A Metamodel of Unit Testing for Object-Oriented Programming Languages

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ABSTRACT
A unit test is a method for verifying the accuracy and the proper functioning of a portion of a program. This work consists to study the relation and the approaches to test Object-Oriented Programming (OOP) programs and to propose a metamodel that enables the programmer to write the tests while writing the source code to be tested.

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Object-Oriented Programming, Unit Testing, Metamodel

1. INTRODUCTION
A unit test [10] is a method for verifying the accuracy and the proper functioning of a portion of a program. This work consists to study the relation and the approaches to test OOP programs and to propose metamodel that enables the programmer to write the tests while writing the source code to be tested.

This paper is organized as follows. Section 2 gives a state of the art about the relation between OOP programs and the tests. Section 3 describes the proposed metamodel of unit testing for OOP languages. Section 4 gives an example of what could looks like an OOP environment which uses the proposed metamodel. Finally, Section 5 contains the conclusion and future possible work.

2. OOP AND UNIT TESTS

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This section contains the motivations of testing OOP languages differently compared to testing procedural languages. Then, the levels of abstraction for the tests are defined. Finally, current approaches to test OOP languages are discussed.

2.1 Motivations of testing OOP languages differently compared to testing procedural languages
This section describes some reasons why an OOP language must be tested completely differently compared to procedural languages.

Intuitively, specialization and aggregation combined to polymorphism increases the difficulty to detect errors during the integration of several components. The primary goal consists of decreasing the maximum effort to test a unit by reusing as much as possible the tests [9, 8].

2.1.1 Test unit
In procedural languages such as (C, Pascal, etc.), the principal units are the procedure and the module. However, the principal unit in an OOP language is the class [9, 1, 4]. This difference has a huge impact on the methodology to test the software since several new OOP concepts are nonexistent in the procedural paradigm.

2.1.2 Object and encapsulation
Traditional techniques to test procedural languages are not necessary application to the object oriented paradigm since the encapsulation reduces or eliminates the possibility to test a specific state of an attribute of an object [9].

2.1.3 Specialization and inheritance
A method is defines by one of the following characteristic [9]:
1. Inherited from the parent class without redefinition.
2. Redefinition without any call to super.
3. Redefinition with a call to super.
4. A new method nonexistent in the parent classes.

Existing works consider that the tests for cases 2, 3 and 4 must be restested completely compared to the first case which does not require any redefinition.

2.1.4 Polymorphism
Let p(z) be a method named p which take a parameter z where z contains a method m. Depending on the dynamic type of z, several different methods m when z.m is called by polymorphism. It has a huge impact on the tests since several permutations of dynamic types must be passed for the parameters in order cover more lines of code.
2.1.5 OOP language entity dimensions

OOP language entities can be categorized as follows [1]:

- **Object**: A class instance composed of several attributes and methods. An object represents a specific state.
- **Class**: A model which factorizes the properties of its instances.
- **Class hierarchy**: A class inherits the properties of its parent classes.
- **Package (or subsystem)**: A subsystem defines an interface presenting services. A subsystem regroups classes with strong semantic relations. Jin et al. has developed a mechanism which uses a metamodel which allows to test the coupling between units [8].
- **System**: Composed of a set of subsystems and links them together.

2.2 Levels of abstraction for the tests

The principal levels of abstraction for the test are the white box, the black box and the grey box [4]:

- **White box**: White box tests consider the implementation of the classes and the methods.
- **Black box**: Black box tests does not take into account the implementation but only the interface units.
- **Grey box**: Grey box tests take into account the white box and the black box levels.

2.3 Current approaches to test OOP languages

The approaches used in practice and in the research community are based on specifications or on programs.

2.3.1 Specification-based

The first approach to test an object-oriented program consists to use a certain specification language which describes what the packages and the classes are actually doing. With this specification, it is possible to generate several tests automatically in order to verify the correctness of the implementation.

Barbey et al. [2] have used an object oriented specification called Concurrent Object-Oriented Petri Nets (CO-OPN/2). In such a language, an interface describing the attributes in the methods is defined. The axioms enable the programmer to define the comportements of the methods. The main problem in this work is that it does not take into account the characteristics of the OOP paradigm such as polymorphism, specialization, etc.

Several researchers [6, 12] have defined that the state of an object is the result of a certain number of method calls. Doong et al. [6] have used a similar approach compared to the work of Barbey and al., however they specified algebraically the behavior of the classes. The verification of the correctness of a method is done by generating a sequence of method calls. Then axioms are used to validate the results.

The main problems with the specification-based approach is that the programmer must manipulate an extra language only in order to test the software. Also, the tests are most likely not near the source code to be tested which is not good by considering that, in practice, the tests are not updated when the software change.

2.3.2 Program-based

The program-based approach consists to get a certain confidence level by writing manually the tests in order to simulate the main possibilities of execution of the software.

