CISC 327
Software Quality Assurance

Lecture 17

White Box Testing:
Mutation Testing

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White Box Testing

- Today we continue our look at white box testing methods with mutation testing
- Definition and role of mutation testing
  - What is a mutation?
  - What is a mutant?
  - How is mutation testing used?
- Mutation testing methods
  - **Value** mutations
  - **Decision** mutations
  - Other mutations

Mutation Testing

- Mutation testing is a white box method for checking the **adequacy** of a test suite
- As you have already discovered, creating a test suite can be an expensive and time consuming effort
- No matter what test method is used, discovering if test suites are adequate to uncover faults is itself an even more difficult task
- Mutation testing offers an almost completely automated way to check the adequacy of a set of tests in uncovering faults in the software

Mutation Testing

- How does it work?
  - To test the adequacy of a test suite, we run the software on the suite and fix problems until the software passes every test
  - We then save the results in a set of files to serve as the correct output to compare to
  - We then use mutation on the source code to create a set of mutants (this step is automated)
  - A **mutant** is a program that is slightly different from the original

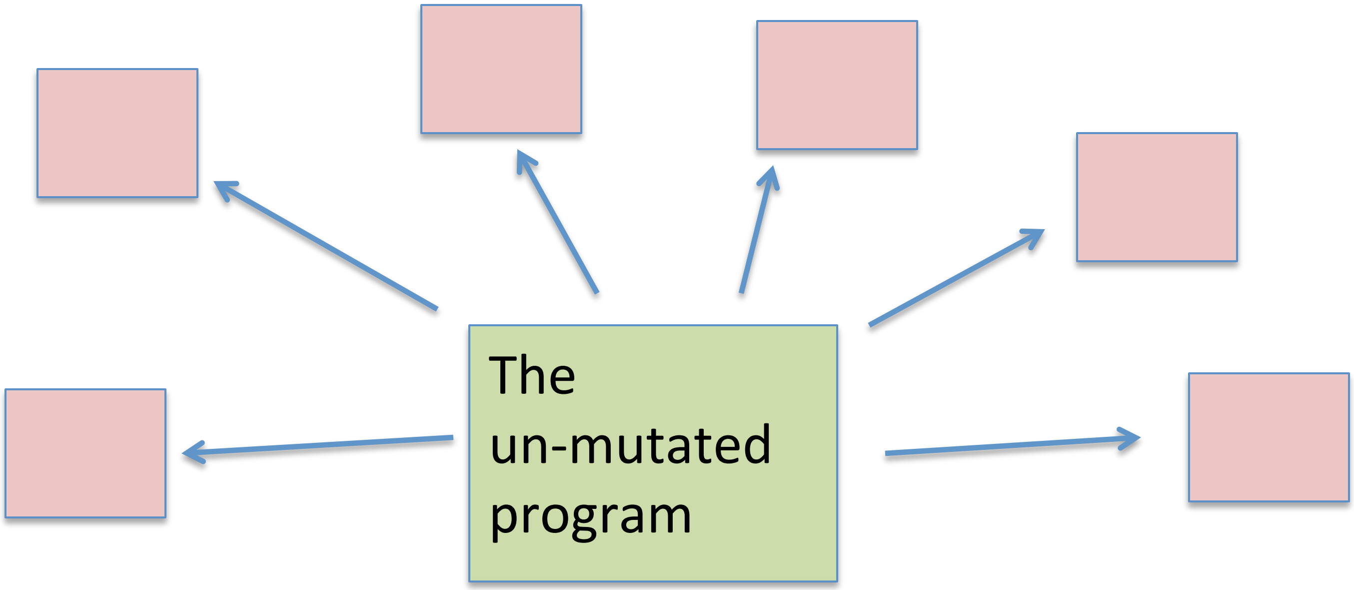
Mutation Testing

- For each mutant, we run the test suite on the mutant and compare the results to the saved results from the original
- If the results differ, then the mutant has been "killed" (detected) by the test suite
- If the results do not differ, then the test suite is inadequate to detect the mutant, and a new test must be added to the suite to kill that mutant

Systematic Mutation

- For mutation testing to be systematic, there must be (1) a system for creating mutants, (2) a completion criterion (knowing when you have enough mutants)
- The **system** is a set of kinds of syntactic changes to the program source, generally expected to cause errors
- Each mutant has exactly one change in it
- We are done when every possible single change mutant of the system has been generated and "killed"

