Testing

Real programmers need no testing!

5) I want to get this done fast,
testing is going to slow me down.

4) I started programming when I was 2.
Don't insult me by testing my perfect code!

3) Testing is for incompetent programmers who
cannot hack.

2) We are not UConn students, our code actually works!

1) "Most of the functions in Graph.java, as implemented, are one or two line functions that rely solely upon functions in HashMap or HashSet.
I am assuming that these functions work perfectly, and thus there is really no need to test them."
– an excerpt from a student's e-mail

Ariane 5 rocket

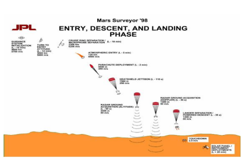


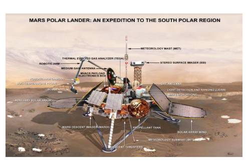
- The rocket self-destructed 37 seconds after launch
- Reason: A control software bug that went undetected
  - Conversion from 64-bit floating point to 16-bit signed integer value had caused an exception
    - The floating point number was larger than 32767 (max 16-bit signed integer)
  - Efficiency considerations had led to the disabling of the exception handler.
  - Program crashed → rocket crashed
- Total Cost: over $1 billion

Therac-25 radiation therapy machine

- Caused excessive radiation, killing patients from radiation poisoning
- What happened?
  - Updated design had removed hardware interlocks that prevent the electron-beam from operating in its high-energy mode. Now all the safety checks are done in the software.
  - The software set a flag variable by incrementing it. Occasionally an arithmetic overflow occurred, causing the software to bypass safety checks.
  - The equipment control task did not properly synchronize with the operator interface task, so that race conditions occurred if the operator changed the setup too quickly.
  - This was evidently missed during testing, since it took some practice before operators were able to work quickly enough for the problem to occur.

Mars Polar Lander





- Sensor signal falsely indicated that the craft had touched down when it was 130-feet above the surface.
  - the descent engines to shut down prematurely
- The error was traced to a single bad line of software code.
- NASA investigation panels blame for the lander's failure, "are well known as difficult parts of the software-engineering process,"

Testing is for *every* system

- Examples showed particularly costly errors
- But every little error adds up
- Insufficient software testing costs $22-60 billion per year in the U.S.
[NIST Planning Report 02-3, 2002]
- If your software is worth writing, it's worth writing right

Building quality software

- What Impacts the Software Quality?
- External
  - Correctness — *Does it do what it suppose to do?*
  - Reliability — *Does it do it accurately all the time?*
  - Efficiency — *Does it do with minimum use of resources?*
  - Integrity — *Is it secure?*
- Internal
  - Portability — *Can I use it under different conditions?*
  - Maintainability — *Can I fix it?*
  - Flexibility — *Can I change it or extend it or reuse it?*
- Quality Assurance
  - The process of uncovering problems and improving the quality of software.
  - Testing is a major part of QA.

The phases of testing

- Unit Testing
  - Is each module does what it suppose to do?
- Integration Testing
  - Do you get the expected results when the parts are put together?
- Validation Testing
  - Does the program satisfy the requirements
- System Testing
  - Does it work within the overall system

Unit Testing

- A test is at the level of a method/class/interface Check that the implementation matches the specification.

  Black box testing
  - Choose test data *without* looking at implementation
- Glass box (white box) testing
  - Choose test data *with* knowledge of implementation

How is testing done?

Basic steps of a test

1) Choose input data / configuration
2) Define the expected outcome
3) Run program / method against the input and record the results
4) Examine results against the expected outcome

What's so hard about testing ?

