Subclassing and Dynamic Dispatch

6.170 Lecture 3

This lecture is about *dynamic dispatch*: how a call `o.m()` may actually invoke the code of different methods, all with the same name `m`, depending on the runtime type of the receiver object `o`.

To explain how this happens, we show how one class can be defined as a subclass of another, and can override some of its methods. This is called *subclassing* or *inheritance*, and it is a central feature of object oriented languages. At the same time, it's arguably a rather dangerous and overrused feature, for reasons that we'll discuss later when we look at subtyping.

The notion of dynamic dispatch is broader than the notion of inheritance. You can write a Java program with no inheritance in which dynamic dispatch still occurs. This is because Java has built-in support for specifications. You can declare an object to satisfy a kind of partial specification called an *interface*, and you can provide many implementations of the same interface. This is actually a more important and fundamental notion than subclassing, and it will be discussed in our lecture on specification.

1 Bank Transaction Code

Here is the code for a class representing a bank account:

```
class Account {
        String name;
        Vector transv;
        int balance;
        Account (String n) {
                transv = new Vector ();
                balance = 0;
                name = n;
        }
        boolean checkTrans (Trans t) {
                return (balance + t.amount >= 0);
        }
        void post (Trans t) {
                transv.add (t);
                balance += t.amount;
        }
}
```

and a class representing a transaction:

```
class Trans {
        int amount;
```

```
        Date date;
          ...
}
```

2 Extending a Class by Inheritance

Suppose we want to implement a new kind of account that allows overdrafts. We might call it `AccountPlus`, and code it like this:

```
class AccountPlus extends Account {
        int creditLimit;
        AccountPlus (String n, int c) {
                super (n);
                creditLimit = c;
        }
        boolean checkTrans (Trans t) {
                return (balance + creditLimit + t.amount >= 0);
        }
}
```

The keyword `extends` indicates that the implementation of `AccountPlus` extends the implementation of `Account` by adding some new features. `AccountPlus` is said to *inherit* features from `Account`; `AccountPlus` is a *subclass* of `Account`, and `Account` is a *superclass* of `AccountPlus`.

There is a new field, `creditLimit`. Because a new `AccountPlus` object needs to have the new field initialized, `AccountPlus` must have its own constructor; this actually calls the constructor of `Account` (see Java text for details of this slightly strange syntax). All the other methods and fields of `Account` are implicitly present in `AccountPlus`.

The method `checkTrans` appears again in `AccountPlus`, with different code in its body. This is called *overriding*. When the code `acc.checkTrans` is executed, which method actually gets called will depend on whether the object referenced by `acc` is an `Account` object or an `AccountPlus` object. The method call is said to be *dynamically resolved*.

At runtime, each object has a type, equal to the class whose constructor created it. A variable that appears in the code also has a type, given by its declaration at compile-time. At runtime, a variable can refer to an object whose type is not the variable's type; it is sufficient that the object type be the type of a subclass of the variable type. (For now, by the way, we're using the term 'type' to mean classification by class name, to distinguish it from the term 'class' which usually carries the connotation of the code in the class too. Later in the course, we'll be more precise about what type means.)

Sometimes, it will be clear in the code what type an object will have at runtime:

```
AccountPlus acc = new AccountPlus ("Zork", 100);
Trans t = new Trans (100, new Date ());
if (acc.checkTrans (t))
        acc.post (t);
```

In this case, since `acc` is declared to be of type `AccountPlus`, and `AccountPlus` has no subclasses, we know that the method of `AccountPlus` will be called. But it's not in general the type declaration in the program text that determines which method gets called. Suppose we wrote this instead:

```
Account acc = new AccountPlus ("Zork", 100);
Trans t = new Trans (100, new Date ());
if (acc.checkTrans (t))
        acc.post (t);
```

where the variable `acc` is declared in the first line above to have the type `Account` rather than the type `AccountPlus`. What happens? The code executes exactly as before. What determines which `checkTrans` method gets called is the *runtime* type of `acc` – that is, the type of the class that provided the constructor used to create it. In general, how variables are declared has no effect whatsoever on the behavior of the program, if it executes successfully without class cast errors (more on that below).

Now suppose we want to handle a collection of accounts. We might have a `Bank` class, implemented something like this:

```
1.      class Bank {
2.              Account [] accounts;
                ...
3.              void chargeMonthlyFee () {
4.                      for (int i = 0; i < accounts.length; i++) {
5.                              Trans fee = new Trans (-1, new Date ());
6.                              if (accounts[i].checkTrans (fee))
7.                                      accounts[i].post (fee);
8.                      }
9.              }
10.     }
```

A `Bank` object holds an array of `Account` objects. An `array` is an object just like a `Vector`, but it can't grow or shrink dynamically.

Look at the method `chargeMonthlyFee` used for charging monthly fees to accounts. This bank is unusual: it doesn't hit you when you're down. If deducting the monthly fee would take you below your limit, it won't do it.

The method works whether the accounts in the array are regular accounts (in the `Account` class), or special accounts (in the `AccountPlus` class). The reason is that the declared type given in the code says only that the object at runtime will belong to that class or one of its subclasses. But at runtime, which `checkTrans` method is selected for the call at Statement `6` will depend on the runtime type of the object.

