
CSE 331
Software Design & Implementation

Kevin Zatloukal
Spring 2022
Generics

Preface

- This lecture will get into the gritty details of generics
- In practice:
 - you will constantly need to **use** generic classes
 - e.g., the collections library
 - but you will rarely need to **write** generic classes
 - (generic methods are a little more common)
 - unless you are writing a container class, you are probably making a mistake by making it generic
- We will go through all the details so that you have seen it once

Pre-generic Collection Use

Checking types were correct was done at run-time.

```
Hashtable h = new Hashtable();  
h.put("abc", new Integer(3));  
...  
Integer val = (Integer) h.get("abc");
```

No compiler help to ensure type constraints are satisfied

Alternative: Many, Many Classes

```
interface ListOfNumbers {  
    boolean add(Number elt);  
    Number get(int index);  
}
```

```
interface ListOfIntegers {  
    boolean add(Integer elt);  
    Integer get(int index);  
}
```

... and many, many more

Why we *love* abstraction

Hide details

- avoid getting lost in details (readability)
- permit details to change later on (changeability)

Give a *meaningful name* to a concept (readability)

Permit *reuse* in new contexts

- avoid duplication: error-prone, confusing, less changeable
- save reimplementation effort

Varieties of abstraction

Abstraction over *computation*: procedures (methods)

```
int x1, y1, x2, y2;  
Math.sqrt(x1*x1 + y1*y1);  
Math.sqrt(x2*x2 + y2*y2);
```

Abstraction over *data*: ADTs (classes, interfaces)

```
Point p1, p2;
```

Abstraction over *types*: polymorphism (generics)

```
Point<Integer>, Point<Double>
```

Related abstractions

```
interface ListOfNumbers {  
    boolean add(Number elt);  
    Number get(int index);  
}
```

```
interface ListOfIntegers {  
    boolean add(Integer elt);  
    Integer get(int index);  
}
```

... and many, many more

// abstracts over element type

```
interface List<E> {  
    boolean add(E n);  
    E get(int index);  
}
```

Lets us use types

```
List<Integer>
```

```
List<Number>
```

```
List<String>
```

```
List<List<String>>
```

```
...
```

An analogous parameter

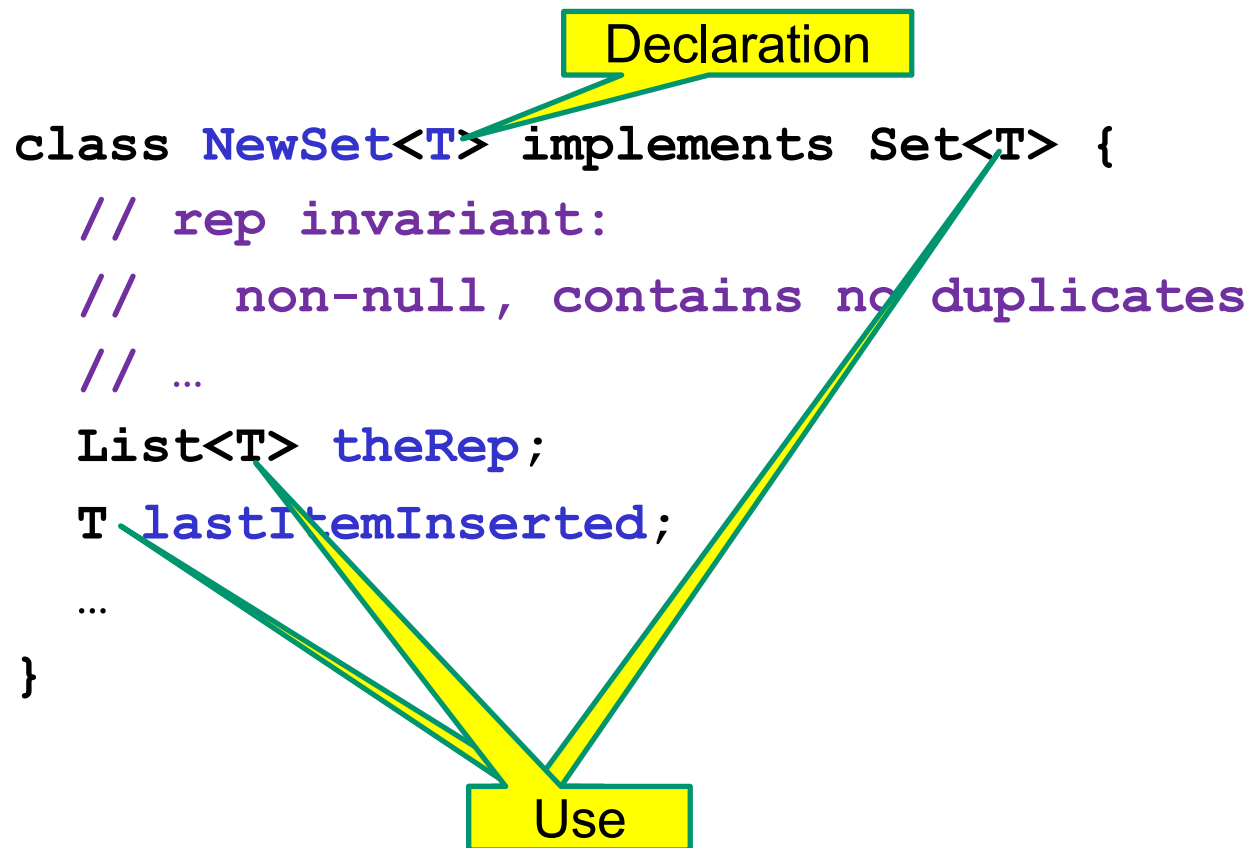
```
interface ListOfIntegers {  
    boolean add(Integer elt);  
    Integer get(int index);  
}
```

