

CS61B Lecture #25: Java Generics

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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.

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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.

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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 StringArrayList 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.

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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 `List<T>`.

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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) {...}
```

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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>`?

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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 `List<String>` \preceq `List<Object>` would violate **type safety**: The compiler is wrong about the type of a value.
- So in general for `T1<X>` \preceq `T2<Y>`, must have `X = Y`.
- But what about `T1` and `T2`?

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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`.

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A Java Inconsistency: Arrays

- The Java language design is not entirely consistent when it comes to subtyping.
- For the same reason that `ArrayList<String>` $\not\preceq$ `ArrayList<Object>`, you'd also expect that `String[]` $\not\preceq$ `Object[]`.
- And yet, Java **does** make `String[]` \preceq `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`.
- Why do it this way? Basically, because otherwise there'd be no way to implement, e.g., `ArrayList`.

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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.

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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. */
static <T> void fill(List<T> L, T x) { ... }
```

?

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Type Bounds (II)

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

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

? -

- Consider

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

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

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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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                           T key)
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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?
- Again, we might have

```
static int findX(List<Object> L) {
    return binarySearch(L, "X");
}
```

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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.

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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.

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