John Hunt

A Beginner's Guide to Scala, Object Orientation and Functional Programming

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This book is dedicated to my son Adam.

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Chapter 1
Introduction

1.1 Introduction

This book is intended as an introduction to Scala for computer science students or those actively involved in the software industry. It assumes some familiarity with standard computing concepts such as the idea of compiling a program and executing this compiled form, etc., and with the basics of procedural language concepts such as variables and allocation of values to variables etc. However, the early chapters of the book do not assume any familiarity with object orientation nor functional programming. They also step through other concepts with which the reader may not be familiar (such as list processing etc.). From this background, it provides a practical introduction to object and functional technology using Scala, one of the newest and most interesting programming languages available.

This book introduces a variety of concepts through practical experience. It also tries to take you beyond the level of the language syntax to the philosophy and practice of object-oriented development and functional programming.

In the remainder of this chapter we will consider what Scala is, why you should be interested in Scala and whether this book is for you.

1.2 What is Scala?

Scala is a new programming language developed by Martin Odersky and his team at the EPFL (Ecole Polythenique Fererale de Lausanne, Lausanne, Switzerland) and now supported by Typesafe. The name Scala is derived from Sca(lable) La(nguage) and is a multi-paradigm language, incorporating Object Oriented approaches with Functional Programming.

What does this mean in practice? It means that you can write applications as pure object oriented solutions using Classes, Objects and Traits. You can exploit inheritance, polymorphism and abstraction and encapsulation techniques. In this respect Scala is very much like any other object oriented language (such as Java,

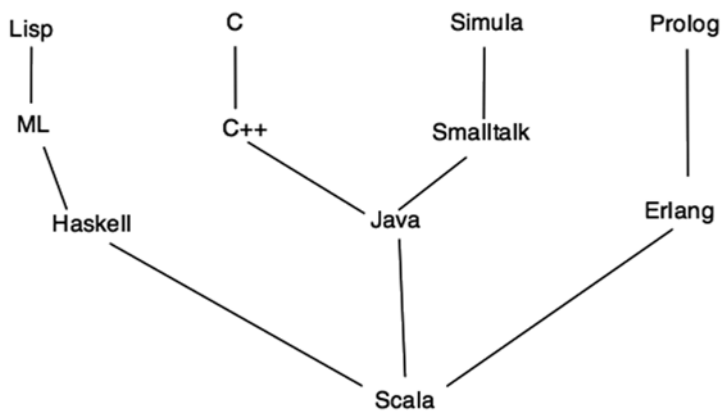


Fig. 1.1 Scala genealogy

C# or C++). However, you can also develop solutions using purely functional programming principles in a similar manner to languages such as Haskell or Clojure. In such an approach programs are written purely in terms of functions that take inputs and generate outputs without any side effects.

Scala though is different in that it is a hybrid programing language. That is, it is possible to combine the best of both worlds when creating a software system. Thus you can exploit object-oriented principles to structure your solution but integrate functional aspects when appropriate. Whilst this approach is not unique (the Common Lisp Object Systems did something similar in the 1980's) it is certainly bringing functional programming to the main stream and integrating it within an environment that can execute almost anywhere.

Of course Scala has not been developed in isolation and has been influenced by many of these and other languages. The influences on the Scala language can be seen in Fig. 1.1.

1.3 Why Scala?

This of course raises the question why Scala and why now? There are a number of reasons why Scala should be a language which is given serious consideration by any development project. We have already mentioned that fact that it coherently brings together two very powerful programming paradigms that combined can allow very elegant, concise and maintainable systems to be created. However, there are other reasons why Scala is of interest. The first is that Scala can be compiled to Java Byte Codes. This means that a Scala system can run on any environment which supports the Java Virtual Machine (or JVM). There are already several languages that compile to Java Byte codes. This list includes Java but also extends to Ada, JavaScript, Python, Ruby, Tcl and Prolog etc. Scala is just another such language. However, this has the additional advantage that Scala can also be integrated with any existing Java code base that a project may have. It also allows Scala to exploit the huge library of Java projects available both for free and for commercial use.

Another reason to consider Scala is that one of the design goals of the Scala development team was to create:

> A scalable language suitable for the construction of component based software within highly concurrent environments.

This means that is has several features integrated into it that support large software developments. For example, the Actor model of concurrency greatly simplifies the development of concurrent applications. In addition the syntax reduces the amount of code that must be written by a developer (at least compared with Java). This is because it avoids a lot of the boilerplate code that any Java developer will be familiar with.

To summarise then, the following points can be made. Scala:

- Provides Object Oriented concepts including classes, objects, inheritance and abstraction.
- Extends these (at least with reference to Java) to include Traits which represent data and behaviour that can be *mixed* into classes and objects.
- Includes functional concepts, such as functions as first class entities in the language, as well as concepts such as partially applied functions and currying which allow new functions to be constructed from existing functions.
- Uses statically typed variables and constants with type inference used whether-ever possible to avoid unnecessary repetition.
- Has interoperability (mostly) with Java.

To return the question of 'Why now?'—now is a good time to be learning about Scala. At the time of writing Scala has been in commercial use (at least to my knowledge) for four years and has stabilised and addressed some of the concerns that commercial development projects had about earlier versions of Scala.

1.4 Java to Scala Quick Comparison

As a comparison, for those who are familiar with Java, the following two listings compare and contrast equivalent code defined in Java and Scala. Do not worry at this point too much about the syntax; it is more for illustration than the specifics of either Java or Scala at this point.

Here is the Java class:

```
class Person {
  private String firstName;
  private String lastName;
  private int    age;

  public Person(String firstName, String lastName, int age) {
    this.firstName = firstName;
    this.lastName  = lastName;
    this.age  = age;
  }

  public void setFirstName(String firstName) {
     this.firstName = firstName; }
  public void String getFirstName() { return this.firstName; }
  public void setLastName(String lastName) {

      this.lastName = lastName; }
    public void String getLastName() { return this.lastName; }
    public void setAge(int age) { this.age = age; }
    public void int getAge() { return this.age; }
  }
```

And here is the equivalent Scala class:

```
class Person(var firstName: String, var lastName: String, var
age: Int)
```

As you can see the Scala version is much shorter but actually captures the same concepts. The core concepts here are that:

A Person has three properties firstName, lastName and age. These properties are readable and writable. When a new Person is constructed you must provide values for the firstName, lastName and the age.

Both listings implement these concepts, however in Java's case it has no concept of a property and thus we must define how the data is held internally to a Person and how it can be accessed or updated via various getter and setter methods. In contrast Scala has a concept of properties and thus we do not need to write the update and access style methods. Instead we need to decide if they are read-only (known as *vals)* or read-write properties (as indicated by the keyword *var*).

1.5 Is This Book for You?

This book does not assume a great deal of programming experience. However it is not a basic introduction to programming. Instead it is aimed at those with little programming and no functional or object oriented experience. It does introduce concepts such as lists, data collections, for loops and conditional control statements. However, it assumes a basic understanding of how programs work, of what a programming stack might be, that memory must be allocated for data etc.

It can also be used to develop some basic knowledge of programming into a more in-depth knowledge of a particular technology. It could also be used to support an introduction to programming course.

1.6 Approach Taken by This Book

In general the book takes a very "hands on" approach to the whole subject and assumes that you will implement the examples as you progress. It supports this through many examples that take you through how to use the Scala IDE to support what you are doing as well as providing complete code examples with indications of the expected outcomes. Unlike many books on Scala the focus is on using Scala within an IDE and constructing simple applications rather than using the interactive Scala interpreter. In addition, all the samples used in the book are available from Springer to be downloaded and used in your own IDEs.

Further Reading

Haskell

- http://www.haskell.org/

Clojure

- http://clojure.org/

Common Lisp Object System

- Sonya E. Keene, Object-Oriented Programming in Common LISP: A Programmer's Guide to CLOS, Pub. Addison Wesley, (Jan 1989) 0201175894.
- List of JVM Languages http://en.wikipedia.org/wiki/List_of_JVM_languages

The Scala programming language home page

- see http://www.scala-lang.org

The Scala mailing list

- see http://listes.epfl.ch/cgi-bin/doc_en?liste=scala

The Scala wiki

- see http://scala.sygneca.com/

Book Materials

- Springer web site

Chapter 2
Elements of Object Orientation

2.1 Introduction

This chapter introduces the core concepts in Object Orientation. It concisely defines the terminology used and attempts to clarify issues associated with hierarchies. It also discusses some of the perceived strengths and weaknesses of the object oriented approach. It then offers some guidance on the approach to take in learning about objects.

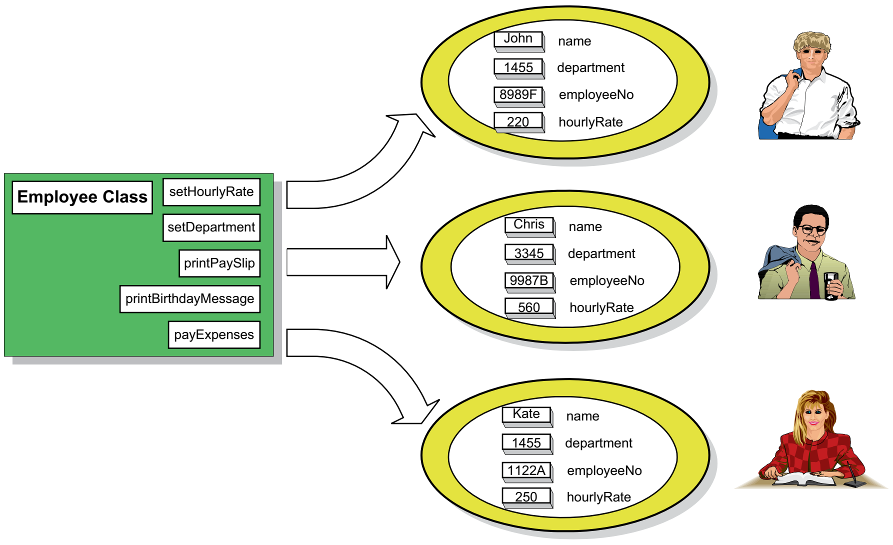
2.2 Terminology

Class A class defines a combination of data and operations that operate on that data. Instances of other classes can only access that data or those procedures through specified interfaces. A class acts as a template when creating new instances. A class does not hold any data but it specifies the data that is held in the instance. The relationship between a class, its superclass and any subclasses is illustrated in Fig. 2.1.

Subclass A subclass is a class that inherits from another class. For example, in the last chapter, Student Employee is a subclass of Temporary Employee. Subclasses are, of course, classes in their own right. Any class can have any number of subclasses.

Superclass A superclass is the parent of a class. It is the class from which the current class inherits. For example, in the last chapter, Temporary Employee is the superclass of Student Employee. In Scala, a class can have only one superclass.

Instance or Object An instance is an example of a class. All instances of a class possess the same data variables but contain their own data. Each instance of a class responds to the same set of requests.



Instance Variable This is the special name given to the data which is held by an object. The "state" of an object at any particular moment relates to the current values held by its instance variables. (In Scala, there are also class-side variables, referred to as static variables, but these will be discussed later). Figure 2.2 illustrates a definition for a class in pseudo code. It includes some instance variable definitions: fuel, mileage and name.

Method A method is a procedure defined within an object. In early versions of Smalltalk, a method was used to get an object to do something or return something. It has since become more widely used; languages such as CLOS and Scala also use the term. Two methods are defined in Fig. 2.2: one calculates the miles per gallon, while the other sets the name of the car object.

Message One object sends a message to another object requesting some operation or data. The idea is that objects are polite, well-behaved entities which carry out functions by sending messages to each other. A message may be considered akin to a procedure call in other languages.

Single or Multiple Inheritance Single and multiple inheritance refer to the number of superclasses from which a class can inherit. Scala is a single inheritance system, in which a class can only inherit from one class. C++ is a multiple inheritance system in which a class can inherit from one or more classes.

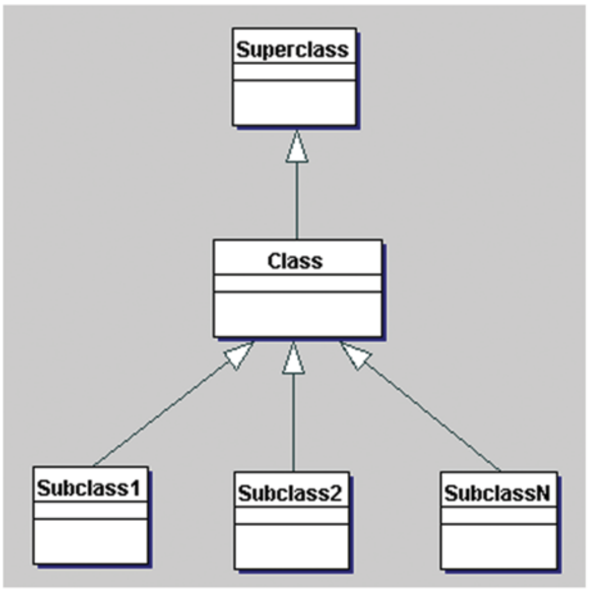
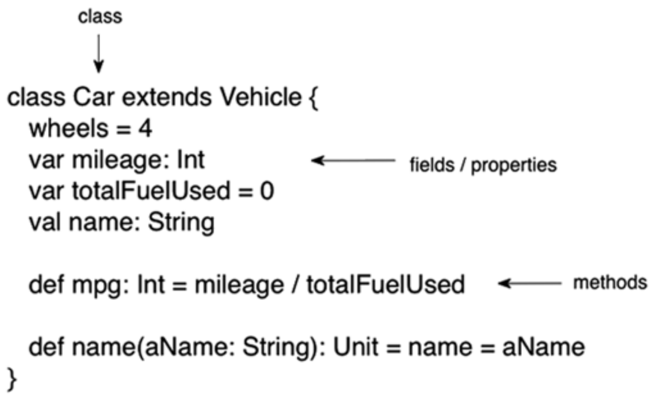


Fig. 2.1 The relationship between class, superclass and subclass


class
fields / properties
methods

```
class Car extends Vehicle {
  wheels = 4
  var mileage: Int
  var totalFuelUsed = 0
  val name: String

  def mpg: Int = mileage / totalFuelUsed

  def name(aName: String): Unit = name = aName
}
```

Fig. 2.2 A simple Scala class definition

2.3 Types of Hierarchy

In most object-oriented systems there are two types of hierarchy; one refers to inheritance (whether single or multiple) and the other refers to instantiation. The inheritance hierarchy (or *extends* hierarchy) has already been described. It is the way in which an object inherits features from a superclass.

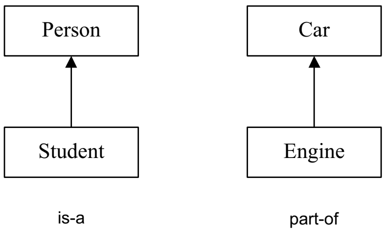


Fig. 2.3 *is-a* does not equal *part-of*

The instantiation hierarchy relates to instances rather than classes and is important during the execution of the object. There are two types of instance hierarchy: one indicates a *part-of* relationship, while the other relates to a using relationship (it is referred to as an *is-a* relationship).

The difference between an *is-a* relationship and a *part-of* relationship is often confusing for new programmers (and sometimes for those who are experienced in one language but are new to object oriented programming languages, such as Scala). Figure 2.3 illustrates that a student *is-a* type of person whereas an engine is *part-of* a car. It does not make sense to say that a student is *part-of* a person or that an engine *is-a* type of car!

In Scala, *extends* relationships are generally implemented by the subclassing mechanism. It is possible to build up large and complex class hierarchies which express these *extends* relationships. These classes express the concept of inheritance, allowing one class to inherit features from another. The total set of features is then used to create an instance of a class. In contrast, *part-of* relationships tend to be implemented using instance variables in Scala.

However, *is-a* relationships and classes are not exactly the same thing. For example, if you wish to construct a semantic network consisting of explicit *is-a* relationships between instances you will have to construct such a network manually. The aim of such a structure is to represent knowledge and the relationships between elements of that knowledge, and not to construct instances. The construction of such a network is outside the scope of the subclassing mechanism and would therefore be inappropriate.

If John is an instance of a class Person, it would be perfectly (semantically) correct to say that John *is-a* Person. However, here we are obviously talking about the relationship between an instance and a class rather than a subclass and its parent class.

A further confusion can occur for those encountering Scala after becoming familiar with a strongly typed language. These people might at first assume that a subclass and a subtype are essentially the same. However, they are not the same, although they are very similar. The problem with classes, types and *is-a* relationships is that on the surface they appear to capture the same sorts of concept. In Fig. 2.4, the diagrams all capture some aspect of the use of the phrase *is-a*. However, they are all intended to capture a different relationship.

The confusion is due to the fact that in modern English we tend to overuse the term *is-a*. We can distinguish between the different types of relationship by being

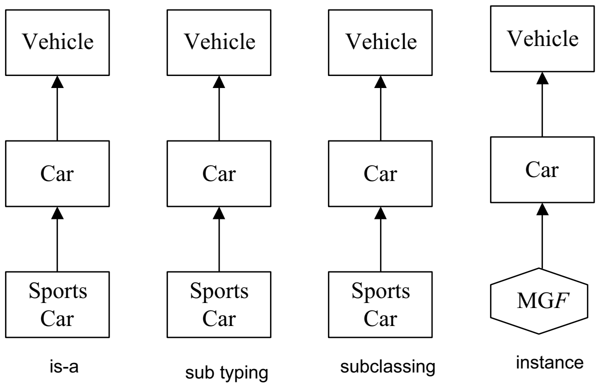


Fig. 2.4 Satisfying four relationships

Table 2.1 Types of *is-a* relationships

Specialization	One thing is a special case of another
Type	One type can be used interchangeably with another type (substitutability relationship)
Subclassing or inheritance	An implementation mechanism for sharing code and representations
Instantiation	One thing is an example of a particular category (class) of things

more precise about our definitions in terms of a programming language, such as Scala. Table 2.1 defines the relationships illustrated in Fig. 2.4.

To illustrate this point, consider Fig. 2.5, which illustrates the differences between the first three categories.

The first diagram illustrates the potential relationships between a set of classes that define the behaviour of different categories of vehicle. The second diagram presents the subtype relationships between the categories. The third diagram illustrates a straight specialization set of relationships. Notice that although *estate car* is a specialization of *car with hatch*, its implementation (the subclassing hierarchy) indicates that it does not share any of its implementation with the *car with hatch* class. It is worth noting that type relationships are specifications, while classes (and subclasses) are implementations of behaviour.

2.4 The Move to Object Technology

At present you are still acclimatizing to object orientation. It is extremely important that from now on you do your utmost to immerse yourself in object orientation, object technology and Scala. This is because when you first encounter a new language or paradigm, it is all too easy to say that it is not good because you cannot do what you could in some other language or paradigm. We are all subject to the "better the devil you know than the devil you don't" syndrome. If you embrace object orientation, warts and all, at least for the present, you will gain most.

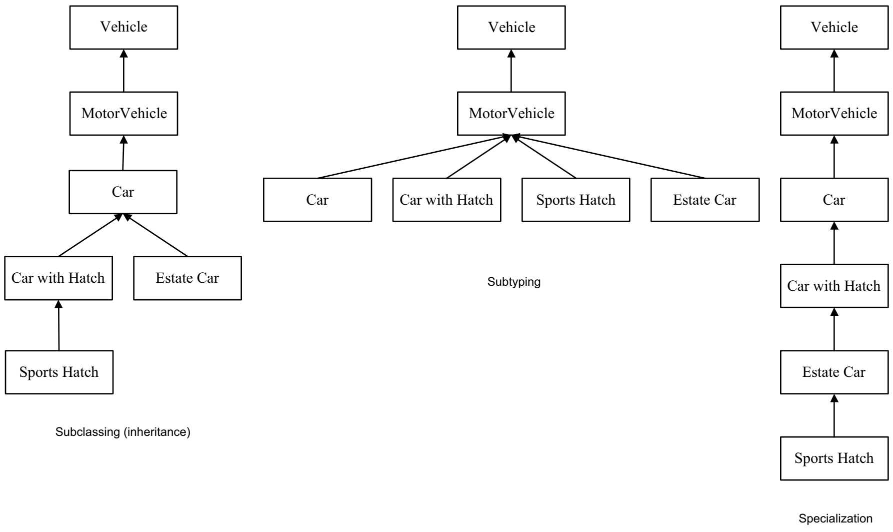


Fig. 2.5 Distinguishing between relationships

In addition, it is a fact of life that most of us tend to fit in learning something new around our existing schedules. This may mean for example, that you are trying to read this book and do the exercises while still working in C, VisualBasic, Ada, etc. From personal experience, and from teaching others about Scala, I can say that you will gain most by putting aside a significant amount of time and concentrating on the subject matter involved. This is not only because object orientation is so different, but also because you need to get familiar not only with the concepts but also with Scala and its development environment.

So have a go, take a "leap of faith" and stick with it until the end. If, at the end, you still cannot see the point, then fair enough, but until then accept it.

2.5 Summary

In this chapter, we reviewed some of the terminology introduced in the previous chapter. We also considered the types of hierarchy which occur in object oriented systems and which can at first be confusing. We then considered the pros and cons of object oriented programming. You should now be ready to start to think in terms of objects. As has already been stated, this will at first seem a strange way to develop a software system, but in time it will become second nature. In the next chapter we examine how an object oriented system might be developed and structured. This is done without reference to any source code as the intention is to familiarize you with objects rather than with Scala. It is all too easy to get through a book on Smalltalk, C++, Scala, etc. and understand the text but still have no idea how to start developing an object oriented system.

2.6 Exercises

Research what other authors have said about single and multiple inheritance. Why do languages such as Smalltalk and Scala not include multiple inheritance for classes?

Look for terms such as class, method, member, member function, instance variable and constructor in the books listed in the further reading section. When you have found them, read their explanation of these terms and write down your understanding of their meaning.

Further Reading

Suggested further reading for this chapter includes Coad and Yourdon (1991), Winston and Narasimhan (2001) and Meyer (1988). In addition all the books mentioned in the previous chapter are still relevant.

Chapter 3
Why *Object* Orientation?

3.1 Introduction

The pervious chapter introduced the basic concepts behind object orientation, the terminology and explored some of the motivation. This chapter looks at how object orientation addresses some of the issues that have been raised with procedural languages. To do this it looks at how a small extract of a program might be written in a language such as C, considers the problems faced by the C developer and then looks at how the same functionality might be achieved in an object oriented language such as Scala, Java or C#. Again do not worry too much about the syntax you will be presented with, it will be Scala but it should not detract from the legibility of the examples.

3.2 The Procedural Approach

As has already been stated, object orientation provides four things:

1. Encapsulation.
2. Abstraction
3. Inheritance
4. Polymorphism

It has been claimed that these four elements combine to provide a very powerful programming paradigm, but why? What is so good about object orientation?

3.2.1 A Naked Data Structure

Consider the following example:

```
record Date {
        int day;
        int month;
        int year;
}
```

This defines a data structure for recording dates. There are similar structures in many procedural languages such as C, Pascal and Ada. It is naked because it has no defenses against procedures accessing and modifying its contents.

So what is wrong with a structure such as this? Nothing, apart from the issue of visibility? That is, what can see this structure and what can update the contents of the structure? For example, code could set the day to 01, the month to 13 and the year to 9999. As far as the structure is concerned the information it holds is fine (that is day = 01, month = 13, year = 9999). This is because the structure only knows it is supposed to hold an integer, it knows nothing about dates per se. This is not surprising, it is only data.

3.2.2 Procedures for the Data Structure

This data is associated with procedures that perform operations on it. These operations might be to test whether the date represents a date at a weekend or part of the working week. It may be to change the date (in which case the procedure may also check to see that the date is a valid one.

For example:

- `isDayOfWeek(date);`
- `inMonth(date, 2);`
- `nextDay(date);`
- `setDay(date, 9, 23, 1946);`

How do we know that these procedures are related to the date structure we have just looked at? By the naming conventions of the procedures and by the fact that one of the parameters is a data (record).

The problem is that these procedures are not limited in what they can do to the data (for example the `setDay` procedure might have been implemented by a Brit who assumes that the data order is day, month and year. However, it may be used by an American who assumes that date order is month, day, year. Thus the mean of `setDay(date, 9, 23, 1946)` will be interpreted very differently. The American views this as the 23rd of September 1946, while the Brit views this as the 9th of the 23rd month, 1946. In either case, there is nothing to stop the `date` record being updated with both versions. Obviously the `setDay()` procedure might check the new date to see it was legal, but then again it might not. The problem is that the data is naked and has no defense against what these procedures do to it. Indeed, it has no defense against what any procedures that can access it, may do to it.

3.2.3 Packages

One possibility is of course to use a package construct. In languages such as Ada packages are commonplace and are used as a way of organising code and restricting visibility. For example,

```
package Dates is
   type Dates is ….
   function isDayOfWeek(d: Date) return BOOLEAN;
   function inMonth(d: Date, m: INTEGER) return
                                            BOOLEAN;
…
```

The package construct now provides some ring fencing of the data structure and a grouping of the data structure with the associated functions. In order to use this package a developer must import the package (for example using `with` and `uses` in Ada). They can then access the procedures and work with data of the specified type (in this case `Date`). There can even be data that is hidden from the user within a *private part*. This therefore increases the ability to encapsulate the data (hide the data) from unwelcome attention.

3.3 Does Object Orientation Do Better?

This is an important question "Does object orientation do any better" than the procedural approach described above? We will first consider packages, then inheritance …

3.3.1 Packages Versus Classes

It has been argued (to me at least) that a package is just like a class. It provides a template from which you can create executable code, it provides wall around your data with well defined gateways etc. However, there are a number of very significant differences between packages and classes.

Firstly, packages tend to be larger (at least conceptually) units than classes. For example, the `TextIO` package in Ada is essentially a library of textual IO facilities, rather than a single concept such as the class `String` in C#. Thus packages are not used to encapsulate a single small concept such as `Date`, but rather a whole set of related concepts (as indeed they are used in C# itself where they are called namespaces). Thus a class is a finer level of granularity than a package even though it provides similar levels of encapsulation.

Secondly, packages still provide a relatively loose association between the data and the procedures. A package may actually deal with very many data structures with a wide range of methods. The data and the methods are related primarily via the related set of concepts represented by the package. In contrast a class tends to closely relate data and methods in a single concept. Indeed, one of the guidelines presented later in this book relating to good class design, is that if a class represents more than one concept, split it into two classes.

Thus this close association between data and code and means that the resulting concept is more than just a data structure (it is closer to a concrete realization of an abstract data type). For example:

```
class Date {
    val day: Int = 1
    val month: Int 1
    val year: Int = 14
    def isDayOfWeek() : Boolean = {..}
}
```

Anyone using an instance of *Date* now gets an object which can tell you whether it is a day of the week or not and can hold the appropriate data. Note that the `isDay-OfWeek()` method takes no parameters, it doesn't need to as it and the date are part of the same thing. This means that a user of a `Date` object will never get their hands on the actual data holding the date (i.e. the integers day, month and year). Instead, they are forced to go via the internal methods. This may only seem a small step, but it is a significant one, nothing outside the object may access the data within the object. In contrast the data structure in the procedural version, is not only held separately to the procedures, the values for day, month or year could be modified directly without the need to use the defined procedures.

