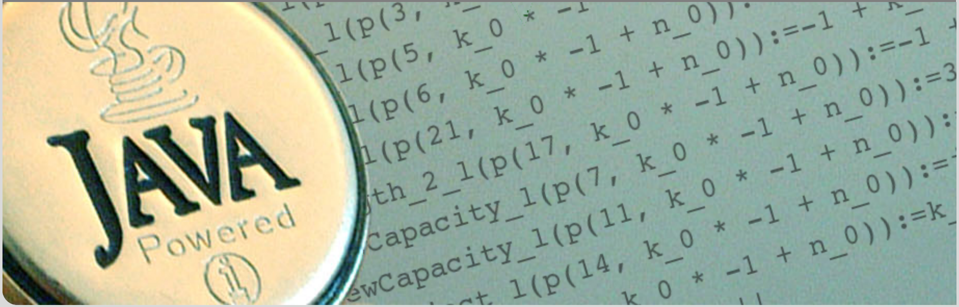
Applications of Formal Verification

Functional Verification of Java Programs: Java Modeling Language

Shmuel Tyszberowicz
based on materials by Bernhard Beckert · Vladimir Klebanov | 2014

MTA



Hoare Logic

Hoare triple

Has the form

$$\{\textit{Precondition}\}\ \text{Prog-Segment}\ \{\textit{Postcondition}\}$$

Expresses partial correctness

If the Prog-Segment starts with a state satisfying the precondition
and it terminates
then the final state of the Prog-Segment satisfies the postscondition

- Example
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Design by Contract

Idea

Specifications fix a contract between caller and callee of a method (between client and implementor of a module)

If the caller guarantees precondition
then the callee guarantees postcondition

- Interface documentation
- Contracts described in a mathematically precise language
  - Higher degree of precision
  - *Automation* of program analysis of various kinds
    - Runtime assertion checking
    - Static verification
- Note: Errors in specifications are at least as common as errors in code

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TEL AVIV-YAFFO ACADEMIC COLLEGE

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JML Annotations

```
/*@ public normal_behavior
  @   requires pin == correctPin;
  @   ensures customerAuthenticated;
  @*/
public void enterPIN (int pin) {
    ...
```

- Java comments with '@' as first character are JML specifications
- Within a JML annotation, an '@' is ignored:
  - If it is the first (non-white) character in the line
  - If it is the last character before '*/'

  ⇒ The blue '@'s are not required, but it is a *convention* to use them
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Visibility Modifiers

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public class ATM {
  private /*@ spec_public @*/
          BankCard insertedCard = null;
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  @ signals(E e) s;
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T m(...);
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Implicitly

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      normal_behavior  =  signals(Exception e) false;
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The keyword `also` separates the contracts of a method

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Pure methods terminate and have no side effects

'**pure**' ≈ '**diverges false;**' + '**assignable \nothing;**'

After declaring

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public /*@ pure @*/ boolean cardIsInserted() {
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Quantification in JML

```
(\forall int i; 0<=i && i<\result.length; \result[i]>0)
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equivalent to
```
(\forall int i; 0<=i && i<\result.length ==> \result[i]>0)
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(\exists int i; 0<=i && i<\result.length; \result[i]>0)
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- Quantifiers bind two expressions: the range predicate and the body expression
- A missing range predicate is by default `true`

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Generalized and Numerical Quantifiers

`(\num_of T i; e)`	$\#\{i \mid [e]\}$, number of elements of type `T` with property `e`
`(\sum T i; p; t)`	$\sum_{i:[p]} [t]$
`(\product T i; p; t)`	$\prod_{i:[p]} [t]$
`(\min T i; p; t)`	$\mathit{min}_{i:[p]}\{[t]\}$
`(\max T i; p; t)`	$\mathit{max}_{i:[p]}\{[t]\}$

e.g.: ensures \result==(\num_of int j; 0$\leq$ j && j <n; a[j] == i);

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  - **`\nothing`**, **`\everything`** (default)

The `diverges` Clause

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diverges e;
```

with a boolean JML expression `e` specifies that the method may not terminate only when `e` is true in the pre-state

Examples

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diverges false;
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The method must always terminate

```
diverges true;
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The method may terminate or not

```
diverges n == 0;
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The method must terminate, when called in a state with `n!=0`

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```

The method must terminate, when called in a state with `n!=0`

The `signals` Clauses

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ensures p;
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signals (E1 e1) s1;
...
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Model Fields

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public interface IBonusCard {







  public void addBonus(int newBonusPoints);

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How to add contracts to abstract methods in interfaces?
Remember: There are no attributes in interfaces
More precisely: Only static final fields

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Implementing Interfaces

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public interface IBonusCard {
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Implementation

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public class BankCard implements IBonusCard{
      public int bankCardPoints;
/*@   private represents bonusPoints = bankCardPoints; @*/

      public void addBonus(int newBonusPoints) {
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Problems with Specifications Using Integers

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/*@ requires y >= 0;
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  @ ensures (\result+1) * (\result+1) > y;
  @ */
 public static int isqrt(int y)
```

For $y = 1$ and $\backslash result = 1073741821 = \frac{1}{2}(MAX\_INT - 5)$ the above postcondition is true, though 1073741821 is not a square root of 1

JML uses the Java semantics of integers:

$$\begin{aligned} 1073741821 * 1073741821 &= -2147483639 \\ 1073741822 * 1073741822 &= 4 \end{aligned}$$

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JML Tools

Many tools support JML (see JML homepage); among them:

- `jml`: JML syntax checker
- `jmldoc`: code documentation (like Javadoc)
- `jmlc`: compiles Java+JML into bytecode with assertion checks
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- ESC/Java2: leightweight static verification
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