Generic Traits for the Java Platform

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Traits

- introduced by Schärli et al., in SQUEAK/SMALLTALK
  - play the role of *units for behavior fine-grained reuse*, in order to counter the problems of class-based inheritance with respect to code reuse
- a trait is
  - a set of methods, independent from any class hierarchy;
  - the common methods can be factored into a trait;
  - traits can be composed to form other traits or classes.

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- a trait is
  - a set of methods, independent from any class hierarchy;
  - the common methods can be factored into a trait;
  - traits can be composed to form other traits or classes.
- Traits can be composed in arbitrary order
- composed traits must resolve possible name conflicts explicitly.

XTRAITJ

- a JAVA-like language for *pure trait-based programming*;
- the declarations of object type, behavior and instance generation are completely separated:
  - *Interfaces*, as pure types, defining only method signatures.
  - *Traits*, as pure units of behavior reuse, defining only methods.
  - *Classes*, as pure generators of instances, implementing interfaces by using traits, and defining fields and constructors.

Design choices

- Full interoperability with Java and its type system
- This allows to reuse all Java libraries and an incremental adoption of traits
- Full IDE support (Eclipse); IDE tooling is crucial for Agile programming

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XTEXT & XBASE

- XTEXT: a framework for language implementations with full Eclipse integration
- XBASE: a reusable JAVA-like expression language
  - interoperable with the JAVA type system (including generics)
  - clean and "less noisy" JAVA-like syntax, with some bonus features (type inference, lambda expressions, extension methods)

Pure Trait programming

- no class hierarchies and consequently no class-based inheritance;
- multiple inheritance is obtained using traits;
- the composite unit has complete control over the composition and must resolve conflicts explicitly.

- Traits are not types;
- to maximize the opportunity for reuse

Pure Trait programming

- no class hierarchies and consequently no class-based inheritance;
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- Traits are not types;
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Avoid statically unintentional name clashing.

Promote code reuse

- programs may look more verbose than standard class-based programs;
- however, the degree of reuse provided by traits is higher than class-based hierarchies;
- the distinction of each programming concept in a separate entity makes each component reusable in different contexts, in an unanticipated way;
- on the contrary, class hierarchies need to be designed from the start with a specific reuse scenario in mind.

Traits and operations

- a trait consists of
  - *provided methods* (methods defined in the trait),
  - *required methods* (abstract methods assumed to be available in a trait or a class using the trait),
  - *required fields* (fields assumed to be available in a class using the trait),
  - the required fields and the required/provided methods can be directly accessed in the body of the trait's provided methods.
- Traits do not specify any state.
- Traits are building blocks to compose classes and other, more complex, traits.
- A suite of trait composition operations allows the programmer to build classes and composite traits.
- The composite unit has complete control over conflicts that may arise during composition and must solve them explicitly.

XTRAITJ classes

- A class in XTRAITJ can
  - implement interfaces by using traits
  - can define fields and constructors
  - but it cannot define methods

XBASE for method bodies

- an extensible and reusable statically typed expression language
- a Java with "less noise"
  - type inference, lambda expressions, extension methods
- integrates completely with Java and Eclipse JDT
- full access to Java type system (including generics)

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Example

```
val personList = newArrayList(
        new Person("James", "Smith", 50),
        new Person("John", "Smith", 40),
        new Person("James", "Anderson", 40),
        new Person("John", "Anderson", 30),
        new Person("Paul", "Anderson", 30))
personList.filter[firstname.startsWith("J")].
    sortBy[age].take(3).map[surname + ", " + firstname].
        join("; ")
```

Examples of traits

```
trait T1 {
    void upd(int n);   // required method
    void inc(int n) {  // provided method
        if (n > 0) this.upd(n) else errs=errs+1
    }
    int errs;   // required field
}
```

Examples of traits

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trait T1 {
    void upd(int n);   // required method
    void inc(int n) {  // provided method
        if (n > 0) this.upd(n) else errs=errs+1
    }
    int errs;   // required field
}

trait T2 {
    void upd(int n) { // provided method
        counter = counter + 1;
    }
    int counter;   // required field
}
```

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```
interface ICounter {
    /* Increment the counter by n, if n > 0.
     * Otherwise, increment the number of errors */
    void inc(int n);
}
```

XTRAITJ classes

- A class in XTRAITJ can
  - implement interfaces by using traits
  - can define fields and constructors
  - but it cannot define methods

```
interface ICounter {
    /* Increment the counter by n, if n > 0.
     * Otherwise, increment the number of errors */
    void inc(int n);
}
class Counter implements ICounter uses T1, T2 {
    int counter = 0;
    int errs = 0;

    Counter(int counter) {
        this.counter = counter;
    }
}
```

The complete example

```
trait T1 {
    void upd(int n);   // required method
    void inc(int n) {  // provided method
        if (n > 0) this.upd(n) else errs=errs+1
    }
    int errs;   // required field
}
```

```
trait T2 {
    void upd(int n) { // provided method
        counter = counter + 1;
    }
    int counter;   // required field
}
```

```
interface ICounter {
    /* Increment the counter by n, if n > 0.
     * Otherwise, increment the number of errors */
    void inc(int n);
}

class Counter implements ICounter uses T1, T2 {
    int counter = 0;
    int errs = 0;

    Counter(int counter) {
        this.counter = counter;
    }
}
```

Flattening semantics

```
trait T1 {
    void upd(int n);   // required method
    void inc(int n) {  // provided method
        if (n > 0) this.upd(n) else errs=errs+1
    }
    int errs;   // required field
}
class Counter implements ICounter uses T1, T2 {
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    int errs = 0;

    Counter(int counter) {
        this.counter = counter;
    }
}
```

```
trait T2 {
    void upd(int n) { // provided method
        counter = counter + 1;
    }
    int counter;   // required field
}
```

Flattening semantics

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}
class Counter implements ICounter uses T1, T2 {
    int counter = 0;
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    Counter(int counter) {
        this.counter = counter;
    }
}
```

```
trait T2 {
    void upd(int n) { // provided method
        counter = counter + 1;
    }
    int counter;   // required field
}
```

```
// "flattened" version
class Counter implements ICounter {
    int counter = 0;
    int errs = 0;

    Counter(int counter) { ... }

    void inc(int n) {
        if (n > 0) this.upd(n)...
    } // from T1

    void upd(int n) {
        counter = counter + 1;
    } // from T2
}
```

The symmetric Sum operation

- Merges two traits to form a new trait
- Requires the summed traits to be
  - disjoint (no identically named provided methods)
  - consistent (identically required fields and methods must have the same type)

Example of sum

```
trait T1 {
    void upd(int n);   // required method
    void inc(int n) {  // provided method
        if (n > 0) this.upd(n) else errs=errs+1
    }
    int errs;   // required field
}
```

```
trait T3 {
    void upd(int n);   // required method
    void dec(int i) {
        if (i>0)
            upd(-i)
    }
}
```

```
trait TCounter uses T1, T3 {
    void reset(int i) {
        if (i>0)
            upd(-i) // required by T1, T3
        else
            errs=errs+1 // required by T1
    }
}
```

Full JAVA generics support

```
trait TStack<T> {
    List<T> collection; // required field

    boolean isEmpty() { return collection.size() == 0; }
    void push(T e) { collection.add(0, e); }
    T pop() {
        if (isEmpty())
            return null;
        return collection.remove(0);
    }
}
```

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trait TStack<T> {
    List<T> collection; // required field

    boolean isEmpty() { return collection.size() == 0; }
    void push(T e) { collection.add(0, e); }
    T pop() {
        if (isEmpty())
            return null;
        return collection.remove(0);
    }
}

class CStack<T> implements IStack<T> uses TStack<T> {
    List<T> collection = new ArrayList();

    CStack() {}
    CStack(Collection<T> c) {
        collection.addAll(c);
    }
}
```

Including bounded and *F*-bounded quantifications

```
trait TStack<T> {
    List<T> collection; // required field

    boolean isEmpty() { return collection.size() == 0; }
    void push(T e) { collection.add(0, e); }
    T pop() {
        if (isEmpty())
            return null;
        return collection.remove(0);
    }
}

class CStackOfSetsOfComparable<T extends Comparable<T>>
            implements IStack<Set<T>> uses TStack<Set<T>> {
    List<Set<T>> collection = new ArrayList();
}
```

