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

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
```

Upper bounds

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

```
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)

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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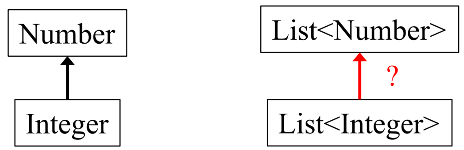
Generics and subtyping



- **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>**

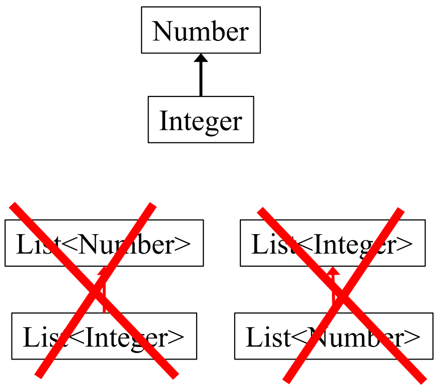
```
interface List<T> {
  boolean add(T elt);
  T get(int index);
}
```

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:

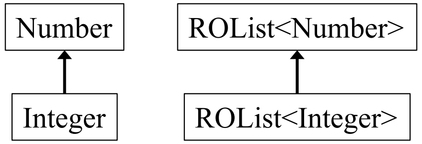
- Observer method prevents one direction
- Mutator/producer method prevents the other direction

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:

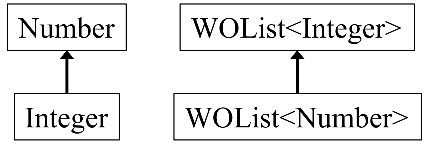
```
  Integer get(int index);
```

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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