- Declares a new **variable**, called a **(formal) parameter**
- **Instantiate** with any **expression** of the right type
 - e.g., `lst.add(7)`
- **Type** of `add` is *Integer -> boolean*

```
interface List<E> {  
    boolean add(E n);  
    E get(int index);  
}
```

- Declares a new **type variable**, called a **type parameter**
- **Instantiate** with any (reference) type
 - e.g., `List<String>`
- **“Type”** of `List` is *Type -> Type*
 - never just use `List` (allowed for backward-compatibility only)

Type variables are types



Declaring and instantiating generics

```
class Name<TypeVar1, ..., TypeVarN> {...}
```

```
interface Name<TypeVar1, ..., TypeVarN> {...}
```

- often one-letter name such as:
T for **T**ype, E for **E**lement,
K for **K**ey, V for **V**alue, ...

To instantiate a generic class/interface, supply type arguments:

```
Name<Type1, ..., TypeN>
```

Restricting instantiations by clients

```
boolean add1(Object elt);  
boolean add2(Number elt);  
add1(new Date()); // OK  
add2(new Date()); // compile-time error
```

Upper bounds



```
interface List1<E extends Object> {...}  
interface List2<E extends Number> {...}
```

```
List1<Date> // OK, Date is a subtype of Object
```

```
List2<Date> // compile-time error, Date is not a  
// subtype of Number
```

Revised definition

```
class Name<TypeVar1 extends Type1,  
        ...,  
        TypeVarN extends TypeN> {...}
```

- (same for interface definitions)
- (default upper bound is `Object`)

To instantiate a generic class/interface, supply type arguments:

```
Name<Type1, ..., TypeN>
```

Compile-time error if type is not a subtype of the upper bound

Using type variables

Code can perform any operation permitted by the bound

- because we know all instantiations will be subtypes!
- an enforced precondition on type instantiations

```
class Foo1<E extends Object> {  
    void m(E arg) {  
        arg.intValue(); // compiler error, E might not  
                        // support intValue  
    }  
}
```

```
class Foo2<E extends Number> {  
    void m(E arg) {  
        arg.intValue(); // OK, since Number and its  
                        // subtypes support intValue  
    }  
}
```

More examples

```
public class Graph<N> implements Iterable<N> {
    private final Map<N, Set<N>> node2neighbors;
    public Graph(Set<N> nodes, Set<Pair<N,N>> edges) {
        ...
    }
}
```

```
public interface Path<N, P extends Path<N,P>>
    extends Iterable<N>, Comparable<Path<?, ?>> {
    public Iterator<N> iterator();
    ...
}
```

(Note: you probably don't want to use this code in your homework.)