And generic methods

With the addition of functional types and lambdas (thanks to XBASE)

```
trait T1<T> {
    Iterable<T> iterable;

    // function type: (T) => R
    <R> List<R> mapToList((T) => R mapper) {
        val result = new ArrayList<R>();
        for (e : iterable)
            result += mapper.apply(e);
        return result;
    }
}

class C1<String> uses T1<String>{...}

val c = new C1()
// inferred as List<Integer>
val sizes = c.mapToList([ element | element.size ])
// inferred as List<String>
val upper = c.mapToList([ element | element.toUpper ])
```

Support for JAVA annotations

- Can annotate:
  - Traits provided methods
  - Class fields
  - It makes no sense to annotate requirements

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Integration with JAVA frameworks

For example, JUnit and Dependency Injection frameworks that rely on annotations

Write JUnit tests in XTRAITJ

```
trait TStackTestCase {
    IStack<String> fixture;

    @Test void testNotEmpty() {
        assertFalse(fixture.isEmpty())
    }
    @Test void testContents() {
        assertEquals("foo", fixture.pop())
        assertEquals("bar", fixture.pop())
        assertNull(fixture.pop())
    }
}

trait TStackAsArrayListSetup {
    IStack<String> fixture;
    @Before void setup() {
        fixture = new CStack<String>(newArrayList("foo", "bar"))
    }
}

trait TStackAsLinkedListSetup {
    IStack<String> fixture;
    @Before void setup() {
        fixture = new CStack<String>(newLinkedList("foo", "bar"))
    }
}
```

Method Alias

The expression `T[`**alias** `m1` **as** `m2]`, where the method `m1` must be provided by `T` and the method `m2` must not be declared by `T`, denotes the trait obtained from `T` by adding a new provided method that is a copy of `m1` with name `m2`

```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}
```

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trait TAuxFactorial uses TFactorial[alias mRec as mAux] {}
```

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```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}

trait TAuxFactorial uses TFactorial[alias mRec as mAux] {}
```

corresponds to the flattened version:

```
trait TAuxFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
    int mAux(int n) { if (n==0) 1 else n*mRec(n-1) }
    // alias does not rename methods in bodies
}
```

Renaming

The expression `T`[**rename** `n1` **to** `n2`], where the method (or field) `n1` must be declared by `T` and the method (resp. field) `n2` must not be declared by `T`, renames references and declaration.

```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
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    int factorial(int n) { return mRec(n) }
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}

trait TRenFactorial uses TFactorial[rename mRec to mNew] {}
```

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trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}

trait TRenFactorial uses TFactorial[rename mRec to mNew] {}
```

corresponds to:

```
trait TRenFactorial {
    int factorial(int n) { return mNew(n) }
    int mNew(int n) { if (n==0) 1 else n*mNew(n-1) }
    // references are renamed as well
}
```

Restrict

The expression `T`[**restrict** `m`], where the method `m` must be provided by `T`, denotes the trait obtained from `T` by making `m` a required method.

```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}
```

Restrict

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```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}

trait TRestrictFactorial uses TFactorial[restrict mRec] {}
```

Restrict

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```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}

trait TRestrictFactorial uses TFactorial[restrict mRec] {}
```

corresponds to:

```
trait TRestrictFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n); // made required
}
```

Combining operations

For example, to simulate method overriding

```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}
trait TNewFactorial
        uses TFactorial[alias mRec as mOldRec, restrict mRec] {
    // since TFactorial.mRec is restricted, this is not a conflict
    int mRec(int n) {
        println("factorial of " + n); return mOldRec(n)
    }
}
```

Combining operations

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trait TFactorial {
    int factorial(int n) { return mRec(n) }
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}
trait TNewFactorial
        uses TFactorial[alias mRec as mOldRec, restrict mRec] {
    // since TFactorial.mRec is restricted, this is not a conflict
    int mRec(int n) {
        println("factorial of " + n); return mOldRec(n)
    }
}
```

corresponds to (note the dynamic binding semantics):

```
trait TNewFactorial {
    int factorial(int n) { return mRec(n) } // invokes the new version
    int mRec(int n) {
        println("factorial of " + n); return mOldRec(n)
    }
    int mOldRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}
```

Private methods

- Qualifying a method `m` as **private** in a trait `T`, hides the name `m` and permanently binds the method `m` to the trait.
- The actual name of a **private** method is immaterial.

