CS 5154: Software Testing

Syntax-Based Coverage and Mutation Testing

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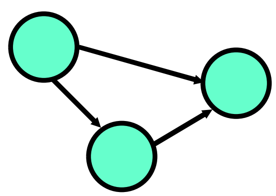
Recall the four software models in this course

Input Domains

A: {0, 1, >1}
B: {600, 700, 800}
C: {cs, ece, is, sds}

Graphs



Logic Expressions

(!x | !y) & a & b

Syntax

```
if (x > y)
   z = x - y;
else
   z = 2 * x;
```

Conversation with a student after ISP HW

Student: I feel like I followed everything that you taught us, but I still don't know if I am doing it right…

Owolabi: How do you mean?

Student: Well, I don't know if the tests that I wrote are good enough and I don't know when to stop!

Owolabi: ☹

Question for you…

- You have followed all the MDTD criteria that we taught you
- You have written test that satisfy "strong" coverage criteria
- But, how good are those tests for finding faults?

CS5154 is organized into six themes

1. How to automate the execution of tests?
2. How to design and write high-quality tests?
3. How to measure the quality of tests?
4. How to automate the generation of tests?
5. How to reduce the costs of running existing tests?
6. How to deal with bugs that tests reveal?

What do we do in mutation testing?

Make small syntactic changes to source code and see if a test suite is strong enough to detect them

Benefits of mutation testing

- Mutation testing provides a way to evaluate the quality of test suites

- Mutation testing also helps discover tests that should be added

- Mutation testing can also help to discover faults in programs

Why learn about mutation testing?

- The “P” in the RIPR model
  - Check whether errors are propagating to the state that test oracles check
- There is a lot of tool support for mutation testing
- Mutation testing is gaining adoption in industry and in open source

Companies are using mutation testing

2018 ACM/IEEE 40th International Conference on Software Engineering: Software Engineering in Practice

State of Mutation Testing at Google

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2018

An Industrial Application of Mutation Testing: Lessons, Challenges, and Research Directions

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2019

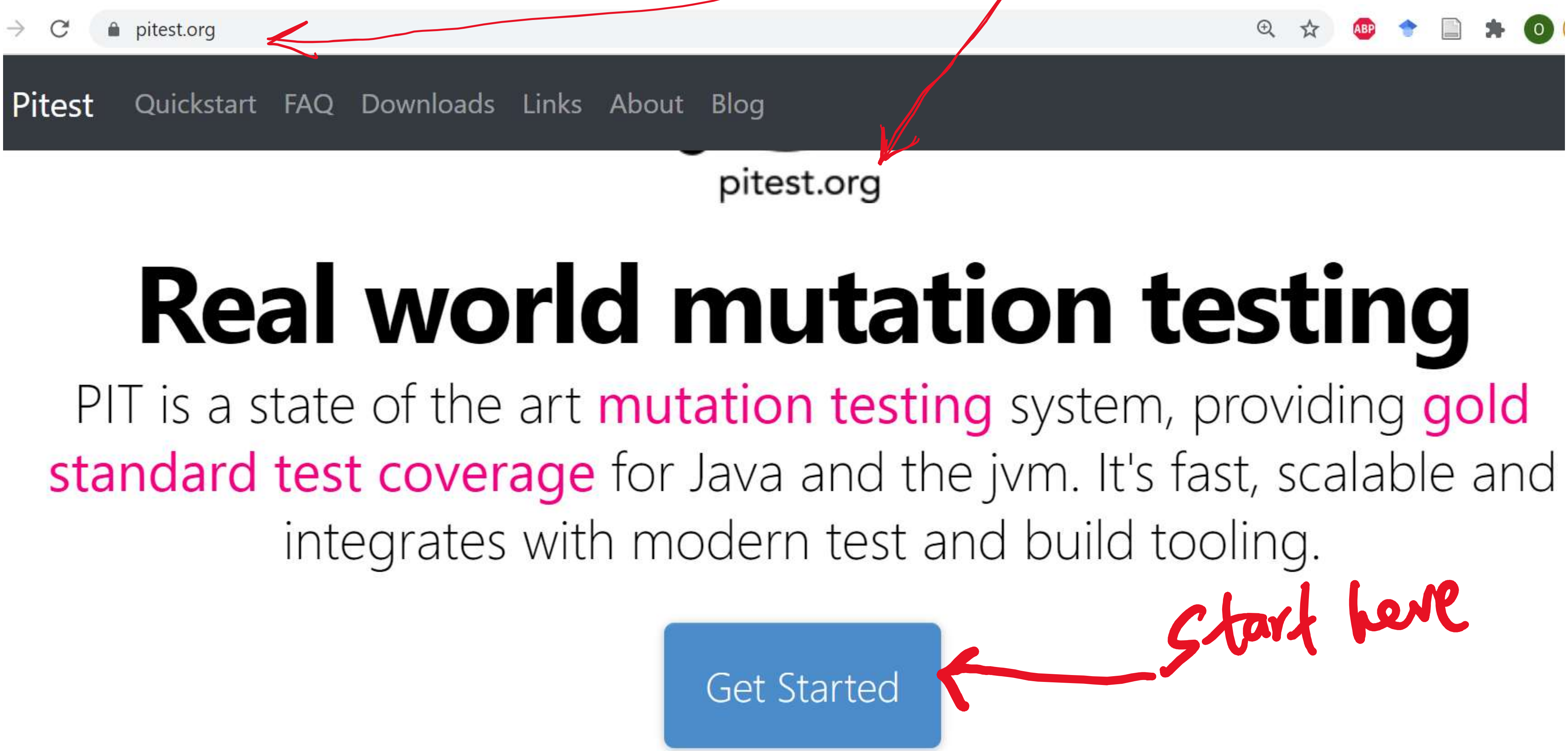
- Articles should be available for FREE @ Cornell Library
- Do NOT pay to read these articles