More bounds

`<TypeVar extends SuperType>`

- an *upper bound*; accepts given supertype or any of its subtypes

`<TypeVar extends ClassA & InterfaceB & InterfaceC & ...>`

- *multiple* upper bounds (superclass/interfaces) with `&`

Example:

```
// tree set works for any comparable type
public class TreeSet<T extends Comparable<T>> {
    ...
}
```

Where are we?

- Done:
 - basics of generic types for classes and interfaces
 - basics of *bounding* generics
- Now:
 - generic *methods* [not just using type parameters of class]
 - generics and *subtyping*
 - using *bounds* for more flexible subtyping
 - using *wildcards* for more convenient bounds
 - related digression: Java's *array subtyping*
 - Java realities: type erasure
 - unchecked casts
 - **equals** interactions
 - creating generic arrays

Not all generics are for collections

```
class Utils {
    static double sumList(List<Number> lst) {
        double result = 0.0;
        for (Number n : lst) {
            result += n.doubleValue();
        }
        return result;
    }
    static Number choose(List<Number> lst) {
        int i = ... // random number < lst.size
        return lst.get(i);
    }
}
```

Weaknesses

- Would like to use `sumList` for any subtype of `Number`
 - for example, `Double` or `Integer`
 - but as we will see, `List<Double>` is not a subtype of `List<Number>`
- Would like to use `choose` for any element type
 - i.e., any subclass of `Object`
 - no need to restrict to subclasses of `Number`
 - want to tell clients more about return type than `Object`
- Class `Utils` is not generic, but the *methods* should be generic

Much better

```
class Utils {
    static <T extends Number>
    double sumList(List<T> lst) {
        double result = 0.0;
        for (Number n : lst) { // T also works
            result += n.doubleValue();
        }
        return result;
    }
    static <T>
    T choose(List<T> lst) {
        int i = ... // random number < lst.size
        return lst.get(i);
    }
}
```

Have to declare type parameter(s)

Have to declare type parameter(s)

Using generics in methods

- Instance methods can use type parameters of the class
- Instance methods can have their own type parameters
 - generic methods
- Callers to generic methods need not explicitly instantiate the methods' type parameters
 - compiler just figures it out for you
 - example of *type inference*

More examples

```
<T extends Comparable<T>> T max(Collection<T> c) {  
    ...  
}
```

```
<T extends Comparable<T>>  
void sort(List<T> list) {  
    // ... use list.get() and T's compareTo  
}
```

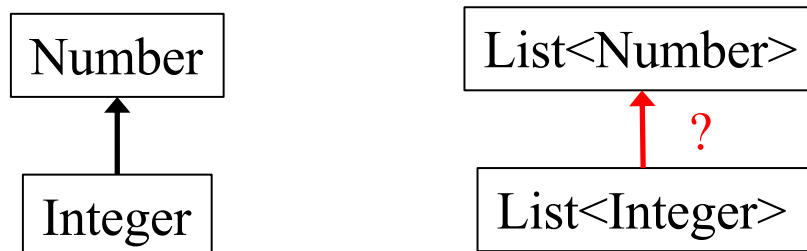
(This works but will be even more useful later with more bounds)

```
<T> void copyTo(List<T> dst, List<T> src) {  
    for (T t : src)  
        dst.add(t);  
}
```

Where are we?

- Done:
 - basics of generic types for classes and interfaces
 - basics of *bounding* generics
- Now:
 - generic *methods* [not just using type parameters of class]
 - *generics and subtyping*
 - using *bounds* for more flexible subtyping
 - using *wildcards* for more convenient bounds
 - related digression: Java's *array subtyping*
 - Java realities: type erasure
 - unchecked casts
 - **equals** interactions
 - creating generic arrays

Generics and subtyping



- **Integer** can be used wherever **Number** is expected
 - this is the notion of a subtype
 - (specifically, the Liskov substitutability principle)
 - i.e, **Integer** satisfies a *stronger spec* than **Number**
 - only adds methods and strengthens existing methods
- Can you safely substitute **List<Integer>** wherever a **List<Number>** is used without possibility of error?

