CS1632, LECTURE 2: TESTING THEORY AND TERMINOLOGY

Wonsun Ahn

Key (🔑) concept to the course

Expected behavior vs observed behavior

Expected vs. Observed Behavior

- *Expected behavior*: What “should” happen
- *Observed behavior*: What “does” happen

- *Testing*: comparing expected and observed behavior
- *Defect*: when expected != observed behavior

- Expected behavior is also known as *requirement*

Example

- Suppose we are testing a function `sqrt`:

  ```
  // returns the square root of num
  float sqrt(int num) { … }
  ```

- When I call `sqrt` with argument `42`,

  `float ret = sqrt(42);`

  Expected behavior: `ret` == `6.48074069841`

- When `float ret = sqrt(9);`,

  Expected behavior: `ret` == `3`

- When `float ret = sqrt(-9);`,

  Mathematically, square root of `-9` can’t be a real number, but requirements should still specify some behavior

THE IMPOSSIBILITY OF EXHAUSTIVE TESTING

- Let's say we want to ensure that `sqrt` is defect-free for all arguments (both positive and negative)
- Assume arg is a Java `int` (signed 32-bit integer)
- How many values do we have to test?

4,294,967,296

What if there are two arguments?

- Suppose we are testing a function `add`:
  ```
  // return the sum of x and y
  int add(int x, int y) { … }
  ```
- How many tests do we have to perform? (Hint: all combinations of `x` and `y`)

4,294,967,296 ^ 2

What if the argument is an array?

- Suppose we are testing a function `add`:

```
// return sum of elements in A
int add(int[] A) { … }
```

- How many tests do we have to perform? (Note: array A can be arbitrarily long)

4,294,967,296 ^ Infinity

Would testing all the combinations of arguments guarantee that there are no problems?

LOL NOPE

- Compiler issues
- Parallel programming issues (e.g. data races)
- Non-functional issues (e.g. performance)
- Floating-point issues (e.g. loss of precision)
- Systems-level issues (e.g. OS/device-dependent defect)
- Misunderstood requirements

Compiler Issues

- The compiled binary, not your source code, runs on the computer
- What if compiler has a bug? (Rare)
- What if compiler *exposes* a bug in your program? (More frequent)

```
int add_up_to (int count) {
  int sum, i;    /* some C compilers will init sum to 0, others will not */
  for(i = 0; i <= count; i++) sum = sum + i;
  return sum;
}
```

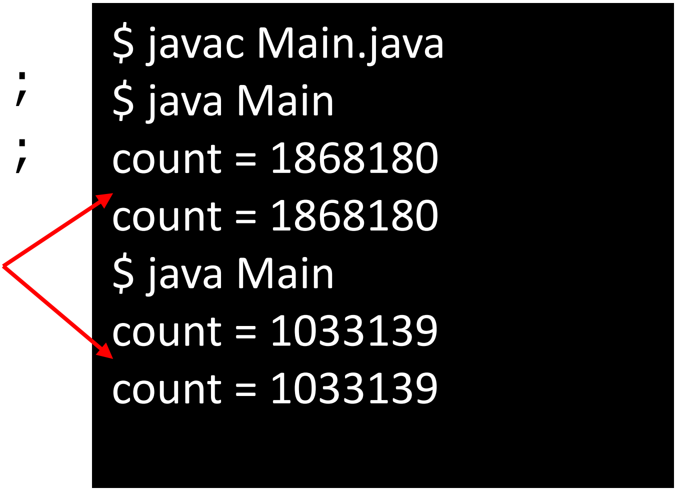
☞ Code will work with some compilers but not with others

- You can avoid this issue by using the same compiler with the same compiler options, but sometimes that is not feasible

Parallel programming issues

```
class Main implements Runnable {
    public static int count = 0;
    public void run() {
        for(int i=0; i < 1000000; i++) { count++; }
        System.out.println("count = " + count);
    }
    public static void main(String[] args) {
        Main m = new Main();
        Thread t1 = new Thread(m);
        Thread t2 = new Thread(m);
        t1.start();
        t2.start();
    }
}
```

Why?



```
$ javac Main.java
$ java Main
count = 1868180
count = 1868180
$ java Main
count = 1033139
count = 1033139
```

