Getting F-Bounded Polymorphism into Shape

Ben Greenman, Fabian Muehlboeck, & Ross Tate

Cornell University

Problem

Type checking with generics, variance, and recursive inheritance is challenging.

There are many difficult corner cases and even subtyping is undecidable [1].

Example 1: Undecidable Subtyping

We attempted to provide type-safe equality on lists by using generics to enforce that list elements support type-safe equality.

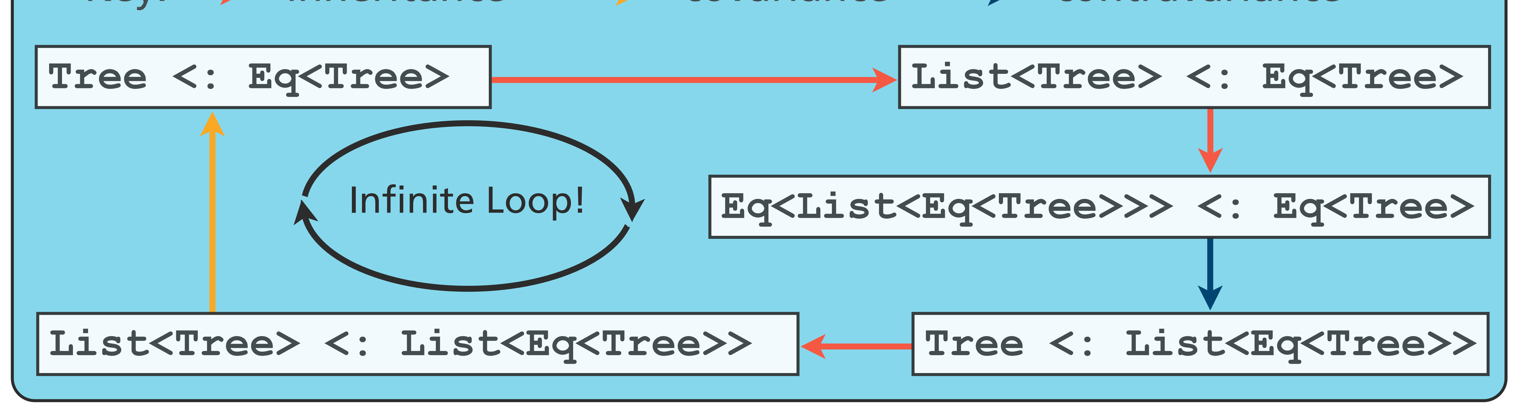
```
class List<out T> extends Eq<in List<out Eq<in T>>>
```

Next, we thought to define *n*-ary trees with type-safe equality by extending our List interface.

```
class Tree extends List<out Tree>
```

But the OpenJDK compiler (version 1.7) crashed when we added variance annotations and asked if Tree was a subtype of Eq<Tree>.

Key: → = inheritance → = covariance → = contravariance



Ex 2: Syntactic Identity

In type systems with syntactic identity, intersection commutes

✓ A & B = B & A

but not within type arguments.

✗ Array<A & B> = Array<B & A>

Ex 4: Imprecise Joins

A language without joins would incorrectly reject this program:

```
<T extends Comparable<T>>
void separate(T middle,
              Iterable<out T> elems,
              ArrayList<in T> smaller,
              ArrayList<in T> bigger){
  for (T elt : elems)
      (elt < middle ?
       smaller : bigger).add(elt);
}
```

Ex 3: Undecidable Equality

Given the following declaration:

```
class Foo extends
   Array<Foo & Array<Foo>>>
```

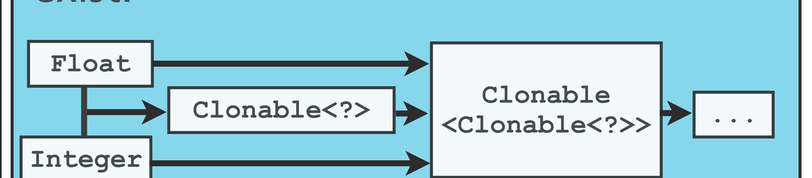
We cannot decide if Foo is a subtype of Array<Foo>.

Ex 5: Imprecise Joins

Suppose we have three classes:

```
class Clonable<out T> { }
class Integer extends Clonable<Integer> { }
class Float extends Clonable<Float> { }
```

The join of Integer and Float does not exist.



Observation

Programmers separate constraints from data. So should the compiler.

Example: The interface Comparable<T> is very different from most familiar types.

>> Comparable is **only used in inheritance or as a constraint.**

>> A programmer never wants a List<Comparable<X>>, but rather a List<T> where the T extends Comparable<T>.

Consequence: We recognize two disjoint groups of classes & interfaces, formalized as **Material-Shape Separation.**

Materials

Summary: Materials are the data transmitted and shared by program components.

Used for:
>> Parameter types
>> Return types
>> Field types
>> Type arguments

Examples: Object, Integer, String, List<T>, Map<K,V>, HashSet<T>, ...

Shapes

Summary: Shapes define the higher-level structure of a type via recursive inheritance.

Used for:
>> Inheritance / Type definitions
>> Type variable constraints

Examples: Clonable<T>, Enum<T>, Equatable<T>, Comparable<T>, Addable<T>, GraphEdge<E,V>

Industry Survey

13.5 million lines of Java code from **60** open-source projects* show these results.

>> Parameterized shapes were **never used** as materials
>> Exactly **one** project used a material in inheritance, but this definition was never used or exposed by an API.
>> Approximately 30% of projects used raw/wildcarded shapes as materials. Our system can provide this functionality by creating for each shape a parameterless material superclass.
>> In total, we found 15 project-specific shapes, each encoding a self type or a type family.

Conclusion: Material-Shape Separation is compatible with modern industry practices.

*All projects were written for Java 1.5 or later. Thanks to the Qualitas Corpus [2] for hosting many of the projects we used.

Applications

Material-Shape Separation simplifies type-checking.

The restriction provides a solid foundation for type-system enhancements.

Decidable Subtyping

Material-Shape Separation **limits** the power of recursive type definitions **to match practical use.** Cyclic and infinitely expansive inheritance are no longer possible and we have simple, decidable subtyping.

Type Equivalence

Our subtyping rules do not rely on syntactic identity, so reliable type equivalence is a free consequence.

Material-Shape Separation also eliminates troublesome corner cases.

✗ class Foo extends Array<Foo & Array<Foo>>

is nonsensical because the material Array should **never** be used to create a recursive definition.

Computable Joins

Joins need only be defined on the acyclic hierarchy of Materials. For example, the least common supertype of Integer and Float in our system is Object because Clonable<?> is not a Material.

Separating concepts lets us use a simple join algorithm without sacrificing the power of recursive type constraints.

Higher-Kinded Types

The well-founded measure we use to prove decidable subtyping and computable joins generalizes naturally to higher-kinded types.

Ceylon Integration

The Ceylon [3] team at Red Hat was our primary industry collaborator. They provided valuable insight and feedback throughout this project.

Material-Shape Separation is compatible with the entire Ceylon codebase and will likely be incorporated into Ceylon 2.0.

[1] Kennedy & Pierce, FOOL/WOOD 2007.

[2] http://qualitascorpus.com/ [3] http://ceylon-lang.org/

Read more: