1. A Framework for Test and Analysis

Angelo Gargantini

February 28, 2024

Goals of Software Testing and Verification

- to assess software qualities

examples of sw qualities

- my program never crashes
- my program works
- my program is useful

- to make it possible to improve the software by finding defects

example of sw defects

- the pointer is not null
- when the user presses OK button, the application ....

Goals of Software Testing and Verification

- to assess software qualities

examples of sw qualities

- my program never crashes
- my program works
- my program is useful

- to make it possible to improve the software by finding defects

example of sw defects

- the pointer is not null
- when the user presses OK button, the application ....

Validation & Verification

Validation

Does the software system meet the user's real needs? are we building the right software?

Specification

A statement (document) about a particular proposed solution to a problem.

Verification

Does the software system meet the requirements specifications? are we building the software right?

Validation & Verification

Validation

Does the software system meet the user's real needs? are we building the right software?

Specification

A statement (document) about a particular proposed solution to a problem.

Verification

Does the software system meet the requirements specifications? are we building the software right?

Validation & Verification

Validation

Does the software system meet the user's real needs? are we building the right software?

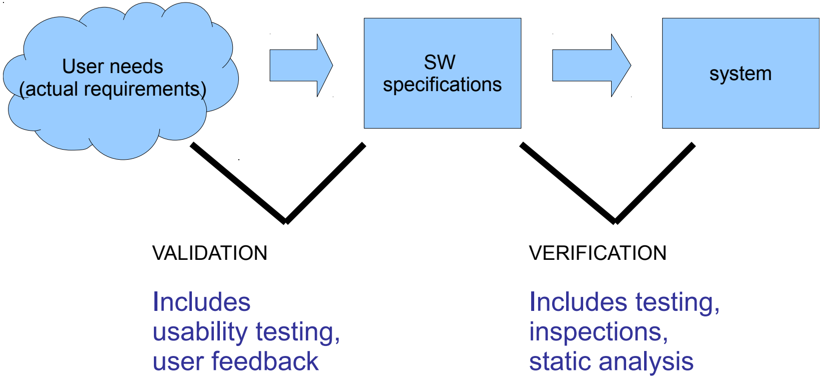
Specification

A statement (document) about a particular proposed solution to a problem.

Verification

Does the software system meet the requirements specifications? are we building the software right?

Validation & Verification



Validation & Verification - standard definitions

IEEE standard in its 4th edition defines the two terms as follows:

Validation. The assurance that a product, service, or system meets the needs of the customer and other identified stakeholders. It often involves acceptance and suitability with external customers. Contrast with verification.

Verification. The evaluation of whether or not a product, service, or system complies with a regulation, requirement, specification, or imposed condition. It is often an internal process. Contrast with validation.

ISO 9001 standard defines them this way :

Verification is the conformation that a product meets identified specifications.

Validation is the conformation that a product appropriately meets its design function or the intended use.

Validation & Verification - standard definitions

IEEE standard in its 4th edition defines the two terms as follows:

Validation. The assurance that a product, service, or system meets the needs of the customer and other identified stakeholders. It often involves acceptance and suitability with external customers. Contrast with verification.

Verification. The evaluation of whether or not a product, service, or system complies with a regulation, requirement, specification, or imposed condition. It is often an internal process. Contrast with validation.

ISO 9001 standard defines them this way :

Verification is the conformation that a product meets identified specifications.

Validation is the conformation that a product appropriately meets its design function or the intended use.

Validation & Verification - standard definitions

Capability Maturity Model (CMMI-SW v1.1):

Software Verification: The process of evaluating software to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase.

Software Validation: The process of evaluating software during or at the end of the development process to determine whether it satisfies specified requirements.

Boehm succinctly expressed the difference between:

Software Verification: Are we building the product right?

Software Validation: Are we building the right product?

Validation & Verification - standard definitions

Capability Maturity Model (CMMI-SW v1.1):

Software Verification: The process of evaluating software to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase.

Software Validation: The process of evaluating software during or at the end of the development process to determine whether it satisfies specified requirements.