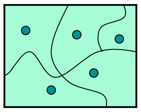
- "just try it and see if it works..."

```
int proc1(int x, int y, int z)
  // requires: 1 <= x,y,z <= 1000
  // effects:  computes some f(x,y,z)
```

- Exhaustive testing would require 1 billion runs!
  - Sounds totally impractical
- Could see how input set size would get MUCH bigger
- Key problem: choosing test suite (set of partitions of inputs)
  - Small enough to finish quickly
  - Large enough to validate the program

Approach: partition the input space

- Input space very large, program small
  ➔ behavior is the "same" for sets of inputs
- Ideal test suite:
  - Identify sets with same behavior
  - Try one input from each set



- Two problems
  - 1. Notion of the same behavior is subtle
    - Naive approach: execution equivalence
    - Better approach: revealing subdomains
  - 2. Discovering the sets requires perfect knowledge
    - Use heuristics to approximate cheaply

Naive approach: execution equivalence

```
int abs(int x) {
 // returns:  x < 0      => returns -x
 //           otherwise  => returns x

  if (x < 0) return -x;
  else       return x;
}
```

All x < 0 are execution equivalent:
program takes same sequence of steps for any x < 0

All x >= 0 are execution equivalent

Suggests that {-3, 3}, for example, is a good test suite

Why execution equivalence doesn't work

Consider the following buggy code:

```
int abs(int x) {
 // returns:  x < 0      => returns -x
 //           otherwise  => returns x

  if (x < -2) return -x;
  else        return x;
}
```

{-3, 3} does not reveal the error!

Two executions:
x < -2 x >= -2
Three behaviors:
x < -2 (OK) x = -2 or -1 (bad) x >= 0 (OK)

Revealing subdomain approach

- "Same" behavior depends on specification
- Say that program has "same behavior" on two inputs if
  - 1) gives correct result on both, or
  - 2) gives incorrect result on both
- Subdomain is a subset of possible inputs
- Subdomain is revealing for an error, E, if
  1) Each element has same behavior
  2) If program has error E, it is revealed by test
- Trick is to divide possible inputs into sets of revealing subdomains for various errors

Example

- For buggy `abs`, what are revealing subdomains?

```
– int abs(int x) {
  if (x < -2) return -x;
  else        return x;
– }
```

{−1} {−2} {−2, −1} {−3, ~~−2,~~ −1}

{−2, −1}

- Which is best?

Heuristics for designing test suites

- A good heuristic gives:
  - few subdomains
  - ∀ errors e in some class of errors E,
    high probability that some subdomain is revealing for e
- Different heuristics target different classes of errors
  – In practice, combine multiple heuristics

Black-box testing

- Heuristic: explore alternate paths through specification
  the interface is a black box; internals are hidden
- Example

```
– int max(int a, int b)
    // effects:  a > b => returns a
    //           a < b => returns b
    //           a = b => returns a
```

– 3 paths, so 3 test cases:
(4, 3) => 4 *(i.e., any input in the subdomain a > b)*
(3, 4) => 4 *(i.e., any input in the subdomain a < b)*
(3, 3) => 3 *(i.e., any input in the subdomain a = b)*

Black-box testing: advantages

- Process not influenced by component being tested
  - Assumptions embodied in code not propagated to test data.
- Robust with respect to changes in implementation
  - Test data need not be changed when code is changed
- Allows for independent testers
  - Testers need not be familiar with code

A more complex example

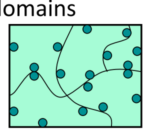
- Write test cases based on paths through the specification

```
– int find(int[] a, int value) throws Missing
  // returns: the smallest i such
  //          that a[i] == value
  // throws:  Missing if value not in a[]
```

- Two obvious tests:
  ([4, 5, 6], 5) => 1
  ([4, 5, 6], 7) => throw Missing
- Have I captured all the paths?
  ([4, 5, 5], 5) => 1
- Must hunt for multiple cases in effects or requires

Heuristic: boundary testing

- Create tests at the edges of subdomains
- Why do this?
  - off-by-one bugs
  - forget to handle empty container
  - overflow errors in arithmetic
  - program does not handle aliasing of objects



- Small subdomains at the edges of the "main" subdomains have a high probability of revealing these common errors

Boundary testing

- To define boundary, must define adjacent points
- One approach:
  - Identify basic operations on input points
  - Two points are adjacent if one basic operation away
  - A point is isolated if can't apply a basic operation
- Example: list of integers
  - Basic operations: create, append, remove
  - Adjacent points: <[2,3],[2,3,3]>, <[2,3],[2]>
  - Isolated point: [] (can't apply remove integer)
- Point is on a boundary if either
  - There exists an adjacent point in different subdomain
  - Point is isolated

