Intersection Types in Java

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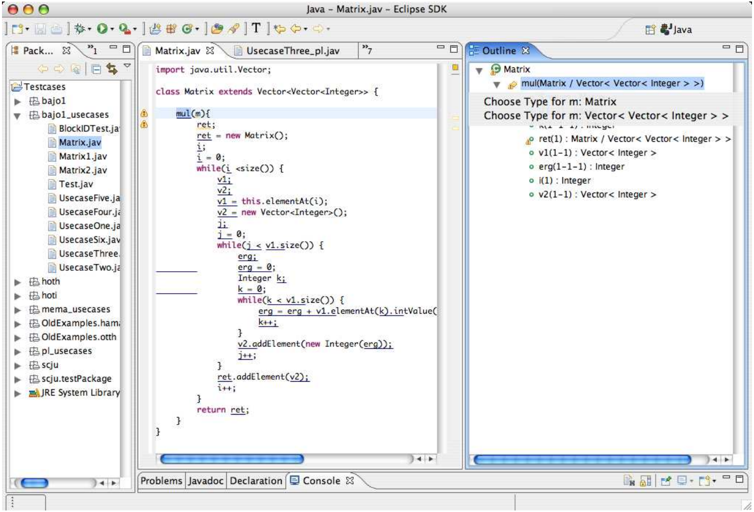
Overview

Motivation/Tooldemonstration

Method calls with intersection types
  Semantics
  First approach
  The algorithm

Principal Typing

Conclusion and Outlook

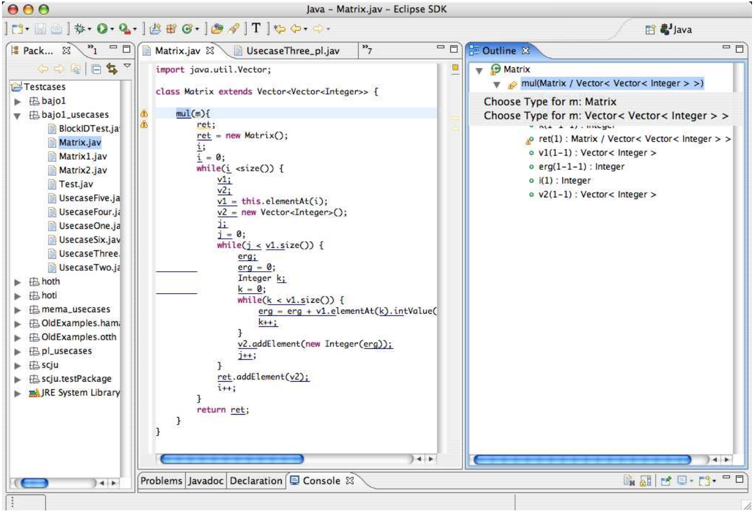


```
import java.util.Vector;

class Matrix extends Vector<Vector<Integer>> {

    mul(m){
        ret;
        ret = new Matrix();
        i;
        i = 0;
        while(i <size()) {
            v1;
            v2;
            v1 = this.elementAt(i);
            v2 = new Vector<Integer>();
            j;
            j = 0;
            while(j < v1.size()) {
                erg;
                erg = 0;
                Integer k;
                k = 0;
                while(k < v1.size()) {
                    erg = erg + v1.elementAt(k).intValue(
                    k++;
                }
                v2.addElement(new Integer(erg));
                j++;
            }
            ret.addElement(v2);
            i++;
        }
        return ret;
    }
}
```

```
Matrix
  mul(Matrix / Vector< Vector< Integer > >)
Choose Type for m: Matrix
Choose Type for m: Vector< Vector< Integer > >
      ret(1) : Matrix / Vector< Vector< Integer > >
      v1(1-1) : Vector< Integer >
      erg(1-1-1) : Integer
      i(1) : Integer
      v2(1-1) : Vector< Integer >
```



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Purpuse: Byte-code generation for methods with intersection types

Semantics of type–inferred Java programs

- control-structures have the same semantics as in standard Java
- method calls differ, as there are intersection types