For example compare the differences between an ADA-esque excerpt from a program to manipulate dates:

```
d: Date;
setDay(d, 28);
setMonth(d, 2);
setYear(d, 1998);
isDayOfWeek(d);
inMonth(d, 2);
```

Not that it was necessary to first create the data and then to set the fields in the data structure. Here we have been good and have used the interface procedures to do this. Once we had the data set up we could then call methods such as `IsDayOfWeek` and `InMonth` on that data.

In contrast the Scala code uses a constructor to pass in the appropriate initialization information. How this is initialized internally is hidden from the user of the class Date. We then call method such as `isDayOfWeek()` and `isMonth(12)` directly on the object date.

```
val d=new Date(12, 2, 1998)
d.IsDayOfWeek()
d.InMonth(12)
```

The thing to think about here is where would code be defined?

3.3.2 Inheritance

Inheritance is the key element that makes an object oriented language more than an object based language. An object-based language possesses the concept of object, but not of inheritance. Indeed, inheritance is the thing that marks an object-oriented language as different from a procedural language. The key concept in inheritance is that one class can inherit data and methods from another, thus increasing the amount of code reuse occurring as well as simplifying the overall system. One of the most important features of inheritance (ironically) is that it allows the developer to get inside the encapsulation bubble in limited and controlled ways. This allows the subclass to take advantage of internal data structures and methods, without compromising the encapsulation a forded to objects. For example, let use define a subclass of the class `Date` (extends is used to indicate inheritance in Scala):

```
class Birthday extends Date {
    val name: String =""
    val age: Int = 0
    def isBirthday(): Boolean = {..}
}
```

The method `isBirthday()` could check to see if the current date, matched the birthday represented by an instance of `Birthday` and return true if it does and false if it does not.

Note however, that the interesting thing here is that not only have I not had to define integers to represent the date, nor have I had to define methods to access such dates. These have both been inherited from the parent class `Date`.

In addition, I can now treat an instance of `Birthday` as either a `Date` or as a `Birthday` depending on what I want to do!

What would you do in languages such as C, Pascal or Ada? One possibility is that you could define a new package Birthday, but that package would not extend `Dates`, it would have to import Dates and add interfaces to it etc? However, you certainly couldn't treat a Birthday package as a `Dates` package.

In languages such as Scala, because of *polymorphism*, you can do exactly that. You can reuse existing code that only knew about Date, for example:

- `def test(Date d): Unit = {.}`
- `t.test(birthday)`

This is because `Birthday` is indeed a type of `Date` as well as being a type of `Birthday`.

You can also use all of the features defined for Date on Birthdays:

- `birthday.isDayOfWeek()`

Indeed you don't actually know where the method is defined. This method could be defined in the class `Birthday` (in which it would override that defined in the class `Date`). However, it could be define in the class `Date` (if no such method is defined in `Birthday`). However, without looking at the source code there is no way of knowing!

Of course you can also use the new methods defined in the class `Birthday` on instance (objects) of this class. For example:

- `birthday.isBirthday()`

3.4 Summary

Classes in an object-oriented language provide a number of features that are not present in procedural languages. Hopefully by the end of the book you will agree that they are useful additions to the developers toolbox. If not, give it time, one of the problems that we all face (myself included) is a reluctance to change. To summarise, the main points to be noted from this chapter on object orientation are:

- Classes provide for inheritance.
- Inheritance provides for reuse.
- Inheritance provides for extension of data type.
- Inheritance allows for polymorphism.
- Inheritance unique feature of object orientation.
- Encapsulation represents a particularly good Software Engineering feature in object orientation.

Chapter 4
Constructing an Object Oriented System

4.1 Introduction

This chapter takes you through the design of a simple object oriented system without considering implementation issues or the details of any particular language. Instead, this chapter illustrates how to use object orientation concepts to construct a software system. We first describe the application and then consider where to start looking for objects, what the objects should do and how they should do it. We conclude by discussing issues such as class inheritance, and answer questions such as “where is the structure of the program?”.

4.2 The Application: Windscreen Wipe Simulation

This system aims to provide a diagnosis tutor for the equipment illustrated in Fig. 4.1. Rather than use the wash–wipe system from a real car, students on a car mechanics diagnosis course use this software simulation. The software system mimics the actual system, so the behaviour of the pump depends on information provided by the relay and the water bottle.

The operation of the wash–wipe system is controlled by a switch which can be in one of five positions: off, intermittent, slow, fast and wash. Each of these settings places the system into a different state:

Switch setting	System state
Off	The system is inactive
Intermittent	The blades wipe the windscreen every few seconds
Slow	The wiper blades wipe the windscreen continuously
Fast	The wiper blades wipe the windscreen continuously and quickly
Wash	The pump draws water from the water bottle and sprays it onto the windscreen

For the pump and the wiper motor to work correctly, the relay must function correctly. In turn, the relay must be supplied with an electrical circuit. This electrical

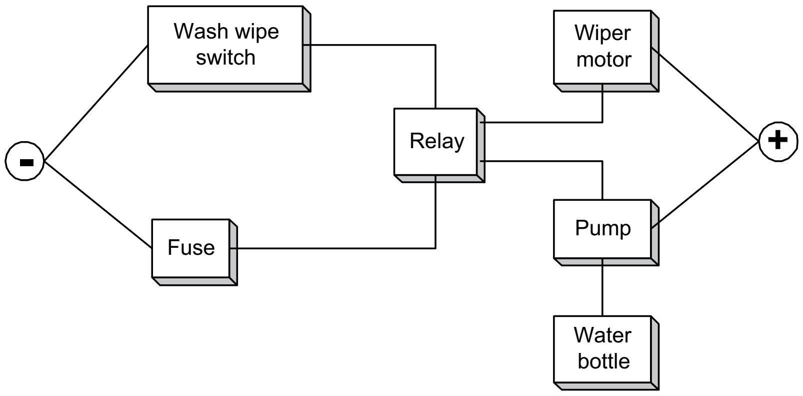


Fig. 4.1 The windscreen wash–wipe system

circuit is negatively fused and thus the fuse must be intact for the circuit to be made. Cars are negatively switched as this reduces the chances of short circuits leading to unintentional switching of circuits.

4.3 Where Do We Start?

This is often a very difficult point for those new to object oriented systems. That is, they have read the basics and understand simple diagrams, but do not know where to start. It is the old chestnut, "I understand the example but don't know how to apply the concepts myself". This is not unusual and, in the case of object orientation, is probably normal.

The answer to the question "where do I start?" may at first seem somewhat obscure; you should start with the data. Remember that objects are things that exchange messages with each other. The things possess the data that is held by the system and the messages request actions that relate to the data. Thus, an object-oriented system is fundamentally concerned with data items.

Before we go on to consider the object-oriented view of the system, let us stop and think for a while. Ask yourself "where would I start if I was going to develop such a system in C or Pascal or even Ada?" In most cases, the answer is "with some form of functional decomposition". That is, you might think about the main functions of the system and break them down into sub-functions and so on. As a natural part of this exercise, you would identify the data required to support the desired functionality. Notice that the emphasis would be on the system functionality.

Let us take this further and consider the functions we might identify for the example presented above:

Function	Description
Wash	Pump water from the water bottle to the windscreen
Wipe	Move the windscreen wipers across the windscreen

Table 4.1 Data items and their associated state information

Data item	States
Switch setting	Is the switch set to off, intermittent, wipe, fast wipe or wash?
Wiper motor	Is the motor working or not?
Pump state	Is the pump working or not?
Fuse condition	Has the fuse blown or not?
Water bottle level	The current water level
Relay status	Is current flowing or not?

We would then identify important system variables and sub-functions to support the above functions.

Now let us go back to the object oriented view of the world. In this view, we place a great deal more emphasis on the data items involved and consider the operations associated with them (effectively, the reverse of the functional decomposition view). This means that we start by attempting to identify the primary data items in the system; next, we look to see what operations are applied to, or performed on, the data items; finally, we group the data items and operations together to form objects. In identifying the operations, we may well have to consider additional data items, which may be separate objects or attributes of the current object. Identifying them is mostly a matter of skill and experience.

The object oriented design approach considers the operations far less important than the data and their relationships. In the next section we examine the objects that might exist in our simulation system.

4.4 Identifying the Objects

We look at the system as a whole and ask what indicates the state of the system. We might say that the position of the switch or the status of the pump is significant. This results in the data items shown in Table 4.1.

The identification of the data items is considered in greater detail in Part 7. At this point, merely notice that we have not yet mentioned the functionality of the system or how it might fit together, we have only mentioned the significant items. As this is such a simple system, we can assume that each of these elements is an object and illustrate it in a simple object diagram (Fig. 4.2):

Notice that I have named each object after the element associated with the data item (e.g. the element associated with the fuse condition is the fuse itself) and that the actual data (e.g. the condition of the fuse) is an instance variable of the object. This is a very common way of naming objects and their instance variables. We now have the basic objects required for our application.

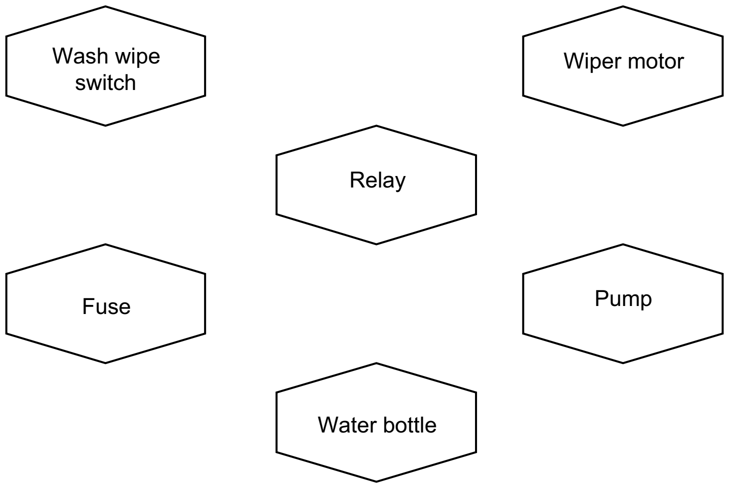


Fig. 4.2 Objects in simulation system (The *hexagonal* shape representing instances is based on the structured cloud used in Unified Modeling Language version 0.8, described in Part 7 of this book)

4.5 Identifying the Services or Methods

At the moment, we have a set of objects each of which can hold some data. For example, the water bottle can hold an integer indicating the current water level. Although object oriented systems are structured around the data, we still need some procedural content to change the state of an object or to make the system achieve some goal. Therefore, we also need to consider the operations a user of each object might require. Notice that the emphasis here is on the **user of the object** and what they **require of the object,** rather than what operations are performed on the data.

Let us start with the switch object. The switch state can take a number of values. As we do not want other objects to have direct access to this variable, we must identify the services that the switch should offer. As a user of a switch we want to be able to move it between its various settings. As these settings are essentially an enumerated type, we can have the concept of incrementing or decrementing the switch position. A switch must therefore provide a *moveUp* and a *moveDown* interface. Exactly how this is done depends on the programming language; for now, we concentrate on specifying the required facilities.

If we examine each object in our system and identify the required services, we may end up with the following table:

We generated this table by examining each of the objects in isolation to identify the services that might reasonably be required. We may well identify further services when we attempt to put it all together.

Each of these services should relate to a method within the object. For example, the `moveUp` and `moveDown` services should relate to methods that change

Table 4.2 Object services

Object	Service	Description
Switch	moveUp	Increment switch value
	moveDown	Decrement switch value
	state?	Return a value indicating the current switch state
Fuse	working?	Indicate if the fuse has blown or not
Wiper motor	working?	Indicate whether the wipers are working or not
Relay	working?	Indicate whether the relay is active or not
Pump	working?	Indicate whether the pump is active or not
Water bottle	fill	Fill the water bottle with water
	extract	Remove some water from the water bottle
	empty	Empty the water bottle

the `state` instance variable within the object. Using a generic pseudo-code, the `moveUp` method, within the `switch` object, might contain the following code:

```
define method moveUp()
   if state == "off" then
      state = "wash"
   elseif state == "wash" then
      state = "wipe"
   endif
end define method
```

This method changes the value of the `state` variable in `switch`. The new value of the instance variable depends on its previous value. You can define `moveDown` in a similar manner. Notice that the reference to the instance variable illustrates that it is global to the object. The `moveUp` method requires no parameters. In object-oriented systems, it is common for few parameters to be passed between methods (particularly of the same object), as it is the object that holds the data.

4.6 Refining the Objects

If we look back to Table 4.2, we can see that fuse, wiper motor, relay and pump all possess a service called `working?` This is a hint that these objects may have something in common. Each of them presents the same interface to the outside world. If we then consider their attributes, they all possess a common instance variable. At this point, it is too early to say whether fuse, wiper motor, relay and pump are all instances of the same class of object (e.g. a Component class) or whether they are all instances of classes which inherit from some common superclass (see Fig. 4.3). However, this is something we must bear in mind later.

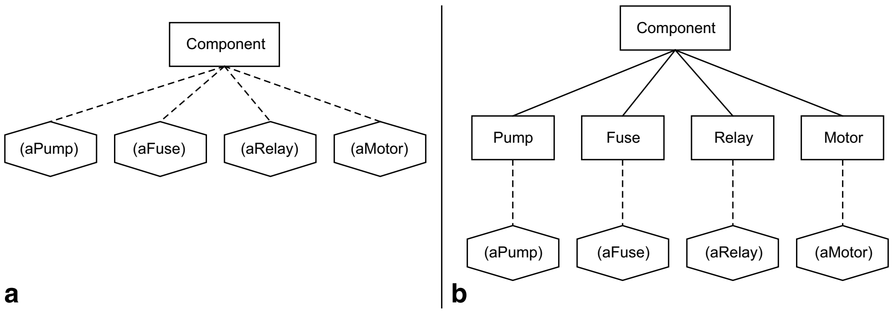


Fig. 4.3 Possible classes for components in the simulation

4.7 Bringing It All Together

So far we have identified the primary objects in our system and the basic set of services they should present. These services were based solely on the data the objects hold. We must now consider how to make our system function. To do this, we need to consider how it might be used. The system is part of a very simple diagnosis tutor; a student uses the system to learn about the effects of various faults on the operation of a real wiper system, without the need for expensive electronics. We therefore wish to allow a user of the system to carry out the following operations:

- change the state of a component device
- ask the motor what its new state is

The `moveUp` and `moveDown` operations on the switch change the switch's state. Similar operations can be provided for the fuse, the water bottle and the relay. For the fuse and the relay, we might provide a `changeState` interface using the following algorithm:

```
define method changeState()
   if state == "working" then
      state = "notWorking"
   else
      state = "working"
   endif
end define method
```

Discovering the state of the motor is more complicated. We have encountered a situation where one object's state (the value of its instance variable) is dependent on information provided by other objects. If we write down procedurally how the value of other objects affect the status of the pump, we might get the following pseudo-code:

```
if fuse is working then
   if switch is not off then
      if relay is working then
          pump status = "working"
      endif
   endif
endif
```

This algorithm says that the pump status depends on the relay status, the switch setting and the fuse status. This is the sort of algorithm you might expect to find in a `main()` program. It links the sub-functions together and processes the data.

In an object-oriented language (such as Scala), we do not have a main program in the same way that a C program has. Instead the `main()` method in Scala is an initiating point for an object-oriented system (in Scala this is simplified further by the use of the App trait). As it is part of an object, the main method can trigger the creation of instances, but it is not itself part of those instances. This can be confusing at first, however if you think of the `main()` method in Scala as initiating a program, that is the starting point for a program, then you are fairly close.

In an object-oriented system, well-mannered objects pass messages to one another. How then do we achieve the same effect as the above algorithm? The answer is that we must get the objects to pass messages requesting the appropriate information. One way to do that is to define a method in the pump object that gets the required information from the other objects and determines the motor's state. However, this requires the pump to have links to all the other objects so that it can send them messages. This is a little contrived and loses the structure of the underlying system. It also loses any modularity in the system. That is, if we want to add new components then we have to change the pump object, even if the new components only affect the switch. This approach also indicates that the developer is thinking too procedurally and not really in terms of objects.

In an object-oriented view of the system, the pump object only needs to know the state of the relay. It should therefore request this information from the relay. In turn, the relay must request information from the switches and the fuse.

Figure 4.4 illustrates the chain of messages initiated by the pump object:

1. pump sends a `working?` message to the relay
2. relay sends a `state?` message to the switch
   the switch replies to the relay
3. relay sends a second `working?` message to the fuse
   the fuse replies to the relay
   the relay replies to the motor

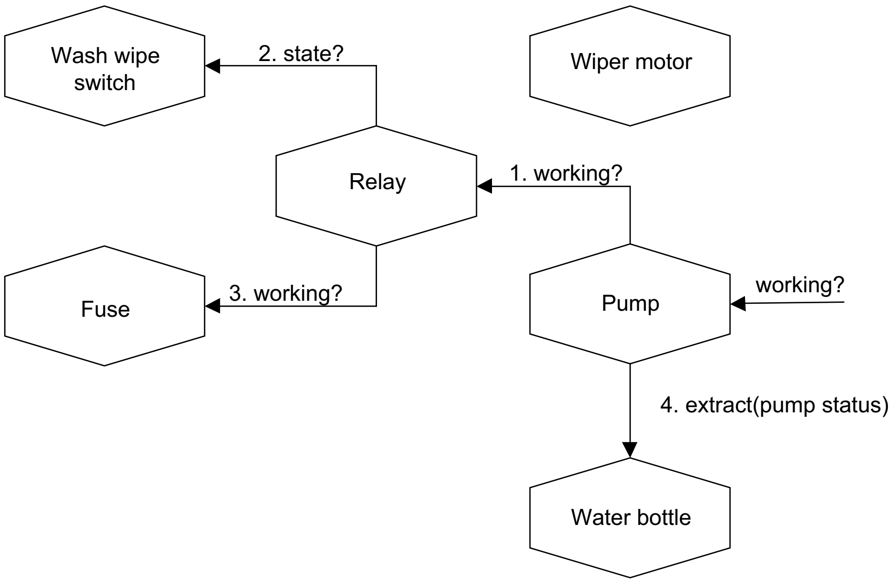


Fig. 4.4 Collaborations between the objects for wash operation

If the pump is working, then the pump object sends the final message to the water bottle

4. pump sends a message `extract` to the water bottle

In step four, a parameter is passed with the message because, unlike the previous messages that merely requested state information, this message requests a change in state. The parameter indicates the rate at which the pump draws water from the water bottle.

The water bottle should not record the value of the pump's *status* as it does not own this value. If it needs the motor's status in the future, it should request it from the pump rather than using the (potentially obsolete) value passed to it previously.

In Fig. 4.4, we assumed that the pump provided the service `working?` which allows the process to start. For completeness, the pseudo-code of the `working?` Method for the pump object is:

```
def working?()
    begin
        this.status = relay.working().
        if this.status == "working" then

    water_bottle.extract(this.status)
        endif
    end
end define method
```

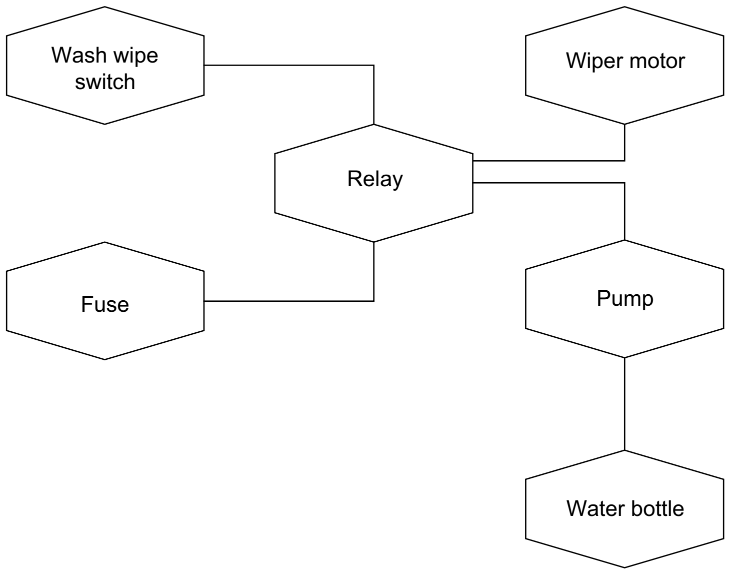


Fig. 4.5 Wash–wipe system structure

This method is a lot simpler than the procedural program presented earlier. At no point do we change the value of any variables that are not part of the pump, although they may have been changed as a result of the messages being sent. Also, it only shows us the part of the story that is directly relevant to the pump. This means that it can be much more difficult to deduce the operation of an object oriented system merely by reading the source code. Some Scala environments (such as the Scala IDE) alleviate this problem, to some extent, through the use of sophisticated browsers.

4.8 Where Is the Structure?

People new to object orientation may be confused because they have lost one of the key elements that they use to help them understand and structure a software system: the main program body. This is because the objects and the interactions between them are the cornerstone of the system. In many ways, Fig. 4.4 shows the object oriented equivalent of a main program. This also highlights an important feature of most object-oriented approaches: graphical illustrations. Many aspects of object technology, for example object structure, class inheritance and message chains, are most easily explained graphically.

Let us now consider the structure of our object-oriented system. It is dictated by the messages that are sent between objects. That is, an object must possess a reference to another object in order to send it a message. The resulting system structure is illustrated in Fig. 4.5.

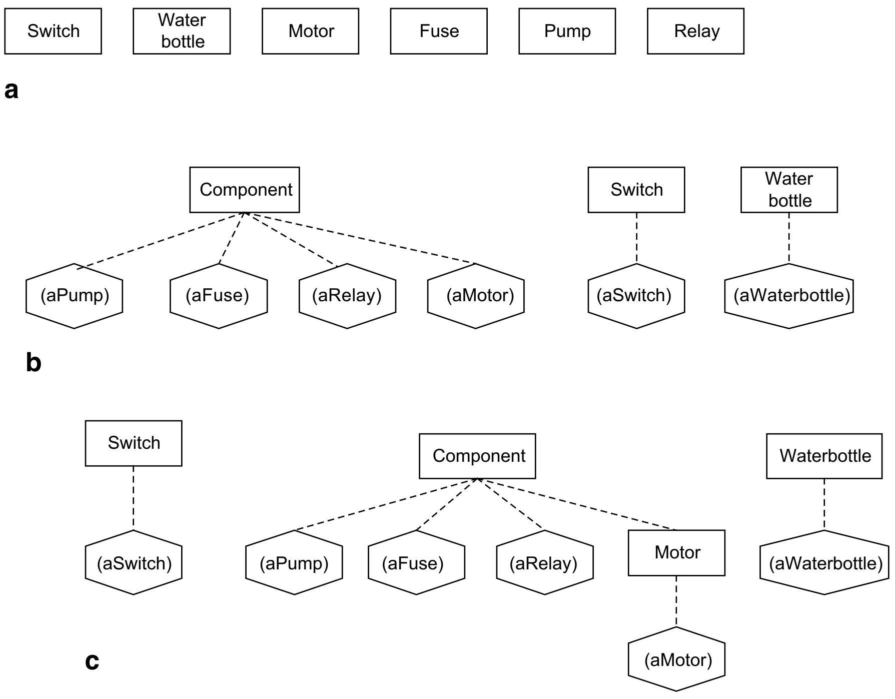


Fig. 4.6 Possible class inheritance relationships

Table 4.3 Comparison of components

	Fuse	Relay	Motor	Pump
Instance variable	state	state	state	state
Services	working?	working?	working?	working?

In Scala, this structure is achieved by making instance variables reference the appropriate objects. This is the structure which exists between the instances in the system and does not relate to the classes, which act as templates for the instances.

We now consider the classes that create the instances. We could assume that each object is an instance of an equivalent class (see Fig. 4.6a). However, as has already been noted, some of the classes bear a very strong resemblance. In particular, the fuse, the relay, the motor and the pump share a number of common features. Table 4.3 compares the features (instance variables and services) of these objects.

From this table, the objects differ only in name. This suggests that they are all instances of a common class such as Component (see Fig. 4.6b). This class would possess an additional instance variable, to simplify object identification.

If they are all instances of a common class, they must all behave in exactly the same way. However, we want the pump to start the analysis process when it receives the message `working?`, so it must possess a different definition of `working?`

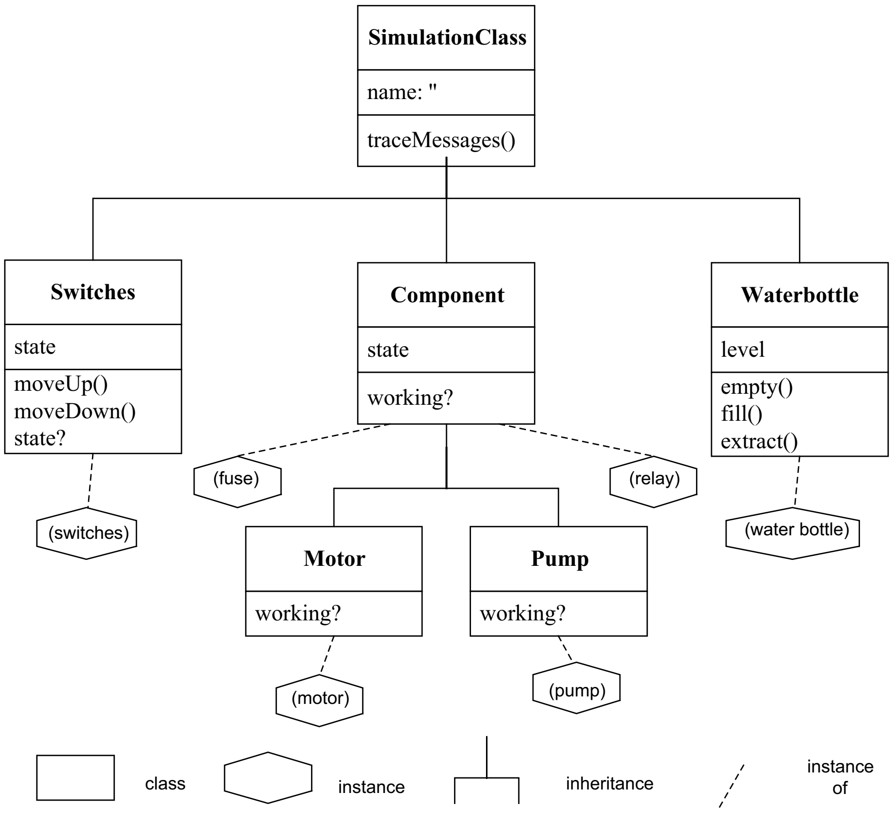


Fig. 4.7 The final class hierarchy and instance diagram

from fuse and relay. In other ways it is very similar to fuse and relay, so they can be instances of a class (say Component) and pump and motor can be instances of classes that inherit from Component (but redefine `working?`). This is illustrated in Fig. 4.6c. The full class diagram is presented in Fig. 4.7.