Common boundary cases

- Arithmetic
  - Smallest/largest values
  - Zero
- Objects
  - Null
  - Circular
  - Same object passed to multiple arguments (aliasing)

Boundary cases: arithmetic overflow

- `public int abs(int x)`
- `// returns: |x|`
- Tests for abs
  - what are some values or ranges of x that might be worth probing?
    - $x < 0$ (flips sign) or $x \geq 0$ (returns unchanged)
    - around $x = 0$ (boundary condition)
    - *Specific tests: say x = -1, 0, 1*
- *How about…*

```
int x = -2147483648; // this is Integer.MIN_VALUE
System.out.println(x<0);            // true
System.out.println(Math.abs(x)<0);  // also true!
```

- From Javadoc for Math.abs:
  - Note that if the argument is equal to the value of Integer.MIN_VALUE, the most negative representable int value, the result is that same value, which is negative

Boundary cases: duplicates and aliases

```
<E> void appendList(List<E> src, List<E> dest) {
// modifies:     src, dest
// effects:      removes all elements of src and
//               appends them in reverse order to
//               the end of dest

    while (src.size()>0) {
        E elt = src.remove(src.size()-1);
        dest.add(elt)
    }
}
```

- What happens if src and dest refer to the same thing?
  - Aliasing (shared references) is often forgotten

Clear (glass, white)-box testing

- Goals:
  Ensure test suite covers (executes) all of the program
  Measure quality of test suite with % coverage
- Assumption:
  High coverage →
  (no errors in test output → few mistakes in program)
- Focus: features not described by specification
  Control-flow details
  Performance optimizations
  Alternate algorithms for different cases

Glass-box motivation

There are some subdomains that black-box testing won't catch:

```
boolean[] primeTable = new boolean[CACHE_SIZE];
  boolean isPrime(int x) {
      if (x>CACHE_SIZE) {
          for (int i=2; i<x/2; i++) {
              if (x%i==0) return false;
          }
          return true;
      } else {
          return primeTable[x];
      }
  }
```

Important transition around *x* = CACHE_SIZE

Glass-box testing: advantages

- Insight into test cases
  - Which are likely to yield new information
- Finds an important class of boundaries
  - Consider `CACHE_SIZE` in `isPrime` example
- Need to check numbers on each side of `CACHE_SIZE`
  - `CACHE_SIZE-1`, `CACHE_SIZE`, `CACHE_SIZE+1`
- If `CACHE_SIZE` is mutable, we may need to test with different `CACHE_SIZE's`

Glass-box challenges

- Definition of all of the program
  - What needs to be covered?
  - Options:
    - Statement coverage
    - Decision coverage
    - Loop coverage
    - Condition/Decision coverage
    - Path-complete coverage

increasing number of cases (more or less)

- 100% coverage not always reasonable target

100% may be unattainable (dead code)
High cost to approach the limit

Regression testing

- Whenever you find a bug
  - Reproduce it (before you fix it!)
  - Store input that elicited that bug
  - Store correct output
  - Put into test suite
  - Then, fix it and verify the fix
- Why is this a good idea?
  - Helps to populate test suite with good tests
  - Protects against regressions that reintroduce bug
    - It happened once, so it might again

Rules of Testing

- First rule of testing: ***Do it early and do it often***
  - Best to catch bugs soon, before they have a chance to hide.
  - Automate the process if you can
  - Regression testing will save time.
- Second rule of testing: ***Be systematic***
  - If you randomly thrash, bugs will hide in the corner until you're gone
  - Writing tests is a good way to understand the spec
    - Think about revealing domains and boundary cases
    - If the spec is confusing → write more tests
  - Spec can be buggy too
    - Incorrect, incomplete, ambiguous, and missing corner cases
  - When you find a bug → fix it first and then write a test for it

Testing summary

- Testing matters
  - You need to convince others that module works
- Catch problems earlier
  - Bugs become obscure beyond the unit they occur in
- Don't confuse volume with quality of test data
  - Can lose relevant cases in mass of irrelevant ones
  - Look for revealing subdomains ("characteristic tests")
- Choose test data to cover
  - Specification (black box testing)
  - Code (glass box testing)
- Testing can't generally prove absence of bugs
  - But it can increase quality and confidence