

Verificarea și Validarea Sistemelor Soft

Informatică – Română

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Java Modeling Language (JML)



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- Motivation
- Formal Specification Languages
- Design by Contract

INTRODUCTION

Motivation



- Why should we use formal methods?
 - civil engineering case

- assuming that we want to build a house...



- How can we make sure that the built house will not collapse?

- Things to do:

- 1) make an (abstract) model
- 2) specify properties for the model
- 3) verify/check the properties



Motivation (2)

- Why should we use formal methods?
 - software engineering case

- assuming that we want to write a software...

```
public interface HouseUtility{  
    public void openWindow();  
    public void closeWindow();  
    // ...  
}
```

- Things to do:

1) make a ***formal model***

2) ***specify properties*** for the model

3) ***verify/check*** the properties

- How can we make sure that the built software works correctly?

Formal Methods in Software Engineering



- Existing formal approaches:
 - 1) **modeling languages:** finite state machines, Z, guarded command language, UML, ...
 - 2) **languages for specifying properties:** predicate logic, Hoare logic, JML, ...
 - 3) **techniques for checking** the specified properties: testing, model checking, theorem proving, ...
- Formal languages guarantee:
 - Precision (no ambiguity);
 - Certainty (modeling errors);
 - Automation (automatic verification tools).

Formal Methods in Software Engineering (2)



- Formal methods and JML:
 - 1) formal model is ***Java programming language***
 - 2) the properties are specified in ***JML***
 - 3) Properties may be
 - ***Tested*** using ***jmlrac***
 - ***Checked*** using ***ESC2Java***

Design by Contract



- Design by Contract (DbC)
 - a general design paradigm
 - states that the first elements of code written for a method, class, or program should be its contracts
- DbC was made popular by the Eiffel programming language, which has contracts built-in
- useful for
 - enabling better compile-time checks
 - enabling easier run-time checks (aspects fit perfectly here)
 - self-documenting code
 - assigning “blame”
- in DbC, contracts are a critical step between understanding what a program should do and implementing a program that does it:
 - once the programmer understands what a section of code should do, he can write contracts for it
 - once contracts have been written, it is more clear what the actual implementation should be

Design by Contract (2)



- Pre- and post-conditions define a **contract** between a class and its clients:
 - Client must:
 - **ensures** precondition
 - **requires** post-condition;
 - Method (software provider) should/must:
 - **requires** precondition;
 - **ensures** post-condition.



What is JML?

Background

JML Annotations

JML Specification Expressions

DbC and JML

Notes on JML

JML

What is JML?



- Java Modeling Language (JML)
 - *formal specification language* for Java
 - allows:
 - to specify behavior of Java classes
 - to record design/implementation decisions
 - by adding *annotations* to Java source code (e.g., *preconditions*, *postconditions*, *class invariants*)



Background

- JML started in 1997 in an effort, led by Gary T. Leavens, to create formal, reusable specification language for Java.
- JML has seen grown in popularity and is used as the specification language for many different tools and research projects, including
 - Runtime assertion checkers (e.g. jmlc/jmlrac)
 - Test generation (e.g. jmlunit)
 - Static checkers (**ESC2Java**)
 - Formal verification tools (e.g. KeY)
 - Design tools (e.g. AutoJML)
- Industry includes verification specification on security-critical applications such as:
 - financial data cards;
 - voting systems.



Pre- and Post-conditions

- method **precondition**
 - says what must be true before call it;
 - example: `//@ requires x >= 0;`
- method **normal postcondition**
 - says what is true when it returns normally (i.e., without throwing an exception);
 - example: `//@ ensures \result >= 0;`
- method **exceptional postcondition**
 - says what is true when a method throws an exception;
 - example: `//@ signals (IllegalArgumentException e) x < 0;`

Invariants



- (class) invariants

- are properties that must be maintained by all methods;
- are implicitly included in all pre- and post-conditions;
- must also be preserved if an exception is thrown!
- Example:

```
public class Account{
    public static final short MAX_VALUE = 1000;
    private short amount;
    /*@ invariant 0 <= amount &&
        @ amount <= MAX_VALUE;
    @*/
    // ...
}
```

- Advantages:
 - document design decisions;
 - help in understanding the code.