The following two trait declarations are equivalent.

```
trait T1 {
    private void update() { ... }
    void m() { update(); }
}

trait T2 {
    private void foobar() { ... }
    void m() { foobar(); }
}
```

Method hiding

The expression `T`[**hide** `m`], where the method `m` must be provided by `T`, denotes the trait obtained from `T` by making the method `m` **private** to the trait.

```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}
trait THideFactorial uses TFactorial[hide mRec] {
    // since TFactorial.mRec is hidden, this is not a conflict
    String mRec(boolean b) { return "something completely different"; }
}
```

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```
trait TFactorial {
    int factorial(int n) { return mRec(n) }
    int mRec(int n) { if (n==0) 1 else n*mRec(n-1) }
}
trait THideFactorial uses TFactorial[hide mRec] {
    // since TFactorial.mRec is hidden, this is not a conflict
    String mRec(boolean b) { return "something completely different"; }
}
```

corresponds to:

```
trait THideFactorial {
    int factorial(int n) { return <boundname>(n) }
    private int <boundname>(int n) { if (n==0) 1 else n*<boundname>(n-1) }
    String mRec(boolean b) { return "something completely different"; }
}
```

Translation into Java

- We do not implement "flattening" directly,
- we translate traits into JAVA with object composition and method delegation.
  - Each method body is translated into exactly one single JAVA method body.
  - Our JAVA code generation is compositional in the presence of alteration operations.
  - No code duplication.
- Similar strategy adopted by other implementation.
- Drawback: overhead due to method forwarding.

Generated JAVA code

- The generated JAVA code has no dependency on XTRAITJ,
- it only depends on XBASE library and Google Guava library.
- These two libraries are less than 2 MB.
- The generated JAVA code can run on any JAVA platform, and
- thanks to the reduced size of the required JAVA libraries, it can be installed on JAVA devices, such as, Android devices.

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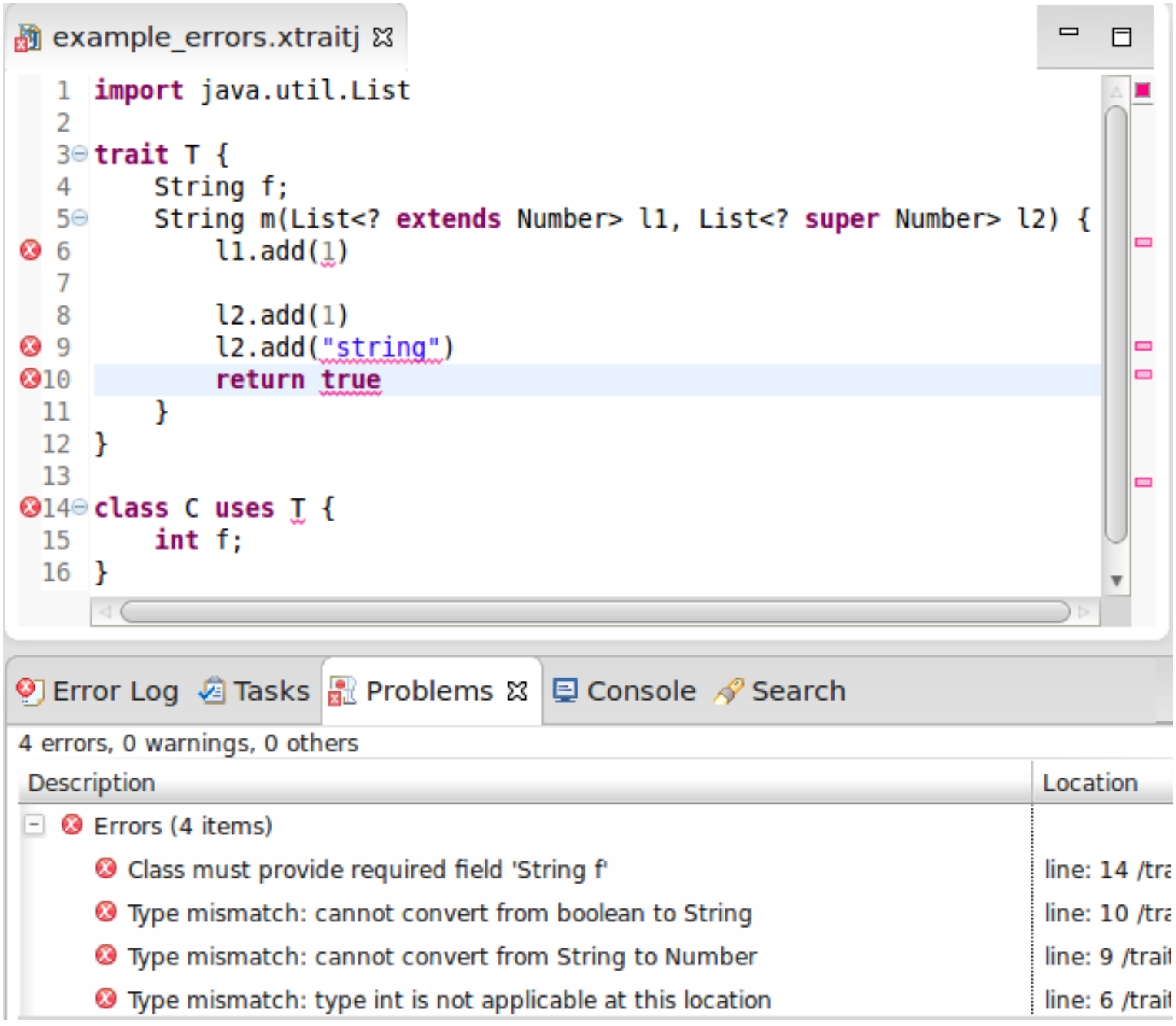
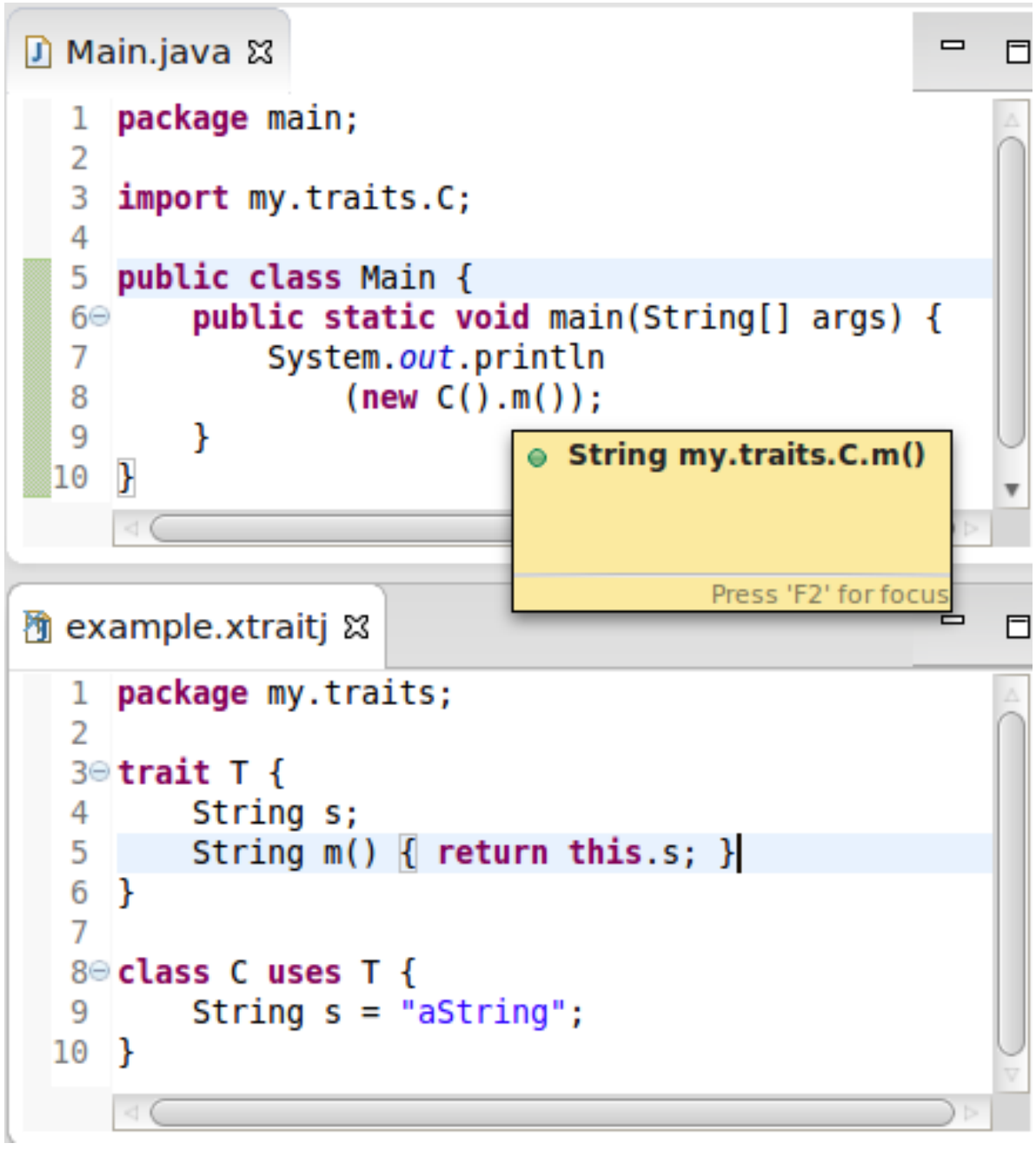
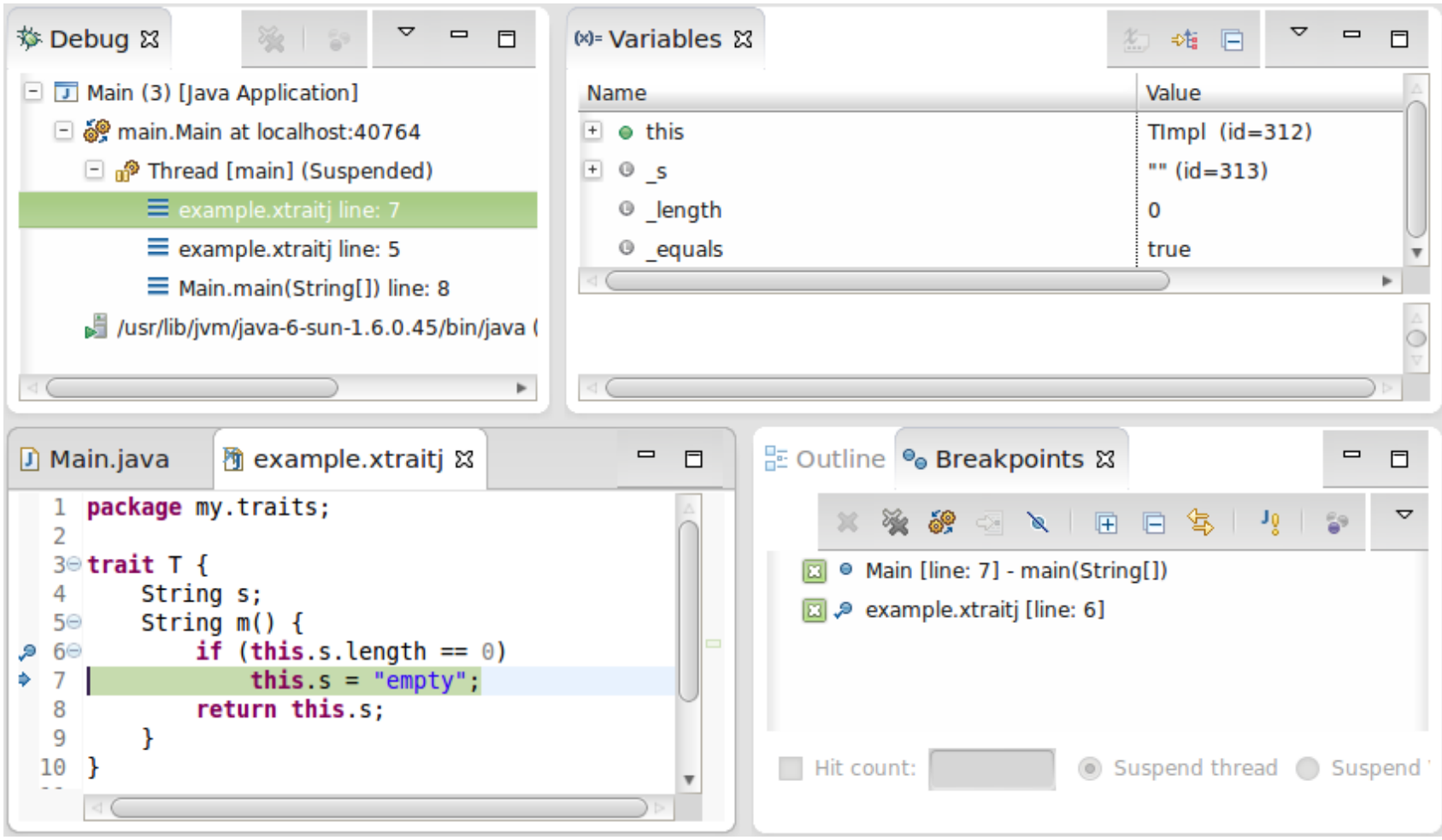
JAVA code and XTRAITJ code coexist and interoperate.

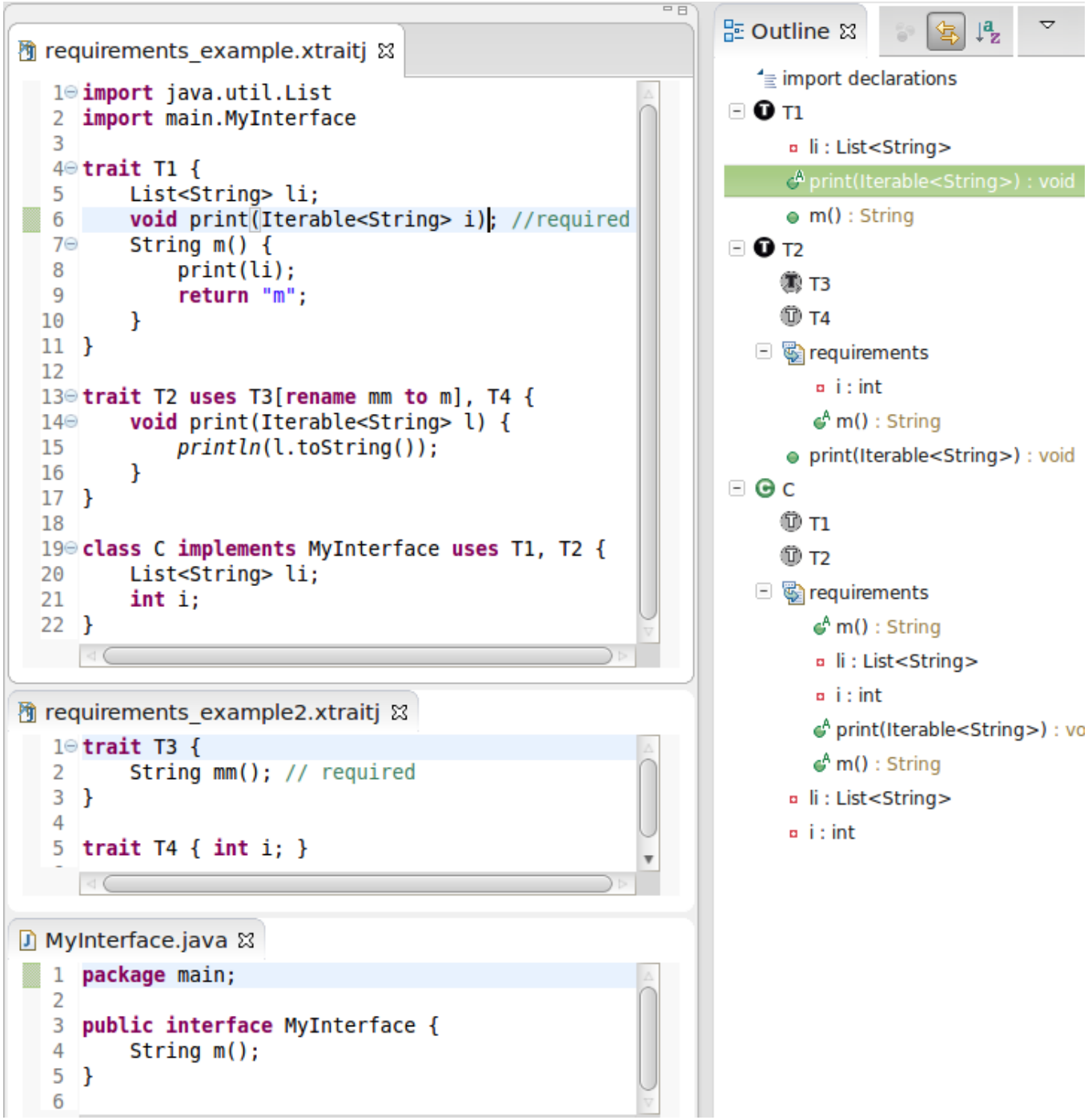
Benefits of XBASE

- Typing of method bodies is done by XBASE: no need to re-implement the JAVA type system;
