CSE 331
Software Design and Implementation

# Lecture 13
# Generics⟨1⟩

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# 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>
```

**Today!**

# Why we ♥ abstraction

*Hide details*

- Avoid distraction
- Permit details to change later

Give a *meaningful name* to a concept

Permit *reuse* in new contexts

- Avoid duplication:  error-prone, confusing
- Save reimplementation effort
- Helps to “Don’t Repeat Yourself”

*Any true wizard knows, once you know the name of a thing you can control it.*

*-- Jerry Sussman*

# Related abstractions

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

# Related abstractions

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

… and many, many more

```
// Type abstraction
// abstracts over element type E
interface List<E> {
  boolean add(E n);
  E get(int index);
}
```

*Type abstraction*
*lets us use these types:*

```
List<String>
List<Number>
List<Integer>
List<List<String>>
…
```

# Formal parameter vs. type 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`** (in Java for backward compatiblity)

# Type variables are types

Declaration

```
class NewSet<T> implements Set<T> {
  // rep invariant:
  //   non-null, contains no duplicates
  // …
  List<T> theRep;
  T lastItemInserted;
  …
}
```

Use

# Declaring and instantiating generics

```
class MyClass<TypeVar1, …, TypeVarN> {…}
interface MyInterface<TypeVar1, …, TypeVarN> {…}
```

– Convention: Type variable has one-letter name such as:
  **`T`** for **`Type`**, **`E`** for **`Element`**,
  **`K`** for **`Key`**, **`V`** for **`Value`**, …

To instantiate a generic class/interface, client supplies *type arguments*:

```
MyClass<String, …, Date>
```

# 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
```

# Declaring and instantiating generics: syntax with bounds

```
class MyClass<TypeVar1 extends TypeBound1,
              ...,
              TypeVarN extends TypeBoundN> {…}
```

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

To instantiate a generic class/interface, client supplies type arguments:

```
MyClass<String, …, Date>
```

- 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.asInt();  // compiler error, E might not
                  // support asInt()
  }
}

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

# More examples

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

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

Do ***NOT*** copy/paste this stuff into your project unless it is what you want

- *And* you understand it!

# 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 `&`

Recursively-defined bounds:

```
// TreeSet works for any type that can be compared
// to itself.
public class TreeSet<T extends Comparable<T>> {
    …
}
```

# Outline

- Basics of generic types for classes and interfaces
- Basics of *bounding* generics
- 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

# Generic classes are not enough

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

Cannot pass `List<Double>`

Independent of **`Number`** above

Reminder: **`static`** means "no receiver (**`this`** parameter)".

**`List<Double>`**
is not a subtype of
**`List<Number>`** !
We will see why soon.

# Weaknesses of generic classes

- 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

# Generic methods solve the problem

Have to declare type parameter(s)

```
class Utils {
  static <T1 extends Number>
  double sumList(List<T1> lst) {
      double result = 0.0;
      for (Number n : lst) { // T1 also works
        result += n.doubleValue();
      }
      return result;
  }
  static <T2>
  T2 choose(List<T2> lst) {
      int i = … // random number < lst.size
      return lst.get(i);
  }
}
```

Have to declare type parameter(s)

# Using generics in methods

- Instance methods can use type parameters of the class
- Instance methods and static methods can have their own type parameters
  - Generic methods
- Callers to generic methods need not explicitly instantiate the methods’ type parameters
  - Compiler usually figures it out for you
  - *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 one works, but we will make it even more useful later by adding more bounds.)

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

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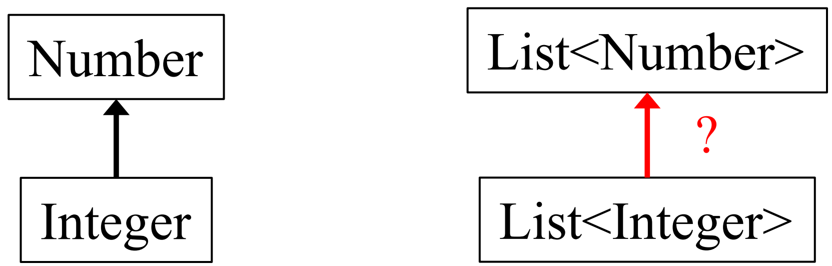
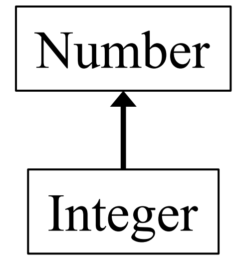
# Generics and subtyping