A standard in the industry is the JUnit Framework [3] well used for the Java programming language. The main components of the JUnit Framework are the tests suites and the tests cases. A test case regroups several tests of a class and the suite is used to contains several tests cases. Let say a system has \( N \) classes. Then if there is one test case for each class, then the system will consists of \( 2N + 1 \) classes (Fig. 1).

Another problem with JUnit is the loss of the semantic relations between test classes (Fig. 2). In fact, classes TestClass2 and TestClass3 could be defined to be the subclass of TestClass1 and reuse the code from TestClass1. However it would be done manually. We need something more automatic in order to reuse the tests.

3. METAMODEL OF UNIT TESTING FOR OOP

The proposed metamodel (Fig. 3) is an extension of the metamodel defined by Ducournau et al. [7]. The main motivation of this extension is to add properties specifically for unit tests in order to write unit tests by taking advantage of the mechanisms and the forces of OOP.
3.1 Class and properties

For tests, the following:\n
- Properties to test classes.
- Properties to test class properties.
- Properties to test packages.

The relations defined in [7] are also used and expressed as follows:

- **Redefines (redef)**: Used to redefine a given entity.
- **Has (has)**: Used to know which knowledge is known by a certain entity. For example, it can be useful to know which tests are attached to a given local property.
- **Introduces (intro)**: Useful to know which entity has introduced a property or a test.
- **Belongs to (belongs)**: Useful to know which global entity is associated to a given local entity.
- **Defines (def)**: Used to know which entity has defined a certain property.

### 3.1.1 Property tests

**Global Test Property.**

Let’s express the global test properties which belongs to a certain global property \( g_e \) of a class \( c \) having super classes. \( Parent_{sc} \) represents the set of all super classes of \( c \):

\[
\forall p \in Parent_{sc}, c \prec p
\]  

Let \( G_c \) be the global properties of \( c \), \( L_{g_c} \) the local properties of a given global property \( g_c \in G_c \) of a class \( c \) and its super classes are defined by:

\[
L_{g_c} = \bigcup_{d \in Parent_{sc} \cup \{c\}} \{l_d | belongs(l_d, g_c), l_d \in L_d\} 
\]  

where \( belongs \) is a relation used to know if a local property belongs to a global property.

Then the global test properties \( GTP_{g_c} \) of a given global global property is given by:

\[
GTP_{g_c} = \bigcup_{l_c \in L_{g_c}} \{gtp | has(l_c, gtp), gtp \in GTP_c\} 
\]  

where \( GTP_c \) represents the global test properties of a class \( c \). The relation \( has(l_c, gtp) \) states that \( l_c \) knows \( gtp \).

A *Global Test Property* (GTP) is either inherited from a local property redefinition or introduced by a local property. The introduced global tests \( IGT P_{g_c} \) represent a sub set of \( GTP_{g_c} \):

\[
\bigcup_{d \in Parent_{sc} \cup \{c\}} \{gtp | intro(d, gtp), \exists l_c \in L_{g_c}, has(l_c, gtp), gtp \in GTP_c\} 
\]  

where \( intro(d, gtp) \) means that \( d \) introduces \( gtp \).

**Local Test Property.**

Let define all local test properties \( LTP_c \) for a given class \( c \), the local test properties of a given global property \( g_t_c \) is defined by:

\[
LTPC_{g_t_c} = \bigcup_{l_t_c \in LTP_c} \{l_t_c | belongs(l_t_c, g_t_c)\} 
\]  

However, redefined tests must be removed:
where \( \text{redef}(t_2, t_1) \) is a relation which expresses that the test \( t_2 \) redefines the test \( t_1 \).

### 3.1.2 Class tests

**Global Test Class.**

A global test class is either inherited from a super class or introduced by a given class. Let \( \text{GTC} \) be the global tests class of a system, \( \text{GTC}_c \) the global tests class of a class \( c \) are defined by:

\[
\text{GTC}_c = \bigcup_{t \in \text{GTC}} \{ t \mid \exists c \in \text{Parents}_c \cup \{ c \} \text{intro}(c, t) \}
\]

(7)

**Local Test Class.**

Let \( \text{LTC} \) be the local tests of a class. The local tests of a class \( c \) is given by:

\[
\text{LTCC}_c = \bigcup_{lt \in \text{LTC}} \{ lt \mid \exists gtc \in \text{GTC}_c \text{ belongs}(lt, gtc) \}
\]

(8)

However, redefinitions must be removed:

\[
\text{LTC}_c = \text{LTCC}_c - \bigcup_{t_1 \in \text{LTCC}_c} \{ t_1 \mid \exists t_2 \in \text{LTCC}_c \text{ redef}(t_2, t_1) \}
\]

(9)

### 3.2 Type-Safety

In static typing languages, the redefinition of the return type must covariant and the redefinition of the parameters must be contravariant in order to have safe types. It does not pose any problem for the proposed metamodel since the metamodel is an extension of the existing properties and the notion of property and class is not altered.