4.9 Summary

In this chapter, you have seen how a very simple system can be broken down into objects. These objects combine to provide the overall functionality of the system. You have seen how the data to be represented determines the objects used and that the interactions between objects determine the structure of the system. You should also have noted that objects and their classes, methods and instance variables are identified by more of an evolutionary process than in languages that are not object oriented.

4.10 Exercises

Take a system with which you are familiar and try to break it down into objects. Carry out a similar set of steps to those described above. Do not worry about how to implement the objects or the classes. Use whatever representation best fits your way of working to describe what the methods do (pseudo-code or a programming language, such as C or Pascal, if you prefer). You can even use a flow chart if you are most comfortable with that. It is very important that you try and do this, as it is a useful exercise in learning to think in terms of objects.

4.11 Further Reading

A good place to start further reading on building object-oriented systems is with the first few chapters of Blaha and Rumbaugh (2004). In addition, Wirfs-Brock and McKean (2002) is an excellent, non-language-specific introduction to structuring object-oriented systems. It uses a rather simplistic approach, which is ideal for learning about object oriented system design but is not generally applicable. This is not a problem as what you want to do at the moment is to get the background rather than specific techniques. Another good reference for further reading is Larman (2008).

References

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Blaha MR, Rumbaugh JR (2004) Object-Oriented modeling and design with UML (2nd Edition) by Blaha, Michael R., Rumbaugh, James R (2004), Prentice Hall, Prentice Hall (8120330161)

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Chapter 5
Functional Programming

5.1 Introduction

Previous chapters have focussed on the object-oriented side of the Scala language. However, Scala is a hybrid Object Oriented (OO) and Functional Programming (FP) language. In this chapter we will now look at Functional Programming and its advantages and disadvantages.

5.2 What is Functional Programming?

Wikipedia describes Functional Programming as:

> … a programming paradigm, a style of building the structure and elements of computer programs, that treats computation as the evaluation of mathematical functions and avoids state and mutable data.

There are a number of points to note about this definition. The first is that it is focussed on the computational side of computer programmes. You might consider that obvious but at least half of what we have looked at around objects and classes has been focussed on the representation of domain concepts and data within those concepts. Thus there is a difference of emphasis between the functional programming world and the object oriented programming world.

Another thing to note is that the way in which the computations are represented emphasises functions that generate results based on data and computations. These functions only rely on their inputs to generate a new output. They do not relying on any side effects and do not depend on the current state of the program. Taking each of these in turn:

1. *Functional Programming aims to avoid side effects*. A function should be replaceable by taking the data it receives and inlining the result generated (this is referred to as referential transparency). This means that there should be no hidden side effects of the function. Hidden side effects make it harder to under-

stand what a program is doing and thus make comprehension, development and maintenance harder. Pure functions have the following attributes:

   1. the only observable output is the return value.
   2. the only output dependency are the arguments.
   3. arguments are fully determined before any output is generated.

2. *Functional Programming avoids concepts such as state.* If some operation is dependent upon the state of the program or some element of a program, then its behaviour may differ depending upon that state. This may make it harder to comprehend, implement, test and debug. As all of these impact on the stability and probably reliability of a system, state based operations may result in less reliable software being developed. As functions do not (should not) rely on any given state (only upon the data they are given) they should as a result be easier to understand, implement, test and debug.
3. *Functional Programming promotes immutable data.* Functional Programming also tends to avoid concepts such as mutable data. Mutable data is data that can change its state. By contrast Immutability indicates that once created, data cannot be changed. In Scala Strings are immutable. Once you create a new string you cannot modify it. Any functions that apply to a string that would conceptually alter the contents of the string, result in a new String being generated. Scala takes this further by having a presumption of Immutability that means that by default all data holding types are immutable. This ensures that functions cannot have hidden side effects and thus simplifies programming in general.
4. *Functional Programming promotes declarative programming* (and is in fact a subtype of declarative programming), which means that programming is oriented around expressions that describe the solution rather than focus on the imperative approach of most procedural programming languages. These languages emphasise aspects of how the solution is derived. For example, an imperative approach to looping through some container and printing out each result in turn would look like this:

```
int sizeOfContainer = container.length
for (int I = 1 to sizeOfContainer) do
 element = container.get(i)
 print(element)
enddo
```

Where as a functional programming approach would look like:

```
container.foreach(print)
```

Functional Programming has its roots in the lambda calculus, originally developed in the 1930s, to explore computability. Many Functional Programming languages can thus be considered as elaborations on this lambda calculus. There have been numerous pure Functional Programming languages including Common Lisp, Clojure and Haskell. Scala allows you to write in a purely Functional Programming style or to combine functions with objects. Care needs to be taken when doing this that the principles of Functional Programming, and thus the advantages of Functional Programming, are not undermined. However, when used judiciously functional programming can be a huge benefit for, and an enhancement to, the purely Object Oriented world.

To summarise then:

Imperative Programming is what is currently perceived as traditional programming. That is, it is the style of programming used in languages such as C, C++, Java and C# etc. In these languages a programmer tells the computer what to do, e.g. x=y + z etc. It is thus oriented around control statements, looping constructs and assignments.

Functional Programming aims to describe the solution, that is *what* the program needs to be do (rather than *how* it should be done).

5.3 Advantages to Functional Programming

There are a number of significant advantages to functional programming compared to imperative programming. These include:

1. *Less code*. Typically a functional programming solution will require less code to write than an equivalent imperative solution. As there is less code to write, there is also less code to understand and to maintain. It is therefore possible that functional programmes are not only more elegant to read but easier to update and maintain. This can also lead to enhanced programmer productivity as they spend less time writing reams of code as well as less time reading those reams of code.
2. *Lack of (hidden) side effects (Referential Transparency).* Programming without side effects is good as it makes it easier to reason about functions (that is a function is completely described by the data that goes in and the results that come back). This also means that it is safe to reuse these functions in different situations (as they do not do unexpected things). It should also be easier to develop, test and maintain such functions.
3. *Recursion is a natural control structure.* Functional languages tend to emphasis recursion as a way of processing structures that would use some form of looping constructs in an imperative language.

Although you can often implement recursion in imperative languages it is often easier to do in functional languages. It is also worth noting that recursion is very expressive and a great way for a programmer to write a solution to a problem, however it is not as efficient at run time as looping. However, any expression that can be written as a recursive routine can also be written using looping constructs. Functional programming languages often incorporate tail end recursive optimizations to convert recursive routines into iterative ones at runtime. Essentially, if the last thing a routine does before it returns is to call another routine, rather than actually invoking the routine and having to set up the context for that routine, it should be possible to reuse the current context and to treat it in an iterative manner as a loop around that routine. This means that both the programmer benefits of an expressive recursive construct, and the runtime benefits of an iterative solution, can be achieved using the same source code. This option is typically not available in imperative languages.

In summary then, Functional Programming:

- *Good for prototyping solutions.* Solutions can be created very quickly for algorithmic or behaviour problems in a functional language. Thus allowing ideas and concepts to be explored in a rapid application development style.
- *Modular Functionality.* Functional Programming is modular in terms of functionality (where Object Oriented languages are modular in the dimension of components). They are thus well suited to situations where it is natural to want to reuse or componentise the behaviour of a system.
- *The avoidance of state based behaviour.* As functions only rely on their inputs and outputs (and avoid accessing any other stored state) they exhibit a cleaner and simpler style of programming. This avoidance of state based behaviour makes many difficult or challenging areas of programming simpler (such as those used in concurrency applications).
- *Additional control structures*. A strong emphasis on additional control structures such as pattern matching, managing variable scope, tail recursion optimizations etc.
- *Concurrency and immutable data*. As functional programming systems advocate immutable data structures it is simpler to construct concurrent systems. This is because the data being exchanged and accessed is immutable. Therefore multiple executing thread or processes cannot affect each other adversely. The Akka Actor model builds on this approach to provide a very clean model for multiple interacting concurrent systems.
- *Partial Evaluation*. Since functions do not have side effects, it also becomes practical to bind one or more parameters to a function at compile time and to reuse these functions with bound values as new functions that take fewer parameters.

5.4 Disadvantages of Functional Programming

If functional programming has all the advantages previously described, why isn't it the mainstream force that imperative programming languages are? The reality is that functional programming is not without its disadvantages, including:

- *Input-output is harder in a purely functional language*. Input output flows naturally align with stream style processing, which does not neatly fit into the data in, results out, nature of functional systems.
- *Interactive applications are harder to develop*. Interactive application are constructed via request response cycles initiated by a user action. Again these do not naturally sit within the purely functional paradigm.

- *Continuously running programs* such as services or controllers may be more difficult to develop, as they are naturally based upon the idea of a continuous loop.
- *Functional programming languages have tended to be less efficient on current hardware platforms*. This is partly because current hardware platforms are not designed with functional programming in mind and also because many of the systems previously available were focussed on the academic community where out and out performance was not the primary focus. However, this has changed to a large extent with Scala and the functional language Heskell.
- *Not data oriented*. A pure functional Language does not really align with the needs of the primarily data oriented nature of many of todays systems. Many (most) commercial systems are oriented around the need to retrieve data from a database, manipulate it in some way and store that data back into a database. Such data can be naturally represented via objects in an Object Oriented language.
- *Programmers are less familiar* with functional programming concepts and thus find it harder to pick up function oriented languages.
- *Functional Programming idioms are often less intuitive* to (traditional) programmers than imperative idioms (such as lazy evaluations) which can make debugging and maintenance harder.
- Many Functional Programming languages have been viewed as *Ivory tower languages* that are only used by academics. This has been true of some older functional languages but is increasingly changing with the advent of languages such as Scala.

5.5 Scala and Functional Programming

Scala overcomes many of the disadvantages of functional programming by providing a hybrid environment in which you can use the Object-Oriented features of the language to represent concepts, data rich elements etc. and use functions to express behaviour oriented aspects of a program. It thus provides a *best of both worlds* approach to your choice of programming language constructs.

Chapter 6
Scala Background

6.1 Introduction

I first encountered the Scala language in 2010. I was working on a graduate training programme for an international banking organisation when I was asked to give an hour talk to the graduates on Scala. At that point I had heard the name mentioned but had no idea what it was. I therefore did some reading, installed the IDE being used and tried out some examples—and was hooked.

Since then I have trained a wide range of people in Scala, used it to develop large commercial systems and written a book on Scala and design patterns. I am still hooked on it and find myself discovering new aspects to the language and the environment on almost every Scala project I am involved with.

6.2 The Class Person

The following sections introduce a class Person that will be used to develop and explore how classes are defined using Scala. Initially the simple class Person that has a first name and a last name and an age (these examples were first introduced in the introduction). A Person is constructed by providing the first and last names and their age and setters and getters are provided for each.

Here is the Java class:

```
class Person {
  private String firstName;
  private String lastName;
  private int    age;

  public Person(String firstName, String lastName, int
age) {
    this.firstName = firstName;
    this.lastName  = lastName;
    this.age  = age;

    }

  public void setFirstName(String firstName) {
this.firstName = firstName; }
  public void String getFirstName() { return this.firstName;
}
  public void setLastName(String lastName) {
this.lastName = lastName; }
  public void String getLastName() { return this.lastName;
}
  public void setAge(int age) { this.age = age; }
  public void int getAge() { return this.age; }
}
```

And here is the equivalent Scala class:

```
class Person(var firstName: String, var lastName: String, var
age: Int)
```

We saw this example earlier in the book, and certainly the Java class is longer than the Scala class, but look at the Java class "How many times have you written something like that?" Most of this Java class is boilerplate code. In fact it is so common that tools such as Eclipse allow us to create the boilerplate code automatically. Which may mean that we do not have to type much more in the Java case than the Scala case. However, when I look back and have to read this code I may have to wade through a lot of such boilerplate code in order to find the actual functionality of interest. In the Scala case this boilerplate code is handled by the language meaning that I can focus on what the class actually does.

Actually the Object Oriented side of Scala is both more sophisticated than that in either Java or C# and also different in nature. For example, many people have found the distinction between the *static* side of a class and the instance side of a class confusing. Scala does away with this distinction by not including the static concept. Instead it allows the user to define singleton objects, if these singleton objects have the same name as a class and are in the same source file as the class, then they are referred to as companion objects. Companion objects then have a special relationship with the class that allows them to access the internals of a class (private fields and methods) and can provide the Scala equivalent of static behaviour.

The class hierarchy in Scala is based on single inheritance of classes but allows multiple traits to be mixed into any given class. A Trait is a structure within the Scala language that is neither a class nor an interface (note Scala does not have interfaces even though it compiles to Java Byte Codes). It can however, be combined with classes to create new types of classes and objects. As such a Trait can contain data, behaviour, functions, type declarations, abstract members etc. but cannot be instantiated itself.

The analogy might be that a class is like a flavour of Ice Cream. You can have vanilla as the basic flavour with all the characteristics of ice cream, Chocolate could be a subclass of Vanilla which extends the concept to a chocolate flavour of ice cream. Separately we could have bowls containing chocolate chips, mint chips, M&Ms, sprinkles of various types. We can combine the Vanilla Ice Cream with the mint chips to create Vanilla Mint Chip Ice Cream. This provides a new type of ice cream but those mint choc chips are not in and of themselves an ice cream. Traits are like the mint chocolate chips, while classes are like the ice cream.

6.3 Functional Programming

So much for the Object Oriented view of Scala, what about this Functional Programming concept? For those of you coming from a Java background this may seem a bit alien, however, functional programming languages have a long history from LISP developed in the late 1950s to more recent functional languages such as ML and Haskell.

Working with functions is *not* that difficult although until you become familiar with the syntax they may seem unwieldy—but the key is to hang in there and keep trying.

The following provides a simple example of a function literal in Scala that takes two numbers and adds them together:

```
val add = (a: Int, b: Int) => a+b
```

This defines a new function that takes two integers in the parameters a and b and returns the result of adding a to b. The function can be accessed via the variable add. This is a variable of type Function. We can invoke this function as following:

```
add(4, 5)
```

Which should return the value 9. In Scala we can then partially apply this function. This means that we can bind one of the parameters to a value to create a new function that only takes one parameter, for example:

```
val addTwo = (2, _: Int)
```

This function, addTwo, now adds 2 to whatever integer is passed to it, for example:

```
addTwo(5)
will return 7.
```

6.4 A Hybrid Language

If all Scala did was provide the ability to program functionally all that would do is provide yet another functional programming language. However it is the fact that Scala mixes the two paradigms that allows us to create software solutions that are both concise and expressive.

The Object Oriented paradigm has been such a success because it can be used to model concepts and entities within problem domains. When this is combined with the ability to treat functions as first class entities we obtain a very powerful Environment.

For example, we can now create classes that will hold data (including other objects) and define behaviours in terms of methods but which can easily and naturally be given functions that can be applied to the members of that object.

```
val numbers = List(1, 2, 3, 4, 5)
println(numbers)
```

In this case I have created a list of integers (note that this is a list of Integers as the type has been inferred by Scala) that are stored in the variable `numbers`.

```
val filtered = numbers.filter((n: Int) => n < 3)
println(filtered)
```

I have then applied a function to each of the elements of the list. This function is an anonymous function that takes an `Int` (and stores that `Int` in the variable `n`). It then tests to see if the value of `n` is less than `3`. If it is it returns `true` otherwise it returns `false`. The method `filter` uses the function passed to it to determine whether the value passed it should be included in the result or not. This means that the variable `filtered` will hold a list of integers where each integer is less than the value `3`. Again note that this is a `List` of `Ints` as Scala has inferred the type.

The output from these statements is shown below:

```
List(1, 2, 3, 4, 5)
List(1,2)
```

Chapter 7
A Little Scala

7.1 Introduction

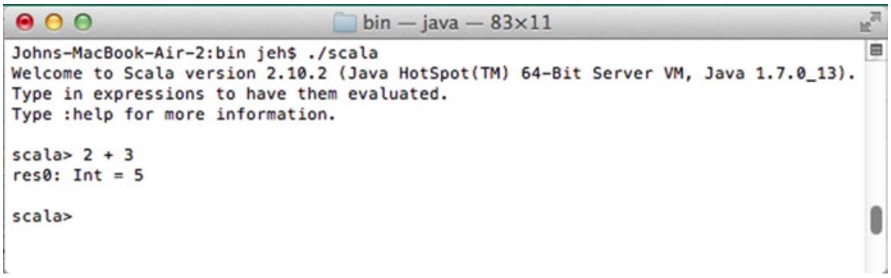
In the last chapter, you learned a little about the history of Scala and the Scala development environment. In this chapter, you encounter a little of the Scala language, what happens when you compile and run a Scala program, the Scala Runtime (Virtual Machine) and the Scala IDE.

7.2 The Scala Environment

There are a number of things that you need in order to develop using the Scala language. First of all you need access to the Scala compiler. The compiler is called `scalac` and you may use it from the command line to compile Scala code files directly or you may use it via an IDE (such as the Scala IDE) that can compile your code for you automatically. It can also be used via various application build tools such as the SBT (Simple Build Tool) for Scala.

When you compile Scala source files (ones with a `.scala` extension) you create byte code files. These files have a `.class` extension. They are not directly executable files (these are files with have a. exe. or .bin type extension and can be run natively by the operating system). Instead a byte code file is a compressed version of your Scala code that is run via a virtual machine. This virtual machine acts like a computer that executes byte code files but is actually a software application that can be ported to numerous different operating systems.

Scala can run on the Scala Virtual Machine (which is the Java Virtual Machine, or JVM allied with the Scala runtime libraries that provide for the various concepts, functionality and frameworks that Scala uses). This combination of the JVM and the Scala libraries can be referred to as the Scala runtime and can be used in either interpreter mode (in which case you can type in Scala code and immediately see the result) and in batch mode in which case you can run applications as you would any other type of environment.



```
Johns-MacBook-Air-2:bin jeh$ ./scala
Welcome to Scala version 2.10.2 (Java HotSpot(TM) 64-Bit Server VM, Java 1.7.0_13).
Type in expressions to have them evaluated.
Type :help for more information.

scala> 2 + 3
res0: Int = 5

scala>
```

Fig. 7.1 Working with the Scala Interpreter

To summarise then, to run the Scala environment you need:

- The Scala Compiler
- The Scala Virtual Machine
- The Scala runtime libraries

If you use the Scala IDE described later in this chapter then you will automatically obtain these. However, you can install Scala without the need for an IDE if you wish. This can be obtained from the main Scala web site.

7.3 The Scala Shell

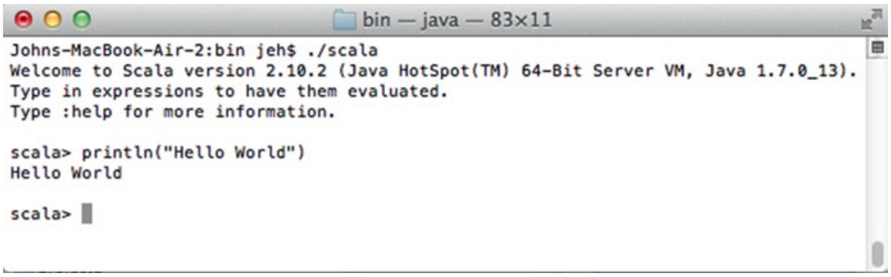
Scala provides an interactive interpreter or *shell* that you can use to try out pieces of Scala code. This interactive shell allows you to type in Scala code and for that Scala code to be immediately evaluated and the results presented to you. This shell is often referred to as REPL for 'R'ead, 'E'valuate, 'P'rint 'L'oop.

To start up the interactive shell all you need to do is to open a command window (on windows) or a terminal (on Mac or Unix) and to type in *scala* (assuming that the scala bin directory is on your path or you are in the bin directory). When you type in *scala* you will enter the interactive interpreter and can enter Scala expressions and immediately see the result. For example, the expression 2+3 is shown in Fig. 7.1.

Note that in this example, we asked the interpreter to add 2 and 3 together. The Scala interpreter evaluated the expression and printed out the result. The result (res0) indicates that the result is an Int (integer) of the value 5. This is because we entered an expression that returned a result. We could also have entered an operation that returned nothing, such as *println*, this is shown in Fig. 7.2.

Here you can see that the result is that the string is printed out.

To leave the Scala interpreter shell use CTRL-D or use the command *exit*.



```
Johns-MacBook-Air-2:bin jeh$ ./scala
Welcome to Scala version 2.10.2 (Java HotSpot(TM) 64-Bit Server VM, Java 1.7.0_13).
Type in expressions to have them evaluated.
Type :help for more information.

scala> println("Hello World")
Hello World

scala> 
```

Fig. 7.2 Printing a string using the interpreter

7.4 The Scala IDE

You will need a Scala environment on your local machine in order to develop, compile, test and run Scala applications. As Scala is a JVM language this also means that you must have a Java environment on your machine. In theory you could install each of these components yourself and use whatever editor you wished (including Emacs, or TextEdit). However the easiest way to get started with Scala is to install one of the Scala IDEs available free on the web. We will be using the Eclipse based Scala IDE in the examples throughout this book.

You can down load the Scala IDE from http://scala-ide.org see Fig. 7.3.

There are versions available for both Windows and Mac systems. Alternatively you can use an Eclipse plugin for Scala if you already have Eclipse installed on your machine. The update site for this is

http://download.scala-ide.org/sdk/e37/scala210/stable/site

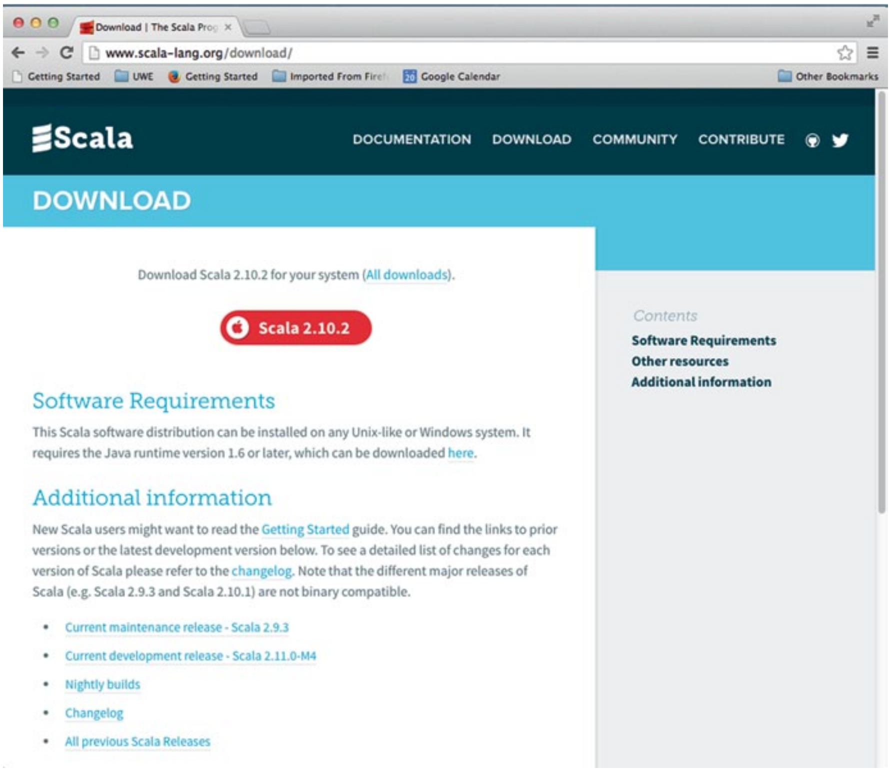
7.4.1 Selecting a Workspace

Eclipse is oriented around the idea of a workspace containing one or more projects. The workspace is associated with a directory location and *typically* projects reside under that workspace location.

Personally I create a directory called *workspaces*, in which I place a workspace for a particular task or tool and inside this I have projects. The workspace is specified when you start up Eclipse as shown in Fig. 7.4.

In the above I have created a directory workspaces containing two sub directories. The projects will all be created in scala210-pracs. Note the directories will be created by Eclipse if they do not already exist. If you are on a PC then the directory structure would start C: etc.

Once you have specified the appropriate location select ‘OK’.



DOWNLOAD

Download Scala 2.10.2 for your system (All downloads).

Software Requirements

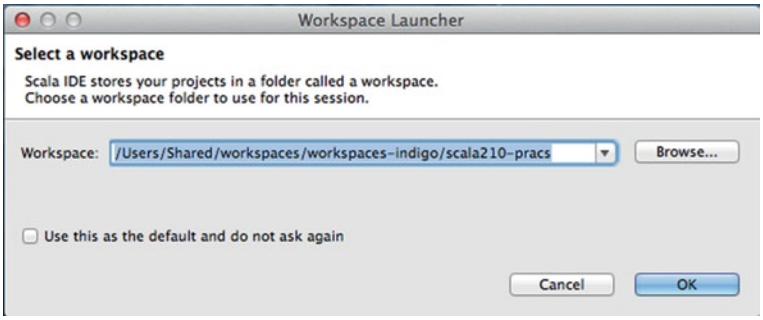
This Scala software distribution can be installed on any Unix-like or Windows system. It requires the Java runtime version 1.6 or later, which can be downloaded here.

Additional information

New Scala users might want to read the Getting Started guide. You can find the links to prior versions or the latest development version below. To see a detailed list of changes for each version of Scala please refer to the changelog. Note that the different major releases of Scala (e.g. Scala 2.9.3 and Scala 2.10.1) are not binary compatible.

- Current maintenance release - Scala 2.9.3
- Current development release - Scala 2.11.0-M4
- Nightly builds
- Changelog
- All previous Scala Releases

Fig. 7.3 Scala Download Site



Select a workspace

Scala IDE stores your projects in a folder called a workspace.
Choose a workspace folder to use for this session.