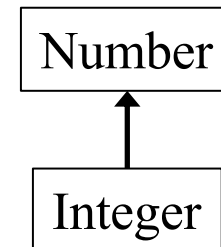
Generics and subtyping

```
List<Number> numList = new List<Number>();  
List<Integer> intList = new List<Integer>();  
  
intList.add(new Integer(3));  
-> numList.add(new Integer(3));    // okay  
numList.add(new Double(3.0));  
-> intList.add(new Double(3.0));  // not legal  
  
Number n = numList.get(0);  
-> Number n = intList.get(0);    // okay  
Integer n = intList.get(0);  
-> Integer n = numList.get(0);   // illegal
```

Neither type can be substituted for the other legally in all situations!

List<Number> and List<Integer>

```
interface List<T> {  
    boolean add(T elt);  
    T get(int index);  
}
```



So type List<Number> has:

```
boolean add(Number elt);  
Number get(int index);
```

So type List<Integer> has:

```
boolean add(Integer elt);  
Integer get(int index);
```

Java subtyping is *invariant* with respect to generics

- Not covariant and not contravariant
- Neither List<Number> nor List<Integer> subtype of other

Hard to remember?

If **Type2** and **Type3** are different,
then **Type1<Type2>** is *not* a subtype of **Type1<Type3>**

Previous example shows why:

- Observer method prevents “one direction”
- Mutator/producer method prevents “the other direction”

If our types have only observers or only mutators, then one direction of subtyping would be sound

- But Java’s type system does not “notice this” so such subtyping is never allowed in Java

Read-only allows covariance

```
interface List<T> {  
    T get(int index);  
}
```

So type `List<Number>` has:
`Number get(int index);`

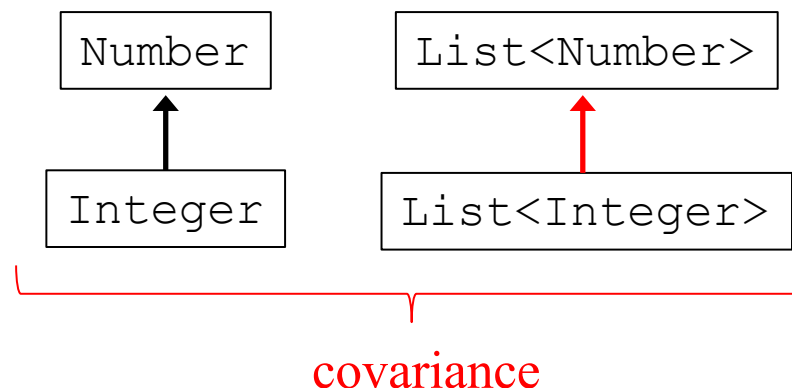
So type `List<Integer>` has:
`Integer get(int index);`

So *covariant* subtyping would be correct:

- `List<Integer>` a subtype of `List<Number>`

But Java does not analyze interface definitions like this

- conservatively disallows this subtyping



Write-only allows contravariance

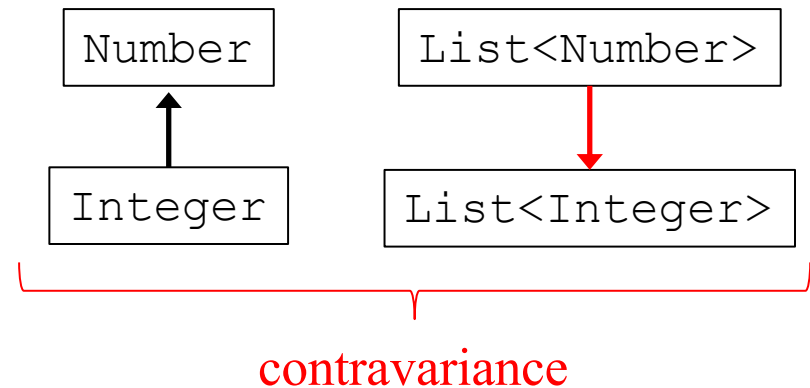
```
interface List<T> {  
    boolean add(T elt);  
}
```

