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.

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

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.

ized 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>.

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) {
```



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


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>?


```
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?


```
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.

sistent 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.

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 `NumbericSet` must be subtypes of `Number` (the "type bound"). `T` can either extend or implement the bound, as appropriate.


```
/** 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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```


? -

- Consider

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

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


```
/** 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");
}
```


constrained by a desire for backward compatibility.

- Actually, when you write

```
class Foo<T> {
    T x;                                   Foo<Integer>
q = new Foo<Integer>();
    T mogrify(T y) { ... }                 Integer
r = q.mogrify(s);
}
```

Java really gives you

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