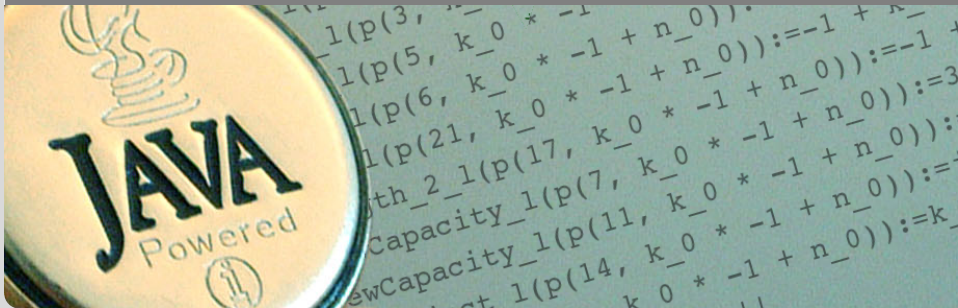


# Applications of Formal Verification

## Functional Verification of Java Programs: Java Modelling Language

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KIT – INSTITUT FÜR THEORETISCHE INFORMATIK



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

If caller guarantees precondition  
then callee guarantees certain outcome

- Interface documentation
- Contracts described in a mathematically precise language (JML)
  - 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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/*@ public normal_behavior
   @   requires pin == correctPin;
   @   ensures customerAuthenticated;
   @*/
public void enterPIN (int pin) {
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- 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
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- ⇒ The blue '@'s are not required, but it's a *convention* to use them.
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public class ATM {  
    private /*@ spec_public @*/ BankCard insertedCard = null;  
    private /*@ spec_public @*/  
        boolean customerAuthenticated = false;  
  
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- Modifiers to specification cases have no influence on their semantics.
- *public* specification items cannot refer to *private* fields.
- Private fields can be declared public for specification purposes only.

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/*@ requires r;  
   @ assignable a;  
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   @ signals_only E1, ..., En;  
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T m(...);
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## Abbreviations

```
normal_behavior = signals(Exception e) false;  
exceptional_behavior = ensures false;
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keyword **'also'** separates the contracts of a method

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/*@ requires r;           //what is the caller's obligation?  
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//@ invariant i;
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- can be placed anywhere in a class (or interface)
- express global consistency properties (not specific to a particular method)
- must hold “always”  
(cf. *visible state semantics*, *observed state semantics*)
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# Pure Methods

Pure methods terminate and have no side effects.

After declaring

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public /*@ pure @*/ boolean cardIsInserted() {  
    return insertedCard!=null;  
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`'pure' ≈ 'diverges false;' + 'assignable \nothing;'`

- All Java expressions without side-effects
- $\implies$ ,  $\iff$ : implication, equivalence
- `\forall`, `\exists`
- `\num_of`, `\sum`, `\product`, `\min`, `\max`
- `\old(...)`: referring to pre-state in postconditions
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(\forall int i; 0<=i && i<\result.length; \result[i]>0)  
equivalent to  
(\forall int i; 0<=i && i<\result.length ==> \result[i]>0)  
  
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- Note that quantifiers bind two expressions, the **range predicate** and the **body expression**.
- A missing range predicate is by default `true`.
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# Generalised and Numerical Quantifiers

<code>(\num_of T i; e)</code>	$\#\{i [e]\}$ , number of elements of type $T$ with property $e$
<code>(\sum T i; p; t)</code>	$\sum_{i:[p]} [t]$
<code>(\product T i; p; t)</code>	$\prod_{i:[p]} [t]$
<code>(\min T i; p; t)</code>	$\min_{i:[p]} \{[t]\}$
<code>(\max T i; p; t)</code>	$\max_{i:[p]} \{[t]\}$

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Comma-separated list of:

- $e.f$  (where  $f$  a field)

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## Example

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C x, y; int i;
//@ assignable x, x.i;
void m() {

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```
C x, y; int i;
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  C tmp = x;
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  x = y;
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C x, y; int i;
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//@ assignable x, x.i;
void m() {
    C tmp = x; //allowed (local variable)
    tmp.i = 27; //allowed (in assignable clause)
    x = y; //allowed (in assignable clause)
    x.i = 27; //forbidden (not local, not in assignable)
}
```

# The assignable Clauses

Comma-separated list of:

- $e.f$  (where  $f$  a field)
- $a[*]$ ,  $a[x..y]$  (where  $a$  an array expression)
- `\nothing`, `\everything` (default)

## Example

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}
```

**assignable** clauses are always evaluated in the pre-state!

```
diverges e;
```

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

## Examples

```
diverges false;
```

The method must always terminate.

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

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diverges n == 0;
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ensures p;  
signals_only ET1, ..., ETm;  
signals (E1 e1) s1;  
...  
signals (En en) sn;
```

- normal termination  $\Rightarrow$  `p` must hold (in post-state)
- exception thrown  $\Rightarrow$  must be of type `ET1, ..., or ETm`
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```
public interface IBonusCard {  
  
    /*@ public instance model int bonusPoints; @*/  
  
    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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public interface IBonusCard {  
  
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## Implementation

```
public class BankCard implements IBonusCard{  
    public int bankCardPoints;  
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# Other Representations

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/*@ private represents bonusPoints  
    = bankCardPoints; @*/
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/*@ private represents bonusPoints  
    = bankCardPoints * 100; @*/
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```
private /*@spec_public non_null@*/ Object x;
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↪ **implicit invariant** added to class: `'invariant x != null;'`

```
void m(/*@non_null@*/ Object p);
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↪ **implicit precondition** added to all contracts:  
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# Problems with Specifications Using Integers

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

For  $y = 1$  and  $\text{\result} = 1073741821 = \frac{1}{2}(\text{MAX\_INT} - 5)$  the above postcondition is true, though we do not want 1073741821 to be a square root of 1.

JML uses the Java semantics of integers:

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

The JML type `\bigint` provides arbitrary precision integers.

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