### 3.3 Property Conflicts

**3.3.1 Global Test Property**

**Name conflict of tests with inheritance:** by using two times the same global test property associated to the same local property of a super class.

The example in Fig. 4 is an example of a name conflict of tests by using two times the same global test property associated to the same local property of a super class. In this example, two tests for the same method \( \text{operation} \) are defined (\( \text{Test1Operation} \) and \( \text{Test2Operation} \)). Both classes \( B \) and \( C \) define a new test \( \text{Test2Operation} \) which causes a name conflict since two global test property with the same exists for the method \( \text{operation} \).

**Solutions:**

1. Factorize \( B.\text{Test2Operation} \) and \( C.\text{Test2Operation} \) in the super class \( A \) if the test in class \( B \) is the same than the one defined in class \( C \).

2. Redefine \( \text{operation} \) in \( B \) and \( C \).

**3.3.2 Local Test Property**

**Local Test Property name conflict with inheritance.**

Let \( A \) be a super class of \( B \) and \( C \) which introduces a method \( \text{add} \) and a test associated (Fig. 5). The subclasses \( B \) and \( C \) redefine the local test property \( \text{Test1Add} \). Without class \( D \), there
exists no conflict. However, with a class $D$ which can inherit both $B.Test1Add$ and $C.Test1Add$ there is a name conflict: which test should be chosen by the compiler? Depending on the test, three strategies exists with multiple inheritance: rename, select and unify.

### 3.4 Tests execution

A compiler of an object oriented programming language can then execute automatically by using the meta information from the metamodel proposed (Algorithm 1).

Algorithm 1: Executing the tests by using the metamodel (Ex-
eTests).

```
Data: $P$, a set of all packages.
1 foreach $p \in P$ do
2   // Test all packages
3       foreach Test Package $tp$ such that $has(p, tp)$ do
4         Execute $tp$
5     end
6     foreach Class $c$ such that $has(p, c)$ do
7       // Test all classes
8           foreach $ltc \in LTC_c$ do
9               Execute $ltc$
10          end
11     // Test all properties:
12     foreach Global Property $gp$ such that $has(c, gp)$ do
13        foreach Global Test Property such that $gtp$
14          in $GTP_{gp}$ do
15            foreach Local Test Property such that $ltp$
16              in $LTP_{gtp}$ do
17                Execute $ltp$
18           end
19     end
20 end
```

### 4. EXAMPLE

This section contains a very basic example showing the strengths of the proposed metamodel in a real OOP environment like Java.

#### 4.1 First example: Cow, grass and mouse

The example (Fig. 7) contains a super class Animal and two subclasses Cow and Mouse. The Animal class defines a method lastFoodEaten which returns the last food that the animal has recently eaten. That class also introduces a new test property TestNotNull associated to the method lastFoodEaten. This test verify that the food exists when the animal has recently eaten something. The class Cow redefines the method lastFoodEaten and adds a new test TestGrassColor in order to verify that the grass has the right color (Green).

The following listing presents the pseudocode of the first example:

```java
public class Food {
    private List<Color> colors = new ArrayList<Color> ();

    public Food ( Color c ) {
        colors.add ( c );
    }

    public Food () {
    }

    // Returns true if the food is c.
    public boolean isColor ( Color c ) {
        /* ... */
    }
}
```
defines a Property Test named TestName associated to the method f. Let say that a compiler tests those classes in the order of the declaration. Then, the following output would be printed:

- Animal.lastFoodEaten() v1
- Animal.TestNotNull
- Mouse.lastFoodEaten() v1
- Mouse.TestNotNull
- Cow.lastFoodEaten() v2
- Cow.TestNotNull
- Cow.lastFoodEaten() v2
- Cow.TestGrassColor

We can clearly observe the benefit of using the proposed metamodel: the tests defined in a class are also used in the subclasses in order to cover more lines of code automatically.

### 5. CONCLUSION AND FUTURE WORK

There exist two approaches in order to test a OOP software: specification-based and program-based. The approach based on a specification enables the programmer to modelize the behavior of the objects, but this technique is not so interesting since it uses an extra language and the mechanisms used does not take into account the advantages of an OOP language.

The proposed metamodel offers a new approach combining the advantages of the current approaches. The metamodel makes it possible to write unit tests inside the classes to be tested. It facilitates the programmer to write and maintain a software unit. The proposed metamodel contains test properties for the class properties, for the classes and for the packages. There exists specialization links between the tests properties. The metamodel enables the compiler to execute automatically the tests.

The future work is to embed the proposed metamodel in a real OOP environment in order to validate the usability and the reliability. Then, existing systems using for example JUnit will be converted to a system using the proposed metamodel in order to compare the testing approaches.

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Listing 1: Pseudocode of the example.

The listing contains a new keyword Current which correspond to a new instance of the current class, allocated only during the test. The following syntax:

```
Test TestName { ... }
```
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