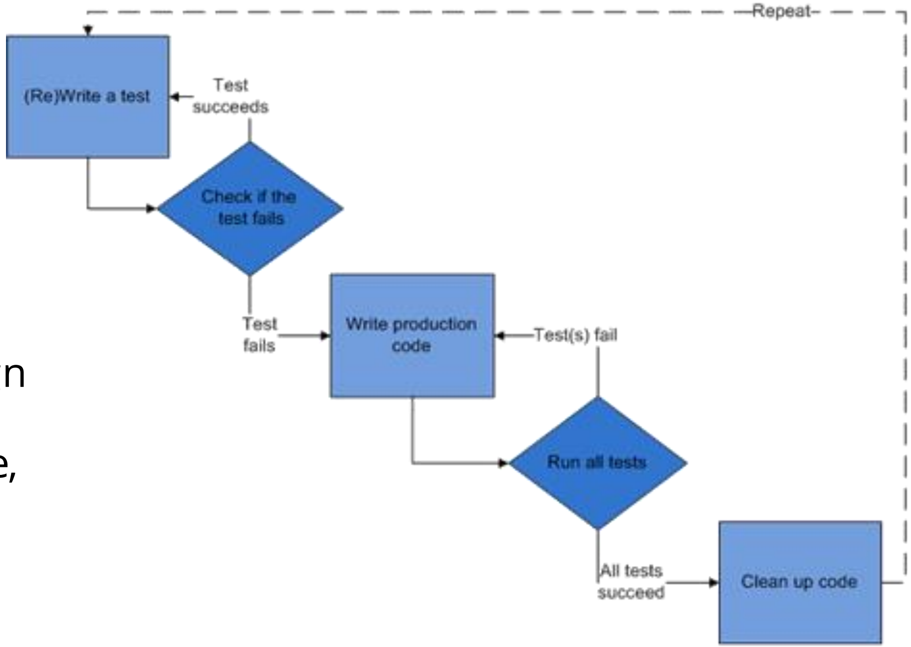
Popular agile technique

Write tests as specifications before code

Never write code without a failing test

Claims:

- Design approach toward testable design
- Avoid writing unneeded code
- Higher product quality (e.g. better code, less defects)
- Higher test suite quality
- Higher overall productivity



Discussion: How do I design my program so it is testable?

Design testing principles

- Purity
- Determinism
- Small input and output sets
- Well-definite input and output sets

Principles of Testing

Principles of Testing #1:
Avoid the *absence of defects* fallacy

- Testing shows the presence of defects
- Testing does not show the absence of defects!
- “no test team can achieve 100% defect detection effectiveness”

Effective Software Testing: A developer's guide. Maurizio Aniche

What about exhaustive testing?

Idea: Try all values!

- **age: int** (2 - 117) years
- **datetime: DateTime** (hh:mm + M/D/Y)
- **rideTime: int** (in minutes, 1 - 2 Hours)
- **is_public_holiday: bool** (2 values)

116 x 1440 (minutes per day) x 1826 (days in the next 5 years) x 120 (ride time) x 2 **~ 72 Billion test cases**

What about exhaustive testing?

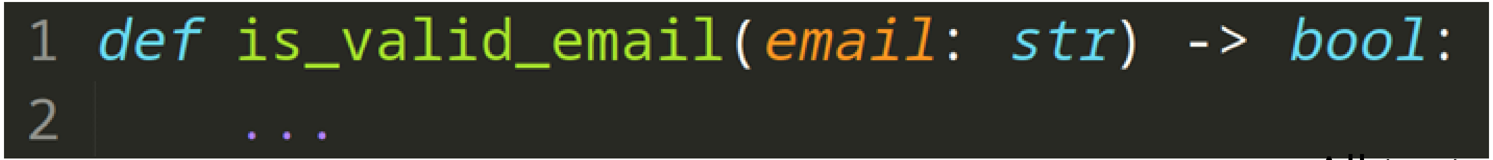
Exhaustive testing is usually impractical – even for trivially small problem

Key problem: choosing test suite

- **Small enough** to finish in a useful amount of time
- **Large enough** to provide a useful amount of validation

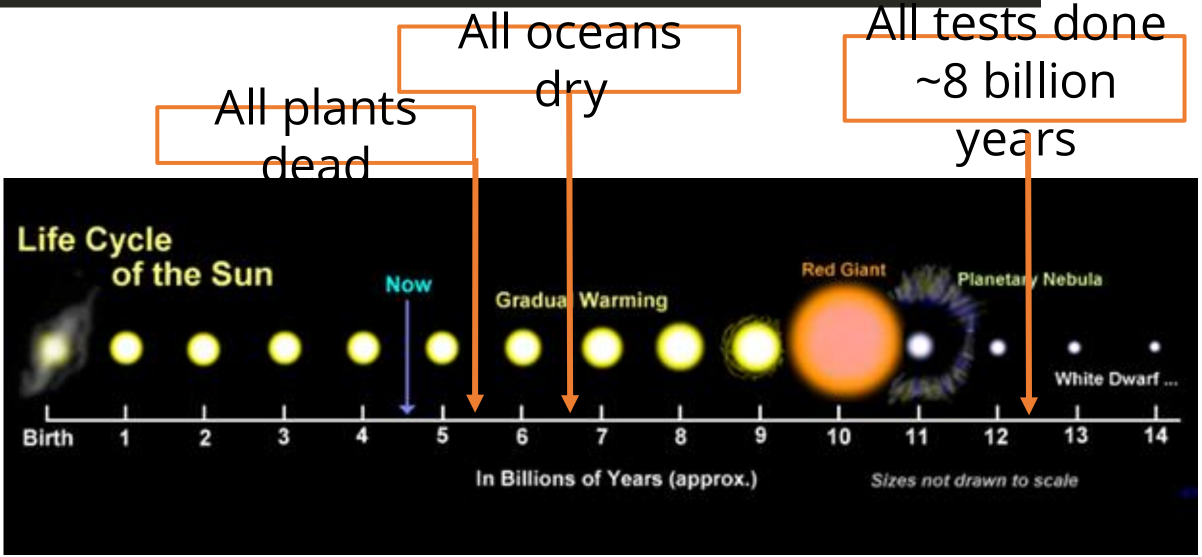
Alternative: **Heuristics**

Principles of Testing #2: Exhaustive testing is impossible



```python
def is_valid_email(email: str) -> bool:
    ...
```