- Complete integration with JAVA libraries;
- No need to define interfaces in XTRAITJ: just define a JAVA interface and use it in a XTRAITJ program;
- Eclipse IDE tooling integrated with JDT
- Debugging: debug XTRAITJ programs directly!


example_errors.xtraitj
1 import java.util.List
2
3 trait T {
4 String f;
5 String m(List<? extends Number> l1, List<? super Number> l2) {
6 l1.add(1)
7
8 l2.add(1)
9 l2.add("string")
10 return true
11 }
12 }
13
14 class C uses T {
15 int f;
16 }
Error Log
Tasks
Problems
Console
Search
4 errors, 0 warnings, 0 others
Description
Location
Errors (4 items)
Class must provide required field 'String f'
line: 14 /tra
Type mismatch: cannot convert from boolean to String
line: 10 /tra
Type mismatch: cannot convert from String to Number
line: 9 /trait
Type mismatch: type int is not applicable at this location
line: 6 /trait


Main.java
1 package main;
2
3 import my.traits.C;
4
5 public class Main {
6 public static void main(String[] args) {
7 System.out.println
8 (new C().m());
9 }
10 }
String my.traits.C.m()
Press 'F2' for focus
example.xtraitj
1 package my.traits;
2
3 trait T {
4 String s;
5 String m() { return this.s; }
6 }
7
8 class C uses T {
9 String s = "aString";
10 }


Debug