Workspace: /Users/Shared/workspaces/workspaces-indigo/scala210-pracs

Use this as the default and do not ask again

Fig. 7.4 Selecting a Workspace

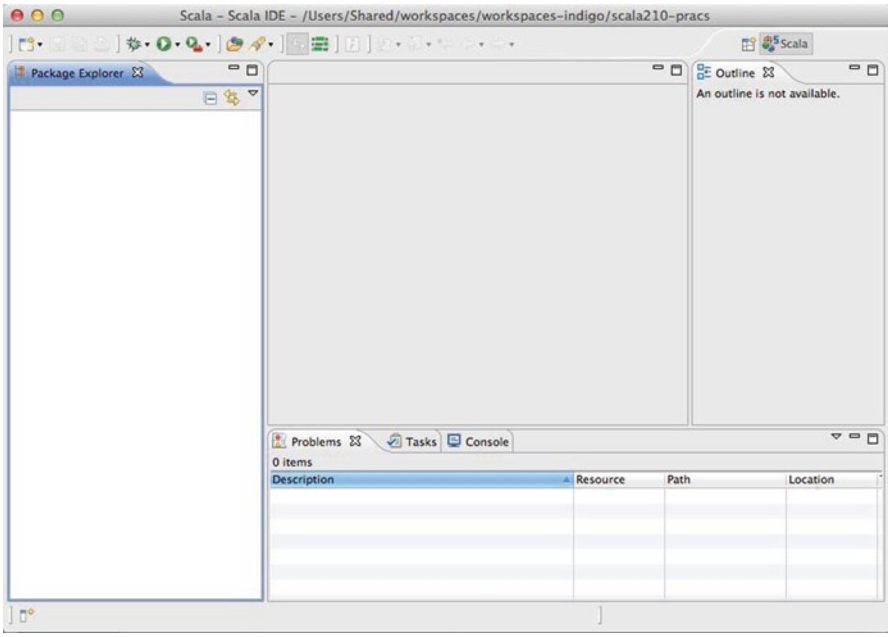

Scala - Scala IDE - /Users/Shared/workspaces/workspaces-indigo/scala210-pracs
Scala
Package Explorer
Outline
An outline is not available.
Problems
Tasks
Console
0 items
Description
Resource
Path
Location

Fig. 7.5 The Scala IDE

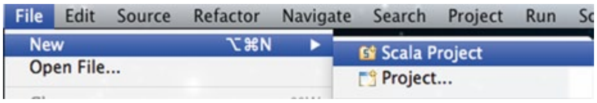


Fig. 7.6 Selecting New Scala Project

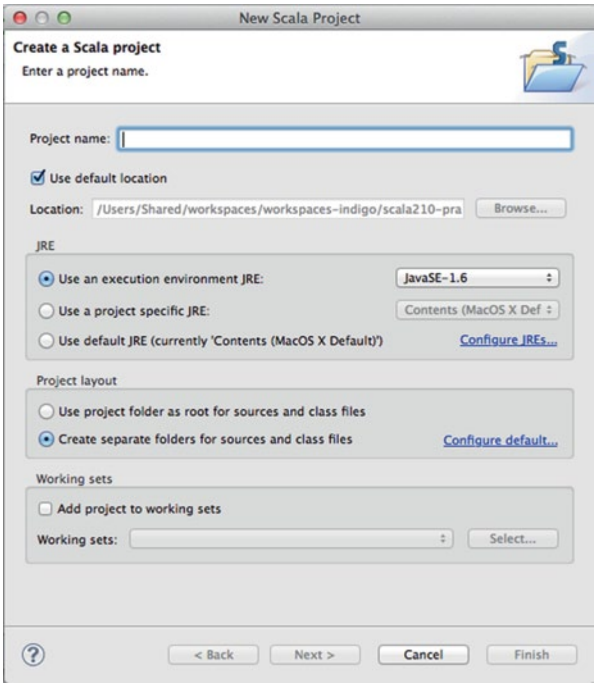
7.4.2 *Inside Eclipse*

You will now be presented with an empty editor (see Fig. 7.5). This editor is made up of views onto the project or projects you are working with. The current display shows the package Explorer on the left, Outline on the right, an area below the middle showing any problems, tasks to be completed and the output console. The currently blank central area is where you code will be displayed.

7.4.3 *Creating a Project*

The first thing we need is a Scala Project. A Project in Eclipse has a number of types of project such as Scala, XML, Java, etc. To create a new project select File->New->Scala Project, as illustrated in Fig. 7.6).

Fig. 7.7 New Project Wizard


New Scala Project

Create a Scala project
Enter a project name.

Project name:

[✓] Use default location

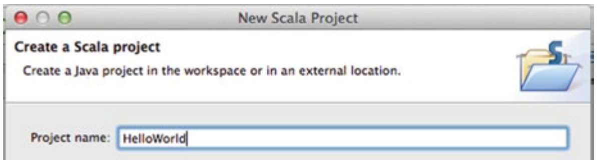
Location: /Users/Shared/workspaces/workspaces-indigo/scala210-pra

JRE
[● Use an execution environment JRE:] JavaSE-1.6
○ Use a project specific JRE: Contents (MacOS X Def
○ Use default JRE (currently 'Contents (MacOS X Default)')

Project layout
○ Use project folder as root for sources and class files
[● Create separate folders for sources and class files]

Working sets
[ ] Add project to working sets
Working sets:

Fig. 7.8 Naming your project


New Scala Project

Create a Scala project
Create a Java project in the workspace or in an external location.

Project name: HelloWorld

This causes the New Scala Project wizard to be displayed, which is displayed in Fig. 7.7.

Note that although this is a Scala project the execution environment is a Java Runtime Environment (as at runtime it is byte codes that are executed by a JVM).

Now name your project *HelloWorld*, for example, the New Scala Project Wizard display is shown in Fig. 7.8.

And click 'Finish'.

You should now see a new Project in the Package Explorer with an 'S' on the open folder indicating that this is a Scala project, see Fig. 7.9.

If you click on the 'arrow head' next to the open folder symbol you will see that the project currently contains a 'src' directory and is linked to the Scala Library and the Scala Runtime Environment (see Fig. 7.10).

We will add a new Scala Object to this project. This is done by using the right mouse menu, from the project node in the Package Explorer tree (i.e. click on

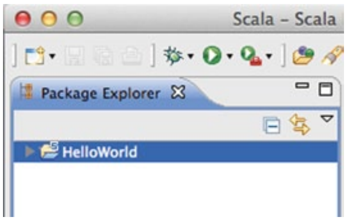


Fig. 7.9 A new project displayed in the project explorer

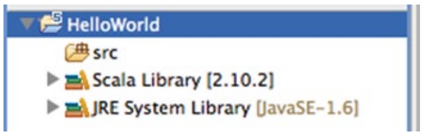


Fig. 7.10 Scala Project Setup

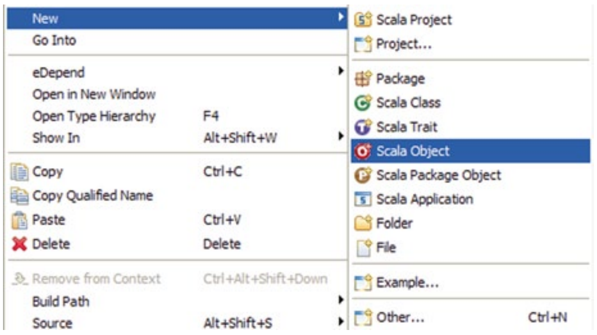


Fig. 7.11 Selecting the Scala Object Wizard

HelloWorld and bring up the right mouse menu). Select New ->Scala Object as shown in Fig. 7.11.

This will display the *Create a new Scala Object* wizard, which is shown in Fig. 7.12.

In the selected *Name* field enter 'Hello', as illustrated in Fig. 7.13.

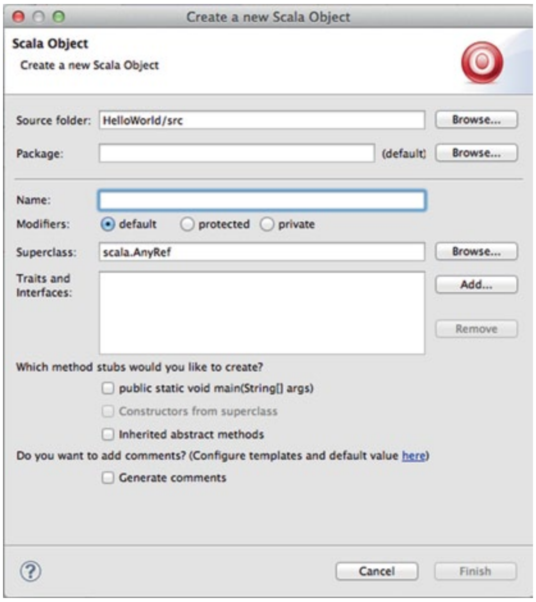
And now click 'Finish'.

This results in a new file Hello.scala being created under *src* and the basic structure of a Scala object will be displayed in the central code area (see Fig. 7.14).

7.4.4 Scala IDE and REPL

The Scala interpreter is also available within the Scala IDE. However, in this case it also provides access to any Scala type you currently have within the current project. This means that you can type in expressiosn involving the types you are developing to test them out interactively. To do this open the Scala Interpreter by

Fig. 7.12 Scala New Object Wizard



Create a new Scala Object

Scala Object

Create a new Scala Object

Source folder: HelloWorld/src

Package: (default)

Name:

Modifiers: [✓ default] protected private

Superclass: scala.AnyRef

Traits and Interfaces:

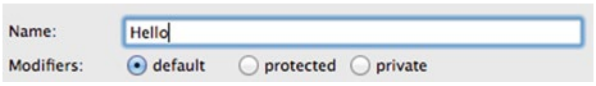
Which method stubs would you like to create?

- [ ] public static void main(String[] args)
- [ ] Constructors from superclass
- [ ] Inherited abstract methods

Do you want to add comments? (Configure templates and default value here)

- [ ] Generate comments

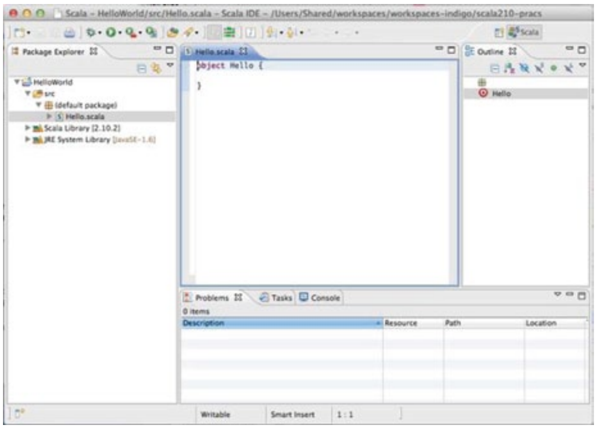
Fig. 7.13 Entering the Object name



Name: Hello

Modifiers: [✓ default] protected private

Fig. 7.14 The Hello Object in the Scala IDE



Scala – HelloWorld/src/Hello.scala – Scala IDE – /Users/Shared/workspaces/workspaces-indigo/scala210-pracs

```
object Hello {

}
```

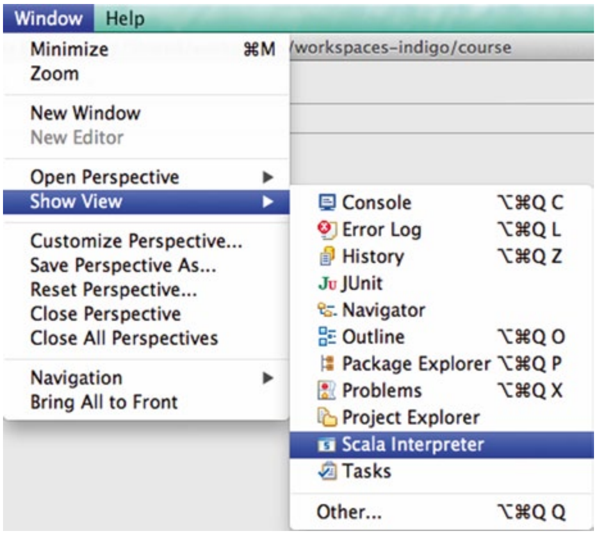
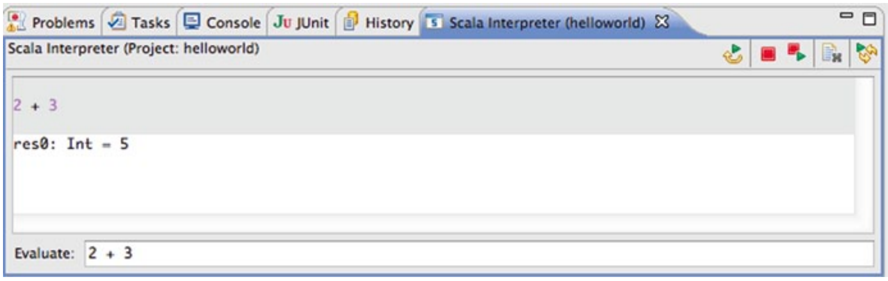


Fig. 7.15 Selecting the Scala Interpreter view


Problems
Tasks
Console
JUnit
History
Scala Interpreter (helloworld)
Scala Interpreter (Project: helloworld)

```
2 + 3

res0: Int = 5
```

Evaluate: 2 + 3

Fig. 7.16 Using the Scala Interpreter within the Scala IDE

selecting Window -> Show View -> Scala interpreter (when in the Scala perspective) as shown in Fig. 7.15.

The Scala Interpreter is shown in Fig. 7.16. This interpreter is linked to the *helloworld* project and shows that you can type in an expression to the Evaluate box. This expression is evaluated and the expression and as well as the result are presented in the main window above the Evaluate box.

7.5 Implementing the Object

To implement the Hello Object we created above, type in the definition for the main method as shown in Fig. 7.17.

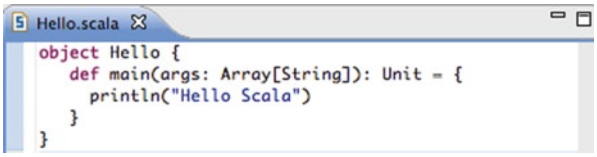


Fig. 7.17 A simple Hello World Application in Scala

```
object Hello {
  def main(args: Array[String]): Unit = {
    println("Hello Scala")
  }
}
```

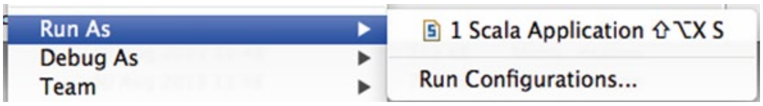


Fig. 7.18 Menu option to run the application

This says that the object *Hello* defines a 'main' method. A 'main' method is the entry point for this application. The main method takes an array of Strings (that is the type) and the parameter that this array is placed into is called *args* (although you can call the parameter whatever you like). The parameter is placed in parentheses.

Following the parameters is a ':' followed by the return type of 'Unit'. This indicates that this *method* does not return a value (Unit indicates no returned value). This is followed by an '=' and the definition of the body of the method (within the '{ …}' brackets).

In this case all that the body of the method does is to printout the string "Hello Scala" using the function *println*, which is automatically made available to all code by the Scala environment.

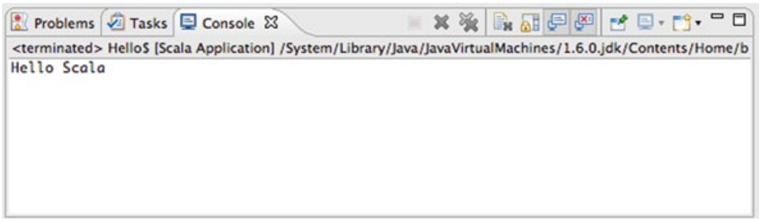
7.6 Running the Application

To run the application, select the file *Hello.scala* in the Package Explorer. Using the right mouse menu select the *Run As* menu option followed by the Scala Application option. This is illustrated in Fig. 7.18.

This will look for a *main* method in the object in *Hello.scala* and run that method. This will result in the Hello Scala string being printed out in the Console window (which is the output window for running applications within Eclipse). This is illustrated in Fig. 7.19.

7.7 Scala Classpath

Whatever your platform, you should be aware of the `CLASSPATH` environment variable. This variable tells Scala (actually the JVM) where to look for class definitions, so it should at least point to the run time library and the current directory. It may also



```
<terminated> Hello$ [Scala Application] /System/Library/Java/JavaVirtualMachines/1.6.0.jdk/Contents/Home/b
Hello Scala
```

Fig. 7.19 Output from the Hello application

point to other directories in which you have defined classes. On Windows, you may change CLASSPATH in the autoexec.bat file by adding the following declaration:

```
SET CLASSPATH = .;c:\Scala\lib\classes.zip
```

Note that on a Windows machine the Classpath is a ';' separated list. Whereas on a Unix machine it is a ':' separated list. Thus for a Unix box you can define the `CLASSPATH` as:

```
setenv  CLASSPATH.:/usr/local/misc/Scala/lib/classes.
zip
```

You should also add the Scala bin directory to your path. You should now be ready to use the Scala tools.

7.8 Compiling and Executing Scala

It is useful and instructive to actually look at what happens when you *compile* and *execute* a Scala program.

If your code is compiles successfully, the compiler will generate a `Hello.class` file that contains the byte codes under the bin directory. For example, on a Windows machine, the directory listing is as shown in Fig. 7.20.

The *.class* files represent the *compiled* version of the Scala object Hello.

So what has happened here—we haven't created any form of executable, rather we have created a set of class files. The effects of compiling your Scala code are illustrated in Fig. 7.21.

As can be seen from this figure, the compiler compiles the `.scala` files into .class files. These in turn run on the Virtual Machine (this is what runs when you type in *scala* to the command prompt). The Virtual Machine (actually the JVM plus the Scala libraries) reads the class files and then runs them. This may involve interpreting the class files, compiling the class files to native code or a combination of the two depending upon the JVM being used. If we take the original approach the JVM interprets the class files. Thus the class files run on the JVM.

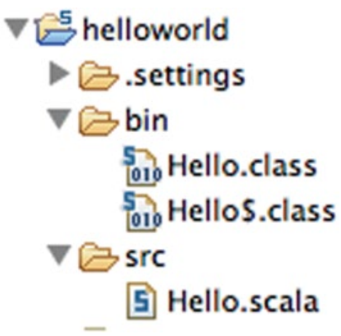


Fig. 7.20 Multiple.class files generated for a Scala type

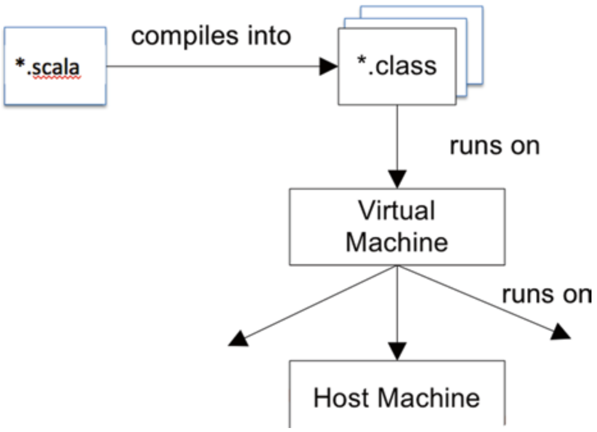


Fig. 7.21 Relationship between the Scala source files and the Virtual Machine Environment

The JVM can be viewed as a virtual computer (that is one that exists only in software). Thus Scala runs on a software computer. This software computer must then execute on the underlying host machine. This means that in effect the JVM has two aspects to it; the part that interprets Scala programs and a back end that must be ported to different platforms as required. Thus although the Scala programs you write are indeed "write once, run anywhere" the JVMs they run on need to be ported to each platform on which Scala will execute.

Although your Scala programs do not need to be re-written to run on Unix, NT, Linux etc. the JVM does. This means that different JVMs on different platforms can (and do) have different bugs in them. Thus it is essential to test your Scala programs on all platforms that they are to be used on. Therefore in reality Scala is actually "write once, run anywhere, test everywhere" that you will use your Scala programs.

Note that there are multiple languages that can be compiled to JVM byte codes (and Scala is just one example, others include Ada, C#, Python etc.) but that the byte code language was originally designed for Scala and thus must directly support the

Scala language. As Scala was not the original source language for byte codes there must be a mapping from the concepts in Scala to these byte codes. Thus one Scala concept may generate one, two or three different implementations at the byte code level. In this case our hello world object results in two byte code elements being created called `Hello.class` and `Hello$.class`. For the most part you can ignore these details; they will typically become relevant if you need to integrate Scala into a Scala application (or Scala code into a Scala application).

7.9 Memory Management

7.9.1 Why Have Automatic Memory Management?

Any discussion of Scala needs to consider how Scala handles memory. One of the many advantages of languages such as Java, C# and Scala over languages such as C++ is that they automatically manage memory allocation and reuse.

It is not uncommon to hear C++ programmers complaining about spending many hours attempting to track down a particularly awkward bug only to find it was a problem associated with memory allocation or pointer manipulation. Similarly, a regular problem for C++ developers is that of memory creep, which occurs when memory is allocated but is not freed up. The application either uses all available memory or runs out of space and produces a run time error.

Most of the problems associated with memory allocation in languages such as C++ occur because programmers must not only concentrate on the (often complex) application logic but also on memory management. They must ensure that they allocate only the memory that is required and de-allocate it when it is no longer required. This may sound simple, but it is no mean feat in a large complex application.

An interesting question to ask is "why do programmers have to manage memory allocation?" There are few programmers today who would expect to have to manage the registers being used by their programs, although 20 or 30 years ago the situation was very different. One answer to the memory management question, often cited by those who like to manage their own memory, is that "it is more efficient, you have more control, it is faster and leads to more compact code". Of course, if you wish to take these comments to their extreme, then we should all be programming in assembler. This would enable us all to produce faster, more efficient and more compact code than that produced by Pascal or C++.

The point about high-level languages, however, is that they are more productive, introduce fewer errors, are more expressive and are efficient enough (given modern computers and compiler technology). The memory management issue is somewhat similar. If the system automatically handles the allocation and de-allocation of memory, then the programmer can concentrate on the application logic. This makes the programmer more productive, removes problems due to poor memory management and, when implemented efficiently, can still provide acceptable performance.

7.9.2 Memory Management in Scala

Scala provides automatic memory management. Essentially, it allocates a portion of memory as and when required. When memory is short, it looks for areas that are no longer referenced. These areas of memory are then freed up (de-allocated) so that they can be reallocated. This process is often referred to as "garbage collection".

The Virtual Machine (the JVM) uses an approach known as *mark and sweep* to identify objects that can be freed up. The garbage collection process searches from any root objects, i.e. objects from which the main method has been run, marking all the objects it finds. It then examines all the objects currently held in memory and deletes those objects that are not marked.

A second process invoked with garbage collection is memory compaction. This involves moving all the allocated memory blocks together so that free memory is contiguous rather than fragmented.

7.9.3 When Is Garbage Collection Performed?

The garbage collection process runs in its own thread. That is, it runs at the same time as other processes within the JVM. It is initiated when the ratio of free memory versus total memory passes a certain point.

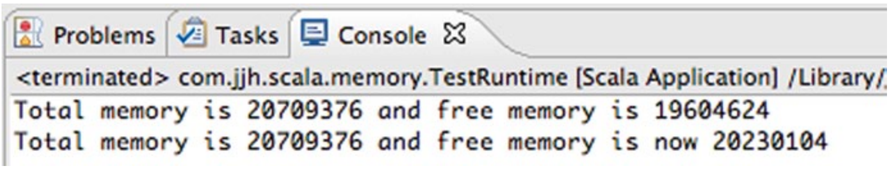
You can also explicitly indicate to the JVM that you wish the garbage collector to run. This can be useful if you are about to start a process that requires a large amount of memory and you think that there may be unneeded objects in the system. You can do this using the sys object:

```
sys.runtime.gc()
```

However, calling sys.runtime.gc is only an indication to the compiler that you would like garbage collection to happen. There is no guarantee that it will run.

7.9.4 Checking the Available Memory

You can find out the current state of your system (with regard to memory) using the `Runtime` environment object. This object allows you to obtain information about the current free memory, total memory, etc.:



```
<terminated> com.jjh.scala.memory.TestRuntime [Scala Application] /Library/
Total memory is 20709376 and free memory is 19604624
Total memory is 20709376 and free memory is now 20230104
```

Fig. 7.22 Output from Memory Application

```
package com.jjh.scala.memory

object TestRuntime {
  def main (args: Array[String]): Unit  = {
    val runtime = sys.runtime
    val freeMemory = runtime.freeMemory()
    val totalMemory = runtime.totalMemory()
    println("Total memory is " + totalMemory +
             " and free memory is " + freeMemory)
    System.gc();
    val newFreeMemory = runtime.freeMemory()
    println("Total memory is " + totalMemory +
             " and free memory is now " + newFreeMemory)
  }

}
```

The result of running this application is shown in Fig. 7.22.

7.10 Scala on .Net

It should be noted that the approach taken in this chapter (and indeed the rest of this book) is to focus on the version of Scala that runs on the Scala Virtual Machine. This version is available across multiple platforms, including various version of Unix and Linux, Mac and Windows and thus is very widely available. An alternative is the.Net environment. Scala is also available for the Microsoft.Net platform which is primarily available on the Windows operating systems (although a version can run on Linux via the Mono framework). However, it appears that at the time of writing that much less effort is currently going into the.Net work and it is trailing behind the JVM efforts by 1–2 years.

References

Scala
To download Scala (without the use of an IDE) see www.scala-lang.org/downloads

The Scala programming language home page
see http://www.scala-lang.org
The Scala mailing list
see http://listes.epfl.ch/cgi-bin/doc_en?liste=scala
The Scala wiki
see http://scala.sygneca.com/
Scala and .Net
http://www.scala-lang.org/old/node/10299
Mono:> Net on Linux Project
http://www.mono-project.com/
Maven: Build tool for Scala and Scala
http://maven.apache.org/
https://code.google.com/p/esmi/wiki/ScalaMavenSupport
Ant: Build tool for Scala and Scala
http://ant.apache.org/
http://www.scala-lang.org/old/node/98
SBT (Simple Build Tool): Build tool for Scala and Scala
http://www.scala-sbt.org
Scala IDE for Eclipse
http://scala-ide.org/
Plugin for Existing Eclipse
If you already have an Eclipse installation and wish to add Scala to that then see the Scala plug-in for Eclipse
see http://www.scala-lang.org/downloads/eclipse/index.html
Scala IDE IntelliJ
http://www.jetbrains.com/idea/features/scala.html
Scala IDE for NetBeans
http://sourceforge.net/projects/erlybird/files/nb-scala/

Further Reading

The Scala Language Specification
See http://www.scala-lang.org/docu/files/ScalaReference.pdf
The busy Scala developer's guide to Scala: Of traits and behaviors Using Scala's version of Scala interfaces
see http://www.ibm.com/developerworks/Scala/library/j-scala04298.html
First Steps to Scala (in Scalazine) by Bill Venners, Martin Odersky, and Lex Spoon, May 9, 2007
see http://www.artima.com/scalazine/articles/steps.html

Chapter 8
Scala Building Blocks

8.1 Introduction

This chapter presents an introduction to the Scala programming language. As such, it is not intended to be a comprehensive guide. It introduces the basic elements of the Scala language, including Apps, discusses the concept of classes and instances and how they are defined, presents methods and method definitions, and considers constructors and their role.

8.2 Apps and Applications

In the previous chapter we wrote a simple Object that possessed a `main` method. This `main` method was the starting point or entry point for an application. That is, unless we are writing software that will be controlled by something else, such as a web application server or a code library, every application needs a starting point. This is provided by the `main` method. In the last chapter this `main` method was defined in the object Hello as shown in Fig. 8.1.

This method is called *main*, takes one parameter (the data passed into it) and this parameter must be of type Array of Strings. This means that a sequence of strings can be made available to the program. It returns `Unit` (which indicates that it does not return anything at all). Any return values must be be managed via an explit call to a special object called sys (e.g. `sys.exit(0)`). This is because in a long running application the value to be returned may not be available in the original `main` method.