This code is said to be *polymorphic*, meaning 'many shapes', since the same piece of code text can handle different types of account. If the `accounts` array contains two objects of the class `Account`, and a third object of class `AccountPlus`, the first and second time round the loop the call to the method `checkTrans` will execute code from `Account`, but the third time round, it will execute code from `AccountPlus`. The call to `post` will always call the same code, since this method has only one body, although sometimes it will be called for an `Account` object, and sometimes an `AccountPlus` object.

3 A Template Method

Instead of making the client of the `Account` class call the `checkTrans` method, we could call it inside the `post` method like this:

```
boolean post (Trans t) {
        if (!checkTrans (t)) return false;
        transv.addElement (t);
        balance += t.amount;
        return true;
}
```

Look at the context this method sits in:

```
class Account {
        boolean post (Trans t) {...}
        boolean checkTrans (Trans t) {...}
}
        ...
class AccountPlus extends Account {
        boolean checkTrans (Trans t) {...}
}
```

Now suppose we have some code that calls `post` on an object of `AccountPlus`:

```
Account a = new AccountPlus ("Zork", 100);
a.post (new Trans (-50, new Date ()));
System.out.println (a.balance);
```

Which `checkTrans` method gets called inside `post`? If the method from `Account` is called, it will return `False`, ignoring the credit limit, and the print statement will print `0` as the balance. If the method from `AccountPlus` is called, it will return `true`, the posting will occur, and the balance will print as `-50`.

The answer depends on the runtime type of the receiver. Although `post` belongs to the class `Account`, since there is no `post` method in `AccountPlus`, its code will be called for both `Account` and `AccountPlus` objects. Executing `acc.post` when `acc` is an `AccountPlus` object will cause the `post` method of `Account` to be executed; inside it, the `checkTrans` method of `AccountPlus`, and not `Account`, will be called. So although the `post` method only appears in the code once, it actually behaves differently for `AccountPlus` and `Account` objects.

This idiom is often used in implementations of ‘frameworks’. A framework supplies a collection of classes that the programmer tailors to her own purpose by extension – by adding new subclasses. The superclass may have a method that defines the skeleton of an algorithm, but actually leaves most of the computation to methods that it calls that are defined in subclasses, by the programmer who extends the framework. Such a method is called a *template*: it lets the programmer redefine steps of an algorithm without changing its overall structure.

4 Downcasting

Arrays aren't very convenient to program with, since they can't grow or shrink. Suppose we implement `Bank` with a vector of accounts instead:

```
// bad code!
1.      class Bank {
```

```
2.              Vector accounts;
            ...
3.              void chargeMonthlyFee () {
4.                      for (int i = 0; i < accounts.size(); i++) {
5.                              Trans fee = new Trans (-1, new Date ());
6.                              if (accounts.elementAt (i).checkTrans (fee))
7.                                     accounts.elementAt (i).post (fee);
9.                      }
10.             }
            ...
        }
```

The class Vector is provided as part of the standard Java library. Unlike arrays, vectors are not part of the language itself. So there's no special syntax to access a vector element: you have to call a method (here, `elementAt (i)` to get the ith element). Also, when you declare a `Vector`, you can't say what it's a vector of. The `elementAt` method has this signature:

```
class Vector {
        ...
        Object elementAt (int i)
        ...
}
```

It returns an object of class `Object`, the superclass of all classes. So there's no way to know that the expression `accounts.elementAt(i)` will actually evaluate to an `Account` or an `AccountPlus` object. If it fails to, the calls on Statements 6 and 7 in the Bank class code to `checktrans` and `post` will be made to objects without these methods defined. Java is a *safe* language, which means that certain kinds of runtime errors cannot occur, and calling a non-existent method is one of them. For this reason, the code above will actually be rejected by the Java compiler.

Instead we have to write this:

```
void chargeMonthlyFee () {
        for (int i = 0; i { accounts.size(); i++) {
                Trans fee = new Trans (-1, new Date ());
                if (((Account) accounts.elementAt (i)).checkTrans (fee)) {
                        ((Account) accounts.elementAt (i)).post (fee);
                }
        }
}
```

or better:

```
        void chargeMonthlyFee () {
                for (int i = 0; i < accounts.size(); i++) {
                        Trans fee = new Trans (-1, new Date ());
                        Account acc = (Account) accounts.elementAt (i);
                        if (acc.checkTrans (fee)) {
                                acc.post (fee);
                        }
```

```
8.                }
9.        }
```

The `(Account)` on Statement 4 is called a *downcast*. At runtime, it checks that the object returned by the expression belongs to `Account` or one of its subclasses. If it does, execution continues normally; if it does not, the program is terminated with a `ClassCastException`. (We'll talk about exceptions in a later lecture.)

For now, it's important just to understand that if execution continues at the next line, the object bound to `acc` is guaranteed to be of class `Account` or `AccountPlus`, and must therefore have the `post` method. So the Java compiler will accept this code, since the presence of the downcast ensures that there will be no attempt to call a method that does not exist.

