The Old Days

- Java library types such as `List` didn’t used to be parameterized. All Lists were lists of `Object`.
- 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
  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
  
  ```java
  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.
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 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 ≺ List and String ≺ Object (using ≺ for “is a subtype of”)... 

• ...So is List<String> ≺ List<Object>?
Subtyping (II)

- Consider this fragment:

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

- So, having `List<String> ≤ List<Object>` would violate type safety:
  The compiler is wrong about the type of a value.

- So in general for `T1<X> ≤ T2<Y>`, 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, $T_1<X> \preceq T_2<X>$ if $T_1 \preceq T_2$. 

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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> ↭ ArrayList<Object>`, you’d also expect that `String[] ↭ Object[]`.

- And yet, Java **does** make `String[] ⪯ 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`.
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 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. */
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Type Bounds (II)

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```

? -

• Consider

```java
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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• Why does this make sense?

• Again, we might have

    static int findX(List<Object> L) {
        return binarySearch(L, "X");
    }
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) { ... }
  }
  
  Foo<Integer> q = new Foo<Integer>();
  Integer r = q.mogrify(s);
  ```

  Java really gives you

  ```java
  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 ofFoo 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 and unboxing have significant costs.