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:

```java
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`:

  ```java
  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

```java
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

```java
class StringArrayList implements StringList {
    public String get(int i) { ... }
    public boolean add(String x) { ... }
}
```

• And, as suggested, `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:

```java
/** 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

```java
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>`. 
Wildcards

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

```java
/** 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

```java
...
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 \( \text{Object} \)):

```java
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:

```java
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> \subseteq List<Object>` would violate type safety:
  The compiler is wrong about the type of a value.

• So in general for `T1<X> \subseteq T2<Y>`, must have `X = Y`.

• But what about `T1` and `T2`?
Subtyping (III)

• Now consider

   ```java
   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> ⪯ T2<X>` if `T1 ⪯ 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\subseteq ArrayList<Object>`, you’d also expect that `String[] \not\subseteq Object[]`.

• And yet, Java does make `String[] \subseteq Object[]`.

• And, just as explained above, one gets into trouble with

```java
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,

  ```java
  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:

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

  means that \( L \) can be a \( \text{List<Q>} \) 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

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

  ?
Type Bounds (III)

- And one more:

```java
/** 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?
Dirty Secrets Behind the Scenes

• Java's design for parameterized types was constrained by a desire for backward compatibility.

• Actually, when you write

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

Java really gives you

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

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, 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:

```java
int sum(ArrayList<Integer> L) {
    int N;  N = 0;
    for (int x : L) { N += x; }
    return N;
}
```

- Unfortunately, boxing/unboxing have significant costs.