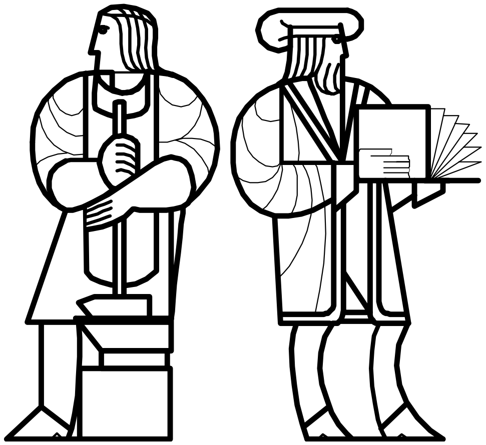
Exceptions and Testing



6.170

Michael Ernst

Saman Amarasinghe

Generic Types

Bugfix to the last lecture

```
public class List<T> {
    private T lst[];
    public void add(int, T) { … }
    public T get(int) { … }
    …
}

List<Integer> lst = new List<Integer>();
Integer fst = lst.get(0);
```

How to handle abnormal situations?

```
public static int Search(int[] lst, int key)
```

requires: none
modifies: none
effects: none
returns: some i such that lst[i] = key if such an i exists,
otherwise -1

Returning `{(insertion point), - 1}` *is very ugly, and an invitation to bugs and confusion.*

How to handle abnormal situations?

```
public static int Search(int[] lst, int key)
```

requires: key is in lst

modifies: none

effects: none

returns: i where lst[i] = key

Partial procedures make the world more complicated.

Who is going to check if key is in a?

Too much burden on the client.

Use an exception

```
public static int Search(int[] lst, int key)
```

requires: none

modifies: none

effects:

throws: `NoSuchElementException` if key is not in lst

returns: some i such that lst[i] = key if such an i exists

How to use an Exception

Declaration:

```
 public static int Search(int[] lst, int key)
                  throws NoSuchElementException {
     for(int i = 0; i < lst.length; i++)
           if(lst[i] == k) return i;
     throw new NoSuchElementException();
}
```

Use:

```
 try {
   j = s.Search(mylist, k);
 } catch (NoSuchElementException e) {
   Handle the exception
 }
```

... continue for both normal and exceptional cases

Catching Exceptions

Caught by catch associated with nearest enclosing try

If no such catch

  Exception propagated up call stack

If not caught at all

  Program terminates

Two Kinds of Exceptions

Checked exceptions

- E.g., class MissingException extends Exception
- Compiler error unless
  - There exists a catch clause, or
  - Caller declared to throw that exception
- ∴ There is guaranteed to be a dynamically enclosing catch

Unchecked exceptions

- E.g., class ArithmeticException extends RuntimeException
- Compiler doesn’t complain

Rule of thumb

- Stick to checked exceptions most of the time
- Use unchecked exceptions to mean failure
  - Expect program to terminate

Why Catch Exceptions Locally?

- Failure to catch exceptions violates modularity
  - Call chain: A → IntegerSet.insert → IntegerList.insert
  - IntegerList.insert throws an exception
    - Implementer of IntegerSet.insert knows how list is being used
    - Implementor of A may not even know that IntegerList exists
- Procedure up the line may think that it is handling an exception raised by a different call
- Even if exception is better handled up a level
  - May be better to catch it and throw it again (“chaining”)
  - Makes it clear to reader of code that it was not an omission

Exceptions in Review

- Use an exception when
  - Used in a broad or unpredictable context
  - Checking the condition is feasible
- Use a precondition when
  - Checking would be prohibitive
    - E.g., requiring that a list be sorted
  - Used in a narrow context in which calls can be checked
- Preconditions should be avoided because
  - Caller may violate precondition
  - Program can fail in uninformative or dangerous way
  - Want program to fail as early as possible

Exceptions in Review, cont.

- Use checked exceptions most of the time
- Handle exceptions sooner rather than later
- Don’t think of them as errors
  - A program structuring mechanism
  - Used for exceptional (unpredictable) circumstances
- Documentation standards and conventions
  - Will be covered in recitation
- Also see Bloch’s *Effective Java*

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 work?

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 if 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

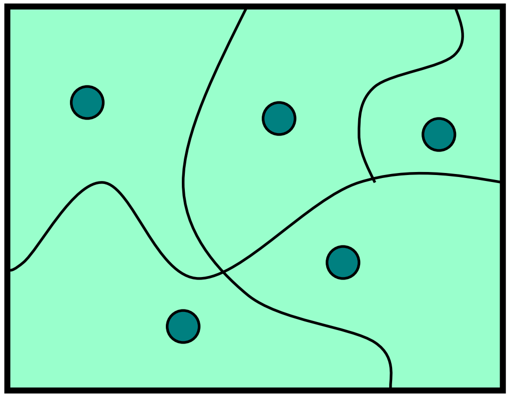
Key problem: choosing test suite (set of partitions of inputs)

- 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;
 }
```

Two executions:

x < -2   x >= -2

Three behaviors:

x < -2 (OK)   x = -2 or -1 (bad)   x >= 0 (OK)

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

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

Procedure an interface is a black box, internals 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

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

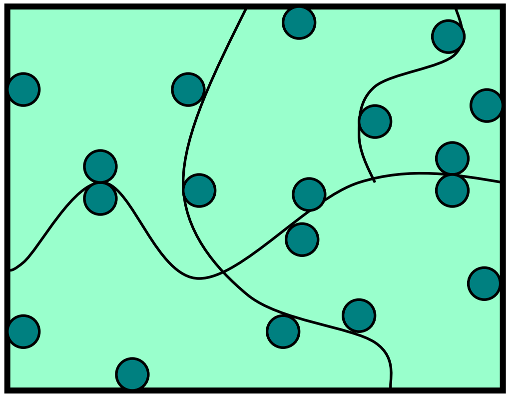
Have I captured all the paths?

([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

Other 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?

- This is aliasing – often forgotten
- Watch out for shared references in inputs

Glass-box Testing

Goal:

Ensure test suite covers (executes) all of the program

Measure quality of test suite with % coverage

Assumption:

high coverage →

(no errors in test suite output

→ few mistakes in the 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 give:

```
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];
    }
}
```

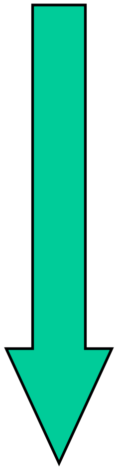
Important transition around x = CACHE_SIZE

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

pragmatics: regression testing

- Whenever you find and fix a bug
  - Store input that elicited that bug
  - Store correct output
  - Put into test suite
- Why is this a good idea
  - Helps to populate test suite with good tests
  - Protects against reversions that reintroduce bug
  - Arguably is an easy error to make (happened at least once, why not 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

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
- Choose test data to cover
  - Specification (black box testing)
  - Code (glass box testing)
- Testing can't generally prove absence of bugs
  - But can increase quality by reducing the bugs