

CS61B Lecture #25: Java Generics

The Old Days

- Java library types such as `List` didn't used to be parameterized. All Lists were lists of `Objects`.
- So you'd write things like this:

```
for (int i = 0; i < L.size(); i += 1)
    { String s = (String) L.get(i); ... }
```

- That is, must explicitly cast result of `L.get(i)` to let the compiler know what it is.
- Also, when calling `L.add(x)`, was no check that you put only `Strings` into it.
- So, starting with 1.5, the designers tried to alleviate these perceived problems by introducing *parameterized types*, like `List<String>`.
- Unfortunately, it is not as simple as one might think.

Basic Parameterization

- From the definitions of ArrayList and Map in java.util:

```
public class ArrayList<Item> implements List<Item> {  
    public Item get(int i) { ... }  
    public boolean add(Item x) { ... }  
    ...  
}  
public interface Map<Key, Value> {  
    Value get(Key x);  
    ...  
}
```

- First (blue) occurrences of Item, Key, and Value introduce formal *type parameters*, whose “values” (which are reference types) get substituted for all the other occurrences of Item, Key, or Value when ArrayList or Map is “called” (as in ArrayList<String>, or ArrayList<int[]>, or Map<String, List<Particle>>).
- Other occurrences of Item, Key, and Value are uses of the formal types, just like uses of a formal parameter in the body of a function.

Type Instantiation

- *Instantiating* a generic type is analogous to calling a function.
- Consider again

```
public class ArrayList<Item> implements List<Item> {  
    public Item get(int i) { ... }  
    public boolean add(Item x) { ... }  
    ...  
}
```

- When we write `ArrayList<String>`, we get, in effect, a new type, somewhat like

```
public String_ArrayList implements List<String> {  
    public String get(int i) { ... }  
    public boolean add(String x) { ... }  
}
```

- And then, likewise, `List<String>` refers to a new interface type as well.

Parameters on Methods

- Functions (methods) may also be parameterized by type. Example of use from `java.util.Collections`:

```
/** A read-only list containing just ITEM. */
static <T> List<T> singleton(T item) { ... }
/** An unmodifiable empty list. */
static <T> List<T> emptyList() { ... }
```

The compiler figures out T in the expression `singleton(x)` by looking at the type of `x`. This is a simple example of *type inference*.

- In the call

```
List<String> empty = Collections.emptyList();
```

the parameters obviously don't suffice, but the compiler deduces the parameter `T` from context: it must be assignable to `String`.

Wildcards

- Consider the definition of something that counts the number of times something occurs in a collection of items. Could write this as

```
/** Number of items in C that are equal to X. */
static <T> int frequency(Collection<T> c, Object x) {
    int n; n = 0;
    for (T y : c) {
        if (x.equals(y))
            n += 1;
    }
    return n;
}
```

- But we don't really care what T is; we don't need to declare anything of type T in the body, because we could write instead

```
...
for (Object y : c) {
```

- Wildcard type parameters* say that you don't care what a type parameter is (i.e., it's any subtype of Object):

```
static int frequency(Collection<?> c, Object x) {...}
```

Subtyping (I)

- What are the relationships between the types

`List<String>`, `List<Object>`, `ArrayList<String>`, `ArrayList<Object>`?

- We know that `ArrayList` \preceq `List` and `String` \preceq `Object` (using \preceq for "is a subtype of")...
- ... So is `List<String>` \preceq `List<Object>`?

Subtyping (II)

- Consider this fragment:

```
List<String> LS = new ArrayList<String>();
List<Object> LObj = LS;           // OK??
int[] A = { 1, 2 };
LObj.add(A);                      // Legal, since A is an Object
String S = LS.get(0);             // OOPS! A.get(0) is NOT a String,
                                  // but spec of List<String>.get
                                  // says that it is.
```

- So, having $\text{List}\langle\text{String}\rangle \preceq \text{List}\langle\text{Object}\rangle$ would violate *type safety*:
The compiler is wrong about the type of a value.
- So in general for $T1\langle X \rangle \preceq T2\langle Y \rangle$, must have $X = Y$.
- But what about $T1$ and $T2$?