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```
... m ( ... ) {
    ... receiver.method(t1, ..., tn); ... }
```

- `method`: $ty_1 \times \ldots \times ty_n \rightarrow ty_0 \;\; \& \ldots \& \;\; ty'_1 \times \ldots \times ty'_n \rightarrow ty'_0$ has an intersection type

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```

- `method`: $ty_1 \times \ldots \times ty_n \rightarrow ty_0 \;\; \& \ldots \& \;\; ty'_1 \times \ldots \times ty'_n \rightarrow ty'_0$ has an intersection type
- `t1` , ... , `tn` have unambiguous types during execution
- by the argument types and the result type the typing of `method` is determined
- `method` is executed with the determined typing.

Semantics example

```
class OL {
     Integer m(x) { return x + x; }   //Integer → Integer
     Boolean m(x) { return x || x; }  //Boolean → Boolean
}

class Main {
    main(x) {    //   Integer → Integer & Boolean → Boolean
       ol;
       ol = new OL();
       return ol.m(x);
    }
}
...
Main rec = new Main();
Integer r = rec.main(x);
```

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Integer r = rec.main(x); main:Integer → Integer is determined
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Code generation for method with intersection types

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- First approach: generate for each element of the intersection type an own method

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Result for `Main`:

```
class Main {
    Integer main(Integer x) {
        OL ol;
        ol = new OL();
        return ol.m(x); }

    Boolean main(Boolean x) {
        OL ol;
        ol = new OL();
        return ol.m(x);
} }
```

Example: Multiplication of matrices I

```
class Matrix extends Vector<Vector<Integer>> {
    mul(m) {
        ret = new Matrix();
        int i = 0;
        while(i <size()) {
            v1; v1 = this.elementAt(i);
            v2; v2 = new Vector<Integer>();
            int j = 0;
            while(j < v1.size()) {
                int erg = 0;
                int k = 0;
                while(k < v1.size()) {
                    erg = erg + v1.elementAt(k)
                        * m.elementAt(k).elementAt(j); k++; }
                v2.addElement(new Integer(erg)); j++; }
            ret.addElement(v2); i++; }
        return ret; }}
```

Example: Multiplication of matrices II

$$\texttt{mul:}\ \&_{\beta,\alpha}(\beta \rightarrow \alpha),$$

where

$\beta \leq^{*}$ `Vector<? extends Vector<? extends Integer>>`,
`Matrix` $\leq^{*} \alpha$

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$$\texttt{mul:}\ \&_{\beta,\alpha}(\beta \rightarrow \alpha),$$

where

$\beta \leq^* \texttt{Vector<? extends Vector<? extends Integer>>}$,
$\texttt{Matrix} \leq^* \alpha$

```
class Matrix extends Vector<Vector<Integer>> {
  Matrix mul(Vector<? extends Vector<? extends Integer>> m) { ... }
  Matrix mul(Vector<? extends Vector<Integer>> m) { ... }
  Matrix mul(Vector<Vector<Integer>> m) { ... }
  ...
  Vector<Vector<Integer>> mul(Vector<Vector<Integer>> m) { ... }
  ...
  Vector<? extends Vector<? extends Integer>> mul(Matrix m) { ... }
```

Example: Multiplication of matrices II

$$\texttt{mul:}\ \&_{\beta,\alpha}(\beta\to\alpha),$$

where

$\beta \leq^{*}$ `Vector<? extends Vector<? extends Integer>>`,
`Matrix` $\leq^{*} \alpha$

