CSE403 ● Software engineering ● sp12

Week 5-6				
Monday	Tuesday	Wednesday	Thursday	Friday
• Testing III • No reading	• Group meetings	• Testing IV	• Section • ZFR due	• ZFR demos • Progress report due • Readings out

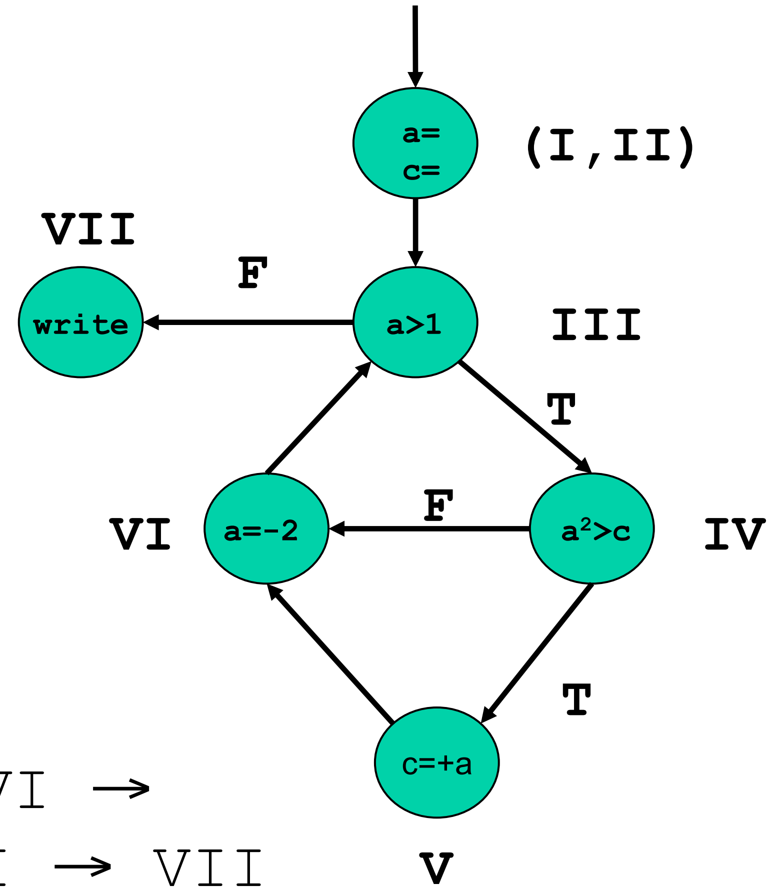
Today: symbolic & mutation testing

- Symbolic example from Michael Beder
  - Basic idea of symbolic testing is to consider inputs as symbols, not values
  - Track predicates and constraints over those symbols through the control flow graph (CFG)
  - Can help in determining inputs that will cause the execution of particular paths
- Mutation testing – an approach to assessing test suites
  - Systematically change (mutate) the program being tested
  - If the test suite cannot distinguish the original program from the mutated program, it has a weakness

Example

all variables are `ints`

```
I   a = read(b)
II  c = 0
III while (a > 1) {
IV     if (a^2 > c)
V         c = c + a
VI     a = a - 2
    }
VII write(c)
```



What input(s) will take path:

(I,II) → III → IV → V → VI →
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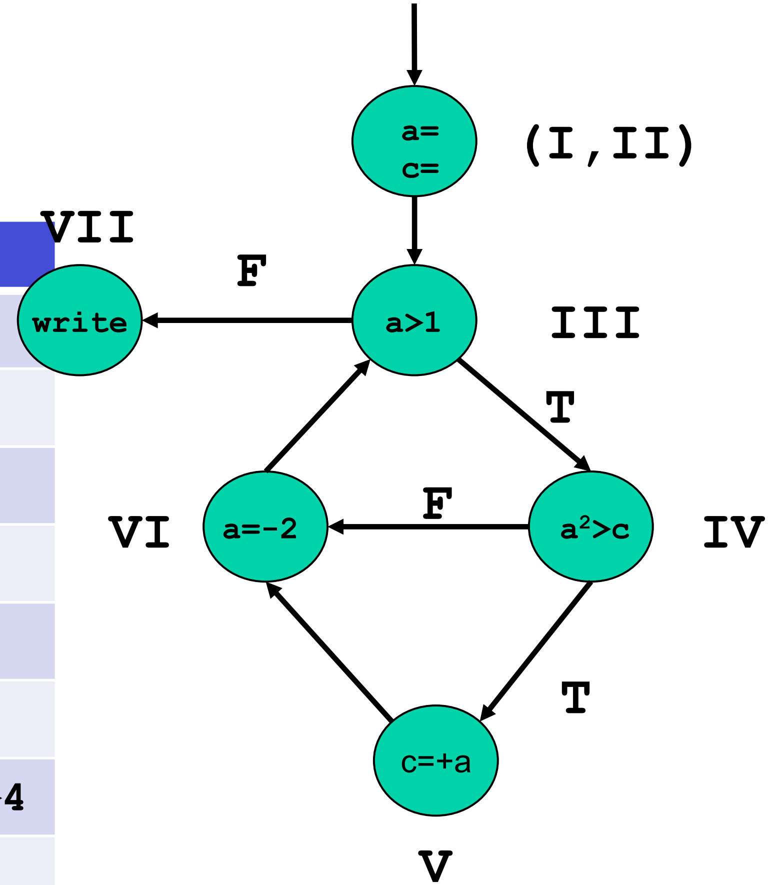
What input(s) will take path:

(I,II)→III → IV → V → VI→ III → IV → V → VI → III→ VII

After-node	[A,B,C]	Condition
(I,III)	(B,B,0)	true
III	(B,B,0)	$B>1$
IV	(B,B,0)	$B>1 \wedge B^2>0 \equiv B>1$
V	(B,B,B)	$B>1$
VI	(B-2,B,B)	$B>1$
III	(B-2,B,B)	$B>1 \wedge B-2>0 \equiv B>3$
IV	(B-2,B,B)	$B>3 \wedge (B-2)^2>B \equiv B>4$
V	(B-4,B,2B-2)	$B>4$
VI	(B-4,B,2B-2)	$B>4$
III	(B-4,B,2B-2)	$B>4 \wedge (B-4)<=1 \equiv B=5$



Expected result for input B=5

What happens when solving …

- $B>3 \land (B-2)^2>B$ (or such) is hard?
- Remember, we have to automate all these steps if they are going to be genuinely useful
- Come on Wednesday…

Mutation testing

- Mutation testing is an approach to evaluate – and to improve – test suites
- Basic idea
  - Create small variants of the program under test
  - If the tests don't exhibit different behavior on the variants then the test suite is not sufficient
- The material on the following slides is due heavily to Pezzè and Young on fault-based testing

Estimation

- Given a big bowl of marbles, how can we estimate how many?
- Can’t count every marble individually

What if I also…

- … have a bag of 100 other marbles of the same size, but a different color (say, black) and mix them in?
- Draw out 100 marbles at random and find 20 of them are black
- How many marbles did we start with?

Estimating test suite quality

- Now take a program with bugs and create 100 variations each with a new and distinct bug
  - Assume the new bugs are exactly like real bugs in every way
- Run the test suite on all 100 new variants
  - ... and the tests reveal 20 of the bugs
  - … and the other 80 program copies do not fail
- What does this tell us about the test suite?

Basic Assumptions

- The idea is to judge effectiveness of a test suite in finding real faults by measuring how well it finds seeded fake faults
- Valid to the extent that the seeded bugs are representative of real bugs: not necessarily identical but the differences should not affect the selection

Mutation testing

- A mutant is a copy of a program with a mutation: a syntactic change that represents a seeded bug
  - Ex: change `(i < 0)` to `(i <= 0)`
- Run the test suite on all the mutant programs
- A mutant is killed if it fails on at least one test case
  - That is, the mutant is distinguishable from the original program by the test suite, which adds confidence about the quality of the test suite
- If many mutants are killed, infer that the test suite is also effective at finding real bugs

Mutation testing assumptions

- Competent programmer hypothesis: programs are nearly correct
  - Real faults are small variations from the correct program and thus mutants are reasonable models of real buggy programs
- Coupling effect hypothesis: tests that find simple faults also find more complex faults
  - Even if mutants are not perfect representatives of real faults, a test suite that kills mutants is good at finding real faults, too

Mutation Operators

- Syntactic change from legal program to legal program and are thus specific to each programming language
- Ex: constant for constant replacement
  - from **`(x < 5)`** to **`(x < 12)`**
  - Maybe select from constants found elsewhere in program text
- Ex: relational operator replacement
  - from **`(x <= 5)`** to **`(x < 5)`**
- Ex: variable initialization elimination
  - from **`int x = 5;`** to **`int x;`**

Live mutants scenario

- Create 100 mutants from a program
  - Run the test suite on all 100 mutants, plus the original program
  - The original program passes all tests
  - 94 mutant programs are killed (fail at least one test)
  - 6 mutants remain *alive*
- What can we learn from the living mutants?

How mutants survive

- A mutant may be equivalent to the original program
  - Maybe changing `(x < 0)` to `(x <= 0)` didn't change the output at all!
  - The seeded "fault" is not really a "fault" – determining this may be easy or hard or in the worst case undecideable
- Or the test suite could be inadequate
  - If the mutant could have been killed, but was not, it indicates a weakness in the test suite
  - But adding a test case for just this mutant is a bad idea – why?

Weak mutation: a variation

- There are lots of mutants – the number of mutants grows with the square of program size
- Running each test case to completion on every mutant is expensive
- Instead execute a “meta-mutant” that has many of the seeded faults in addition to executing the original program
  - Mark a seeded fault as “killed” as soon as a difference in an intermediate state is found – don’t wait for program completion
  - Restart with new mutant selection after each “kill”

Statistical Mutation: another variation

- Running each test case on every mutant is expensive, even if we don’t run each test case separately to completion
- Approach: Create a random sample of mutants
  - May be just as good for assessing a test suite
  - Doesn’t work if test cases are designed to kill particular mutants

In real life ...

- Fault-based testing is a widely used in semiconductor manufacturing
  - With good fault models of typical manufacturing faults, e.g., “stuck-at-one” for a transistor
  - But fault-based testing for design errors – as in software – is more challenging
- Mutation testing is not widely used in industry
  - But plays a role in software testing research, to compare effectiveness of testing techniques
- Some use of fault models to design test cases is important and widely practiced

Summary

- If bugs were marbles ...
  - We could get some nice black marbles to judge the quality of test suites
- Since bugs aren't marbles ...
  - Mutation testing rests on some troubling assumptions about seeded faults, which may not be statistically representative of real faults
- Nonetheless ...
  - A model of typical or important faults is invaluable information for designing and assessing test suites

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• Testing III • Readings due	• Group meetings	• TBA	• Section • ZFR due	• ZFR demos