Software testing

Fault-based testing

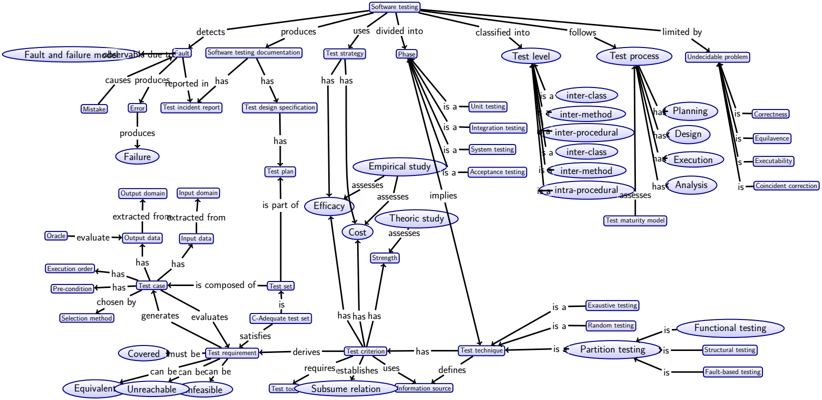
Marco Aurélio Graciotto Silva[1], Ellen Francine Barbosa[1], Márcio Eduardo Delamaro[1], Auri Marcelo Rizzo Vincenzi[2], José Carlos Maldonado[1]

[1]University of São Paulo (USP)
São Carlos, SP, Brazil

[2]Federal University of Goiás (UFG)
Goiânia, GO, Brazil

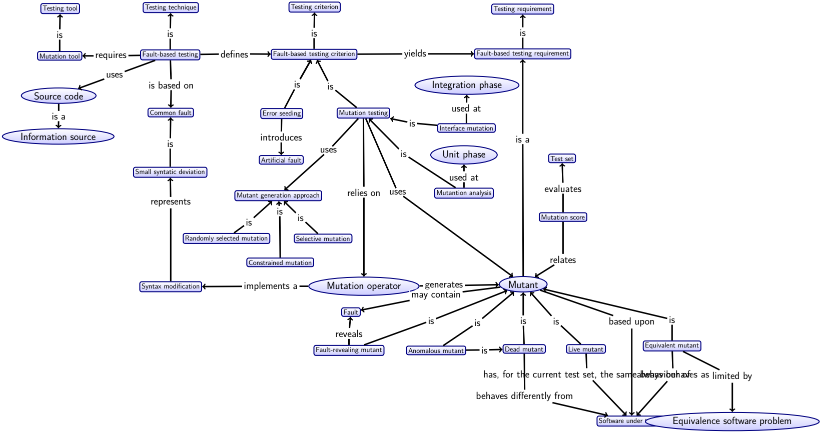
February 2011

Software testing



Software testing
detects
produces
uses
divided into
classified into
follows
limited by
Fault and failure models
observable due to
Fault
Software testing documentation
Test strategy
Phase
Test level
Test process
Undecidable problem
causes
produces
reported in
has
has
has
has
Mistake
Error
Test incident report
Test design specification
produces
Failure
has
Test plan
is a
Unit testing
is a
Integration testing
is a
System testing
is a
Acceptance testing
is a
inter-class
is a
inter-method
is a
inter-procedural
is a
inter-class
is a
inter-method
is a
intra-procedural
has
Planning
has
Design
has
Execution
has
Analysis
assesses
Test maturity model
is
Correctness
is
Equilavence
is
Executability
is
Coincident correction
Empirical study
assesses
assesses
implies
Efficacy
Theoric study
Cost
assesses
Strength
is part of
Output domain
Input domain
extracted from
extracted from
Oracle
evaluate
Output data
Input data
has
has
Execution order
has
Pre-condition
has
Test case
is composed of
Test set
chosen by
Selection method
generates
evaluates
is
C-Adequate test set
satisfies
has
has
has
Covered
must be
Test requirement
derives
Test criterion
has
Test technique
can be
can be
can be
Equivalent
Unreachable
Infeasible
requires
establishes
uses
defines
Test tool
Subsume relation
Information source
is a
Exaustive testing
is a
Random testing
is a
Partition testing
is
Functional testing
is
Structural testing
is
Fault-based testing

Fault-based testing



Testing tool

Testing technique

Testing criterion

Testing requirement

is

is

is

is

Mutation tool

requires

Fault-based testing

defines

Fault-based testing criterion

yields

Fault-based testing requirement

uses

is based on

is

is

Integration phase

Source code

used at

is a

Common fault

Error seeding

Mutation testing

is

Interface mutation

Information source

introduces

is a

is

uses

is

Unit phase

Artificial fault

Test set

Small syntactic deviation

used at

evaluates

Mutant generation approach

relies on

uses

Mutantion analysis

represents

is

is

is

Randomly selected mutation

Selective mutation

Mutation score

Constrained mutation

relates

Syntax modification

implements a

Mutation operator

generates

may contain

Mutant

Fault

is

is

is

is

based upon

is

reveals

Fault-revealing mutant

Anomalous mutant

is

Dead mutant

Live mutant

Equivalent mutant

has, for the current test set, the same behaviour as

behaves as

limited by

behaves differently from

Software under

Equivalence software problem

Fault-based testing

Fault-based testing

Fault-based testing is a technique in which testing is based on historical information about common faults detected during the software development life cycle.