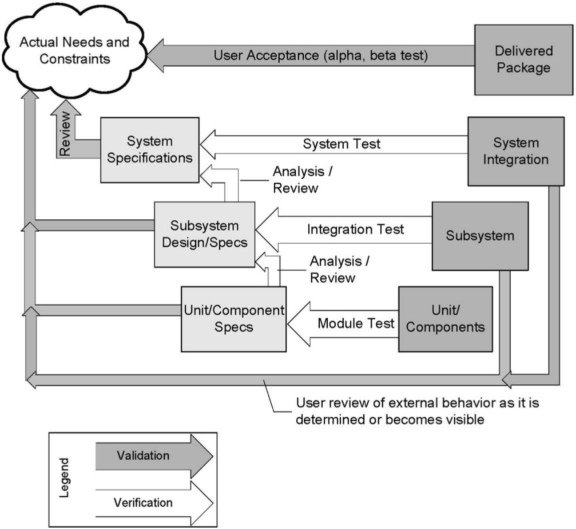
Boehm succinctly expressed the difference between:

Software Verification: Are we building the product right?

Software Validation: Are we building the right product?

Example

Validation & Verification



Verification

- Verification generally compares two or more artifacts
- Verification can consist in checking for *self-consistency* and well-formedness **one** artifact.
  - For example, we can certainly determine that some programs are "incorrect" because they are ill-formed.
  - We may likewise determine that a specification itself is ill-formed because it is inconsistent (requires two properties that cannot both be true) or ambiguous (can be interpreted to require some property or not),
  - or because it does not satisfy some other well-formedness constraint that we impose, such as adherence to a standard imposed by a regulatory agency.

Verification

- Validation against actual requirements necessarily involves human judgment
- Verification can be automatized

Validation & Verification

1. Can we arrive at some logically sound argument or proof that a program satisfies the specified properties?
2. Alan Turing proved that some problems cannot be solved by any computer program.
3. an undecidable problem is a decision problem for which it is known to be impossible to construct a single algorithm that always leads to a correct yes-or-no answer.
4. for instance the halting problem
5. every interesting property regarding the behavior of computer programs can be shown to "embed" the halting problem,

HALTING PROBLEM

Given the description of an arbitrary program and a finite input, decide whether the program finishes running or will run forever.

Validation & Verification

1. Can we arrive at some logically sound argument or proof that a program satisfies the specified properties?
2. Alan Turing proved that some problems cannot be solved by any computer program.
3. an undecidable problem is a decision problem for which it is known to be impossible to construct a single algorithm that always leads to a correct yes-or-no answer.
4. for instance the halting problem
5. every interesting property regarding the behavior of computer programs can be shown to "embed" the halting problem,

HALTING PROBLEM

Given the description of an arbitrary program and a finite input, decide whether the program finishes running or will run forever.

Validation & Verification

1. Can we arrive at some logically sound argument or proof that a program satisfies the specified properties?
2. Alan Turing proved that some problems cannot be solved by any computer program.
3. an undecidable problem is a decision problem for which it is known to be impossible to construct a single algorithm that always leads to a correct yes-or-no answer.
4. for instance the halting problem
5. every interesting property regarding the behavior of computer programs can be shown to "embed" the halting problem,

HALTING PROBLEM

Given the description of an arbitrary program and a finite input, decide whether the program finishes running or will run forever.

Validation & Verification

1. Can we arrive at some logically sound argument or proof that a program satisfies the specified properties?
2. Alan Turing proved that some problems cannot be solved by any computer program.
3. an undecidable problem is a decision problem for which it is known to be impossible to construct a single algorithm that always leads to a correct yes-or-no answer.
4. for instance the halting problem
5. every interesting property regarding the behavior of computer programs can be shown to "embed" the halting problem,

HALTING PROBLEM

Given the description of an arbitrary program and a finite input, decide whether the program finishes running or will run forever.

Validation & Verification

1. Can we arrive at some logically sound argument or proof that a program satisfies the specified properties?
2. Alan Turing proved that some problems cannot be solved by any computer program.
3. an undecidable problem is a decision problem for which it is known to be impossible to construct a single algorithm that always leads to a correct yes-or-no answer.
4. for instance the halting problem
5. every interesting property regarding the behavior of computer programs can be shown to "embed" the halting problem,

HALTING PROBLEM

Given the description of an arbitrary program and a finite input, decide whether the program finishes running or will run forever.