Visualizing Mutation



Each arrow represents **one small change**, such as replacing a constant 1 with 0, or exchanging addition for subtraction

Radioactivity
It's in the air for you and me

Chain reaction and mutation
Contaminated population (Kraftwerk)

Kinds of Systematic Mutation

- **Value** mutations (changing constants, subscripts, or parameters by adding or subtracting one, etc.)
- **Decision** mutations (inverting or otherwise modifying the sense of each decision condition in the program)
- **Statement** mutation (deleting or exchanging individual statements in the program)

Why does this make sense?

- As we discussed weeks ago:

  quality is not accidental
- **Almost any change** to a high-quality program, or even a middling-quality program, will create a bug
- (Analogies: math, literature...)

Example 1: Value Mutation

- System: Mutate the value of each constant (or more generally, each integer expression) in the program by adding or subtracting 1
- Completion criterion:
  One mutant for each constant in the program
- Note that there are many other possible value mutations:
  - Constants modified in some other way, e.g. off by -1
  - All integer expressions modified (not just constants) e.g. x changed to x+1, etc.
  - Floating-point: off by 0.00001, ...

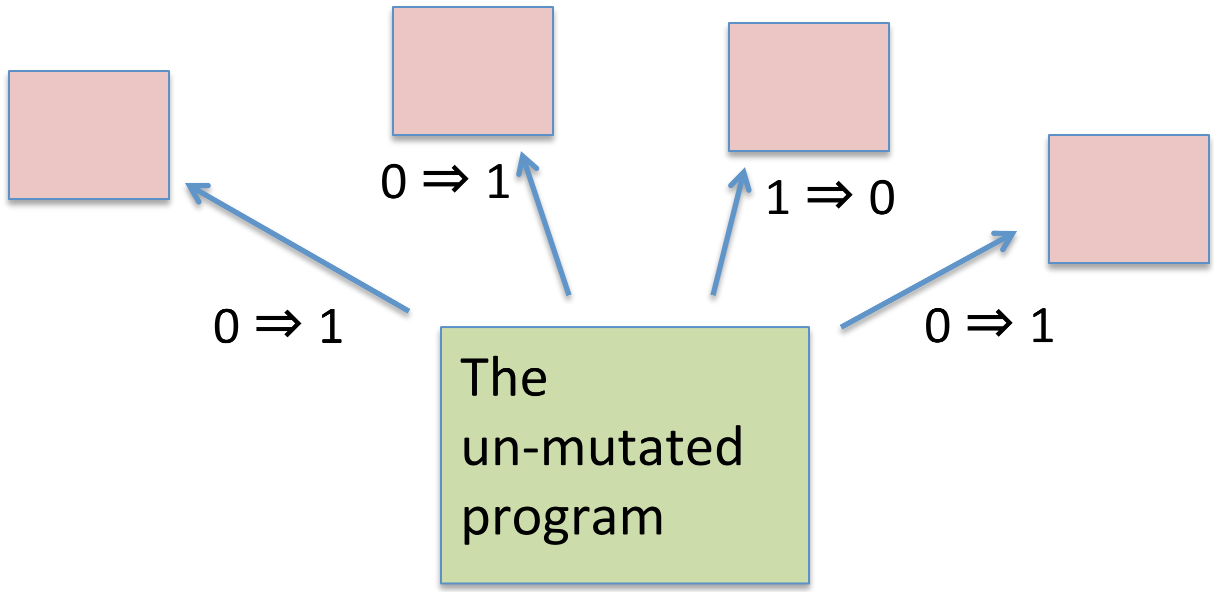
Example 1: Value Mutation

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Example test suite (statement coverage)

Test	x	y	output
T1	0	0	"y is 0"
T2	0	1	"x is 0"
T3	1	1	1

Visualizing Mutation



Each arrow represents **one small change**, such as replacing a constant 1 with 0, or exchanging addition for subtraction

Example 1: Value Mutation

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 1)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Test	x	y	output of original	output of mutant
T1	0	0	"y is 0"	"x is 0"
T2	0	1	"x is 0"	"y is 0"
T3	1	1	1	"y is 0"

