Course updates

- Literature review feedback on Moodle
- All presentations graded
- Project plan assignment due April 11
- Midterm next week, April 13
- We’ll start review this Thursday, finish next Tuesday
- HW 1, 2, and 3 solutions on Moodle
- All presentation slides on class webpage
- Homework 4 extended until April 20, 9 AM EDT

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 Notre Dame 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

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.

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 32,767 (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

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

```c
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:

```c
int abs(int 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}

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
  ```java
  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 \( a = b \))

A more complex example

- Write test cases based on paths through the specification
  ```java
  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) \(\Rightarrow 1\)
  (\[4, 5, 6\], 7) \(\Rightarrow\) throw Missing
- Have I captured all the paths?
  (\[4, 5, 6\], 5) \(\Rightarrow 1\)
- Must hunt for multiple cases in effects or requires

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

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

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 (flip sign) or x > 0 (returns unchanged)
  - x = 0 (boundary condition)
  - Specific test: say x = 0, 1
- **How about...**
- 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

```java
<@
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); // also true!
        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:

```java
boolean[] primeTable = new boolean[CACHE_SIZE];
boolean isPrime(int x) { // Cache size
    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'ems

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
- **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