Exhaustive testing

```
static int sum(int a, int b) {return a+b;}
```

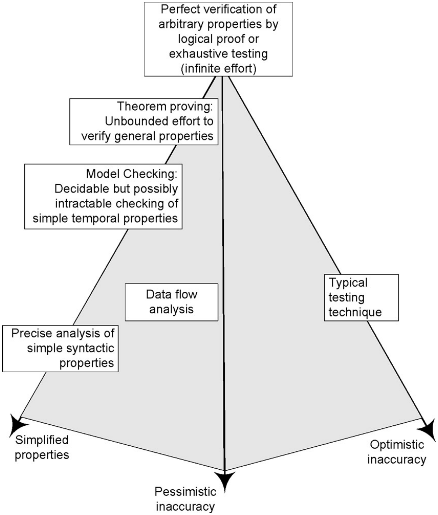
1. Exhaustive testing, that is, executing and checking every possible behavior of a program, would be a "proof by cases," which is a correct way to construct a logical proof. How long would this take?
2. there are only $2^{32} \times 2^{32} = 2^{64} \approx 10^{21}$ different inputs on which the method Trivial.sum() need be tested to obtain a proof of its correctness. At one nanosecond (10^{-9} seconds) per test case, this will take approximately 10^{12} seconds, or about 30,000 years.

Exhaustive testing

```
static int sum(int a, int b) {return a+b;}
```

1. Exhaustive testing, that is, executing and checking every possible behavior of a program, would be a "proof by cases," which is a correct way to construct a logical proof. How long would this take?
2. there are only $2^{32} \times 2^{32} = 2^{64} \approx 10^{21}$ different inputs on which the method Trivial.sum() need be tested to obtain a proof of its correctness. At one nanosecond (10^{-9} seconds) per test case, this will take approximately 10^{12} seconds, or about 30,000 years.

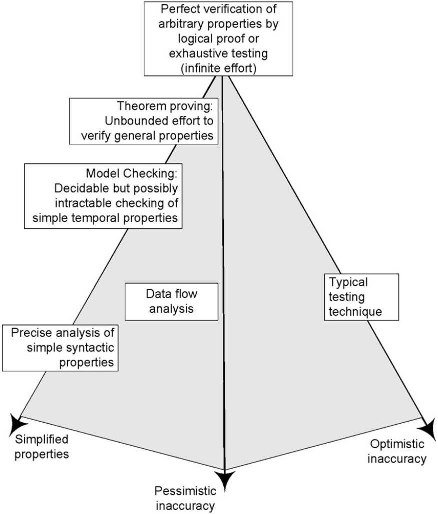
Pessimistic and Optimistic inaccuracy



A (testing/analysis) technique can be approximate:

1. pessimistic : it is not guaranteed to accept a program even if the program does possess the property being analyzed
2. optimistic : if it may accept some programs that do not possess the property (i.e., it may not detect all violations)

Simplification/abstraction



1. we want to verify a property S, but
   1. we cannot accept the optimistic inaccuracy of testing for S
   2. precise analysis is too difficult
2. a simpler property S' is a sufficient, but not necessary, condition for S
3. we check S' rather than S
4. we require S' to be satisfied

Simplification/abstraction Example

```
int i, sum;
bool first=true;
for (i=0; i<10; ++i) {
  if (first) {
    sum=0; first=false;
  }
  sum += i;
}
```

Property: each variable should be initialized with a value before its value is used in an expression

1. P vale??
2. in C language?
3. in Java ???

Simplification/abstraction Example

```
int i, sum;
bool first=true;
for (i=0; i<10; ++i) {
  if (first) {
    sum=0; first=false;
  }
  sum += i;
}
```

Property: each variable should be initialized with a value before its value is used in an expression

1. P vale??
2. in C language?
3. in Java ???

Simplification/abstraction Example

```
int i, sum;
bool first=true;
for (i=0; i<10; ++i) {
  if (first) {
    sum=0; first=false;
  }
  sum += i;
}
```

Property: each variable should be initialized with a value before its value is used in an expression