- A simple function, 1 input, string, max. 26 lowercase characters + symbols (@, ., _, -)
- Assume we can use 1 zettaFLOPS: 10^{21} tests per second



All plants dead

All oceans dry

All tests done ~8 billion years

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Principles of Testing #3:
Start testing early

- To let tests guide design
- To get feedback as early as possible
- To find bugs when they are cheapest to fix
- To find bugs when have caused least damage

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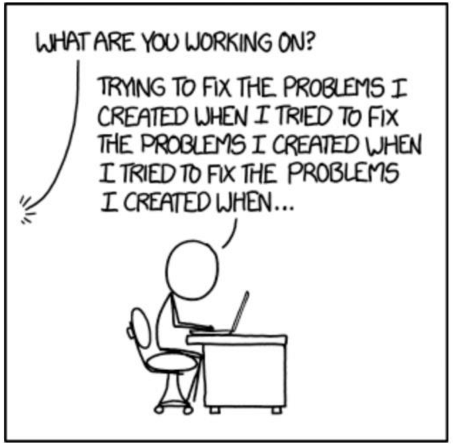
Principles of Testing #4: Defects are usually clustered

- “Hot” components requiring frequent change, bad habits, poor developers, tricky logic, business uncertainty, innovative, size, …
- Use as heuristic to focus test effort


WHAT ARE YOU WORKING ON?
TRYING TO FIX THE PROBLEMS I CREATED WHEN I TRIED TO FIX THE PROBLEMS I CREATED WHEN I TRIED TO FIX THE PROBLEMS I CREATED WHEN...

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Principles of Testing #5: The pesticide paradox

"Every method you use to prevent or find bugs leaves a residue of subtler bugs against which those methods are ineffectual."

- Re-running the same test suite again and again on a changing program gives a false sense of security
- Variation in testing

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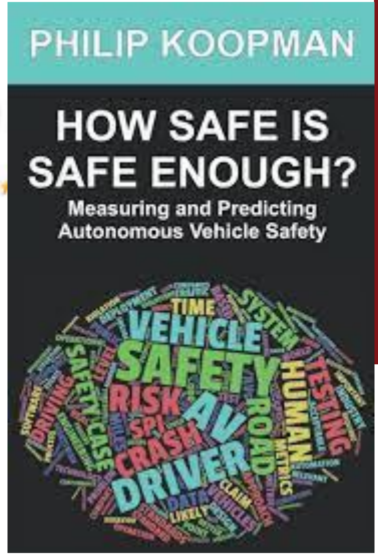
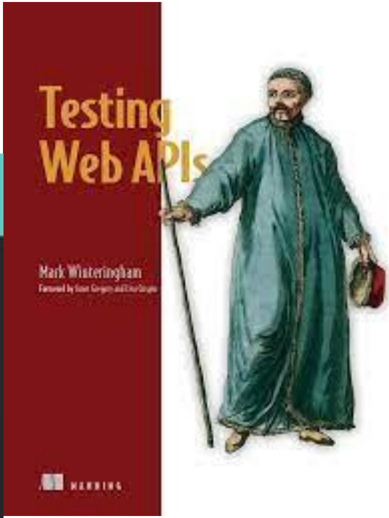
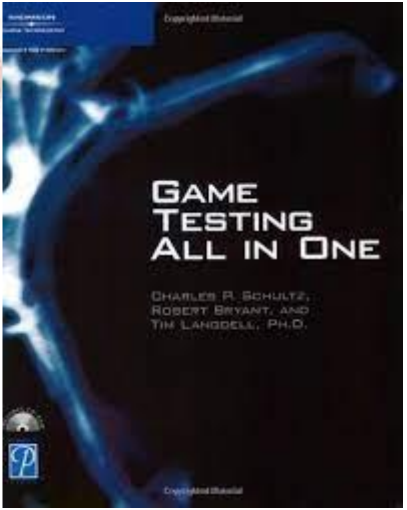
Principles of Testing #6: Testing is context-dependent

DANIEL KNOTT
HANDS-ON MOBILE APP TESTING
2nd Edition
A GUIDE FOR SOFTWARE TESTERS AND ANYONE INVOLVED IN THE MOBILE APP BUSINESS


PHILIP KOOPMAN
HOW SAFE IS SAFE ENOUGH?
Measuring and Predicting Autonomous Vehicle Safety
VEHICLE SAFETY RISK AV DRIVER CRASH ROAD HUMAN TESTING SYSTEM TIME





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Principles of Testing #7: Verification is not validation

Verification

- Does the software system meet the requirements specifications?
- Are we building the **software right**?

Validation

- Does the software system meet the user's real needs?
- Are we building the **right software**?

Credit: Philip Koopman

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Manual testing isn’t the only way to assess quality

- Later in this course:
    - Dynamic Analysis
    - Static Analysis
    - Property-based Testing
    - Fuzzing