How we will learn mutation testing

- Today: see mutation testing in action
- Next: discuss mutation testing in more detail

Demo on mutation testing

www.pitest.org



start here

Getting Started

Pitest   Quickstart   FAQ   Downloads   Links   About   Blog

Quickstart

Improve this page

Out of the box PIT can be launched from the command line, ant or maven. Third party components provide integration with Gradle, Eclipse, IntelliJ and others (see the links section for details).

The impatient can jump straight to the section for their chosen build tool - it may however be helpful to read the basic concepts section first.

Getting started

Maven quick start

We showed how to set up for maven

Command line quick start

Basic Concepts

Read the whole page

pitest.org/quickstart/basic_concepts/

Pitest Quickstart FAQ Downloads Links About Blog

Basic Concepts

Improve this page

Mutation Operators

PIT applies a configurable set of mutation operators (or mutators) to the byte code generated by compiling your code.

For example the `CONDITIONALS_BOUNDARY_MUTATOR` would modify the byte code generated by the statement

```
if ( i >= 0 ) {
    return "foo";
} else {
    return "bar";
}
```

To be equivalent to

```
if ( i > 0 ) {
    return "foo";
} else {
    return "bar";
```

Mutation Operators (or mutators)

pitest.org/quickstart/mutators/

Pitest Quickstart FAQ Downloads Links About Blog

Available mutators and groups

why groups?

The following table list available mutators and whether or not they are part of a group :

Mutators	"OLD_DEFAULTS" group	"DEFAULTS" group	"STRONGER" group	"ALL" group
Conditionals Boundary	yes	yes	yes	yes
Increments	yes	yes	yes	yes
Invert Negatives	yes	yes	yes	yes

Be familiar with all default mutators

What we covered in the demo

- GitLab pages setup for Jacoco and PIT
- Parsing the PIT Maven output
- Parsing the PIT reports
- Killed Mutants and Surviving Mutants
- Equivalent Mutants
- Benefits of mutation testing: strengthening test suites and finding faults
- Mutation Operators
- Saving costs by using groups with fewer mutators
- Higher-order mutants

Task: read more about these concepts

- See “notes” links for mutation testing dates on the course webpage
- Those “notes” contain the relevant PIT web pages that we discussed in the demo
- Focus on the relevant parts, but you can learn a lot by reading them all
  - 40 pages, but lots of space in there

Task: play with the demo code

- See your group's "mutationdemo" project on GitLab

Killing Mutants

Given a mutant $m \in M$ for a program P and a test t, t is said to kill m if and only if the output of t on P is different from the output of t on m.