- **`Integer`** is a subtype of **`Number`**
- Is **`List<Integer>`** a subtype of **`List<Number>`**?
- Use subtyping rules (stronger, weaker) to find out…

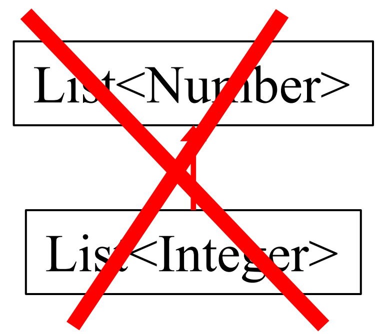
# List<Number> and List<Integer>

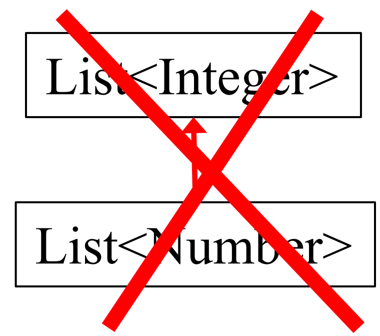
```
interface List<T> {
  boolean add(T elt);
  T get(int index);
}
```




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

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

# How to remember the invariant rule

If **`Type2`** and **`Type3`** are different,

then **`Type1<Type2>`** is *not* a subtype of **`Type1<Type3>`**

Previous example shows why:

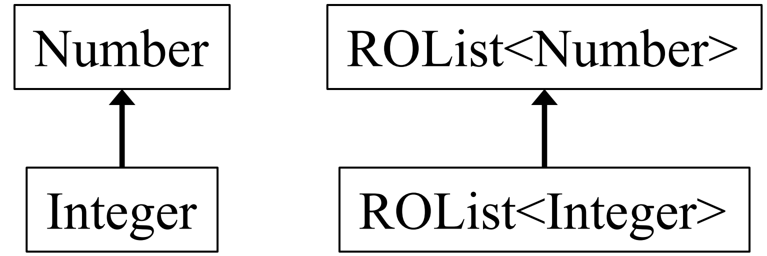
- Observer method prevents one direction
- Mutator/producer method prevents the other direction

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

- Java's type system is not expressive enough to allow this

# Read-only allows covariance

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




Type **ReadOnlyList<Number>** has method:

```
Number get(int index);
```

Type **ReadOnlyList<Integer>** has method:

```
Integer get(int index);
```

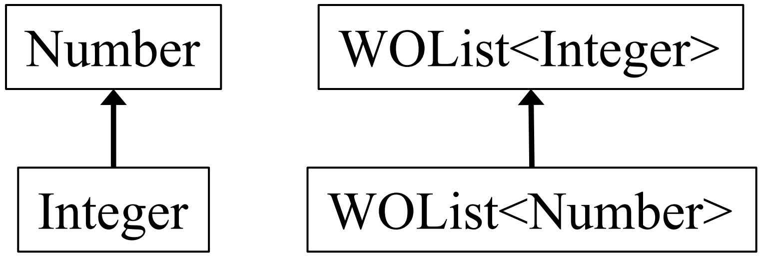
So *covariant* subtyping would be correct:

- **ROList<Integer>** is a subtype of **ROList<Number>**
- Covariant = type of **ROList<T>** changes the same way **T** changes

The Java type system conservatively disallows this subtyping

# Write-only allows contravariance

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




Type **`WriteOnlyList<Number>`** has method:

```
  boolean add(Number elt);
```

Type **`WriteOnlyList<Integer>`** has method:

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

So *contravariant* subtyping would be correct:

- **`WOList<Number>`** is a subtype of **`WOList<Integer>`**
- Contravariant = type of **`ROList<T>`** changes opposite to **`T`**

The Java type system conservatively disallows this subtyping

# Generic types and subtyping

- **`List<Integer>`** and **`List<Number>`** are not subtype-related
- Generic types can have subtyping relationships
- 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>`**
  - …

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