However, you cannot change the definition of the `main` method—it must be as shown, i.e.

```
def main(args: Array[String]): Unit = {…}
```

This is because the underlying JVM expects there to be a main method with this signature available.

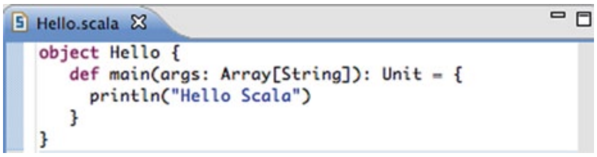
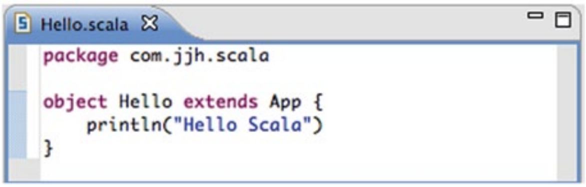


Fig. 8.1 Hello Object with main method

```
object Hello {
   def main(args: Array[String]): Unit = {
     println("Hello Scala")
   }
}
```

However, from Scala's point of view this is boilerplate code—that is it is always the same and in general in Scala where something can be inferred by Scala let Scala do that and we can simplify our code. In this case you must remember to provide a parameter to the method main even if you never expect to pass any data into your program! You must also remember (or learn) the syntax for array in Scala—which we will not be looking at for a while. Actually the name of the parameter (*args* in this case) is not fixed but by convention is called *args*.

To simplify this issue Scala provides a way of avoiding the need to write the main method. If the object that will be used as the entry point to your application extends a trait called `App` then any code not placed into any named function or method (main is an example of a named method) will be assumed to be part of the `main` method. Thus we could rewrite the `Hello` object from above as:



```
package com.jjh.scala

object Hello extends App {
    println("Hello Scala")
}
```

This is clearly simpler to write and remember than having to include the `def main` … element.

It should be noted that if you search Scala applications on the web you may well find a reference to a trait called `Application`. This plays a similar role to `App` but was replaced by `App` in Scala 2.9 (`App` is more effective as it is implemented in a different way to `Application`). You should also remember that if you to include the App trait (using the keyword `extends`) you cannot also write the `main` method—you can choose one or other approach—but not both.

You may be wondering at this point about the term *trait* that has been used to describe both `App` and `Application`—for the moment just treat this as some functionality that can be incorporated into or mixed into an object (or indeed a class). We will return to *traits* again later in the book.

8.3 The Basics of the Language

All Scala programmers make extensive use of the existing Scala libraries even when they write relatively trivial code. For example, the following version of the "Hello World" program reuses existing classes rather than just using the language (for the moment do not worry too much about the syntax of the definition or use of keywords such as extends—this just allows us to mix in the App trait):

```
object HelloJohn extends App {
  val myName = "John Hunt"
  if (myName.endsWith("Hunt")) {
    println("Hello " + myName)
  } else {
    println("Hello World")
  }
}
```

In this example, I have reused the String class to represent the string "John Hunt" and to find a substring in it using the message endsWith(). Some of you may say that there is nothing unusual in this and that many languages have string handling extensions. However, in this case, it is the String contained within myName which decides how to handle the endsWith message and thus whether it contains the substring "Hunt". That is, the data itself handles the processing of the string! What is printed to standard output (i.e. the Console) thus depends on which object receives the message. These features illustrate the extent to which existing classes are reused: you cannot help but reuse existing code in Scala, you do so by the very act of programming.

As well as possessing objects and classes, Scala also possesses an inheritance mechanism. This feature separates Scala (and languages such as Java and C#) from object-based languages, such as Ada, which does not possess inheritance. For example, in the simple program above, I reuse the class Any (the root of all classes in Scala) and the class HelloJohn automatically inherits all the features of Any.

Inheritance is very important in Scala. It promotes the reuse of classes and enables the explicit representation of abstract concepts that can then be turned into concrete concepts.

8.3.1 Some Terminology

We now recap some of the terminology introduced so far in this book, explaining it with reference to Scala.

In Scala programs, actions or operations are performed by passing *messages* to and from instances. An intance (the *sender* of the message) uses a message to request that a some behaviour (referred to in Scala as a *method* or indeed a *function*) be performed by another instance (the *receiver* of the message). Just as procedure calls can contain parameters, so can messages.

Scala is a strongly typed language, however the typing relates to the class of an object (or the trait a class mixes in—we will return to this later) rather than its specific type. Thus, by saying that a method can take a parameter of a particular type, you actually mean that any instance of that class (or one of its subclasses) can be passed into that method.

8.3.2 The Message Passing Mechanism

The Scala message passing mechanism is somewhat like a procedure call in a non-object oriented language:

- The point of control moves to the receiver; the object sending a message is suspended until it receives a response.
- The receiver of a message is not determined when the code is created (at *compile time*); it is identified when the message is sent (at *run time*).

This dynamic (or *late*) binding mechanism is the feature that gives Scala its polymorphic capabilities (see Chap. 1 for a discussion of polymorphism).

8.3.3 The Statement Terminator

In Scala, although a semicolon can be used as a statement terminator, the majority of statements do not need an explicit statement termination (as this can be inferred by the compiler) and thus for the majority of your code a semicolon is not required at the end of a statement. Thus the following are equivalent:

```
println("Hello");
println("World");

And
println("Hello")
println("World")
```

Generally, in Scala, the latter style is preferred.

Chapter 9
Scala Classes

9.1 Introduction

This chapter considers the constructs in Scala used to define classes.

9.2 Classes

A class is one of the basic building blocks of Scala. Classes act as *templates* which are used to construct instances. Classes allow programmers to specify the *structure* of an instance (i.e., its instance variables or fields, etc.) and the behaviour of an instance (i.e., its methods and functions) separately from the instance itself. This is important, as it would be extremely time-consuming (as well as inefficient) for programmers to define each instance individually. Instead, they define classes and create *instances* of those classes.

9.2.1 Class Definitions

In Scala, a class definition has the following format:

```
class nameOfClass extends SuperClass / Trait {
  scope properties;
   scope methods
   scope functions
}
```

Although you should note that you can mix the order of the definition of properties, functions and methods as required within a single class.

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You need not remember this format precisely, as the meaning of the various parts of the class definition are explained later in the book. Indeed, the above is far from complete, but it illustrates the basic features. The following code is an example of a class definition:

```
class Person extends AnyRef {
  var age = 0
  var name = ""
}
```

This code defines a new class, `Person`, which is a subclass of the predefined Scala class `AnyRef` (all reference classes extend `AnyRef` by default, it is stated here only as an illustration and would normally be omitted). The new class possesses two *properties* (or instance variables) called `name` and `age`. It has no functions nor methods defined.

Notice that the `age` instance variable contains a value of type *Int* (this is a basic data type), while the instance variable `name` possesses an instance of the class `String`. Here Scala is inferring the type of the properties based on the initial assignments made to the `age` and `name`—they are statically typed but that type is determined by the compiler at compile time (not at runtime). Both variables are initialized: `age` to zero and `name` to the empty string "".

Classes are not just used as templates. They have three further responsibilities: holding methods, providing facilities for inheritance and creating instances.

9.2.2 Developing a Class Definition

Let us return to the class `Person` and explore the definition of this class a bit further. A slightly different version of the definition for this class is presented again below where it is now called Person1:

```
class Person1() {
  var name = ""
  var age = 0
}
```

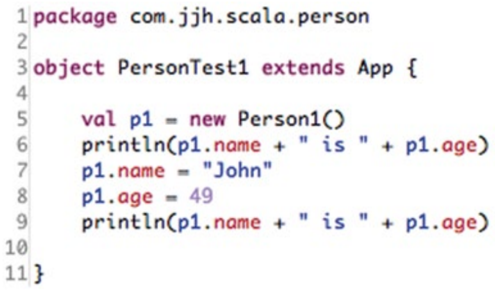
What does this class actually say. In fact it defines a number of things:

It states that both name and age are read/write properties. This can be determined by the fact that they are **vars** and not **vals**. A *var* is a property (or local variable) that can be written to multiple times. A *val* is a property (or local variable) that can only be set once. In both cases they can be read as many times as required. Thus in this case both name and age can be read and reset as required by the application. If we had made name a *val* then it would only be possible to write to it once, thus after a value has been set it cannot be reset.

This definition also defines what is known as a zero parameter constructor. These are the ‘()’ after the name of the class. Every class in Scala will have at least one constructor. A Constructor is actually used to initialise values within the object created from the class. In this case that constructor does not take any parameters and merely provides a default placeholder. In Scala such definitions are typically optional and this is the case here. We could also have defined `Person1` as

```
class Person1 {
  var name = ""
  var age = 0
}
```

In either case when we create a new instance of the `Person1` class, we cannot provide the appropriate name and age until later. Thus a test program for this class might look like:



```
 1 package com.jjh.scala.person
 2 
 3 object PersonTest1 extends App {
 4 
 5     val p1 = new Person1()
 6     println(p1.name + " is " + p1.age)
 7     p1.name = "John"
 8     p1.age = 49
 9     println(p1.name + " is " + p1.age)
10 
11 }
```

In this case line 5 causes a new instance of the class `Person1` to be created. Note that it is the keyword *new* that is being used here to create a new instance of the class and the ‘()’ which are used to indicate the constructor to execute when that new instance is created. The result of this creation is that the address of this new object is stored in the variable `p1` which is a variable that can hold references to (i.e. the address of) an instance of type Person1. This could have been written in long hand form as:

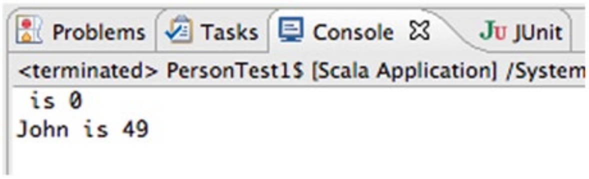
```
val p1: Person1 = new Person1()
```

Here we explicitly specify the type of the variable p1. In the earlier example (in PersonTest1) Scala inferred the type of `p1` for us.

Line 6 then accesses the current values of name and age for the instance referenced by p1 and prints them to the console (standard output) of your Eclipse IDE.

In lines 7 and 8 we actually assign the values we want to the name and age properties of p1. After line 8 p1 now represents John who is 49. Line 9 the reprints this data out.

We can see the effect of running this program on the Console in the IDE, for example:



```
<terminated> PersonTest1$ [Scala Application] /System
 is 0
John is 49
```

As can be seen from this, the effect of the first print out is that the empty string and Zero are first printed—which seems a little confusing. The second print out then shows 'John' and 49, which appears to make more sense.

9.2.3 Classes and Messages

When a message is sent to an instance of a class, it is not the instance which possesses the method but the class. This is for efficiency reasons: if each object possessed a copy of all the methods defined for the class then there would be a great deal of duplication. Instead, only the class possesses the method definitions. Thus, when an object receives a message, it searches its class for a method with the name in the message. If its own class does not possess a method with the appropriate name, it goes to the superclass and searches again. This search process continues up the class hierarchy until either an appropriate method is found or the class hierarchy terminates (with the class `Any`). If the hierarchy terminates, an error is raised.

If an appropriate method is found, then it executes *within the context of the object,* although the definition of the method resides in the class. Thus, different objects can execute the same method at the same time without conflict.

Do not confuse methods with the data held by a property. Each instance possesses its own copy of the data (as each instance possesses its own state). Figure 9.1 illustrates this idea more clearly.

9.2.4 Instances and Instance Variables

In Scala, an *instance* is an example of a *class*. All instances of a class share the same responses to messages (methods or functions), but they contain different data (i.e., they possess a different "state"). For example, the instances of class `Point` all

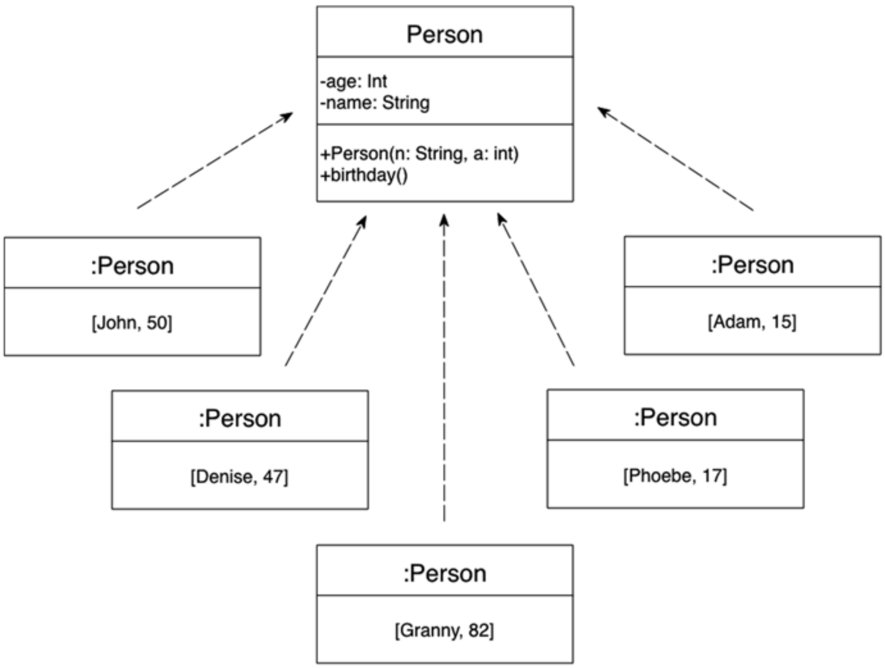


Fig. 9.1 Multiple instance variables but a single method

respond in the same way to messages inquiring about the value of the `x`-coordinate, but they may provide different values.

The class definition consists of variable declarations and method definitions. The state of each instance is maintained in one or more instance variables/properties (also known as fields).

Figure 9.1 contains five instances of the class `Person`. Each instance contains copies of the instance variable definitions for `name` and `age`, thus enabling them to have their own values for these instance variables. In contrast, each instance references the single definition for the method `birthday`, which is held by the class.

9.2.5 Classes and Inheritance

It is through classes that an object inherits facilities from other types of object. That is, a subclass inherits properties from its superclass. For example, the `Person` definition above is a subclass of `AnyRef` Which in turn is a subclass of `Any`. Therefore, `Person` inherits all the methods and instance variables that were defined in `AnyRef` and `Any` (except those that were overwritten in `Person`).

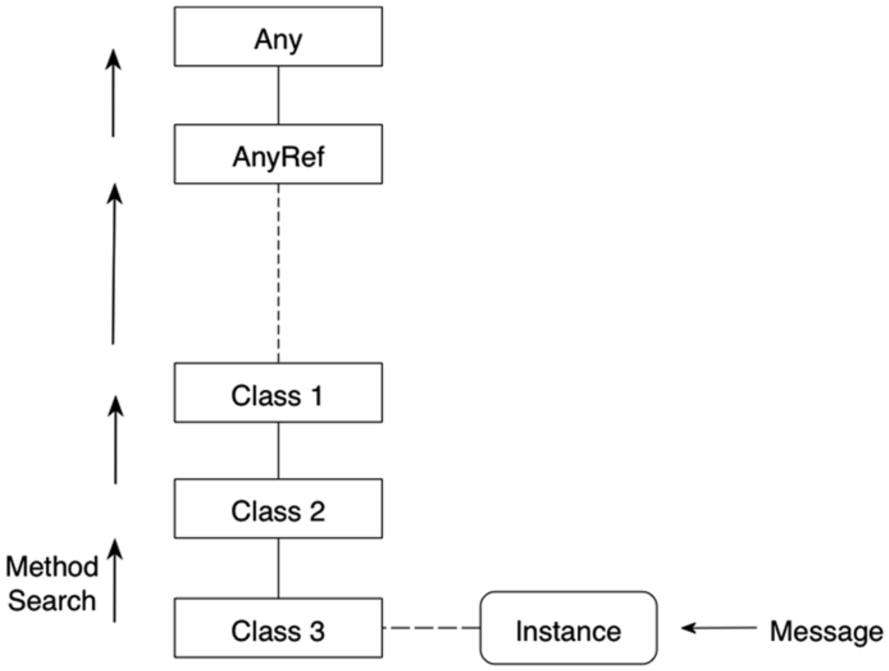


Fig. 9.2 Method selection in Scala

Subclasses are used to refine the behaviour and data structures of a superclass. It should be noted that Scala supports single inheritance (as does Java and C#) while some object-oriented languages (most notably C++) support multiple inheritance.

Multiple inheritance is where a subclass can inherit from more than one superclass. However, difficulties can arise when attempting to determine where methods are executed. Scala introduces the concept of *traits* to overcome one of the most significant problems with single inheritance. However, the discussion of Scala traits comes later in this book.

9.2.5.1 An Example of Inheritance

To illustrate how single inheritance works, consider Fig. 9.2. There are several classes: `Class1` is a subclass of `AnyRef, Class2` is a subclass of `Class1` and `Class3` is a subclass of `Class2`. Note that `AnyRef` is a direct subclass of `Any`. In Scala `Any` is the root of all types.

When an instance of `Class3` is created, it contains all the instance variables defined in Classes 1 to 3 and class `AnyRef`. If any instance variable has the same name as an instance variable in a higher class, then the `Class3` instance uses the instance variable definition from the nearest class. That is, `Class3` definitions take priority over `Class2` and `Class2` definitions take priority over `Class1`, etc.

We can send an instance of `Class3` a message requesting that a particular method is executed. Remember that methods are held by classes and not by instances. This means that the system first finds the class of the instance (in this case `Class3`) and searches it for the required method. If the method is found, then the search stops and the method is executed. However, if the method is not found, then the system searches the superclass for `Class3`, in this case `Class2`. This process is repeated until the method is found. Eventually, the search through the super classes may reach the class `Any` (which is the root class in the Scala system). If the required method is not found here, then the search process terminates and the `doesNotUnderstand`: method in the class `Any` is executed instead. This method raises an exception stating that the message sent to the original instance is not understood.

This search process is repeated every time a message is sent to the instance of `Class3`. Thus, if the method that matches the original message sends a message to itself (i.e. the instance of `Class3`), then the search for that method starts again in `Class3` (even if it was found in `Class1`).

9.2.5.2 The Yo-Yo Problem

The process described above can pose a problem for a programmer trying to follow the execution of the system by tracing methods and method execution. This problem is known as the Yo-Yo problem (see Fig. 9.3) because, every time you encounter a message that is sent to "this" (the current object), you must start searching from your own class. This may result in jumping up and down the class hierarchy.

The problem occurs because you know that the execution search starts in the current instance's class, even if the method which sends the message is defined in a superclass of the current class. In Fig. 9.3, the programmer starts the search in `Class3`, but finds the method definition in `Class1`, however this method sends a message to "this" which means that the programmer must restart the search in `Class3`. This time, the method definition is found in the class `Any`, etc. Even with the browsing tools provided, this can still be a tedious and confusing process (particularly for those new to Scala).

9.2.6 Instance Creation

A class creates an instance in response to a request, which is handled by a constructor. The request is represented by the key word *new* followed by the name of class. The constructor to be invoked once the class is created is indicated by the parameters that follow the name of the class in parentheses (with the empty parameter list often being referred to as the no parameter constructor).

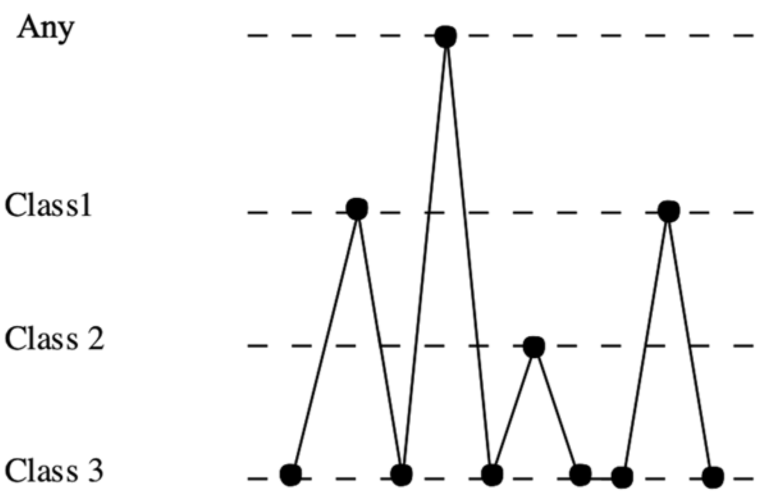


Fig. 9.3 The Yo-Yo problem

A programmer requests a new instance of a Scala class using the following construct:

```
new ClassName()
```

Any parameters which need to be passed in to the constructor can be placed between the parentheses. They are then passed onto an appropriate constructor. Constructors are special as every class has a primary constructor and can optionally have one or more auxiliary constructors (which must eventually invoke the primary constructor). As previously mentioned, constructors are used to initialize a new instance of the class in an appropriate manner (you do not need to know the details of the process).

The whole of this process is referred to as *instantiation*. An example of instantiating the class `Person` is presented below:

```
new Person("John", 50)
```

The class `Person` receives the message `new` which causes the Scala to generate a new instance of the class, with its own copy of the instance variables `age` and `name` (see Fig. 9.4). The name property of the instance is “John” and the age property is set to 50.

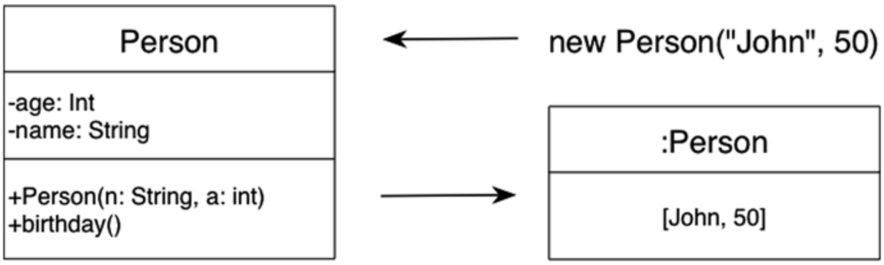


Fig. 9.4 Instance creation

9.2.7 Constructors

A constructor is not a method but a special operation that is executed when a new instance of a class is created. Depending on the arguments passed to the class when the instance is generated, a different constructor can be called. For example, a class may need to have three fields initialized when it is instantiated. However, the programmer may allow the user of the class to provide one, two or three values. They can do this by defining auxiliary constructors that take one or two in addition to the primary three parameter constructor.

The syntax for a constructor is:

```
class classname(.. primary constructor parameters ..) {
  auxiliary constructors ( ... parameters ...) {
  ... statements ...
  }
}
```

By default every class has a single primary constructor. It is up to the programmer to decide if this is a no parameter constructor or one that takes a set of parameters. It is defined following the class name in the class definition. An example of a primary constructor for the class Person3 is shown below:

```
class Person3 (var name: String = "Denise",
               var age:Int = 45)
```

The above is complete as a class definition. It defines a class *Person3* with a primary constructor that takes two parameters and defines no additional methods (beyond the defaults provided). As such no braces are needed unless you want to add any code, fields or methods to the body of the class.

The primary constructor defines two properties for name and age and also provides default values for these properties. Note that both properties are *vars* and therefore both readers and writers are generated for them by Scala.

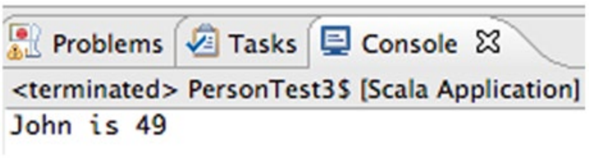
The main advantage of this class `Person3` over the version defined for `Person1` is that the `name` and `age` can be provided at the same time as the class is instantiated, rather than having to create the instance and then set the name and age separately. Thus we can now write:

```
var p = new Person3("John Hunt", 49)
```

Thus we can now write:

```
object PersonTest3 extends App {
  val p = new Person3("John", 49)
  println(p.name + " is " + p.age)
 }
```

Now a `Person` type object can be created with a `name` and an `age` which seems more meaningful and understandable. The output generated from this application is illustrated below:



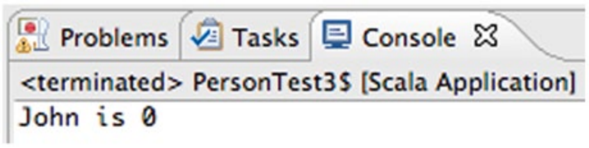
```
<terminated> PersonTest3$ [Scala Application]
John is 49
```

Rather than having a null string and 0 printed out we have ‘John” and 49 right from the start.

However, because we have provided default values for both the name and the age, they are in fact optional. If we omit the age and only provide the name as in:

```
object PersonTest3 extends App {
     val p = new Person3("John")
     println(p.name + " is " + p.age)
}
```

Then the result is that we set the age to Zero and thus if we run this example we would find that the output is:



```
<terminated> PersonTest3$ [Scala Application]
John is 0
```

Similarly we can omit the name and the age:

```
val p3 = new Person3()
```

Which would result in the name being set to the empty string and the age to 0.

Note that we cannot omit the name and just provide the age as Scala would try and bind an integer (e.g. 18) to the name field which is invalid. However as we are not passing in any parameters we can omit the brackets e.g.:

```
val p0 = new Person3
```

9.2.8 Auxiliary Constructors

Every class in Scala has a primary constructor, however optionally any class in Scala can also have one or more *auxiliary constructors*.

If we wanted to allow a Person to be instantiated with just an age, then one way to do it would be to define an Auxiliary Constructor. An auxiliary constructor must be called *this* and must call another constructor. It can either call the primary constructor or another auxiliary constructor defined within the same class (you can have any number of auxiliary constructors) as their *first* action. They *cannot* simply call the superclass's constructor explicitly or implicitly as they can in Java. This ensures that the primary constructor is the sole point of entry to the class.

The following example defines an auxiliary constructor for the Person3 class that takes an integer to use for a Persons age without the need to define the person's name:

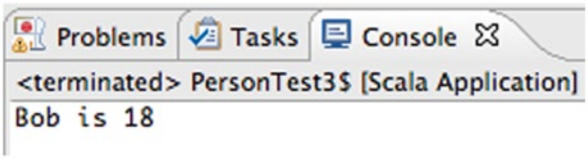
```
class Person3 (var name: String="", var age:Int=0) {
  def this(a: Int) = this("Bob", a)
}
```

Note that the only thing this auxiliary constructor does is to call the primary constructor providing a default name for all *unnamed* person. This is a very common idiom for auxiliary constructors to use.

We can now use this constructor to construct a new instance of the Person3 class using only an age (but who will be default be called Bob):

```
object PersonTest3 extends App {
    val p = new Person3(18)
    println(p.name + " is " + p.age)
}
```

The result of executing this program is:



```
<terminated> PersonTest3$ [Scala Application]
Bob is 18
```

As you can see the name has been set to Bob (by the Auxiliary constructor) and the age to 18.