```
class Matrix extends Vector<Vector<Integer>> {
  Matrix mul(Vector<? extends Vector<? extends Integer>> m) { ... }
  Matrix mul(Vector<? extends Vector<Integer>> m) { ... }
  Matrix mul(Vector<Vector<Integer>> m) { ... }
  ...
  Vector<Vector<Integer>> mul(Vector<Vector<Integer>> m) { ... }
  ...
  Vector<? extends Vector<? extends Integer>> mul(Matrix m) { ... }
```

Not a correct Java program

Group elements of the intersection type

Idea:

1. Group all elements which
    - executes the same code
    - have a common supertype
2. Generate new methods only for the groups

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Code–execution: Callgraph of the method declarations

$$\mathcal{CG}(\, cl.m : \tau \,)$$

Callgraph of the method m in the class cl with the typing τ.

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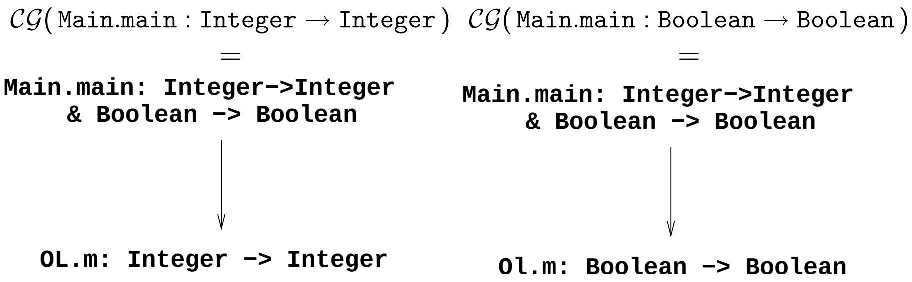
Callgraph of the method m in the class cl with the typing τ.

Supertype of function types: Subtyping ordering
$\theta_i \leq^* \theta'_i, \theta \leq^* \theta' \Rightarrow$

$$\theta_1 \times \ldots \times \theta_n \rightarrow \theta' \leq^* \theta'_1 \times \ldots \times \theta'_n \rightarrow \theta$$

Example class OL I

Callgraph



$\mathcal{CG}(\,\texttt{Main.main} : \texttt{Integer} \rightarrow \texttt{Integer}\,) = $

`Main.main: Integer->Integer & Boolean -> Boolean`

`OL.m: Integer -> Integer`

$\mathcal{CG}(\,\texttt{Main.main} : \texttt{Boolean} \rightarrow \texttt{Boolean}\,) = $

`Main.main: Integer->Integer & Boolean -> Boolean`

`Ol.m: Boolean -> Boolean`

Example class OL I

Callgraph

$\mathcal{CG}(\texttt{Main.main} : \texttt{Integer} \rightarrow \texttt{Integer})$

$=$

`Main.main: Integer->Integer & Boolean -> Boolean`

↓

`OL.m: Integer -> Integer`

$\mathcal{CG}(\texttt{Main.main} : \texttt{Boolean} \rightarrow \texttt{Boolean})$

$=$

`Main.main: Integer->Integer & Boolean -> Boolean`

↓

`Ol.m: Boolean -> Boolean`

Supertype

$\texttt{Integer} \rightarrow \texttt{Integer}$

$\texttt{Boolean} \rightarrow \texttt{Boolean}$

Example class OL II

Code generation

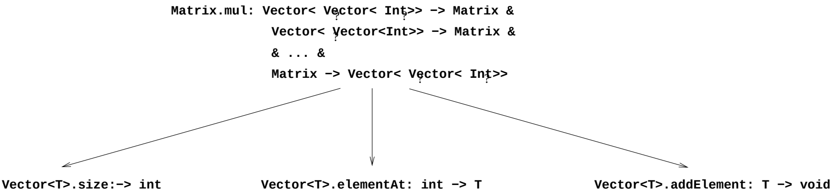
```
class Main {
    Integer main(Integer x) {
        OL ol;
        ol = new OL();
        return ol.m(x); }

    Boolean main(Boolean x) {
        OL ol;
        ol = new OL();
        return ol.m(x);
    } }
```

Code is unchanged in comparison to the first approach

Example class `Matrix` I

Callgraph $\mathcal{CG}($`Matrix.mul`$:\tau)$ for all τ

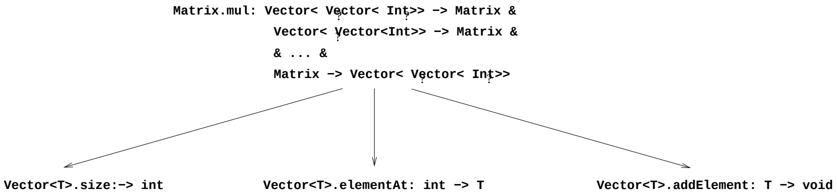