Rationale

- Fault-based testing technique uses information about:
  - faults which are frequently found in software developments, and
  - specific types of faults that one may want to uncover.

Error seeding

Error seeding

Error seeding introduces a known number of artificial faults in the program under testing before it is tested.

Rationale

- Error seeding is based on the assumption that faults are uniformly distributed in the program.

Error seeding

How it works

- After testing using the error seeding criterion, it is possible to estimate the number of remaining natural faults from the total number of faults found and the rate between natural and artificial faults.

Error seeding

Limitations

- Error seeding requires programs that can support 10,000 faults or more in order to obtain a statistically reliable result.
- The artificial faults generated by error seeding may hide natural faults.
    - This is in general is not the case, as real programs present long pieces of simple code with few faults and small pieces of high complexity and with many faults.

Mutation testing

Mutation testing

Mutation testing is a fault-based test criterion that uses a set of products that differ slightly from product P under testing, named mutants, in order to evaluate the adequacy of a test set T.

Effectiveness

- Mutation testing criterion is one of the most effective test criteria in detecting faults.
- It is frequently used to evaluate the quality of other testing criteria.
- It is frequently used to evaluate the efficacy of a test set.

Mutation testing

Rationale

- Mutation testing is based upon two principles:
  - The competent programmer hypothesis.
  - Coupling effect

Mutantion testing
Competent programmer hypothesis

Competent programmer hypothesis

A good programmer writes correct or close-to-correct programs.

Coupling effect

Complex errors are composition of simple ones.

Mutation testing

Goal

- The goal of mutation testing is to find a test set which is able to reveal the differences between a product P and its mutants (making them behave differently).
- The ideal situation in mutation testing would reveal all the mutants ead, which would indicate that the test set T is adequate for testing P.

Mutation testing

Mutation testing basic procedure

1. The tester should provide a product under testing P and a test set.
2. The program is executed against T and, if a failure occurs, a fault has been revealed and the test is over.
3. If no problem is observed, P may still have hidden faults that T is unable to reveal.
   - In this case, P is submitted to a set of mutation operators which transform P into a set of products called mutants of P.
4. Mutants are executed against the same test set T, generating either live mutants or dead mutants.
5. After executing the mutants and identifying the equivalent ones, an objective measure of test set adequacy is provided by the mutation score.

Mutation testing

Limitations

- The main problem with the mutation testing is the high number of generated mutants and, therefore, the high cost of executing a large number of mutants.
- Mutation testing faces the problem of deciding mutant equivalence which in general is undecidable.
- Mutation testing requires tester intervention in order to determine equivalent mutants.
  - Mutation testing requires good knowledge about the product implementation to ease the task of analyzing live mutants.

Mutant

Mutation testing

- In mutation testing, a single mutation is applied to the program P under testing.
    - Each mutant has a single syntactic transformation related to the original program.
- Tester has to create test cases that show that mutations create incorrect products.

Live mutant

A live mutant is a mutant that has the same behavior of the product P for each test case T.

How to identify one?

- A live mutant must be analyzed by the tester to check whether it is equivalent to product P or whether it can be killed by a new test case, thus promoting the improvement of the test set T.

Mutation testing
Dead mutant

Dead mutant

A dead mutant is a mutant that has a diverse behavior from product P on at least one test case T.

Mutation testing
Equivalent mutant

Equivalent mutant

A mutant M is said equivalent to a product P if, for all input data $d \in D$, $M(d) = P(d)$.

- An equivalent mutant is created by a mutation operation that does not result in a behavioral change for a product P, and, for every test datum in the input domain, P and the mutant always compute the same results.

Fault-revealing mutant

A mutant M is a fault-revealing mutant to a product P if for any test case t such that $P(t) \neq M(t)$ we can conclude that $P(t)$ is not in accordance with the expected result

- The presence of a fault is revealed by killing the mutant.

Mutation testing
Mutation score

Mutation score

Mutation score is the relation between the number of mutants killed by the test set T and the difference between the total number of mutants and the number of mutants equivalent to P.

Meaning

- Mutation score is an objective measure to evaluate the test set adequacy against mutation testing.
  - Mutation score ranges from 0 to 1.
  - The higher the mutation score, the more adequate is the test set.

Mutation testing
Mutation operator

Mutation operator

Mutation operators are rules that define the changes to be carried out in a product P in order to create a mutant.

- Mutation operators model the most frequent faults or syntactic deviations related to a given programming language.

Objectives

- Mutation operators are designed for a target language and should fulfill one of the following objectives:
    - Create a simple syntactic change based on typical errors made by programmers.
    - Force test cases to have a desired property (covering a given branch in the program, for instance).

Test strategy

- Mutation operators can be selected according to the classes or faults to be addressed, allowing the creation of mutants to be done stepwise or even to be divided between testers working independently.

Mutation approaches

- Different mutation approaches can be used to execute mutants against a test set and that may reduce the number of generated mutants.

Mutation approaches

- Randomly selected mutation;
- Constrained mutation;
- Selective mutation.

References

Credits