To summarise Auxiliary Constructors:

- Any class can have any number of additional, auxiliary constructors
- The first statement within an auxiliary constructor must be a call to another auxiliary constructor, or to the primary constructor
- Thus, every object creation eventually ends up at the primary constructor

9.2.9 Class Initialisation Behaviour

It may seem somewhat strange but you can place freestanding code anywhere within the body of the class. Here freestanding code means executable statements that are not part of a method, function or constructor, but are defined within the scope of the class as a whole. Such freestanding code is executed after a new instance has been created and after any values have been assigned to any properties defined within the primary constructor. Such code can be treated as part of the initialization process and may be treated as the way in which you can define your own initialization behaviour. Freestanding code is typically used for validation checks, additional processing and auditing functions, for example:

```scala
class Currency(a: Long, d: String) {

  // Auxiliary Constructor
  def this(a: Long) = this(a, "GBP")

  // Validates the data being received
  // If not met will throw a
  // java.lang.IllegalArgumentException
  require(a > 0)
  // Runs when the object is first created
  // Can't use toString as not set yet
  println("Created: " + d + " " + a)

}
```

In the above example we have a class Currency, which possesses:

- A primary constructor with two parameters
- An auxiliary constructor which one parameter and which defaults the type of the currency to “GBP”.
- A validation statement that checks that the parameter ‘a’ is greater than Zero. If it is not then an illegal argument exception is thrown (a type of error).
- A logging (`println`) statement that indicates what has been created.
- The require statement and the `println` statements are free standing statements and are therefore part of the initialization routine of the class.

An important point to note is that the initialization behaviour (the freestanding code) runs before the code in the Auxiliary constructor. This is because it is associated with the instantiation of the class and allows behaviour to be defined for the primary construction process. The Auxiliary constructor can then override this if it needs to. This is achieved by requiring the auxiliary constructor to always call another constructor (e.g. the primary constructor) as the first thing that it does.

9.2.10 Review of classes and constructors

The synax of a class is

```
class ClassName(constructor parameters) { body }
```

The ClassName should begin with a capital letter and be in Camel Case to follow Scala conventions. The constructor is indicated by the parenthesis ‘()’ following the class name. Within the constructor there can be specific meanings for the parameters:

- A **var** parameter will cause a field, getter, and setter to be included.
- Setter and getter methods can be redefined inside the method.
- A **val** parameter will create a field and a getter, but no setter.
- A parameter with neither **val** nor **var** does not create a field or any methods, but it can be used within the body of the class—it is a local field to the class.
- However, note that if a case class is used then parameters to the primary constructor default to **val** (see below).

When a new instance of a class is defined, the fields are created, the methods are defined, and any “loose” code (not within a `def`) is executed.

To make some of the terminology clearer here are some definitions:

- *Class* acts as a template for defining the structure and behaviour of a type of thing.
- *Instance* is an example of a class that maintains its own state (copy of the data held within it).

- *Instance variables* are defined in the class, but a copy is maintained in each instance, which has its own value.
- *Instance methods* are defined in the class, with a single copy maintained in the class, but they are executed within the context of an object.
- *Constructors* are used to initialise properties once the instance has been constructed in memory but before any other code has access to the instance.
- *Auxiliary constructors* can be used to extend the functionality of the base constructor but must either directly or indirectly invoke the base constructor.

9.3 Case Classes

There is another construct that can be used when defining a class, this is a `case` class. A `case` class is defined in the same way as a normal class, with an additional keyword placed in front of the `class` keyword. This keyword is `case`. For example

```
case class Person (name: String="Denise", var age:Int=0)
```

The effect of this is that a number of additional features are provided for your class. The first obvious different is that it appears that you no longer have to use the keyword new to create a new instance of a class, instead you can apparently just use the name of the class, for example:

```
val p = Person(“John”, 49)
```

Actually a factory facility has been created that is named after the class and hides the use of the new Keyword (although logically it is still new that is being used to construct the instance). A Factory is a recurring software pattern that is used to produce instances of things (in the same way that a physical car factory produces cars).

Actually, the use of the `case` keyword provides a number of enhancements to the basic class definition including:

1. A default factory creation facility—no need to use *new*
2. All arguments to the constructor are *val* by default, no need to state that they are *vals* (although you can override with a *var*).
3. Default implementation of `toString` method. This method is used to convert the object into a printable string format. The normal default provides the name of the class form the instance was created and an indication of where it resides in memory.

4. Default value based implementation of the *equals* method (used by ==). That is, equality is based on the values held in the parameters to the primary constructor.
5. Default *copy* method to create a copy of an object
6. Default implementation of the `hashcode` method. This is a unique code used to represent a unique instance in memory and which is suitable for use in a hash map data structure (which relies on a key to value mapping).

The use of a case class also allows some additional comparison tests, which we will look at when we consider pattern matching in Scala.

9.3.1 A Sample Class

Let us bring together the concepts that we have looked at so far in another version of the class Person, this time Person4. The class Person4 is shown below:

```
class Person4(val name:String, var age: Int) {

  def birthday(): Unit = {

    print("Happy Birthday, you were " + age)
    age = age + 1
    println("today you are now " + age)
  }

  def isPensioner(): Boolean = age > 65

  def isToddler = age > 0 && age < 3

  override def toString() =
        "Person[" + name + ", " + age + "]"
}
```

This class exhibits several features we have seen already and expands a few others:

- The class has a two parameter constructor that takes a String and an Int.
- It defines two properties a read-only name and a read/write age (i.e. a val and a var) as part of the constructor definition.
- It redefines the `toString` method so that the details of the person object can be used in the string representation of an instance of the class.
- It defines three methods birthday, `isPensioner` and isToddler.
- The method `isTodder` does not include '()' and thus can only be invoked without brackets.
- The method borthid returns Unit (i.e. it does not return a value) and is comprised of three statements, two print statements and an assignment and the method body must therefore be plced in curly brackets '{…}'.
- `isPensioner` and `isToddler` represent short hand forms written in a single line.

- `isPensioner` returns a Boolean value (i.e. one that returns true or false).
- Scala infers the value returned by `isToddler` will also be a `boolean`.

It also illustrates a few other ideas:

- The test '>' is a Boolean operator which returns a true of false value depending upon the left and right hand values
- The && represents another Boolean operation, this time the 'and' operation that will return true if and only if both the right hand expression (age > 0) and the left hand expression (age < 3) are true.

These Boolean operators will be explored in more detail later in the book.

Chapter 10
Scala Methods

10.1 Introduction

This chapter presents how methods and associated behaviour is defined in Scala.

10.2 Method Definitions

Methods provide a way of defining the behaviour of an object i.e. what the object does. For example, a method may change the state of the object or it may retrieve some information. A method is the equivalent of a procedure in most other languages. A method can only be defined within the scope of an object. It has a specific structure:

```
access-control-modifier
def methodName(args: argTypes): returnType = {
    /* comments */
    local variable definitions
    statements
}
```

The *access control modifier* is one of the keywords that indicate the visibility of the method. The `returnType` is the type of the object returned, for example, String, or Int. `methodName` represents the name of the method and `args` represents the types and names of the arguments. These arguments are accessible within the method:

```
    def max(x: Int, y: Int): Int = {
      if (x > y)
        return x
      else
        return y
  }
```

The above definition defines a method 'ma' that takes two parameters both of type Int. One accessible via the parameter x and the other via the parameter y. The return type of the method is explicitly specified to be Int. The both of the method contains an ‘if’ conditional statement which will return x if x is greater than y. otherwise it will return y.

Scala is quiet flexible in the way that methods are defined. The above could also be re-written as:

```
def max2(x: Int, y: Int) = if (x>y) x else y
```

Both `max and max2` do exactly the same thing and seen by Scala as exactly the same (as Scala infers much of what has been omitted).

In the following example class the different variations on defining the method *greet* are all valid.

```
object BasicMethodTest {

  def greet(): Unit = {
    println("Hello World!");
  }

  def greet2() = {
    println("Hello World!");
  }

  def greet3() = println("Hello World")

  def greet4() { println("Hello World!") }

  def greet5 = println("Hello World")

}
```

The methods are discussed below:

- The `greet()` method. This is a long hand definition of a method. It has a set of parentheses indicating that no parameters are required. It explicitly states that `Unit` (nothing) is the return type. And the body of the method follows the ‘=’ symbol surrounded by curly brackets.
- The `greet2()` method. This version defaults the return type to be Unit; this is the default if nothing is stated as the return type of `println` is also `Unit`.
- The `greet3()` method. This method defaults the return type and does not include {} as it is a single line definition.
- The `greet4()` method. This includes brackets around the statements but defaults the return type and does not include the ‘=’ – this is known as *procedural* style.
- The `greet5` method does not even include the () as they are not needed.

Invoking methods `greet` to `greet4` can be invoked with or without ‘`()`’. However it should be noted that `greet5` can only be involved without parameters, for example:

```
object TestMethods extends App {
  BasicMethodTest.greet()
  BasicMethodTest.greet

  BasicMethodTest.greet2()
  BasicMethodTest.greet2

  BasicMethodTest.greet3()
  BasicMethodTest.greet3

  BasicMethodTest.greet4()
  BasicMethodTest.greet4

  // BasicMethodTest.greet5() - invalid
  BasicMethodTest.greet5
}
```

10.2.1 Method Parameters

Methods can take parameters. Parameters are values or instances that are passed into a functional unit such as a method. If the parameters are reference types (that is instances) then a copy of the reference is passed in. However, as the reference is essentially the address of the underlying object in memory this means that a parameter refers to the same instance as any values that hold that reference externally to the method.

In Scala a method can take zero or more parameters. The `main` method that you have seen several times in the last chapter takes a single parameter of type `Array[String]`. That is, it holds a reference to an array of strings. This is shown in the following example.

```
object MethodTest {

  def main(args: Array[String]): Unit = {
    println(max(2, 3))
  }

  def max(x: Int, y: Int): Int = {
    if (x > y) x else y
  }

}
```

In this example, as well as the main method, a second method has also been defined within the `MethodTest` object. This method is called max and takes two parameters. That is, there are two parameters in the parameter list for the method. In this case x and y. The anatomy of the method is explored in more detail in Fig. 10.1.

The keyword *def* started the declaration. Here the method name is *max* it has two parameters in its parameter list (of type Int) called x and y and it returns an Int. Within the {..} is the method body. Which in this case considers x relative to y and returns (by default) either x or y.

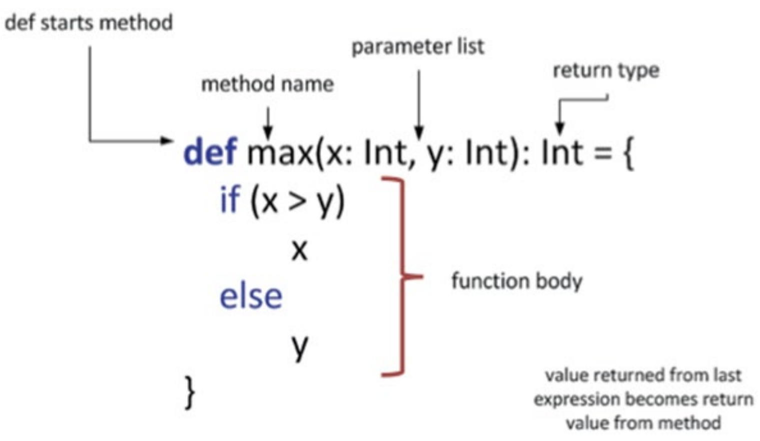

def starts method
parameter list
method name
return type
def max(x: Int, y: Int): Int = {
if (x > y)
x
else
y
}
function body
value returned from last expression becomes return value from method

Fig. 10.1 Structure of a method

Within the method all parameters are *vals*, that is it is not possible to assign a new value to a parameter to the method. That is, you cannot reassign a value to x or y in the above example. Thus it is not possible to write:

```
def add(i: Int): Unit {
    i = i + 1    // won't compile i is a val
}
```

10.2.2 Comments

The /* comments */ section describes the operation performed by the method and any other useful information. Comments cannot be nested in Scala, which can be awkward if you wish to comment out some code for later. For example, consider the following piece of code:

```
/*
val x = 12 * 4
/* Now calculate y */
val y = x * 23
*/
```

The Scala compiler reads this as a comment, followed by the code `y = x * 23;`, followed by the end of another comment. This causes an error. However, Scala has two other types of comment. You can instruct the Scala compiler to ignore everything until the end of the line, using the // indicator:

```
val; x = 12 * 4
// Now calculate y
val y = x * 23
```

The final type of comment, the documentation comment, starts with /** and ends with */. Note the two asterisks at the beginning of this statement. They are picked up and processed by the documentation utility (scaladoc), which generates HTML pages that can be viewed in a Web browser. They can contain wiki parkup and other control directives. These directives are defined as @<directive>, for example:

@constructor—used to provide documentation for the constructor
@param—used to provide documentation for a parameter
@return—used to provide documentation on a return type.

An example of such Scaladoc comments is shown below:

```
package com.jjh.scala.person

/**
 * A person who uses our application.
 *
 * @constructor create a new person with a name and age.
 * @param name the person's name
 * @param age the person's age in years
 */
class Person(val name: String, var age: Int) {
 }
```

The result of running the scaladoc tool against this class is shown in Fig. 10.2.

In fact the whole of the reference material available for Scala has been produced using Scaladoc. A more complex example of which is shown in Fig. 10.3 which shows the contents of the *scala* package.

10.2.3 The Local Variables Section

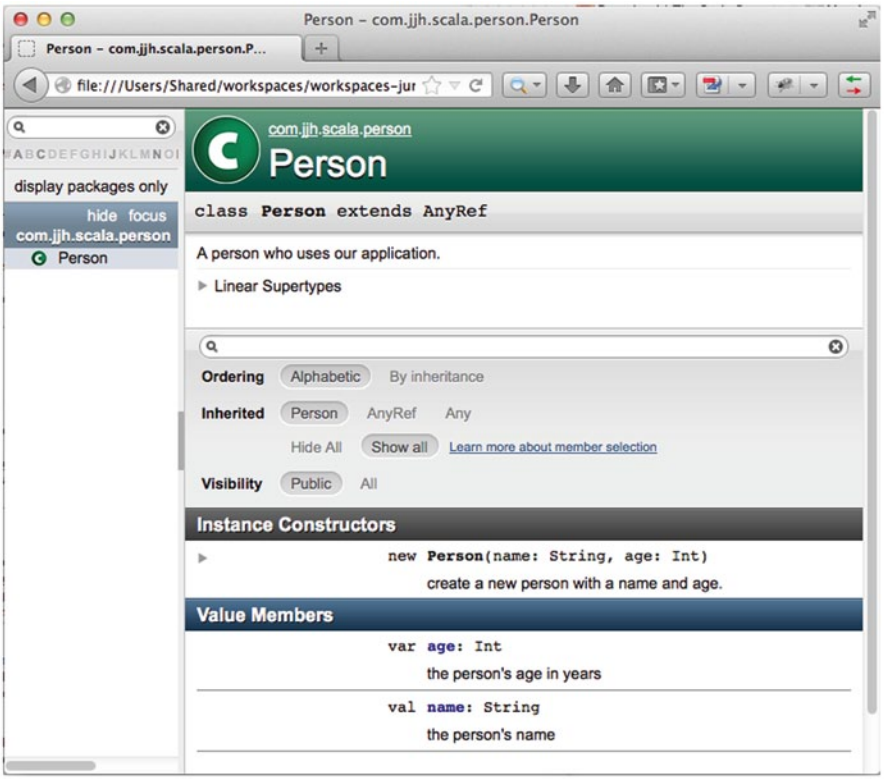
In the local variable definition section, you define variables which are local to the method. These variables are typed and can appear anywhere in the method definition. They are only available within the method definition itself and have no meaning elsewhere / are not visible elsewhere.

```
birthday()
 val newAge = 0;
 ...
```

The variables may be vals or vars depending on whether you want to allow reassignment of them or not.

10.2.4 The Statements Section

The statements section represents any legal set of Scala statements that implement the behaviour of the method.


Person – com.jjh.scala.person.Person
file:///Users/Shared/workspaces/workspaces-jur
display packages only
hide focus
com.jjh.scala.person
Person
Ordering Alphabetic By inheritance
Inherited Person AnyRef Any
Hide All Show all Learn more about member selection
Visibility Public All

com.jjh.scala.person
Person

`class Person extends AnyRef`

A person who uses our application.

Linear Supertypes

Instance Constructors

`new Person(name: String, age: Int)`
create a new person with a name and age.

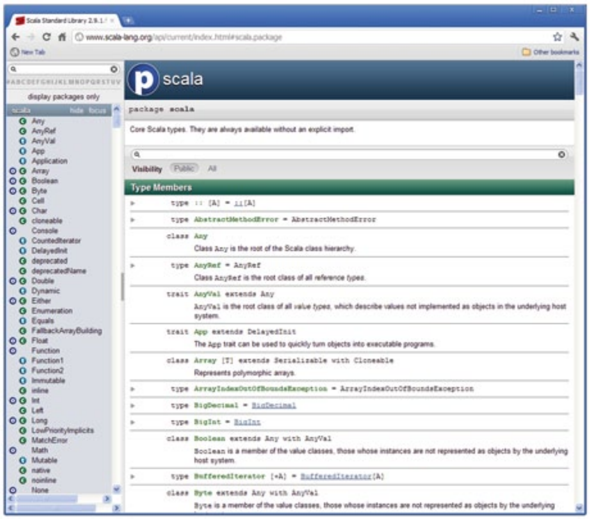
Value Members

`var age: Int`
the person's age in years

`val name: String`
the person's name

Fig. 10.2 Viewing the Scaladoc generated reference material for the Person class

Fig. 10.3 Scala reference documentation generated from Scaladoc



scala

`package scala`

Core Scala types. They are always available without an explicit import.

Type Members

`type :: [A] = ::[A]`

`type AbstractMethodError = AbstractMethodError`

`class Any`
Class Any is the root of the Scala class hierarchy.

`type AnyRef = AnyRef`
Class AnyRef is the root class of all reference types.

`trait AnyVal extends Any`
AnyVal is the root class of all value types, which describe values not implemented as objects in the underlying host system.

`trait App extends DelayedInit`
The App trait can be used to quickly turn objects into executable programs.

`class Array [T] extends Serializable with Cloneable`
Represents polymorphic arrays.

`type ArrayIndexOutOfBoundsException = ArrayIndexOutOfBoundsException`

`type BigDecimal = BigDecimal`

`type BigInt = BigInt`

`class Boolean extends Any with AnyVal`
Boolean is a member of the value classes, those whose instances are not represented as objects by the underlying host system.

`type BufferedIterator [+A] = BufferedIterator[A]`

`class Byte extends Any with AnyVal`
Byte is a member of the value classes, those whose instances are not represented as objects by the underlying

10.2.5 The Return Operator

Once a method has executed, an answer can be returned to the sender of the message. The value returned (whether an object, a basic type or an instance of a subclass) must match the return type specified (or inferred by Scala) in the method definition. The return expression in Scala is the last expression executed in a method, although it need not be the last expression in the method.

The Scala keyword to return a value is `return` (just as in Java), however it is optional as the result of the last expression will automatically be returned if the method returns something other than Unit, thus the following are equivalent:

```
if (x == y)
 return x;
else
 return y;
```

Or

```
if (x == y)
 x;
else
 y;
```

In both these cases, the value of x or y is returned, depending upon whether x and y are equal or not.

10.2.6 An Example Method

Let us examine a simple method definition in Scala. We wish to define a procedure to take in a number, add 10 to it and return the result.

```
def addTen(aNumber: Int): Int = {
  var result = 0
  result = aNumber + 10
  return result
}
```

Although the format may be slightly different from code that you have been used to, it is relatively straightforward. If you have C or C++ experience you might think that it is exactly the same as what you have seen before. Be careful with that idea—things are not always what they seem!

Let us look at some of the constituent parts of the method definition. The method name is `addTen`. In this case, the method has one parameter, called `aNumber`, of the basic type `Int`. Just as in any other language, the parameter variable is limited to the scope of this method (and is a val). The method also defines a temporary variable, `result`, also of the basic type `Int` and limited to the scope of this method (and this is a var).

Variable names are identifiers that contain only letters and numbers and must start with a letter (the underscore, _, and the dollar sign, $, count as letters). Some examples are:

```
anObject     MyCar     totalNumber     $total
```

A capitalization convention is used consistently throughout Java and most Scala programmers adhere to this standard:

- *Private variables and methods* (i.e. instance or temporary variables and almost all methods) start with a lower case letter.
- *Shared constants* are all in upper case.
- *Class* always start with an upper case letter.

Another convention is that if a variable or method name combines two or more words, then you should capitalize the first letter of each word, from the second word onwards, e.g. `displayTotalPay`, `returnStudentName`. This is referred to as modified Camel Case.

10.2.7 Overriding toString

One of the facilities that is available for all types is the ability to convert itself to a string. This is particularly useful when printing an instance out (for example to help with debugging scenarios). The println functionality we have been using is written in such a way that if it is given an instance to print it will ask that instance to convert itself to a string and then print that string It does this by calling a method called toString on the instance. Given the following class, we can therefore print the string representation of instances to the console:

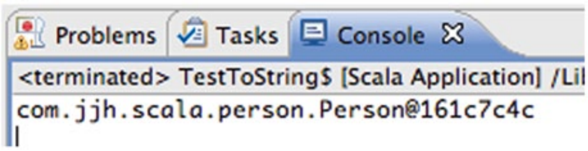
```
package com.jjh.scala.person

class Person(val name: String, var age: Int)
```

This can be shown by the following test harness application:

```
object TestToString extends App {
  val p = new Person("John", 49)
  println(p)
}
```

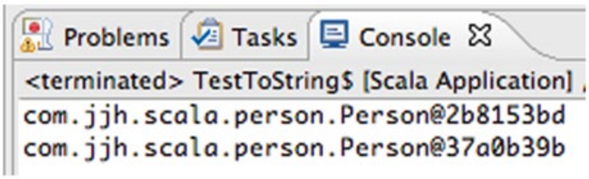
The result of running this program is shown in the console of the Eclipse IDE. However, the output might not be what you expect. See Fig. 10.4 for an example of the default output generated by `toString`.

As you can see from this example, the *default* behaviour for an object is to convert itself into a string version based on the fully qualified class name (i.e. com.jjh.scala.person.Person), followed by an '@' sign, followed by the hashcode for the object (the hexadecimal number following the '@'). The hashcode should be



```
<terminated> TestToString$ [Scala Application] /Lil
com.jjh.scala.person.Person@161c7c4c
```

Fig. 10.4 Default output from toString



```
<terminated> TestToString$ [Scala Application] ,
com.jjh.scala.person.Person@2b8153bd
com.jjh.scala.person.Person@37a0b39b
```

Fig. 10.5 Output from TestToString application

unique and allows us to distinguish between one instance of a class and another, for example:

```
object TestToString extends App {
  val p1 = new Person("John", 49)
  println(p1)
  val p2 = new Person("Denise", 46)
  println(p2)
}
```

The result of executing this application is shown in Fig. 10.5.

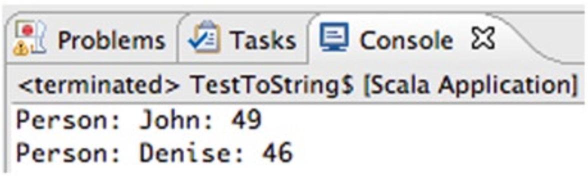
As you can see the hexadecimal numbers following the '@' are different. However, this is not very useful when need to distinguish between the instance representing *John* and the instance representing *Denise*.

The problem is that the default toString behaviour is defined at a more *abstract* level than the class Person. That is, the default behaviour does not know about the name and age properties. We can overcome this problem by redefining the way in which instances of the class Person convert themselves to a String. We do this by redefining the toString method mentioned earlier.

For example, in the following listing we have redefined the *toString* to return a string constructed from the string "Person", followed by the instances current values for name and age:

```
class Person(val name: String, var age: Int) {
  override def toString() = "Person: " + name + ":
" + age
}
```

Be very careful how you define this method. It must be called *toString* (with a capital 'S') Scala is very case sensitive and the method *tostring* and the method *toString* are two completely different methods. As we are redefining the default behaviour for *toString* we must make sure the spelling and capitalisation are the same. Also note that we must use the keyword *override* before the *def* keyword to indicate we are expecting to be redefining the default method (it is called override as it is



```
<terminated> TestToString$ [Scala Application]
Person: John: 49
Person: Denise: 46
```

Fig. 10.6 Custom toString output

actually via inheritance that we obtain the default implementation of *toString* but we will return to this in the chapter that focuses on inheritance). Also note that the *toString* method must return a String!

Now when we rerun our simple application the output is modified such that we now obtain a far more meaningful result (see Fig. 10.6).

10.2.8 Defining Property Methods

In the previous section we described `name` and `age` as properties of the instance `p1`; but what does this mean? A Property is an item of data, held within an instance of a class, that can be accessed externally to that instance either as a read-only property or as a read/write property.

Essentially Scala creates a reader (also known as a getter) method and a writer (also known as a setter) method associated with each property. If the properties were marked as *vals*, then it would only create the reader methods.

Depending upon the context in which you reference the property, Scala knows whether to invoke the reader or writer. For example if you are attempting to access the value of the property then it knows to invoke the writer. Where as if you are attempting to set the value of the property it knows to use the writer method.

Scala also allows a programmer to override the default readers and writers if required; it is just that the default behaviour provided by Scala generally meets the requirements of most developers.

If you wish to define your own readers and writers (or to help understand what is being created for you) then there are a few additional things to understand. The first is that the properties you have defined are by default public—that is visible outside of your instances to anything within the Scala world. An alternative would have been to mark them as private (note you do not need to say anything for them to be made public but you need to make a conscientious decision to make them private).

The second thing you need to be aware of is that Scala does not actually distinguish between a property, a method or a function to any great extent and it is the way that it is defined and invoked which actually allows Scala to work out what you want. Therefore if you are defining your own readers and writers then you will need to ensure that the name of the field that will hold the data is different to the name of the methods used to access that field. Although any name could be used, by convention the field name is prefixed by an underbar ('_').

Thirdly to distinguish between a method that should be used on the left hand side of an assignment and one that should be used to retrieve a value, a writer method is post fixed by an underbar ('_').

Given the above, `Person2` is a class that defines the same behaviour as `Person1` but we have done it long hand ourselves rather than rely on Scala to create the getters and setter methods for us:

```
package com.jjh.scala.person

class Person2 {

  private var _name = ""
  private var _age = 0

  // Getters
  def age = _age
  def name = _name

  // Setters
  def age_=(value: Int): Unit = _age = value
  def name_=(value: String): Unit = _name = value

}
```

In the above code we have created two private properties _name and _age. These are accessed by two methods each; one to return the value (the getter) and one to set the value (the setter).