So type `List<Number>` has:
`boolean add(Number elt);`

So type `List<Integer>` has:
`boolean add(Integer elt);`

So *contravariant* subtyping would be correct:
– `List<Number>` a subtype of `List<Integer>`

But Java does not analyze interface definitions like this
– conservatively disallows this subtyping



Co- and Contra-variance

```
interface List<T> {  
    boolean add(T elt);  
    T get(int index);  
}
```

In general, `List<T>` should be

- covariant if `T` only appears as a return value
- contravariant if `T` only appears as an argument

Some languages (e.g., Scala and C#) allow this

Java does not:

- cannot substitute `List<T1>` for `List<T2>` unless `T1 = T2`

About the parameters

- So we have seen `List<Integer>` and `List<Number>` are not subtype-related
- There is “as expected” subtyping on the generic types themselves
- Example: If `HeftyBag` extends `Bag`, then
 - `HeftyBag<Integer>` is a subtype of `Bag<Integer>`
 - `HeftyBag<Number>` is a subtype of `Bag<Number>`
 - `HeftyBag<String>` is a subtype of `Bag<String>`
 - ...

Where are we?

- Done:
 - basics of generic types for classes and interfaces
 - basics of *bounding* generics
- Now:
 - generic *methods* [not just using type parameters of class]
 - generics and *subtyping*
 - using *bounds* for more flexible subtyping
 - using *wildcards* for more convenient bounds
 - related digression: Java's *array subtyping*
 - Java realities: type erasure
 - unchecked casts
 - **equals** interactions
 - creating generic arrays

Best type for addAll

```
interface Set<E> {  
    // Adds all elements in c to this set  
    // (that are not already present)  
    void addAll(_____ c);  
}
```

What is the best type for `addAll`'s parameter?

- Allow as many clients as possible...
- ... while allowing correct implementations

Best type for addAll

```
interface Set<E> {  
    // Adds all elements in c to this set  
    // (that are not already present)  
    void addAll(_____ c);  
}
```

```
void addAll(Set<E> c);
```

Too restrictive:

- does not let clients pass other collections, like `List<E>`
- better: use a supertype interface with just what `addAll` needs

Best type for addAll

```
interface Set<E> {  
    // Adds all elements in c to this set  
    // (that are not already present)  
    void addAll(_____ c);  
}
```

```
void addAll(Collection<E> c);
```

Still too restrictive:

- cannot pass a `List<Integer>` to `addAll` for a `Set<Number>`
- that should be okay because `addAll` implementations only need to read from `c`, not put elements in it
- but Java does not allow it
 - this is the invariant-subtyping limitation

Best type for addAll

```
interface Set<E> {  
    // Adds all elements in c to this set  
    // (that are not already present)  
    void addAll(_____ c);  
}
```

```
<T extends E> void addAll(Collection<T> c);
```

The fix: bounded generic type parameter

- *can* pass a `List<Integer>` to `addAll` for a `Set<Number>`
- `addAll` implementations won't know what element type `T` is, but will know it is a subtype of `E`
 - it cannot add anything to collection `c` refers to
 - but this is enough to implement `addAll`

Generic methods get around invariance

You cannot pass `List<Integer>` to method expecting `List<Number>`

- Java subtyping is invariant with respect to type parameters

Get around it by making your **method** generic:

```
<T extends Number> void sumList(List<T> nums) {  
    double s = 0;  
    for (T t : nums)  
        s += t.doubleValue();  
    return s;  
}
```

Revisit copy method

Earlier we saw this:

```
<T> void copyTo(List<T> dst, List<T> src) {  
    for (T t : src)  
        dst.add(t);  
}
```

Now we can do this (which is more general):

```
<T1, T2 extends T1> void copyTo(List<T1> dst,  
                                List<T2> src) {  
    for (T2 t : src)  
        dst.add(t);  
}
```