Parallel programming issues

- Why does this happen?
  - Threads `t1` and `t2` run on separate CPUs
  - Two threads try to increment `count` at the same time
  - Often, they step on each other's toes (a data race)
- If there is a data race, result is undefined
  - Java language specifications say so!
  - Every time you run it, you may get a different result
  - Passing a test once does not guarantee correctness
- Worst part: often, result is correct 99% of the time

  ☞ Must test thousands of times to find defect

Parallel programming issues

```
class Main implements Runnable {
    public static int count = 0;
    public void run() {
        for(int i=0; i < 1000000; i++)
            synchronized(this) { count++; }
        System.out.println("count = " + count);
    }
    public static void main(String[]
        Main m = new Main();
        Thread t1 = new Thread(m);
        Thread t2 = new Thread(m);
        t1.start();
        t2.start();
    }
}
```

```
$ javac Main.java
$ java Main
count = 1065960
count = 2000000
$ java Main
count = 1061149
count = 2000000
```

Solved?

Parallel programming issues

- `synchronized` removes the data race
  - Now `count` = 2000000 in the end, as expected
- How?
  - `synchronized` "locks" the code region so that the other thread cannot interfere while incrementing `count`
- But note that value of intermediate `count` is still nondeterministic. Why?
  - Speed of threads `t1` and `t2` are nondeterministic

☞ Data-race-free programs can still pose problems

For the purposes of this course…

- Let’s ignore these issues for now
  - Compiler issues
  - Parallel programming issues
  - Non-functional issues
  - Floating-point issues
  - Systems-level issues
- Testing a sequential program using a single compiler on a single device is hard enough due to the test explosion problem
- Test explosion problem is what we will focus on

Testing = ART + SCIENCE

- Exhaustive testing is impossible
- Goal: achieve "sufficient" test coverage
- How would you define test coverage?
    - Ideally: defects_found / total_defects
    - But is there a way to measure total_defects?
      (Hint: if you knew all the defects, you wouldn't be testing)
    - So we need a proxy metric for test coverage
      (e.g. lines_of_code_tested / total_lines_of_code)
- Deciding "sufficient" using this inexact proxy is an art
    - In the end, must rely on domain knowledge to decide

Improving Test Coverage

- QA engineers have a limited testing time budget
  - Must choose a subset of tests maximizing test coverage
- Q) Which test maximizes test coverage?
  - Obviously, one that uncovers a new defect
    (But as we pointed out, that is impossible to know)
- Q) Which test is likely to uncover a new defect?
  - One that exercises new behavior in the code
  - This is the idea behind *equivalence class partitioning*

Equivalence Class Partitioning

- Partition the input values into “equivalence classes”
  - Equivalence class = group of values with similar behavior
- E.g., equivalence classes for our `sqrt` method: {positive numbers, 0, negative numbers}
- Behavior for each class:
  - positive numbers: returns a positive number
  - 0: returns 0
  - negative numbers: returns an imaginary number

Equivalence Classes should be *Strictly* Partitioned

- *Strictly*: a value belongs to one and ONLY one class
- If an input value belongs to multiple classes
  - Means you expect input to have two different behaviors
  - Either there is a bug in the requirements or you misunderstood it
- If an input value belongs to no class
  - Means this input does not match any pre-existing behavior
  - Add a new equivalence class for this input

Values do not have to be numeric

- For a spell checker, input values are strings
- Equivalence classes: {strings_in_dictionary, strings_not_in_dictionary}
- Behaviors:
    - strings_in_dictionary: do nothing
    - strings_not_in_dictionary: red underline string

Values do not have to be numeric

- Input values can be tuna cans
- Equivalence classes: {not_expired, expired_but_not_smelly, expired_and_smelly}
- Behaviors:
    - not_expired: eat
    - expired_but_not_smelly: first feed it to your cat
    - expired_and_smelly: discard

Test Each Equivalence Class

- Pick at least one value from each equivalence class
- Ensures you cover all behavior expected of program
- Gets you good coverage without exhaustive testing!

- How to pick the value? Well, that is part of the art.
    - However, there are some good guidelines!