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x == 1)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Test	x	y	output of original	output of mutant
T1	0	0	"y is 0"	"y is 0"
T2	0	1	"x is 0"	
T3	1	1	1	"x is 0"

Example 1: Value Mutation

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 2; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Test	x	y	output of original	output of mutant
T1	0	0	"y is 0"	"y is 0"
T2	0	1	"x is 0"	"x is 0"
T3	1	1	1	

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 1)
            c.println (i);
    }
}
```

Test	x	y	output of original	output of mutant
T1	0	0	"y is 0"	"y is 0"
T2	0	1	"x is 0"	"x is 0"
T3	1	1	1	

Example 2: Decision Mutation

- **System**: Invert the sense of each decision condition in the program
  - e.g., change > to < (or <=), == to !=, and so on
- **Completion criterion**: One mutant for each decision condition in the program

Example 2: Decision Mutation

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Example test suite (statement coverage)

Test	x	y	output
T1	0	0	"y is 0"
T2	0	1	"x is 0"
T3	1	1	1

Example 2: Decision Mutation

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y != 0)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Test	x	y	output of original	output of mutant
T1	0	0	"y is 0"	"x is 0"
T2	0	1	"x is 0"	"y is 0"
T3	1	1	1	"y is 0"

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x != 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Test	x	y	output of original	output of mutant
T1	0	0	"y is 0"	"y is 0"
T2	0	1	"x is 0"	
T3	1	1	1	"x is 0"

Example 2: Decision Mutation

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i > x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Test	x	y	output of original	output of mutant
T1	0	0	"y is 0"	"y is 0"
T2	0	1	"x is 0"	"x is 0"
T3	1	1	1	

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y != 0)
            c.println (i);
    }
}
```

Test	x	y	output or original	output of mutant
T1	0	0	"y is 0"	"y is 0"
T2	0	1	"x is 0"	"x is 0"
T3	1	1	1	

Example 3: Statement Mutation

- System: Delete each statement in the program
- Completion criterion:
  One mutant for each statement
- Many other possible statement mutations:
  - Interchanging adjacent statements
  - Reordering sequences of statements
  - Doubling statements
  - …

Example 3: Statement Mutation

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    c.println ("y is 0");
else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Example test suite (statement coverage)

Test	x	y	output
T1	0	0	"y is 0"
T2	0	1	"x is 0"
T3	1	1	1

Example 3: Statement Mutation

```
// calculate numbers less than x
//   which are divisible by y

int x, y;
x = c.readInt ();
y = c.readInt ();

if (y == 0)
    

else if (x == 0)
    c.println ("x is 0");
else {
    for (int i = 1; i <= x; i++) {
        if (i % y == 0)
            c.println (i);
    }
}
```

Test	x	y	output of original	output of mutant
T1	0	0	"y is 0"	
T2	0	1	"x is 0"	"x is 0"
T3	1	1	1	1

- This time, we show only one example - you can make the rest!
- All statement mutants of this program turn out to be “killed” by our simple test set

Determining Test Suite Adequacy

- If D is the number of dead mutants (program variations that were caught by our existing test suite),
  and M is the total number of mutants

mutation adequacy score = D / M

Some Observations

- In practice, simple statement coverage will suffice to "kill" most kinds of mutants
- Thus they can detect most kinds of accidental faults that might be introduced into a working program
  - Quality is not accidental; this is why coverage tests are worth doing
- However, mutation can catch missing test cases even in coverage tests
- Since most projects use primarily black box techniques, automated mutation testing can be valuable in making test suites more effective

Advantages and Disadvantages

- Advantages
  - Provides a good check for quality of a test suite, however created
  - Once “baseline” of correct results of a test suite has been checked, testing adequacy of the suite using mutation can be automated
- Disadvantages
  - Expensive - generates a huge number of mutants, many really checking the same cases
  - Detecting mutant equivalence is a big problem

Summary

- Mutation Testing
  - Mutation testing is a white box method for automatically checking test suites for completeness
  - Mutations are simple, syntactic variants of programs that can be generated automatically
  - Typical mutations are value mutations, decision mutations, statement mutations
  - Mutation can find missing test cases in a test suite
  - Statement coverage is a strong testing system, usually "kills" most kinds of mutants

Summary

- References
  - Van Vliet ch. 13.6
- Next Time
  - Continuous testing methods
- Then
  - **Mini-Exam #2**, Mon. October 22nd