Assertions



- **assert** clause
 - specifies a property that should hold at some point in the code;
 - example:

```
if (i <= 0 || j < 0) {  
    //...  
} else if (j < 5) {  
    //@ assert i > 0 && 0 < j && j < 5;  
} else {  
    //@ assert i > 0 && j > 5;  
    //...  
}
```

- JML keyword `assert` introduced in Java (since Java 1.4).

Pure Methods



- **pure** method

- a method without side-effects;
- example:

```
public /*@ pure @*/ int getAmount() {  
    return amount;  
}
```

- only pure methods, can be used in specifications

- example:

```
/*@ invariant 0<=getAmount() && getAmount()<=MAX_VALUE;
```




Common Pragmas - Summary

Pragma Syntax	Place to Appear	Semantics
<code>requires E</code>	Before a method	E must hold whenever the method is invoked
<code>ensures E</code>	Before a method	E must hold after the method terminates normally
<code>signals (T t) E</code>	Before a method	E must hold after the method terminates with exception of type T
<code>invariant E</code>	Class body	E must hold whenever no method of that class is running
<code>non_null</code>	Variable	Variable must never contain <i>null</i>
<code>spec_public</code>	Field	Field is considered public as far as specifications are concerned

- E – boolean *specification expression*

JML Annotations



- JML Annotation
 - a Java comment line starting with @;
 - may be composed of semicolon-separated pragmas:
 - examples:
 - `//@ This is an JML annotation;`
 - `/*@ This is the first pragma`
`@ in the current annotation;`
`@ This is the second pragma`
`@*/`
 - *at*-sign (@) on the beginning of lines is ignored within Java Annotations;
 - @ must be right next to the start of comment characters.

JML Comments



- JML Comment
 - syntax: `(* JML comment *)`
 - is actually considered an expression that returns `true`;
 - examples:
 - `//@ requires (* x is positive *)`;
 - `/*@ ensures (* \result is an approximation to
@ the square root of x *)
@
@ && \result >= 0;
@*/`
- The easiest way to *comment out JML*?
 - solution: ***comment out the comment***, i.e., insert a `<space>` within the annotation;
 - example:
 - `// @ requires x >= 0.0;`
 - `/* @ ensures 0 <= amount &&
@ amount <= MAX_VALUE;
@*/`

JML Specification Expression



- **JML specification expression**

- similar to a Java expression, with some differences that include:
 - no use of : assignment (`=`), object creation (`new`), increment (`++`) , decrement (`--`) , or method invocation (`m(a, b)`);
 - calls of “pure” methods are allowed;
 - special variables, operators, and loops;
 - special functions.

Syntax	Semantics
<code>a ==> b</code>	<code>a implies b</code>
<code>a <== b</code>	<code>b implies a</code>
<code>a <==> b</code>	<code>a iff b</code>
<code>a <!=> b</code>	<code>! (a <==> b)</code>



JML Special Specification Expressions

Syntax	Semantics
<code>\result</code>	the value returned from the method
<code>\old(A)</code>	The value of A as it was before the method was invoked
<code>(\forall T V; E)</code>	Declares all variables in V to be of type T , then verified E holds for every valid value for every variable
<code>(\exists T V; E)</code>	As <code>\forall</code> , only a single variable for which E will hold is enough

- E – boolean specification expression
- A – any specification expression
- T – type expression
- V – comma-separated list of variable names

DbC and JML



- DbC is emphasized within JML

- example:

```
//@ requires x >= 0.0;  
/*@ ensures JMLDouble.approximatelyEqualTo(x,  
      @      \result * \result, eps);  
@*/  
double sqrt(double x) {...}
```

Rights		Obligations
Client	to get a square root approximation	to pass a non-negative value
Implementation/ Provider	to assume/ require the argument is a non-negative value	to compute/ ensure the returned values is square root

Notes on JML



- JML syntax is not very well organized
 - Multiple keywords with the same meaning, inconsistent assertion syntax, etc.
- Why not use Java annotations?
 - This is a classical use-case for annotations!
 - Unfortunately, JML started before Java 1.6, and many tools already exist to support that form, so no conversion very soon.
- The programmer still has to figure out what specifications are needed.