Subtyping (III)

- Now consider

```
ArrayList<String> ALS = new ArrayList<String>();  
List<String> LS = ALS;           // OK??
```

- In this case, everything's fine:
 - The object's dynamic type is `ArrayList<String>`.
 - Therefore, the methods expected for `LS` must be a subset of those for `ALS`.
 - And since the type parameters are the same, the signatures of those methods will be the same.
 - Therefore, all the legal calls on methods of `LS` (according to the compiler) will be valid for the actual object pointed to by `LS`.
- In general, $T1<X> \preceq T2<X>$ if $T1 \preceq T2$.

A Java Inconsistency: Arrays

- The Java language design is not entirely consistent when it comes to subtyping.
- For the same reason that `ArrayList<String> $\not\leq$ ArrayList<Object>`, you'd also expect that `String[] $\not\leq$ Object[]`.
- And yet, Java *does* make `String[] \leq Object[]`.
- And, just as explained above, one gets into trouble with

```
String[] AS = new String[3];  
Object[] AObj = AS;  
AObj[0] = new int[] { 1, 2 }; // Bad
```

- So in Java, the **Bad** line causes an `ArrayStoreException`—a (dynamic) runtime error instead of a (static) compile-time error.
- Why do it this way? Basically, because otherwise there'd be no way to implement, e.g., `ArrayList`.

Type Bounds (I)

- Sometimes, your program needs to ensure that a particular type parameter is replaced only by a subtype (or supertype) of a particular type (sort of like specifying the “type of a type.”).
- For example,

```
class NumericSet<T extends Number> extends HashSet<T> {  
    /** My minimal element */  
    T min() { ... }  
    ...  
}
```

Requires that all type parameters to `NumericSet` must be subtypes of `Number` (the “type bound”). `T` can either extend or implement the bound, as appropriate.

Type Bounds (II)

- Another example:

```
/** Set all elements of L to X. */  
static <T> void fill(List<? super T> L, T x) { ... }
```

means that L can be a List<Q> for any Q as long as T is a subtype of (extends or implements) Q.

- Why didn't the library designers just define this as

```
/** Set all elements of L to X. */  
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? -

- Consider

```
static void blankIt(List<Object> L) {  
    fill(L, " ");  
}
```

This would be illegal if L were forced to be a List<String>.

Type Bounds (III)

- And one more:

```
/** Search sorted list L for KEY, returning either its position (if
 * present), or k-1, where k is where KEY should be inserted. */
static <T> int binarySearch(List<? extends Comparable<? super T>> L,
                           T key)
```

- Here, the items of L have to have a type that is comparable to T's or to some supertype of T.
- Does L have to be able to contain the value key?
- Why does this make sense?

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- Here, the items of L have to have a type that is comparable to T's or to some supertype of T.
- Does L have to be able to contain the value key?
- Why does this make sense?
- As long as the items in L can be compared to key, it doesn't really matter whether they might include key (not that this is often useful).

Dirty Secrets Behind the Scenes

- Java's design for parameterized types was constrained by a desire for backward compatibility.
- Actually, when you write

```
class Foo<T> {  
    T x;  
    T mogrify(T y) { ... }  
}
```

```
Foo<Integer> q = new Foo<Integer>();  
Integer r = q.mogrify(s);
```

Java really gives you

```
class Foo {  
    Object x;  
    Object mogrify(Object y) { ... }  
}
```

```
Foo q = new Foo();  
Integer r =  
    (Integer) q.mogrify((Integer) s);
```

That is, it supplies the casts automatically, and also throws in some additional checks. If it can't guarantee that all those casts will work, gives you a warning about "unsafe" constructs.

Limitations

Because of Java's design choices, there are some limitations to generic programming:

- Since all kinds of `Foo` or `List` are really the same,
 - `L instanceof List<String>` will be true when `L` is a `List<Integer>`.
 - Inside, e.g., class `Foo`, you cannot write `new T()`, `new T[]`, or `x instanceof T`.
- Primitive types are not allowed as type parameters.
 - Can't have `ArrayList<int>`, just `ArrayList<Integer>`.
 - Fortunately, automatic boxing and unboxing makes this substitution easy:

```
int sum(ArrayList<Integer> L) {  
    int N;  N = 0;  
    for (int x : L) { N += x; }  
    return N;  
}
```
 - Unfortunately, boxing and unboxing have significant costs.