```
Matrix.mul: Vector<? Vector<? Int>> -> Matrix &
            Vector<? Vector<Int>> -> Matrix &
            & ... &
            Matrix -> Vector<? Vector<? Int>>
```

```
Vector<T>.size:-> int
Vector<T>.elementAt: int -> T
Vector<T>.addElement: T -> void
```

Example class `Matrix` I

Callgraph $\mathcal{CG}(\,\texttt{Matrix.mul} : \tau\,)$ for all τ



```
Matrix.mul: Vector< Vector< Int>> -> Matrix &
            Vector< Vector<Int>> -> Matrix &
            & ... &
            Matrix -> Vector< Vector< Int>>
```

`Vector<T>.size:-> int`

`Vector<T>.elementAt: int -> T`

`Vector<T>.addElement: T -> void`

Supertype:

$$\texttt{Vector<? extends Vector<? extends Integer>>} \longrightarrow \texttt{Matrix}$$

Example class `Matrix` II

Code generation (only one method!)

```
Matrix mul(Vector<? extends Vector<? extends Integer>> m) {
   Matrix ret = new Matrix();
   int i = 0;
   while(i <size()) {
       Vector<Integer> v1 = this.elementAt(i);
       Vector<Integer> v2 = new Vector<Integer>();
       int j = 0;
       while(j < v1.size()) {
           int erg = 0;
           int k = 0;
           while(k < v1.size()) {
               erg = erg + ...; k++; }
           v2.addElement(new Integer(erg)); j++; }
       ret.addElement(v2); i++; }
   return ret; }}
```

The Algorithm

Input: A Java program p with inferred (intersection) types.

Output: A Java program p', where the methods have standard Java types. The semantics of p and p' are equal.

1. Step: For every class cl in p consider for each method m the intersection type ty_m:
    - Build the callgraph $\mathcal{CG}(\ cl.m : \tau\ )$ for each function type τ of the intersection type ty_m.
    - Group all elements τ of ty_m, where $\mathcal{CG}(\ cl.m : \tau\ )$ is the same graph and there is a supertype.
2. Step: Determine the supertype of the respective group.
3. Step: Generate for each group of function types the corresponding Java code with the supertype as standard typing in p'.

Principal Typing

Definition [Damas, Milner 1982]:

"A type-scheme for a declaration is a *principal type-scheme*, if any other type-scheme for the declaration is a generic instance of it."

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Generalization to the Java type system [Plümicke 2007, PPPJ07]

"An intersection type-scheme for a declaration is a *principal type-scheme*, if any (non–intersection) type-scheme for the declaration is a subtype of a generic instance of one element of the intersection type-scheme."

Example principal typing I

```
import java.util.Vector;
import java.util.Stack;

class Put {
    <T> putElement(T ele, Vector<T> v) {
      v.addElement(ele);
    }

    <T> putElement(T ele, Stack<T> s) {
      s.push(ele);
    }

    main(ele, x) {
      putElement(ele, x);
    }
}
```

Example principal typing II

The inferred intersection type:

$$\mathtt{main} : \mathtt{T} \times \mathtt{Vector<T>} \rightarrow \mathtt{void} \;\&\; \mathtt{T} \times \mathtt{Stack<T>} \rightarrow \mathtt{void}.$$

is a principal type.

Example principal typing II

The inferred intersection type:

$$\texttt{main} : \texttt{T} \times \texttt{Vector<T>} \rightarrow \texttt{void} \;\&\; \texttt{T} \times \texttt{Stack<T>} \rightarrow \texttt{void}.$$

is a principal type.

But there is another principal type:

$$\texttt{main} : \texttt{T} \times \texttt{Vector<T>} \rightarrow \texttt{void},$$

as $\texttt{Stack<T>} \leq^{*} \texttt{Vector<T>}$.

Example principal typing III