Students are often confused about downcasts, and think that some kind of conversion is taking place. This is not true. The downcast is simply a test; no change to the object occurs.

5 Downcasts are not Typecasts

Typecasts are a different matter. Executing this code

```
1.      double d = 1.23;
2.      int i = (int) d;
3.      System.out.println (d);
4.      System.out.println (i);
```

causes the following to be printed

```
1.23
1
```

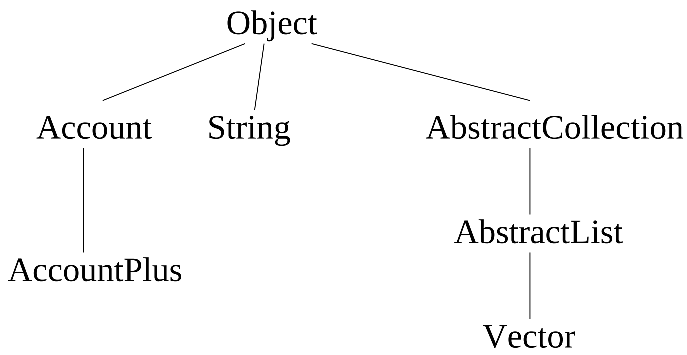
The phrase `(int)` in Statement `2` is a *typecast* or *coercion*; it ensures the type safety of the program by actually converting the double created at Statement `1` to an integer, so that `d` and `i` have different values. No such thing happens with a downcast; if the statement

```
Account acc = (Account) accounts.elementAt (i);
```

completes successfully, the object referenced by `acc` after the statement is the same object, unmodified, as the object returned by the expression on the right-hand side.

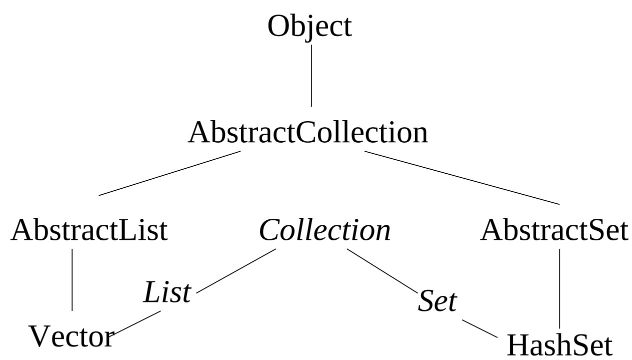
6 Type Hierarchy and Safety

Types can be arranged in a hierarchy. Here is such a hierarchy showing some of the types we have discussed:



All these types correspond to classes. The root of the tree, `Object` is a superclass, directly or indirectly, of every other class. You can see that `Vector` is actually positioned quite deep in the tree: its code is built by inheritance from the classes `AbstractCollection` and `AbstractList` which provide skeletal implementations of collections and lists respectively.

Not every type is a class, though. Java has specification types, called *interfaces*, that do not correspond to executable code. An interface is just a collection of method signatures. A class that satisfies the specification of an interface is said to *implement* it; this is indicated in the text of the class by the keyword `implements`. A variable can be declared to have an interface type, and interfaces thus contribute to the type hierarchy. Here is a fragment of the type hierarchy that shows some interfaces implemented by `Vector`:



The interface names are italicized to distinguish them from the names of classes.

Because the runtime type of an object is given by the constructor that created it, and because interfaces have no code, it follows that the runtime type of an object is always a class. The declared type of a variable can be a class or an interface. We'll say that a type (interface or class) `T` is a subtype of a type `T'` if there is a path going up in the type hierarchy from `T` to `T'`. The edges in the path may be `extends` or `implements` edges.

Given this background, we can now state the key type safety property of Java. Java is said to be a *statically typed* language. What this means is that the types that appear in declarations in the program text tell you something about what will happen when the program runs:

Static typing: If a variable of (declared) type `T` holds a reference to an object of (runtime) type `T'`, then `T'` is a subtype of `T`.

And we can now explain downcasts like this. In the assignment

```
T x = e;
```

the expression `e` must evaluate to an object that is a subtype of `T`, otherwise this guarantee cannot be maintained. So if the compiler is unable to determine that this is true, we must insert a downcast like this

```
T x = (T) e;
```

so that now the test performed by the downcast guarantees the typing property. If the cast fails (that is, `e` evaluates to an object of the wrong type), the assignment is aborted; if it succeeds, the expression `e` must have evaluated to an object of an appropriate type – that is, a subtype of `T`.

7 Conclusion

We have distinguished between the declared type of a variable, and the constructed type of an object, and we have seen how the code for a method is chosen according to the constructed type of the receiver object. In polymorphic code, this type cannot be predicted at compile time, and a call that appears syntactically once in the code may cause different methods to be invoked at runtime. For this reason, the dispatching mechanism is said to be 'dynamic'.

We've seen how downcasts allow polymorphic code to be type checked at compile time, by introducing runtime tests when the compiler cannot statically determine the type that an expression will evaluate to an runtime. We noted how downcasts are just tests, and unlike typecasts, have no side effects.