Interior and boundary values

- Empirical truth:
  - Defects are more prevalent at boundaries of equivalence classes than in the middle.
- Why?
  - Due to the prevalence of off-by-one errors

Off-by-one Error

- Suppose expected behavior is:
  - Method shall take the age of a person as argument
  - Method shall determine whether person can be US president
  - Rule: Person must be 35 years or older to be US president

- Suppose code implementation is:

```
boolean canBePresident(int age) {
   return age > 35;
}
```

- Is observed behavior the same as expected behavior?

Equivalence class partitioning

CANNOT_BE_PRESIDENT =
[…19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34]

CAN_BE_PRESIDENT =
[35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50…]

Try to test boundary values

CANNOT_BE_PRESIDENT =
[…19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34]

CAN_BE_PRESIDENT =
[35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50…]

- Test boundary values (shown in red)
- In fact, there is a bug at: `age > 35`

Also test interior values

CANNOT_BE_PRESIDENT =
[…19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34]

CAN_BE_PRESIDENT =
[35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50…]

- Testing interior values (shown in green) is also important to see behavior at the interior

Are we done?

CANNOT_BE_PRESIDENT =
[…19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34]

CAN_BE_PRESIDENT =
[35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50…]

- Input values so far: {26, 30, 34, 35, 39, 42}

“Hidden” (IMPLICIT) boundary values

- Boundary values we’ve added so far are explicit – that is, they are defined by requirements
- Some boundaries are implicit – they are generated from the language, hardware, domain, etc.:
  - Language boundaries:
    MAXINT, MININT
  - Hardware boundaries:
    memory space, hard drive space, etc.
  - Domain boundaries:
    weight can’t be negative, score can’t exceed 100, etc.

Add implicit boundary values

CANNOT_BE_PRESIDENT =
[MININT,…-2,-1,0,1,…,25,26,27,28,29,30,31,32,33,34]

CAN_BE_PRESIDENT =
[35,36,37,38,39,40,41,42,43,44,45,46,47,…,MAXINT]

- MININT, MAXINT: language boundaries
- -1, 0: domain boundaries (age can’t be negative)
- Inputs: {MININT, -1, 0, 26, 30, 34, 35, 39, 42, MAXINT}

Base, edge, and corner cases

- **Base case**: An interior value, OR an expected use case
- **Edge case**: A boundary value, OR an unexpected use case
- **Corner case** (or **pathological case**):
  Value far outside of normal operating parameters, OR
  multiple edge cases happening simultaneously

Black-, white, and grey-box testing

- **Black-box testing**:
  - Testing with no knowledge of interior structure or source code
  - Tests are performed from the user's perspective
  - Can be performed by lay people who don't know how to program
- **White-box testing**:
  - Testing with explicit knowledge of the interior structure and codebase
  - Tests are performed at the code-level (e.g. tests targeting specific methods or even specific lines of code)
- **Grey-box testing**:
  - Testing with some knowledge of the interior structure and codebase
  - Knowledge may come from partial inspection of code or a design document
  - Tests are performed from the user's perspective, but informed by tester's knowledge

Black-box testing examples

- Testing a website using a web browser
- Running a script against an API endpoint
- Checking to see that changing fonts in a word processor works

White-box testing examples

- Testing that a function returns the correct result
- Testing that instantiating a class creates a valid object
- Checking that there are no unused variables
- Checking that exceptions are caught and handled

Grey-box testing examples

- *Reviewing code* and noticing that bubble sort is used. Then writing a *user-facing test* involving a large input.
- *Reviewing code* in a web app and noticing user input is not properly sanitized. Then writing a *user-facing test* which attempts SQL code injection.
- *Reading a design document* and noticing a critical network connection through which a lot of data passes through. Then writing a *user-facing test* that stresses that network connection.

Static vs dynamic testing

- Dynamic testing = code is executed (at least the part that is exercised in that test run)
- Static testing = code is not executed

Dynamic testing

- If you're thinking about testing, probably what you are thinking about.
  - Code is executed under certain circumstances (e.g. input values, environment variables, compiler, OS, runtime library, etc.)
  - Observed results are then compared with expected results
- Much more commonly used in industry
- The majority of the class will be about dynamic testing

Static testing

- Code is reviewed by a person or testing tool, without being executed
- Examples:
  - Code walkthroughs and reviews
  - Source Code Analysis
    - Linting
    - Model checking
    - Complexity analysis
    - Code coverage
    - Finite state analysis
    - … COMPILING!

Now Please Read Textbook Chapters 2-4