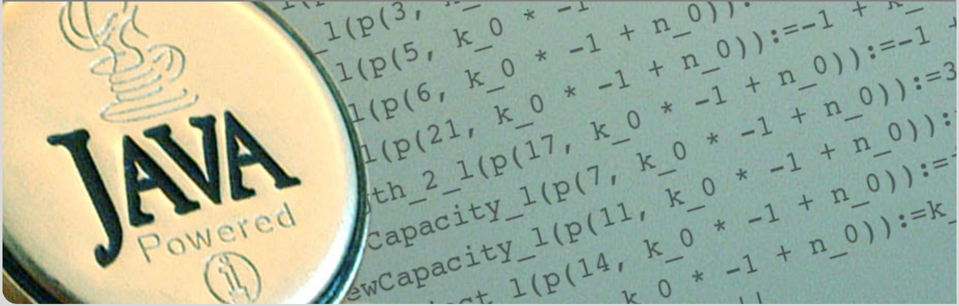
Specification & Formal Analysis of Java Programs

Java Modelling Language

Prof. Dr. Bernhard Beckert | ADAPT 2010

KIT – INSTITUT FÜR THEORETISCHE INFORMATIK



Design by Contract

Idea

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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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
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Visibility Modifiers

```
public class ATM {
  private /*@ spec_public @*/ BankCard insertedCard = null;
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- *public* specification items cannot refer to *private* fields.
- Private fields can be declared public for specification purposes only.

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

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

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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*)
- **`instance`** invariants *can*, **`static`** invariants *cannot* refer to **`this`**
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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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could replace

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Pure Methods

‘`pure`’ $\approx$ ‘`diverges false;`’ + ‘`assignable \nothing;`’

Expressions

- All Java expressions without side-effects
- `==>`, `<==>`: implication, equivalence
- `\forall`, `\exists`
- `\num_of`, `\sum`, `\product`, `\min`, `\max`
- `\old`(...): referring to pre-state in postconditions
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Quantification in JML

```
(\forall int i; 0<=i && i<\result.length; \result[i]>0)
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equivalent to
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(\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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equivalent to
```
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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`.
- JML excludes `null` from the range of quantification.

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Generalised and Numerical Quantifiers

`(\num_of C c; e)`	$\#\{c \mid [e]\}$,number of elements of class with property `e`
`(\sum C c; p; t)`	$\sum_{c:[p]} [t]$
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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

```
C x, y;
//@ 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)
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Comma-separated list of:

- `e.f` (where `f` a field)
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with a boolean JML expression `e` specifies that the method may not terminate only when `e` is true in the pre-state.

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The method must always terminate.

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...
signals (En en) sn;
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Model Fields

```
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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Implementation

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

      public void addBonus(int newBonusPoints) {
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Nullity

JML has modifiers **`non_null`** and **`nullable`**

```
private /*@spec_public non_null@*/ Object x;
```

⇝ implicit invariant added to class: '`invariant x != null;`'

```
void m(/*@non_null@*/ Object p);
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⇝ implicit precondition added to all contracts:
'`requires p != null;`'

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/*@non_null@*/ Object m();
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Problems with Specifications Using Integers

```
/*@ requires y >= 0;
  @ ensures
  @  \result * \result <= y &&
  @ y < (abs(\result)+1) * (abs(\result)+1);
  @ */
  public static int isqrt(int y)
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For $y = 1$ and $\backslash result = 1073741821 = \frac{1}{2}(max\_int - 5)$ 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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Many tools support JML (see JML homepage). Among them:

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- KeY: full static verification
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