For example, the *def age* method returns the value of `_age`. Note it could have been written long hand as:

```
def age(): Int = {
  return _age
}
```

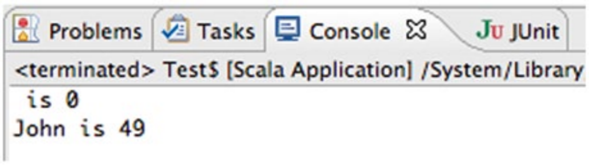
However we are using Scala's ability to infer much of the template from above and thus merely need to write:

```
def age = _age
```

The setter methods are a little more complex. We have had to call the methods `age_` and `name_`. They are defined to take a value (of an appropriate type which we are explicitly specifying here). And we are indicating that they do not themselves return anything (hence the `Unit` return type). Within the body of the methods we then indicate that the value passed in is assigned to the appropriate property. Even so this is still a short hand for the long hand from which would be (for the age setter method):

```
def age_=(value: Int): Unit = {
    _age = value
}
```

Fig. 10.7 Output from test application



```
<terminated> Test$ [Scala Application] /System/Library
 is 0
John is 49
```

We can now use the same test program with this class as we have previously used for the `Person1` class:

```
object Test extends App {
  val p = new Person2()
  println(p.name + " is " + p.age)
  p.name = "John"
  p.age = 32
  println(p.name + " is " + p.age)
}
```

And it produces the output shown in Fig. 10.7.

This approach may be useful if you wish to add some non-default behaviour to either the setter or getter methods.

10.3 Named Parameters

In most situations, when you invoke a Constructor, a Method or a Function each argument is matched, in sequence with the parameters of the constructor, method or function. Thus given the method *mult* in the object `Processor`:

```
object Processor {
  def mult(x: Int, y: Int): Int = x * y
}
```

Then we can invoke this method as follows:

```
val r1 = Processor.mult(2, 3)
println(r1)
```

In this case the value 2 is bound to the parameter '`x`' and the value 3 is bound to the parameter `y` and thus we multiply 2 by 3 to obtain 6.

However, an alternative approach is to use the names of the parameters. Named parameters allow you to pass in argument to a constructor, method or function as name-value pairs. These pairs can be in any order and Scala will work out how to bind them. The syntax for this is based on `name=value`, with each parameter separated by a comma (','). For example, the above invocation of `mult` could be rewritten as:

```
val r2 = Processor.mult(x=2, y=3)
println(r2)
```

Now we are explicitly binding the value 2 to x and the value 3 to y. The end result is that the value 6 is again printed out. However, the order of the parameters is no longer significant as we can now write:

```
val r3 = Processor.mult(y=3, x=2)
println(r3)
```

This again binds the value 2 to x and the value 3 to y and once again results in the value 6 being printed out.

Note that you can also mix positional arguments with named arguments (in which case the positional arguments come first), for example:

```
val r4 = Processor.mult(2, y=3)
println(r4)
```

Named parameters are most often used with default parameters. This allows the optional values to be used for all omitted parameters, but the named parameters to be used for those to be specified. For example:

```
class Activity(var date: Date = new Date(),
               var title: String = "activity",
               var owner: String = "anon",
               var live: Boolean = true) {
  override def toString(): String = {
    "Activity[" +
      date + ", " +
      title + ", " +
      owner + ", " +
      live + "]"
  }
}
```

The class `Activity` defines a primary constructor that takes four parameters. Each of these parameters has a default value. However, if we used position based parameters then we could not just provide the 2nd, 3rd or fourth parameter when we create an `Activity`. However, using named parameters allows us to do exactly this. For example, to create a new `Activity` with the owner set to “John” but with the defaults used or the other three parameters we can write:

```
val a1 = new Activity(owner = "John")
println(a1)
```

The result of running this code is shown below:

```
Activity[Wed Dec 11 12:56:15 GMT 2013, activity, John,
true]
```

As you can see the default values for date, title and live have been used with the owner set to “John”.

It is also common to find that the sue of named parameters is used with the alternative curly bracket ‘{ }’ syntax used for parentheses. This form results in a construct that looks more as if it is part of the language than a user defined type. For example, using the alternative syntax we can create a new `Activity` specifying the type of activity and the owner (as “Presentation” and “Denise” respectively).

```
val a2 = new Activity {
    owner = "Denise"
    title = "Presentation"
}
println(a2)
```

The result of running this is shown below:

```
Activity[Wed  Dec  11  12:57:24  GMT  2013,  Presentation,
Denise, true]
```

Note that the order of *owner* and *title* is not significant and that *date* and *live* are still defaulted. Also note that Activity now appears to be a language construct.

Chapter 11
Building a Class

11.1 Introduction

This chapter we will work through the creation of a simple class to represent a Company.

11.2 Create a New Project

You may like to start this practical be creating a suitable project in which to create your application. A new project can be created from the File menu under New -> Scala Project (see Fig. 11.1).

This will cause the 'New Scala Project' wizard to be displayed as shown in Fig. 11.2.

You can name the project anything. In this case we will call the project practical2. Enter the project name into the 'Project name' field as shown in (Fig. 11.3).

I would also create a package to place your code in. A package is an organizational construct that helps you manage your code. It also relates to name spacing (what can be seen where) and is a good programming technique to get into.

11.3 Create a New Package

To create a new package select your project and from the right mouse menu select New -> Package as shown in Fig. 11.4.

This will display the new Package Wizard (note it says Java but is being reused for Scala packages in the Scala IDE). This dialog is shown in Fig. 11.5.

You can use whatever name you wish although you should note that a Scala package is a series of names separated by '.'s which are typically prefixed by the domain of the organization creating the code, as illustrated in Fig. 11.6.

Once you have provided a package name click 'Finish'.

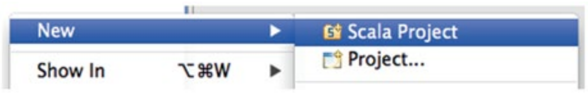
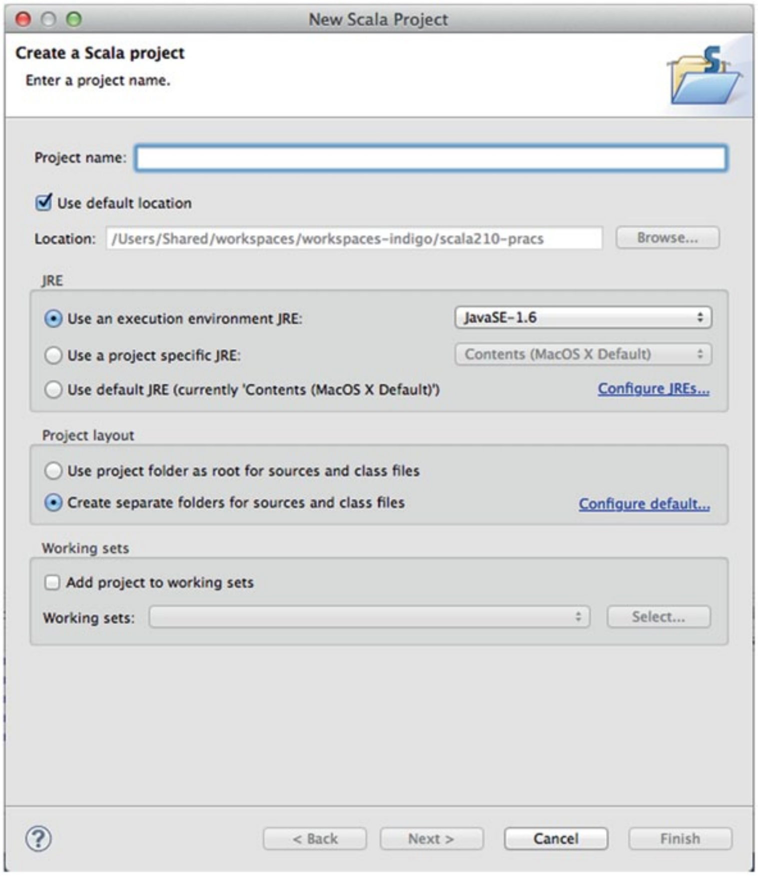


Fig. 11.1 Selecting the create a new 'Scala Project' option



Create a Scala project

Enter a project name.

Project name:

[✓] Use default location

Location: /Users/Shared/workspaces/workspaces-indigo/scala210-pracs

JRE

[✓ Use an execution environment JRE:] JavaSE-1.6

Use a project specific JRE: Contents (MacOS X Default)

Use default JRE (currently 'Contents (MacOS X Default)')

Project layout

Use project folder as root for sources and class files

[✓ Create separate folders for sources and class files]

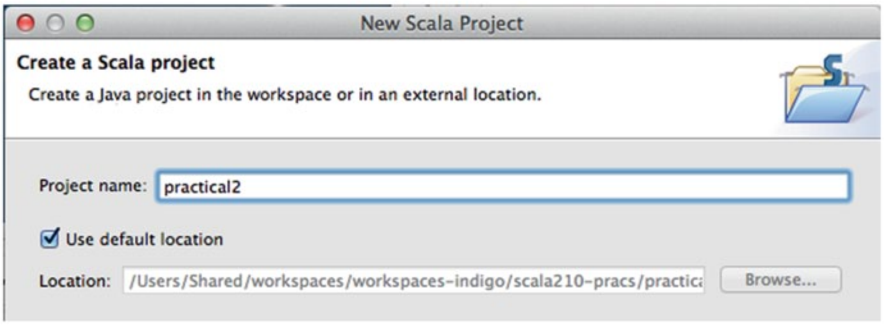
Working sets

Add project to working sets

Working sets:

Fig. 11.2 New project wizard

You will now see a new package provided for you in the Package Explorer view of the IDE. An example of the structure created under the project heading is shown in Fig. 11.7.


New Scala Project

Create a Scala project

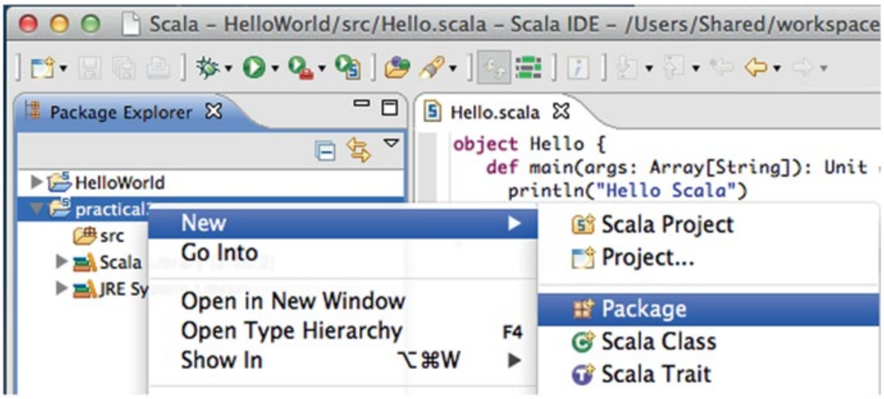
Create a Java project in the workspace or in an external location.

Project name: practical2

☑ Use default location

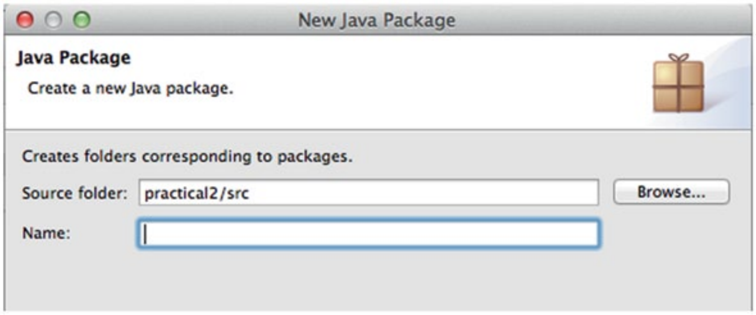
Location: /Users/Shared/workspaces/workspaces-indigo/scala210-pracs/practica

Fig. 11.3 Naming the project


Scala - HelloWorld/src/Hello.scala - Scala IDE - /Users/Shared/workspace

```
object Hello {
  def main(args: Array[String]): Unit
    println("Hello Scala")
```

Fig. 11.4 Selecting the New Package option


New Java Package

Java Package

Create a new Java package.

Creates folders corresponding to packages.

Source folder: practical2/src

Name:

Fig. 11.5 The new Package dialog

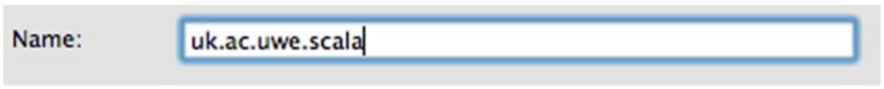

Name: uk.ac.uwe.scala

Fig. 11.6 Defining the package

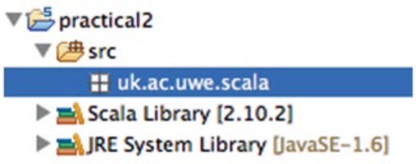

practical2
src
uk.ac.uwe.scala
Scala Library [2.10.2]
JRE System Library [JavaSE-1.6]

Fig. 11.7 The project containing the created package and Scala libraries

11.4 Create a New Class

We will now add a new class to the package we just created. This can be done using the New Scala Class Wizard. Select the package we just create din the Package Explore and form the right mouse menu select New -> Scala Class (as shown in Fig. 11.8).

You will now be shown the 'Create a new Scala Class' wizard (Fig. 11.9).

Specify the name of the class you want to create using the Name field. In our case we will create a new Scala class called Company as shown in Fig. 11.10.

Now click 'Finish'.

You should now find that you have a new class *Company*, in a file called *Company.scala* under the *uk.ac.uwe.scala* package Fig. 11.11. While in the middle of the IDE in the code presentation area you should see the outline skeleton code for the class Company.

11.5 Defining the Class

The simple class you just created now needs to be expanded to a company. The class must have the following information:

- The name of the company
- The address of the head office of the company
- The phone number of the company
- The company registration number
- The company VAT number

The address of the company could be a separate type including county, postcode/zipcode etc. However we will keep things simple for the moment.

The fields of the company will all be of type String and will have some form of default value, for example the empty or null string represented by " ". String is referred to as a type as it represents a concept with the programming language. As

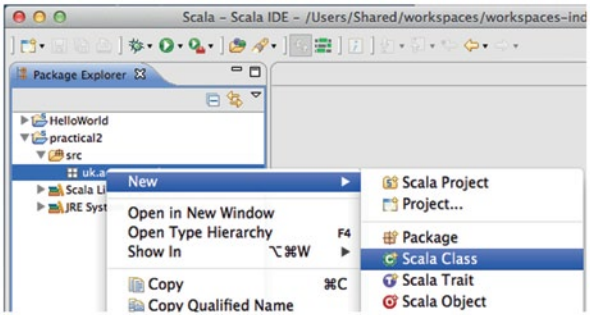
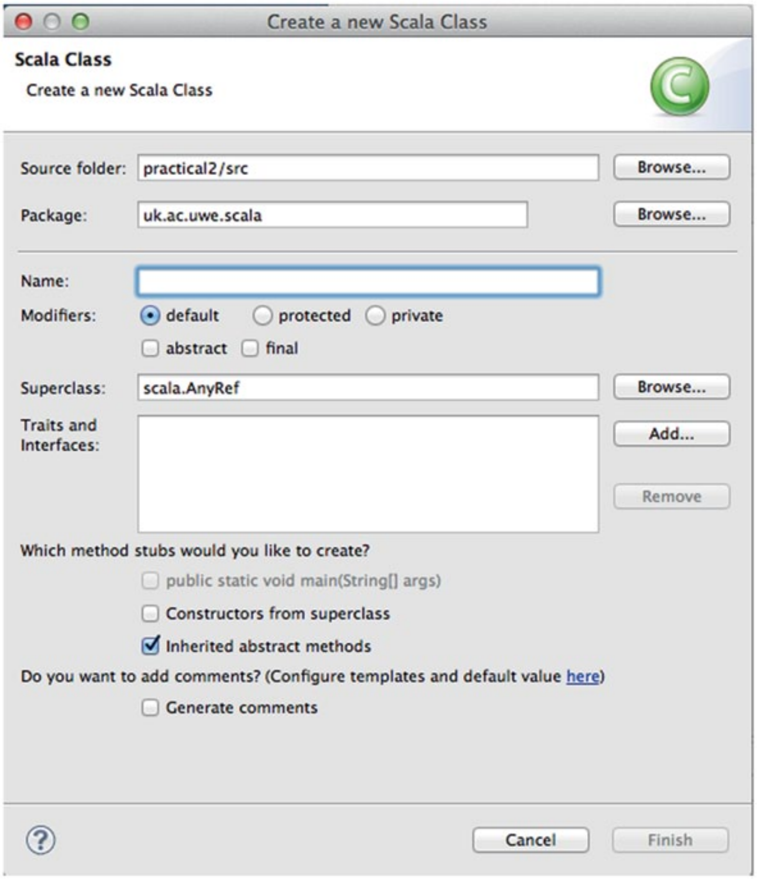


Fig. 11.8 Selecting the New Class wizard



Create a new Scala Class

Scala Class

Create a new Scala Class

Source folder: practical2/src [Browse...]

Package: uk.ac.uwe.scala [Browse...]

Name:

Modifiers: [✓ default] protected private

abstract final

Superclass: scala.AnyRef [Browse...]

Traits and Interfaces: [Add...] [Remove]

Which method stubs would you like to create?

- [ ] public static void main(String[] args)
- [ ] Constructors from superclass
- [x] Inherited abstract methods

Do you want to add comments? (Configure templates and default value here)

- [ ] Generate comments

[Cancel] [Finish]

Fig. 11.9 The new Scala Class wizard

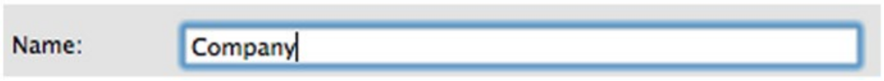
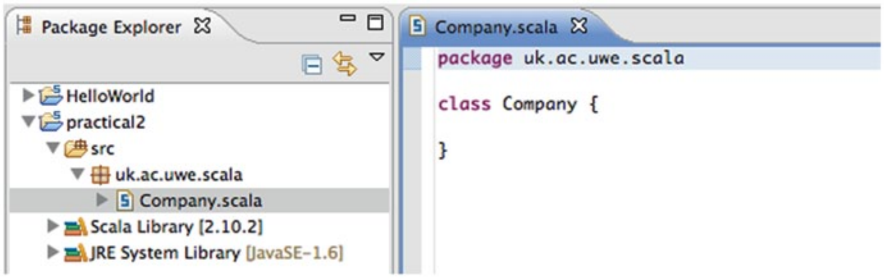

Name: Company

Fig. 11.10 Naming the Scala class



```
package uk.ac.uwe.scala

class Company {

}
```

Fig. 11.11 The empty Company class

such a string is zero or more characters which respond to certain operations such as substring, length etc.

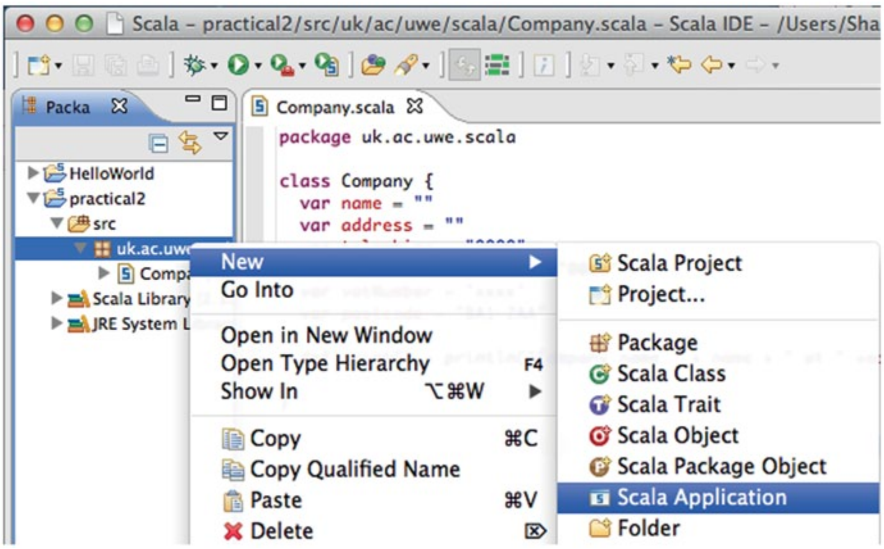
Update your definition of the Company class so that it resembles the following listing:

```
package uk.ac.uwe.scala

class Company {
  var name = ""
  var address = ""
  var telephone = "0000"
  var registrationNumber = "000"
  var vatNumber = "xxxx"
  var postcode = "xxx xxx"
}
```

11.6 Adding Behaviour

We can also add some behavior to this class by providing a *print* method that will print out the Company details in an appropriate format.

The printer method will be done first. This method will not return a *value* as it will be used to print information on the Company out to the Console.



```
package uk.ac.uwe.scala

class Company {
  var name = ""
  var address = ""
```

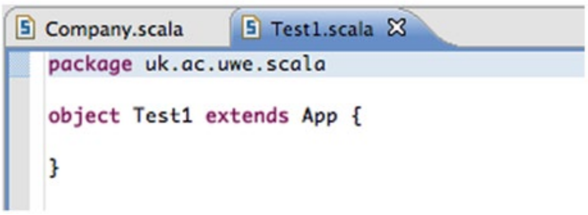
Fig. 11.12 Selecting the Scala Application wizard

```
package uk.ac.uwe.scala

class Company {
  var name = ""
  var address = ""
  var telephone = "0000"
  var registrationNumber = "000"
  var vatNumber = "xxxx"
  var postcode = "xxx xxx"

  def print() = println("Company name " + name + " at
" + address)
 }
```

Note that we have used the single line form of defining a method—this is not the only option and you could experiment with other formats one you have this version working.

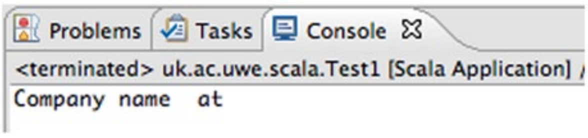
11.7 Test Application

You should then create a simple test application (use the App trait with a Scala object type) to create new instances of the Company class. For example, using the right mouse Menu from the package view select New -> Scala Application (see Fig. 11.12).



```
package uk.ac.uwe.scala

object Test1 extends App {

}
```

Fig. 11.13 The central editor of the Scala IDE



```
<terminated> uk.ac.uwe.scala.Test1 [Scala Application]
Company name  at
```

Fig. 11.14 Output from the Test1 program

You will now be presented with the 'New Scala Application' wizard. This wizard allows you to select the package were you want to place the Application Object and a box for you to enter the name of your application. Provide a name for your application in the rest of this section Test1 will be used as the name of the application. Once you have entered the name, then click 'Finish'.

You should now see a new tab on in the central code editor area of the IDE as shown in Fig. 11.13.

This contains the skeleton of the Test1 application (remember as you are using the App trait you do not need to define a main method declaration—you only need to add what the application needs to do.

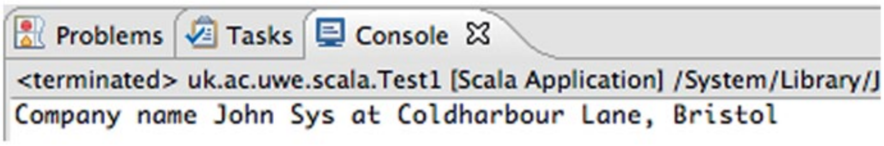
In our case we will create a new instance of the Company class and print out its details:

```
package uk.ac.uwe.scala

object Test1 extends App {
   val company = new Company()
   company.print
}
```

Recall that we do not need to define the type of the val we will hold our company reference in (this will be inferred by Scala) but that new instances are created using the keyword *new*.

We can now run this application either using the right mouse menu form the file Test1.scala in the Package Explorer (Run As) or using the green circle containing an arrow at the top of the IDE:

In the console you should see output similar to that shown in Fig. 11.14.



```
<terminated> uk.ac.uwe.scala.Test1 [Scala Application] /System/Library/J
Company name John Sys at Coldharbour Lane, Bristol
```

Fig. 11.15 Updated output from Test1 program

This is because the Company object does not yet have any data defined by you. We will now add that data:

```scala
package uk.ac.uwe.scala

object Test1 extends App {
  val company = new Company()
  company.name = "John Sys"
  company.address = "Coldharbour Lane, Bristol"
  company.telephone = "123456"
  company.registrationNumber = "99999999"
  company.vatNumber = "BB112233AA"
  company.postcode = "BS16 1QY"
  company.print
}
```

In the above example we have populated the fields that are defined within the Company instance with suitable data. If you now rerun this application you should see more comprehensible output in the Console view (see Fig. 11.15).

11.8 Override toString

In general however, we would not define a custom method such as print to print out the Company instances. Typically we would use the println method directly with the company instance. To do this we must override the *toString* method as we did in the last chapter. In this case our *toString* method must include information for all of the fields. We can thus add a *toString* method to the Company class with the result that we can print out a Company instance directly. The Company class would now look like:

```
package uk.ac.uwe.scala
class Company {
  var name = ""
  var address = ""
  var telephone = "0000"
  var registrationNumber = "000"
  var vatNumber = "xxxx"
  var postcode = "xxx xxx"

  def print() = println("Company name " + name + " at
" + address)

  override def toString(): String = {
    "Company[" + name + ", " +
      address + ", " +
      telephone + ", " +
      registrationNumber + ", " +
      vatNumber + ", " +
      postcode + "]"
  }

}
```

The test program could be updated to include a println for the company instance (e.g. println(company):

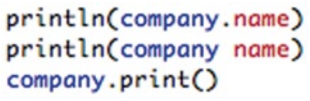
```
package uk.ac.uwe.scala

object Test1 extends App {
  val company = new Company()
  company.name = "John Sys"
  company.address = "Coldharbour Lane, Bristol"
  company.telephone = "123456"
  company.registrationNumber = "99999999"
  company.vatNumber = "BB112233AA"
  company.postcode = "BS16 1QY"
  // company.print
  println(company)
}
```

The output of this program is now:

```
Company[John  Sys,  Coldharbour  Lane,  Bristol,  123456,
99999999, BB112233AA, BS16 1QY]
```

11.9 Extras

You could try out different syntax options for example:



```
println(company.name)
println(company name)
company.print()
```

Chapter 12
Packages & Encapsulation

12.1 Introduction

This chapter discusses the encapsulation and packaging features of Scala. The concept of packages is discussed, along with some concrete examples. It then illustrates how the encapsulation facilities can allow quite fine-grained control over the visibility of the elements of your programs.

12.2 Packages

You can bring a set of related classes together in a single compilation unit by defining them all within one file. By default, this creates an implicit (unnamed) package; classes can access variables and methods that are only visible in the current package. However, only one of the classes can be publicly visible (the class with the same name as the file). A much better approach is to group the classes together into an explicit, named package.