- Testers can keep adding tests until all mutants are killed
- Or, the process of killing mutants can help developers to find faults

Some types of mutants

- *Dead mutant* : A test case has killed it
- *Stillborn mutant* : Syntactically illegal
- *Trivial mutant* : Almost every test can kill it
- *Equivalent mutant* : No test can kill it (same behavior as original)
- *Higher-order mutant* : differs from original in more than one location

Mutation operators

- Rules for making small syntactic changes to the original program
- Mutation testing: can the tests can detect those changes?
- Well-designed mutation operators yield very powerful tests
- Operators are designed for different prog. languages and goals

One syntax-based coverage criteria

Mutation Coverage (MC) : For each $m \in M$, TR contains exactly one requirement, to kill m.

Mutation testing and the RIPR model

- *Reachability* : Tests cause faulty (i.e., mutated) statements to be reached
- *Infection* : Tests cause faulty statement to result in an incorrect state
- *Propagation* : The incorrect state propagates to incorrect output
- *Revealability* : The oracles must observe part of the incorrect output

RIPR model yields two variants of mutation coverage

Variant 1: Strongly Killing Mutants

Given a mutant $m \in M$ for a program P and a test t, t is said to *strongly kill* m if and only if the output of t on P is different from the output of t on m

Variant 2: Weakly Killing Mutants

Given a mutant $m \in M$ that modifies a location *l* in a program *P*, and a test *t*, *t* is said to *weakly kill m* if and only if the state of the execution of *P* on *t* is different from the state of the execution of *m* on *t* immediately after *l*

Weakly killing satisfies reachability and infection, but not propagation

Strong vs. Weak Mutant Killing

```
1 boolean isEven (int X){
2   if (X < 0)
3     X = 0 - X;
Δ3    X = 0;
4   if (double) (X/2) == ((double) X) / 2.0
5     return (true);
6   else
7     return
8 }
```

Reachability : X < 0

(X = -6) will kill mutant Δ3 under weak mutation

Propagation : ((double) ((0-X)/2) == ((double) 0-X) / 2.0)

!=   ((double) (0/2) == ((double) 0) / 2.0)

That is, X is not even …

Thus (X = -6) does *not* kill the mutant under strong mutation

Exercise: More on Weak mutant killing

```
int Min (int A, int B) {
   int minVal;
   minVal = A;
Δ1 minVal = B;
   if (B < A){
      minVal = B;
   }
   return (minVal);
} // end Min
```

1. Find a test input that weakly kills the mutant, but not strongly
2. Generalize : What predicate must be true to weakly kill the mutant, but not strongly?
3. Write down the conditions needed to (i) reach the mutated statement, (ii) infect the program state, and (iii) propagate to the output

More on Weak Mutation (contd)

1. Find a test that weakly kills the mutant, but not strongly

   A = 5, B = 3

2. Generalize : What predicate must be true to weakly kill the mutant, but not strongly?

   B < A // minVal is set to B for both

3. RIP conditions

   Reachability : *true* // we always reach

   Infection : *A ≠ B // minVal has a different value*

   Propagation : (*B < A) = false // Take a different branch*

Recall from last class

Given a mutant $m \in M$ that modifies a location l in a program P, and a test t, t is said to *weakly kill* m if and only if the state of the execution of P on t is different from the state of the execution of m on t immediately after l

Weakly killing satisfies reachability and infection, but not propagation

Q: If weak killing does not propagate to test output, why do we say that the mutant is killed?

Why does mutation testing work?

Fundamental Premise of Mutation Testing

If the software contains a fault, there will usually be a set of mutants that can only be killed by a test case that also detects that fault

- This is not an absolute! (note the “usually”)
- The mutants guide the tester to an effective set of tests
- Of course, this depends on the mutation operators …

Some notes on mutation operators

- At the method level, mutation operators for different programming languages are similar

- Mutation operators do one of two things :
  - Mimic typical programmer mistakes (incorrect variable name)
  - Encourage common test heuristics (cause expressions to be 0)

Exercise: Mutation Testing and Subsumption

- Mutation subsumes other (ISP, graph-based, and logic-based) criteria by including specific mutation operators

- See pages 251 to 255 in the textbook

What we saw so far

- Mutation is widely considered the strongest test criterion
  - And most expensive !
  - By far the most test requirements (each mutant)
  - Usually, mutation test requirements yield the most tests

Next

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