Main (3) [Java Application]
main.Main at localhost:40764
Thread [main] (Suspended)
example.xtraitj line: 7
example.xtraitj line: 5
Main.main(String[]) line: 8
/usr/lib/jvm/java-6-sun-1.6.0.45/bin/java (
Variables
Name
Value
this
TImpl (id=312)
_s
"" (id=313)
_length
0
_equals
true
Main.java
example.xtraitj
1 package my.traits;
2
3 trait T {
4 String s;
5 String m() {
6 if (this.s.length == 0)
7 this.s = "empty";
8 return this.s;
9 }
10 }
Outline
Breakpoints
Main [line: 7] - main(String[])
example.xtraitj [line: 6]
Hit count:
Suspend thread
Suspend


requirements_example.xtraitj
1 import java.util.List
2 import main.MyInterface
3
4 trait T1 {
5 List<String> li;
6 void print(Iterable<String> i); //required
7 String m() {
8 print(li);
9 return "m";
10 }
11 }
12
13 trait T2 uses T3[rename mm to m], T4 {
14 void print(Iterable<String> l) {
15 println(l.toString());
16 }
17 }
18
19 class C implements MyInterface uses T1, T2 {
20 List<String> li;
21 int i;
22 }
requirements_example2.xtraitj
1 trait T3 {
2 String mm(); // required
3 }
4
5 trait T4 { int i; }
MyInterface.java
1 package main;
2
3 public interface MyInterface {
4 String m();
5 }
6
Outline
import declarations
T1
li : List<String>
print(Iterable<String>) : void
m() : String
T2
T3
T4
requirements
i : int
m() : String
print(Iterable<String>) : void
C
T1
T2
requirements
m() : String
li : List<String>
i : int
print(Iterable<String>) : vo
m() : String
li : List<String>
i : int

Future work

- [1], refactoring JAVA class hierarchies into traits.
- Dynamic trait replacement [2].
- [3], a compositional proof systems for the verification of pure traits.
- Parametric Traits [4]: (not generic: more similar to C++ templates).


L. Bettini, V. Bono, and M. Naddeo.
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L. Bettini, S. Capecchi, and F. Damiani.
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F. Damiani, J. Dovland, E. B. Johnsen, and I. Schaefer.
Verifying traits: an incremental proof system for fine-grained reuse.
Formal Aspects of Computing, 2013. In press.


L. Bettini, F. Damiani, and I. Schaefer.
Implementing type-safe software product lines using parametric traits.
Science of Computer Programming, 2013. In press.

Software

http://xtraitj.sourceforge.net

Git repository:
https://github.com/LorenzoBettini/xtraitj

Eclipse update site:
http://sourceforge.net/projects/xtraitj/files/updates

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Thanks!