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# CSE 331

# Software Design & Implementation

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Generics

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# Preface

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- 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

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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

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```
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

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## *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 reimplementing effort

# Varieties of abstraction

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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

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```
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

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```
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`

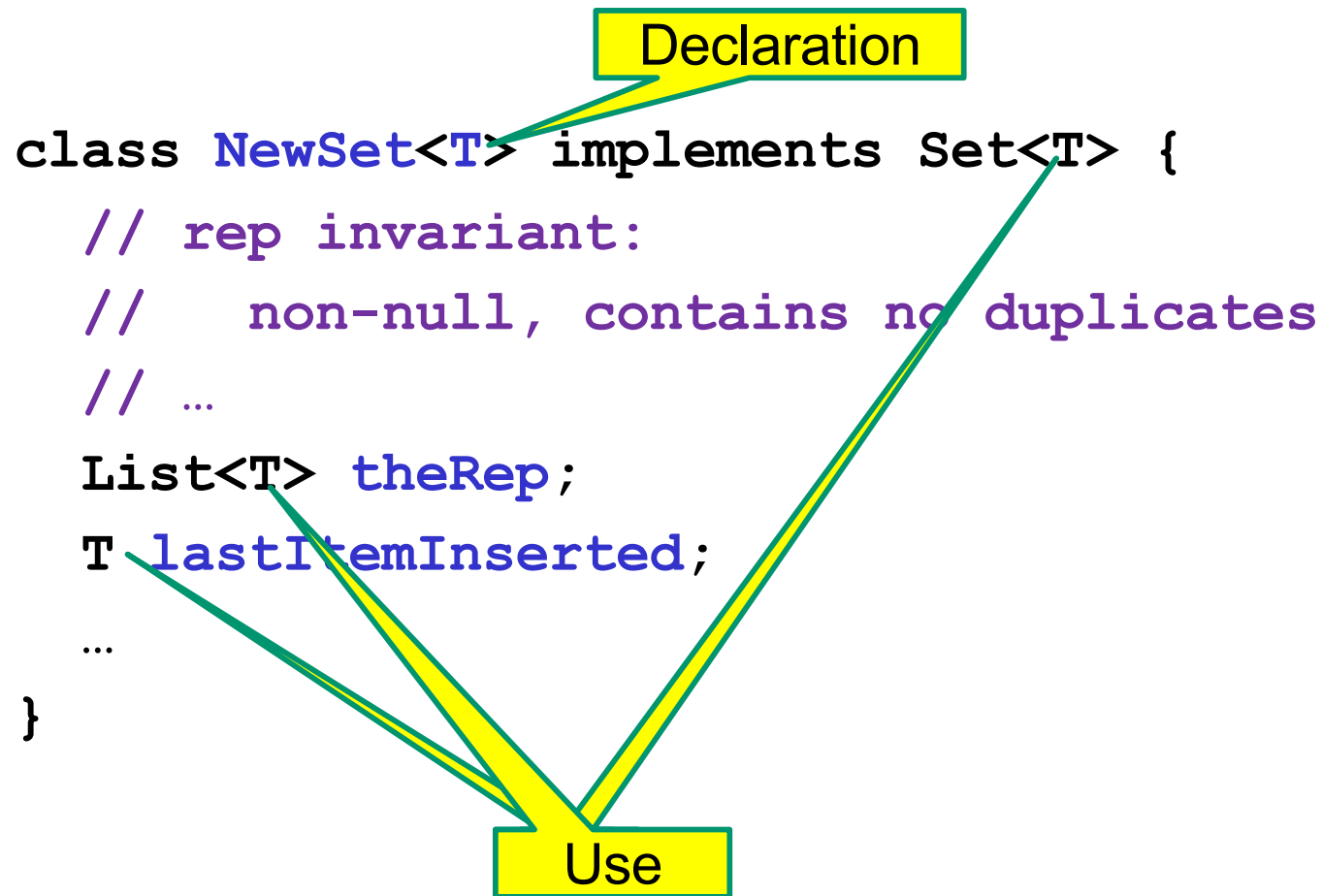
```
interface List<E> {  
    boolean add(E n);  
    E get(int index);  
}
```

- 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

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# Declaring and instantiating generics