1. P vale??
2. in C language?
3. in Java ???

Simplification/abstraction Example

```
int i, sum;
bool first=true;
for (i=0; i<10; ++i) {
  if (first) {
    sum=0; first=false;
  }
  sum += i;
}
```

Property: each variable should be initialized with a value before its value is used in an expression

1. P vale??
2. in C language?
3. in Java ???

Example of simplified property: Unmatched Semaphore Operations

Property: every semaphore it is eventually unlocked

```
if ( .... ) {
...        lock(S);
}
...
if ( ... ) {
    ...        unlock(S);
}
```

Static checking for match is necessarily inaccurate ...

Java solution: synchronized statements specify the object that provides the intrinsic lock

```
synchronized(S) {
        ...
}
```

It is guarenteed that the lock S is released.

Example of simplified property: Unmatched Semaphore Operations

Property: every semaphore it is eventually unlocked

```
if ( .... ) {
...       lock(S);
}
...
if ( ... ) {
    ...       unlock(S);
}
```

Static checking for match is necessarily inaccurate ...

Java solution: synchronized statements specify the object that provides the intrinsic lock

```
synchronized(S) {
        ...
}
```

It is guarenteed that the lock S is released.

How to deal with undecideble problems

1. optimistic inaccuracy: we may accept some programs that do not possess the property (i.e., it may not detect all violations).
   - testing
2. pessimistic inaccuracy: it is not guaranteed to accept a program even if the program does possess the property being analyzed
   - automated program analysis techniques
3. simplified properties: reduce the degree of freedom for simplifying the property to check

How to deal with undecideble problems

1. optimistic inaccuracy: we may accept some programs that do not possess the property (i.e., it may not detect all violations).
   - testing
2. pessimistic inaccuracy: it is not guaranteed to accept a program even if the program does possess the property being analyzed
   - automated program analysis techniques
3. simplified properties: reduce the degree of freedom for simplifying the property to check

How to deal with undecideble problems

1. optimistic inaccuracy: we may accept some programs that do not possess the property (i.e., it may not detect all violations).
    - testing
2. pessimistic inaccuracy: it is not guaranteed to accept a program even if the program does possess the property being analyzed
    - automated program analysis techniques
3. simplified properties: reduce the degree of freedom for simplifying the property to check

Some Terminology

Safe (Sicuro): A **safe** analysis has no optimistic inaccuracy, i.e., it accepts only correct programs.

- if a program is “wrong” it is rejected.

Some Terminology - 2

Sound (Corretto): An analysis of a program P with respect to a formula F is sound if the analysis returns true only when the program does satisfy the formula.

- if a program is accepted, it is correct
- no wrong program is accepted
- there may be correct programs that are not accepted (conservative - pessimistic)
- testing is not sound.

Complete (Completo): An analysis of a program P with respect to a formula F is complete if the analysis always returns true when the program actually does satisfy the formula.

- every correct program is accepted
- a wrong program maybe accepted (optimistic - if unsound)

Sound and Complete: difficult to apply (consider the complexity)

Some Terminology - 2

Sound (Corretto): An analysis of a program P with respect to a formula F is sound if the analysis returns true only when the program does satisfy the formula.

- if a program is accepted, it is correct
- no wrong program is accepted
- there may be correct programs that are not accepted (conservative - pessimistic)
- testing is not sound.

Complete (Completo): An analysis of a program P with respect to a formula F is complete if the analysis always returns true when the program actually does satisfy the formula.

- every correct program is accepted
- a wrong program maybe accepted (optimistic - if unsound)

Sound and Complete: difficult to apply (consider the complexity)

Some Terminology - 2

Sound (Corretto): An analysis of a program P with respect to a formula F is sound if the analysis returns true only when the program does satisfy the formula.

- if a program is accepted, it is correct
- no wrong program is accepted
- there may be correct programs that are not accepted (conservative - pessimistic)
- testing is not sound.

Complete (Completo): An analysis of a program P with respect to a formula F is complete if the analysis always returns true when the program actually does satisfy the formula.

- every correct program is accepted
- a wrong program maybe accepted (optimistic - if unsound)

Sound and Complete: difficult to apply (consider the complexity)