```
class Put {
    <T> void putElement(T ele, Vector<T> v) { ... }

    <T> void putElement(T ele, Stack<T> s) { ... }

    <T> void main(T ele, Vector<T> x) {
      x.putElement(ele, x); }

    <T> void main(T ele, Stack<T> x) {
      x.putElement(ele, x); }}
```

Example principal typing III

```
class Put {
    <T> void putElement(T ele, Vector<T> v) { ... }

    <T> void putElement(T ele, Stack<T> s) { ... }

    <T> void main(T ele, Vector<T> x) {
      x.putElement(ele, x); }

    <T> void main(T ele, Stack<T> x) {
      x.putElement(ele, x); }}
```

The principal type

$$\texttt{main} : \texttt{T} \times \texttt{Vector<T>} \rightarrow \texttt{void}$$

is correct but not meaningful!!

Refined definition of *Principal typing*

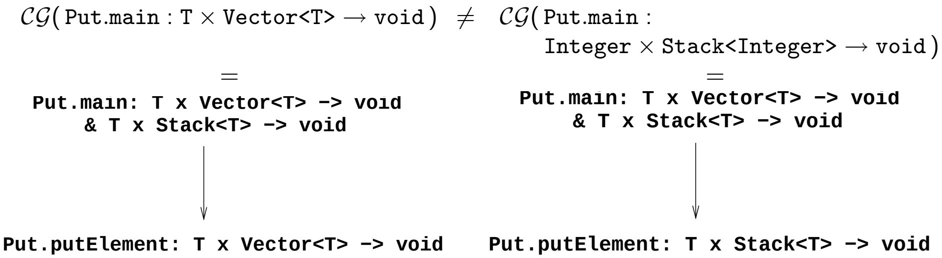
"An intersection type-scheme for a declaration is a *principal type-scheme*, if any (non–intersection) type-scheme θ for the declaration is a subtype of a generic instance of one element of the intersection type-scheme τ and θ and τ have the same callgraph."

Refined definition of *Principal typing*

“An intersection type-scheme for a declaration is a *principal type-scheme*, if any (non–intersection) type-scheme θ for the declaration is a subtype of a generic instance of one element of the intersection type-scheme τ and θ and τ have the same callgraph.”

This refined definition guarantees, that for each method, which is generated by the resolving algorithm, at least one typing is contained in the principal type.

Example Put (cont.)



$$\mathcal{CG}(\texttt{Put.main} : \texttt{T} \times \texttt{Vector<T>} \longrightarrow \texttt{void}) \neq \mathcal{CG}(\texttt{Put.main} : \texttt{Integer} \times \texttt{Stack<Integer>} \longrightarrow \texttt{void})$$

$=$

Put.main: T x Vector<T> -> void & T x Stack<T> -> void

Put.putElement: T x Vector<T> -> void

$=$

Put.main: T x Vector<T> -> void & T x Stack<T> -> void

Put.putElement: T x Stack<T> -> void

$\texttt{main} : \texttt{T} \times \texttt{Vector<T>} \longrightarrow \texttt{void}$ is no principal type, but

$\texttt{main} : \texttt{T} \times \texttt{Vector<T>} \longrightarrow \texttt{void}\ \&\ \texttt{T} \times \texttt{Stack<T>} \longrightarrow \texttt{void}$ is a principal type.

Conclusion and Outlook

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- Semantics for Java methods with intersection types
- Resolving algorithm of intersection types
- Code generation for methods with intersection types possible
  ⇒ type selection is not longer necessary in the Eclipse plugin.
- (Redefined) Principal type property

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Outlook

At the moment: Type inference algorithm infers typings, which are later erased as subtypes by the resolving algorithm.

Purpuse: Type inference algorithm infers only supertypes, such that no typings are erased in the resolving algorithm.