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```
class Name<TypeVar1, ..., TypeVarN> {...}
interface Name<TypeVar1, ..., TypeVarN> {...}
  – often one-letter name such as:
    T for Type, E for Element,
    K for Key, V for Value, ...
```

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

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

# Restricting instantiations by clients

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```
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

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```
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

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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

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```
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

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`<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?

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- 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

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```
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

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- 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

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```
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

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- 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

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```
<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);  
}
```

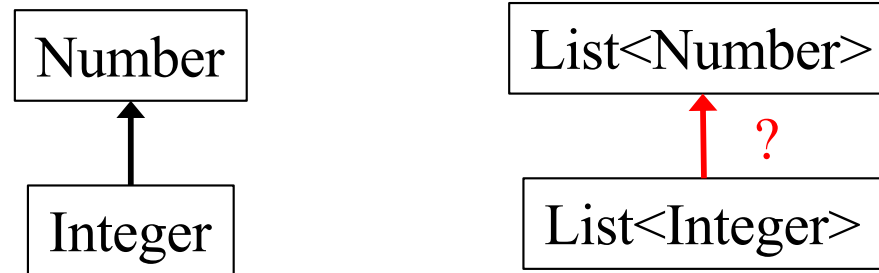
# Where are we?

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- Done:
  - basics of generic types for classes and interfaces
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- 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
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    - unchecked casts
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# Generics and subtyping

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- **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

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```
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
```

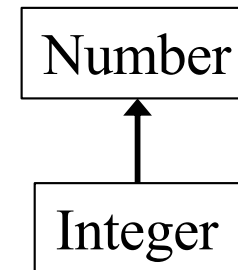
Neither type can be substituted for the other legally in all situations!



# 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?

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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

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

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

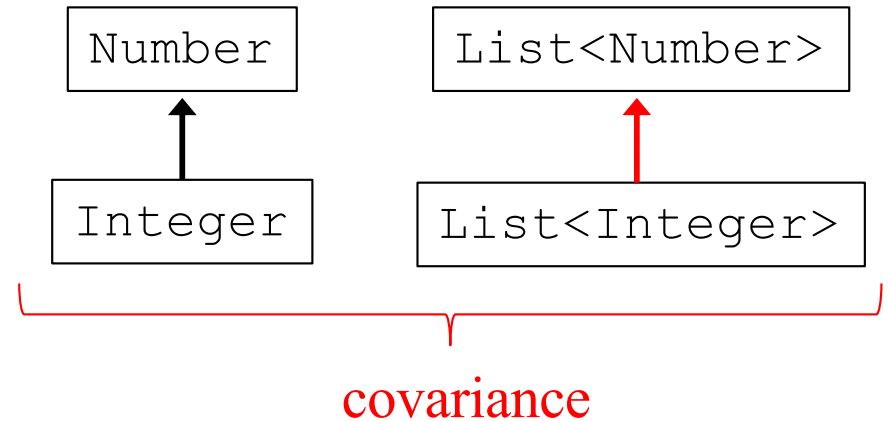
So type `List<Integer>` has:  
`Integer get(int index);`

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:

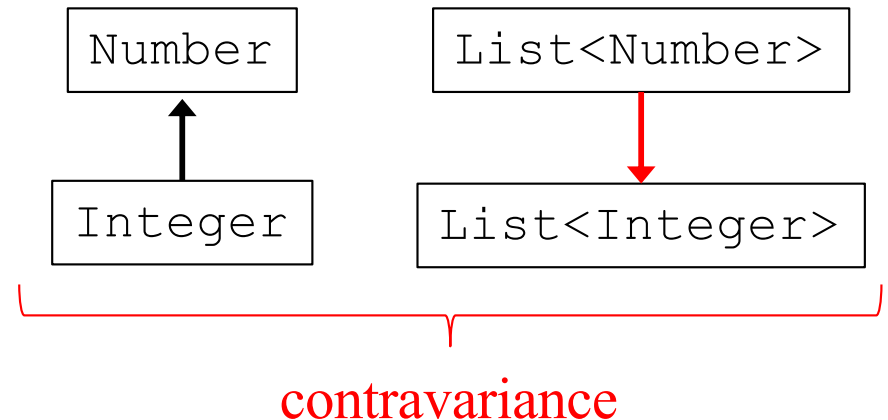
```
boolean add(Integer elt);
```

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

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```
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

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- 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>`
  - ...