Many Tools, One Language

`jmlc/jmlrac` and `Esc2Java`

Runtime Assertion Checker and Static Checker

JML TOOLS

Many Tools, One Language



- There are several types of tools that work on JML:
 - **JML compiler:** `jmlc`;
 - **static checker:** `ESC2Java`;
 - **run-time checker:** `jmlrac`;
 - unit tester: `jmlunit`;
 - model testing: `BOGOR`;
 - web pages: `jmldoc`;
 - correctness proof: `JACK`, `Jive`, `KeY`, `LOOP`, `Krakatoa`;
 - data trace file: `Daikon`;
 - etc.



jmlc / jmlrac and Esc2Java

JML Compiler and Runtime Assertion Checker

default (no specification checking)

javac & java usage

- **class** `Account.java`
 - **compile:**
 - `javac Account.java`
 - **output:** a bytecode file `Account.class`
 - ignores any comments, i.e., JML specification
 - **run with the standard VM:**
 - `java Account`
 - possible specification inconsistencies not highlighted

specification checking

jmlc & jmlrac usage

- **class** `Account.java`
 - **compile:**
 - `jmlc Account.java` or `jmlc -Q Account.java`
 - **output:** a bytecode file `Account.class` that enables automatic checks of JML assertions at the run time
 - **jmlc acts as a preprocessor for javac**
 - **run the JML run-time assertion checker:**
 - `jmlrac Account`
 - possible specification inconsistencies identified and `Errors` are thrown
 - `jmlrac` script enables the automatic use of JML runtime classes (`jmlruntime.jar`) from the Java boot class path, required to run the checks on the assertions
 - **jmlrac acts as a wrapper for the standard VM**



jmlc / jmlrac and Esc2Java

Runtime Assertion Checker and Static Checker

compile-time checking

Esc2Java

- checks specifications at compile-time
- proves the specification correctness
- warns about likely runtime exceptions and violations.
- automatically tries to prove simple JML assertions at compile time

run-time checking

jmlc & jmlrac

- checks specifications at run-time
- tests the specification correctness only
- finds the specification violations at runtime
- **jmlc** = special compiler that inserts runtime tests for all JML assertions;
- **jmlrac** - any assertion violation results in a special exception at run-time.

Run-time vs. Compile-time (static) Checking



- ESC2Java may miss an error that is actually present ;
- ESC2Java may warn of errors that are impossible;
- finds potential bugs quickly ;
- good at proving absence of runtime exceptions (e.g., Null-, ArrayIndex-OutOfBounds-, ClassCast-) and verifying relatively simple properties;
- ESC2Java independent of any test suite;
- results of runtime testing are only as good as the test suite;
- ESC2Java provides higher degree of confidence, for all pre- and post-conditions of methods and invariants.



Tool Installation

compile-time checking

Esc2Java

- download:
 - <http://www.cs.virginia.edu/cs201j/escjava.html> ;
 - <http://www.kindsoftware.com/products/opensource/ESCJava2/download.html> ;
- as Eclipse plug-in
 - <http://kindsoftware.com/products/opensource/Mobius/updates/>
- tutorials:
 - <http://kindsoftware.com/products/opensource/ESCJava2/>
 - https://piazza.com/class/profile/get_resource/h6i0bbjqlhy5wh/h7ft2ccr1jr4k2

run-time checking

jmlc & jmlrac

- download:
 - www.jmlspecs.org ;
 - <http://www.openjml.org/documentation/installation.shtml>
- as Eclipse plug-in
 - <http://jmlspecs.sourceforge.net/openjml-updatesite>
- JML installation notes:
 - http://www.cse.chalmers.se/edu/year/2012/course/courses_2011/TDA566/JML-Installation-Notes.html
- tutorials:
 - <http://www.cs.ru.nl/E.Poll/talks/jmlrac.pdf>



Demos

compile-time checking

Esc2Java

- [Factorial.zip](#)
- [Account.zip](#)

run-time checking

jmlc & jmlrac

- [FastExponentiation.zip](#)
- [Bag.zip](#)