Packages are encapsulated units that can possess classes, interfaces and sub-packages. Packages are extremely useful:

- They allow you to associate related classes and interfaces.
- They resolve naming problems that would otherwise cause confusion.
- They allow some privacy for classes, methods and variables that should not be visible outside the package. You can provide a level of encapsulation such that only those elements that are intended to be public can be accessed from outside the package.

The Scala libraries provide a number of packages, some of which are inherited from the underlying Java runtime. In general, you use these packages as the basis of your programs.

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12.2.1 Declaring a Package

An explicit package is defined by the `package` keyword at the start of the file in which one or more classes (or interfaces) are defined:

```
package benchmarks
package com.jjh.transport
```

Package names should be unique to ensure that there are no name conflicts. Scala does not require, although it is common to find that a naming convention is adopted across projects. This naming convention is derived from the Java world in which a package name is made up of a number of components separated by a full stop. The start of such a name is often your organisations domain in reverse; this ensures uniqueness across all software systems.

The package name components actually correspond to the location of the files. Thus if the files in a particular package are in a directory called benchmarks, within a directory called tests, then the package name is given as:

```
package tests.benchmarks
```

Notice that this assumes that all files associated with a single package are in the same directory. It also assumes that files in a separate package will be in a different directory. Any number of files can become part of a package, however, any one file can only specify a single package. Also note that any number of directories can make up the package (particularly if they are arranged in different jar files).

All components in the package name are relative to the contents of the `CLASSPATH` variable. This environment variable tells the Scala compiler where to start looking for class definitions. Thus, if the `CLASSPATH` variable is set to `C:\jjh\Scala` then the following path is searched for the elements of the package:

```
c:\jjh\Scala\tests\benchmarks
```

All the files associated with the `tests.benchmarks` package should be in the benchmarks directory.

12.2.2 Additional Package Definitions Options

12.2.2.1 Package per File

The simplest way to define a package is to use a single package statement at the start of a file. It must be the first line of Scala (other than any comments in the file). It defines the whole contents of the file as being part of that package:

package com.jeh.transport

12.2.2.2 Chained Package Definitions

A further package definition approach is Scala is what is called *chaining* package definitions together. This allows multiple package declarations to be specified with subsequent package declarations being chained to the earlier declaration. For example, the following defines a package x.y containing the class Ship:

```
package x
package y

class Ship {

}
```

The style presented here indicates how packaging chaining can be used with the package declaration at the start of a file. In terms of package chaining, it is a style that you should be familiar with as you may encounter it in examples presented on the web. However it is not a style that is generally used. The style of nested packages which leads to package name chaining is more common, although the most common from of package is a single one line declaration at the start of the file.

12.2.2.3 Nested Package Definoitions

Scala packages can also be nested one inside another. In this case the scope of one packaged needs to be indicated via the presence of curly braces '{…}'. For example,

```
package test {
…
}
```

Actually the curly braces can always be used with a package definition it is just that if they are omitted it is assumed that the whole of the file represents the contents of the same package.

Curley braces are normally used to when defining one or more nested packages so that the scoep of one package can be represented. For example:

```
package test {
  ...
  package demo {
    …
  }
  ...
}
```

The above dots imply that there are members defined in the package test and members defined in the package test.demo. It is also clear from this that in Scala you can therefore have more than one package in a single file. In fact you have multiple packages for example:

```
package test {
  ...
  package demo {
    …
  }
  ...
 package util{
    …
  }
  ...
  }
```

The above example would have three packages in a single file, these packages would be:

- Package test
- Package test.demo
- Package test.util

Note that we could further nest packages so that package demo could have a further nested package print:

```
package test {
  ...
  package demo {
    …
    package print {
      ...
    }
  }
  ...
 package util {
    …
  }
  ...

}
```

As a concrete example of this consider the following listing:

```
package com.jeh.transport {

  package personal {
    class Bike
  }

  case class Car

  package group {
    class TaxiFleet {
      val c = Car()
      }
    }
  }
```

This example defines the package com.jeh.transport as the top level package (note that it is perfectly legal to name a package with multiple elements and then to provide nested packages that build on that namespace. The top level package contains two nested packages personal and group. The full name of these packages is:

- com.jeh.transport.personal
- com.jeh.transport.group

If you were importing these packages to use in your own code then these are the names that you would have to use.

An interesting set of questions to ask is what is the scope or visibility of the classes:

- Car defined in com.jeh.transport
- Bike defined in com.jeh.transport.personal
- TextFleet defined in com.jeh.transport.personal

The answers are that:

- the Car class is directly visible in com.jeh.transport and in the nested packages personal and group. This is why it can be directly referenced within the class TaxiFleet.
- The Bike is only visible directly within the package personal.
- The TaxiFleet is only directly visible within the nested package group.

From this we can see one of the key aspects of packages—helping to organise our code elements (and to restrict the default namespaces of such elements).

However, this approach is not without its problems and it can actually led to namespace issues of its own. For example, consider the following listing:

```
package engine {
  class Petrol1
}

package family {
  package economy {
    package engine {
     class Petrol2
    }
    class Control {
      val b1 = new engine.Petrol2
      val b2 = new economy.engine.Petrol2
      val b3 = new family.engine.Petrol3
      // val b4 = new engine.Petrol1
      val b5 = new _root_.engine.Petrol1
    }
  }
  package engine {
    class Petrol3
  }
}
```

This example has the following packages with the following contents:

- Package engine with the class Petrol1
- Package family with two nested packages economy and engine
- Package family.economy with the class Control and a nested package engine
- Package family.economy.engine with the class Petrol2
- Package family.engine.Petrol3

All this looks fine except when you realise that currently there is no way for the commented out line

val b4 = new engine.Petrol1

to compile? Why is this? It is because in Scala when you reference a class or a package Scala always attempts to din the most local version of that class or package. For the class Control the package engine which is *nearest* to it in terms of = name space is the package engine defined within the package family and as it is a nested package within family as is the package economy, there is no need for code within either package to have to mention the root package family in order to access each other (it is implied by their nested status). However, as there is an external package called engine also present this means that there is a name conflict between the two packages engine.

To get around this problem, Scala provides a special root package reference which can be used to indicate that you do not want to use the locally scoped package but to start at the root location of all package names and find a package from there. This root package reference is referred to by pre-fixing a package name with '_root_', for example:

```
val b5 = new _root_.engine.Petrol1
```

This ensures that the search for the package engine starts at the root of all packages rather than looking locally. This approach works as *root* is essentially a special package that pre-fixes all packages.

12.2.3 An Example Package

As an example, the files for the `com.jeh.lights` package are stored within a directory called `lights`, within a directory called `jeh`, within the `com` directory. The directory contains three classes that make up the contents of the `lights` package: `Light`, `WhiteLight` and `ColoredLight`. The header for the `Light.Scala` file contains the following code:

```
package com.jeh.lights

abstract class Light {

}
```

The `WhiteLight.Scala` and `ColoredLight.Scala` files are similar, for example:

```
package com.jeh.lights

class ColouredLight extends Light { }
```

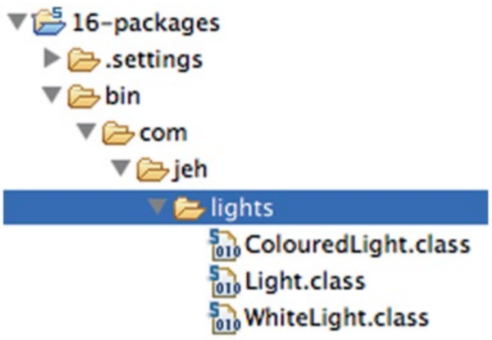
And

```
package com.jeh.lights

class WhiteLight extends Light { }
```

Note in the above example we have placed each class in a separate file, however we could have defined all three classes in the same source file and this would have produced the same set of .class files as are described below.

The directory containing the compiled (byte code) version of the `lights` package is shown below:



The `CLASSPATH` variable (set up by the Scala IDE) includes the path `bin` directory of the current project, so the package specification, `com.jeh.lights`, completely specifies the location of the byte code files.

12.2.4 Accessing Package Elements

There are two ways to access an element of a package. One is to name the element in the package fully; this is referred to as the fully qualified class name. For example, we can specify the `Light` abstract class by giving its full designation:

```
class NewLight extends com.jeh.lights.Light {...}
```

This tells the Scala compiler exactly where to look for the definition of the class `Light`. However, this is laborious if we refer to the `Light` class a number of times.

The alternative is to import the `Light` class, which makes it available to the package within which we are currently working:

```
import com.jeh.lights.Light
class NewLight extends Light
```

However, in some situations, we wish to import a large number of elements from another package. Rather than generate a long list of import statements, we can import all the elements of a package at once using the '_' wildcard. For example,

```
import com.jeh.lights._
```

This imports all the elements of the `com.jeh.lights` package into the current package. Notice that this can slow down the compilation time (although it has no effect on the run time performance). Also note that this only imports the contents of the `com.jeh.lights` package—it has no affect on any sub packages of lights. Also note that if you are a Java programmer that the wild card here is '_' and not '*' as it is in Java. Also note that we do not include the (optional) ';' statement terminator in Scala—you can use the ';' to terminate both the package declaration and the import statements, it is just that it is considered superfluous and thus not good style.

It is also possible to import all the methods or functions defined on a type using the name of the type followed by the '_' wild card, for example:

```
import transport.Car._  // import all members from Car
```

To summarize then it is possible to import the whole contents of a package, a single type from a package, use an alias with a type and to import the functionality for a given type.

12.2.5 An Example of Using a Package

The `lights` package described above has been used within a code outside the package. This application defined in the com.jeh.test packages uses the `Colored-Light` class. It therefore imports it into the current package. For example:

```
package com.jeh.test

import com.jeh.lights.ColouredLight

object LightTest extends App {
  val l = new ColouredLight()
  println(l)
}
```

Notice that we have chosen to import the ColoredLight class explicitly rather than the whole package. Also note that we can import any number of classes, objects, traits, types etc. as required into a single file but that these imports are only in scope for the current file.

12.3 Import Options

Scala actually has a wider set of import options than Java. In Java an import can only be specified at the top of a file after any (optiona0 package declaration and before any other Java declarations (such as a class or interface). In Scala an import can appear anywhere and affects the scope within which it was specified. Thus imports can appear in a:

- Package
- Class
- Method or function
- Package object

For example, the following example illustrates importing a set of functions define don the object utill.PrintUtil into a method so that they can be accessed directly within that method (but only that method):

```
package banking

class Bank {
  def print(acc: Account) {
    import util.PrintUtils._
    printAccount(acc)
  }
}
```

PrintUtil is a singleton object defined in the package util, for example:

```
package util

object PrintAccount {
  def printAccount(acc: Account) {
        println(acc.name + ": " + number)
  }
}
```

Scala also allows you to import more than just classes, objects or traits. You can import the methods on instances of a given class. For example, in the following example the method printShip *imports* the methods defined on the parameter car so that it does not need to prefix model and spec with car (e.g. car.model and car.spec) thus making the code simpler:

```
class Car(val model: String, val spec: String)

object Test extends App {

  // Main behaviour
  val c = new Car("Ford", "SE")
  printCar(c)

  // Support method
  def printCar(car: Car) {
    import car._
    println(model + ": " + spec)
  }
}
```

12.4 Additional Import Features

It is also possible to provide an alias as part of an import, for example:

```
import transport.{Car => Audi}
```

This indicates that the type transport.Car will be alias to (and accessible via) Audi in the current context (e.g. the current file).

It is also possible to indicate what should not be imported, for example:

import transport.{Car=>_, _}

This import indicates that everything should be imported from the package transport with the exception of Car. This is because the first part of the contents of the curly brackets '{…}' indicates what not to import, e.g. Car=>_ and the second part is the wild card that indicates what should be imported (that is the second '_').

A further way in which the types to import can be specified is via the curly bracket '{..}' notation. This can be used to reduce the number of import statements when several (but not all) of the types in a particular package should be imported. This is written in the following way:

```
import java.sql.{Connection, DriverManager, ResultSet}
```

Note that this statement imports the Connection, DriverManager and ResultSet types from the java.sql package.

12.5 Package Objects

A package can also (optionally) have a *package object* associated with it. A package object is an object that is part of the package (and has the same name as the package) that can be used to hold utility functions or methods. Any members defined in the package object are considered to be top-level members of the package and can be accessed by other members of the package directly.

As an example of a package object consider the following listing:

```
package com.jeh

package object banking {
  def printAccount(acc: Account) {
    import acc._
    println(name + ": " + number)
  }
}
```

This defines a package object for the package com.jeh.banking. Note that it is defined by a keyword for the package level above banking (com.jeh) with a package object definitions for the banking element of the package. This banking package object defines a single utility method printAccount that can be used by any other members of the com.jeh.banking package to print out bank account information. For example:

```
package com.jeh.banking

case class Account(val name: String, val number: Int)

object TestAccount extends App {
  val acc = Account("John", 1234)
  printAccount(acc)
}
```

You can also use the printAccount method in other packages by importing it. For example the following code is in a separate package com.jeh.test. It imports both the Account case class and the printAccount method from the com.jeh.banking package. Notice that from this you cannot see that com.jeh.banking is both a package and a package object. We can then use the Account class to create an account instance and print its details via printAccount (the utility methods define don the package object).

```
package com.jeh.test

import com.jeh.banking.printAccount
import com.jeh.banking.Account

object Test extends App {
   val acc = Account("John", 123)
   printAccount(acc)
}
```

12.6 Key Scala Packages

There are very many packages in Scala but the core or central ones are:

- *scala*—the core types
- *scala.collection* provide basis of the Scala collections (data structures) frameworks
- *scala.collection.immutable* provides the definitions for the immutable versions of the collection classes in Scala
- *scala.collection.mutable* provides definitions for the mutable versions of the collection classes in Scala.
- *scala.actors* provides the actor based concurrency types
- *scala.io* provides for input and output type definitions
- *scala.math* which provides basic mathematical functions and additional numeric types
- *scala.sys* which provides types for interacting with other processes and the operating system.
- *scala.util.matching* which provides pattern matching in text using regular expressions.
- *scala.xml* containing types to be used when parsing, manipulating and serializing XML structures.

12.7 Default Imports

There are also a set of default imports that are imported into every Scala file, these are:

- The java.lang package
- The scala package
- The `Predef` object.

The core java.lang package is imported as it provides some of the basic concepts that underpin the Scala (and Java) runtime such as the definition of a String.

The scala package contains definitions for the core Scala types and as such it is always available in any Scala code without the need for an explicit import.

The `Predef` object in Scala provides type aliases for commonly used Scala types (such as the immutable collection classes), some simple functions for Console I/O (such as println), basic assertions (such as require) and some implicit conversion routines. The inclusion of the `Predef` object reduces the amount of explicit code that needs to be written in Scala.

12.8 Encapsulation

In Scala, you have a great deal of control over how much encapsulation is imposed on a class, a trait and an object. You achieve it by applying *modifiers* to classes, objects and trait properties, methods and functions. Some of these modifiers refer to the concept of a package and others to the type itself.

12.8.1 Scala Visibility Modifiers

By default all the members of a package, a class, an object or a trait are public. Thus the following holds true:

```
package com.jeh.sample

object PublicObject {
  val publicVal
  var publicVar
  def publicMethod = println("Hello")
}
```

That is everything above is publically available, you only need to import the contents of the package com.jeh.sample._ or the object itself com.jeh.sample. PublicObject to be able to access everything. You do not need to use a special keyword public to make it so.

However, not all members of a type should be public, indeed in many cases you specifically do not want them to be publically available. In these cases there are two additional keywords that can be used to control visibility these are private and protected.

This means that you can choose whether these elements of your program are publically visible everywhere (the default), only visible to inherited types (protected) or only visible within the context they are defined (private). Thus these visibility modifiers can be used to restrict the access to (or visibility of) these members to other regions of code. In general to use an access modifier you need to include the appropriate keyword (private or protected) in the definition of the member of a package, class or object.

However, a word of caution is advisable here. Protected and private in Scala are not the same as in Java. For example, protected din Scala means that the member is only available in the current class and subclasses—it is not available in the current package. However, this is a default, both protected and private can be modified to indicate the scope they should be applied to. In the case of private it means that in Scala we can distinguish between private to an instance and private to a class.

12.8.2 Private Modifier

A private member is (by default) on visible to the class or object that it is defined in. Thus in the following example, the method print is only available to methods defined within the class Account:

```
package com.jeh.banking

case class Account(val name: String, val number: Int) {
   private def print = println(name)
}
```

However, an issue is that it is available to all instances of the class Account. Thus johns account can access the private method of the Denise's Account. This is the approach taken by Java and it is the default approach taken by Scala and represents class based privacy. If we want instance based privacy, that is the method print can only be called from within the same instance of the class Account then we need to qualify its scope. This can be done with a scope associated with the keyword in square brackets, for example private[this], for example:

```
package com.jeh.banking

case class Account(val name: String, val number: Int) {
   private[this] def print = println(name)
}
```

In this case private means private to this instance and not the whole class.

Interestingly you can also provide a package name within the square brackets so that you can indicate that a method is private to the package, for example:

```
package com.jeh.banking

case class Account(val name: String, val number: Int) {
   private[banking] def print = println(name)
}
```

In this revised version the method print is private to the package (that is it is available anywhere in the current package). This equates to package visibility in Java.

In fact the qualifier can be any from of scope thus the from private[x] can be used where x is one of an enclosing package, class or singleton object.

Also note that the keyword private can be applied to properties, methods and functions within a class, trait or object.

12.8.3 Protected Modifier

The protected modifier indicates that a member of a class, trait or object is visible within subtypes in any package (by default). For example, given the following definition:

```
package com.jeh.test

class Super {
    protected def print = println("Super")
}

class Sub extends Super {
  print
}

class Other {
  val s = new Super()
  // s.print - error is not visible
}
```

The class Super defines a protected method print. This method is only accessible (visible) in subclass of Super. The class Sub extends Super and therefore can reference the method *print* directly. It happens that this class is defined in the same package as Super but it could have been defined anywhere. However, even though the class Other is defined in the same package as Super and can create an instance of Super, it cannot reference the method print on an instance of Super as it is only visible/ accessible to subclasses of Super.

As with the private access modifier, the protected access modified can be qualified with a scope. For example, we can indicate that the protected member is protected up to a particular scope. Thus the previous example could be redefined such that the qualified test is added to the protected method print:

```
package com.jeh.test

class Super {
    protected[test] def print = println("Super")
}

class Sub extends Super {
  print
}

class Other {
  val s = new Super()
  s.print // No longer an error as it is now visible
}
```

In this way we can indicate that a member should be visible up to a certainly level and after that is only accessible to subclasses. Thus the example above in which we specify protected[test] is the equivalent of Java's version of protected as it indicates that the method *print* is visible in the current package and in an y subclass in any package.

As with the private access modifier the protected modifier can be qualified with a range of scopes. In fact the qualifier can be any from of appropriate scope thus the form protected[x] can be used where x is one of an enclosing package, class or singleton object.

Also note that the keyword *protected* can be applied to properties, methods and functions within a class, trait or object

Chapter 13
Classes, Inheritance and Abstraction

13.1 Introduction

Inheritance is one of the most powerful features of Object-Orientation. It is the difference between an encapsulated language that provides an object-based model and an object-oriented language. Inheritance is also one of the main tools supporting reuse in an object-oriented language (although in Scala's case Traits are also a major tool for reuse). You will use inheritance all the time without even realising it, indeed you have already been doing so every time you have benefited from the default implementation of toString (which is inherited through the class AnyRef by your classes if you do not explicitly extend any specific class).

Scala has single class inheritance although it does have a form of multiple inheritance via Traits.

13.1.1 What Are Classes For?

In some object-oriented languages, classes are merely templates used to construct objects (or instances). In these languages, the class definition specifies the structure of the object and a separate mechanism is often used to create the object using this template.

In some other languages (for example Java, C#, Smalltalk), classes are objects in their own right; this means that they can not only create objects, they can also hold data, receive messages and execute methods just like any other object. However, many programmers find this distinction confusing and Scala has adopted the Companion Object approach instead (see later in this book). Which means that a class is supported by a singleton object that can hold data and provide a placeholder for additional supporting behaviours.

Thus, in Scala, classes are unique within a program and can be:

- defined using the keyword class
- used to create instances (via the keyword new),
- inherited by subclasses (and can inherit from existing classes),
- mix in traits,

- define properties
- define methods,
- define functions
- define instance variables and values,
- be sent messages.

Objects on the other hand, are:

- defined using the keyword `object`
- singleton entities within the systems,
- cannot be instantiated (and do not support the *new* operation)
- cannot be used to create new instances
- accessed directly via their name rather than via any val or var

Confusingly many object-oriented languages use the term object to refer to an instance of a class. In Scala an instance of a class is exactly that, an instance of a class, an object *is a different concept.* Instances can be

- created from a class (using the keyword new),
- hold their own copy of their state (in terms of properties or instance variables),
- be sent messages,
- execute instance methods,
- execute functions,
- have many copies in the system (all with their own data).

The next chapter will consider the different between an instance and an object in Scala in more detail.

13.2 Inheritance Between Types

To recap on the concept of inheritance. Inheritance is supported between types within Scala. For example, a class and extend (subclass) another class. A trait (another type) can extend other traits etc. And objects can extend traits or classes. All of these types support and enable inheritance.

In terms of the inheritance we say:

- A subtype inherits from a supertype
- A subtype obtains all code and data from the super type
- A Subtype can add new code and data
- A subtype can override inherited code and data
- A subtype can invoke inherited behaviour or access inherited data.

13.3 Inheritance Between Classes

Inheritance is achieved in Scala using the `extends` keyword (as was discussed in Chap. 6). Scala is a single class inheritance system, so a Scala class can only inherit from a single class (although it can mix in multiple traits; to be discussed later).

The following class definition, builds on the class `Person` presented earlier:

```
class Person(val name: String, var age: Int)

class Student(var subject: String,
              n: String,
              a: Int)
       extends Person(n, a) {

}
```

This class extends the class `Person` by adding a new variable property, `subject`. As this is a **var** the class `Student` also provides reader and writer functionality for the `subject` property. We say that `Student` is a subclass of `Person` and that `Person` is the super class of `Student`.

Note that as the class `Person` defined two properties in its primary constructor, the class `Student` must invoke the constructor explicitly. It does this by indicating the data to pass to this constructor after the parent class name following the extends expression. For the student class we take these values in as part of its own constructor. However the parameters ‘n’ and ‘a’ are not properties they are local fields which can be used within the definition of the class Student. We are only using them to pass the data up to the definition of the constructor in the class Person. As a result you can only instantiate the class Student by providing the *subject* to be studied, the students *name* and their *age*. For example:

```
object StudentTest extends App {
   val s = new Student("Computer Science", "John", 18)
   println(s.name + " is studying " + s.subject)
}
```

The end result is that a new instance of the class `Student` is created that has a `subject` property and also a `name` property and an age property *inherited* from the class `Person`. In fact the instance referred to by the variable s is a `Student` and is also a Person (in the same way that any human is also a Mammal etc.).

Note that it is necessary to invoke a parent class’s constructor explicitly. The only exceptions to this are if the parent class only defines a zero parameter constructor or if the primary constructor provides default values for all of its parameters.

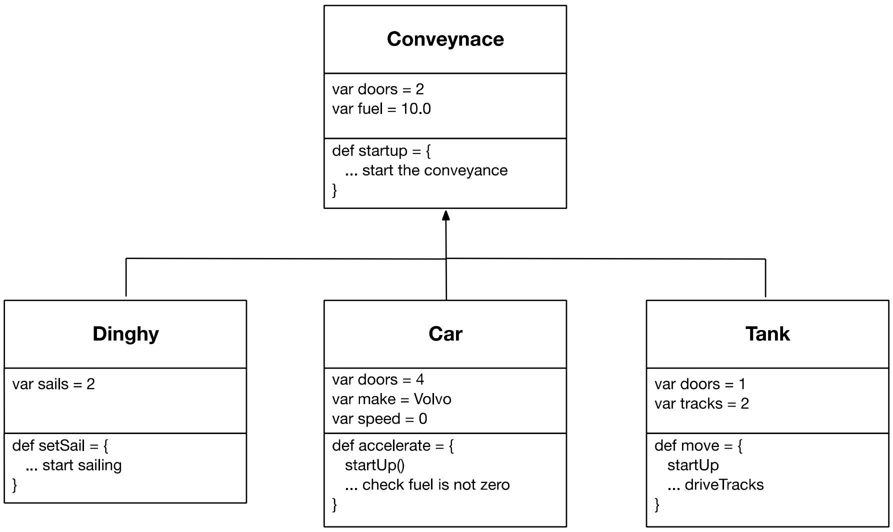


Fig. 13.1 A Class and its subclasses

13.3.1 The Role of a Subclass

There are only a small number of things that a subclass should do relative to its parent or super class. If a proposed subclass does not do any of these then your selected parent class is not the most appropriate super class to use.

A subclass should modify the behaviour of its parent class or extend the data held by its parent class. This modification should refine the class in one or more of these ways:

- Changes to the external protocol, the set of messages to which instances of the class respond.
- Changes in the implementation of the methods; i.e. the way in which the messages are handled.
- Additional behaviour that references inherited behaviour.

If a subclass does not provide one or more of the above, then it is incorrectly placed. For example, if a subclass implements a set of new methods, but does not refer to the instance variables or methods of the parent class, then the class is not really a subclass of the parent (it does not extend it).

As an example, consider the class hierarchy illustrated in Fig. 13.1. A generic root class has been defined. This class defines a `Conveyance` which has doors, fuel (both with default values) and a method, `startUp`, that starts the engine of the conveyance. Three subclasses of `Conveyance` have also been defined: `Dinghy`, `Car` and `Tank`. Two of these subclasses are appropriate, but one should probably not inherit from `Conveyance`. We shall consider each in turn to determine their suitability.

The class `Tank` overrides the number of doors inherited, uses the `startUp` method within the method `fire`, and provides a new instance variable. It therefore matches all three of our criteria.

Similarly, the class `Car` overrides the number of doors and uses the method `startUp`. It also uses the instance variable `fuel` within a new method `accel-erate`. It also, therefore, matches our criteria.

The class `Dinghy` defines a new instance variable `sails` and a new method `setSail`. As such, it does not use any of the features inherited from `Convey-ance`. However, we might say that it has extended `Conveyance` by providing this instance variable and method. We must then consider the features provided by `Conveyance`. We can ask ourselves whether they make sense within the context of `Dinghy`. If we assume that a dinghy is a small sail-powered boat, with no cabin and no engine, then nothing inherited from `Conveyance` is useful. In this case, it is likely that `Conveyance` is misnamed, as it defines some sort of a motor vehicle, and the `Dinghy` class should not have extended it.

The exceptions to this rule are subclasses of `Any` and `AnyRef`. This is because these classes are the root types in the Scala type hierarchy. `AnyRef` is the root of all reference types—that is classes in Scala. As you must create a new class by subclassing it from an existing class, you can subclass from `AnyRef` when there is no other appropriate class.

13.3.2 Capabilities of Classes

A subclass or class should accomplish one specific purpose; it should capture only one idea. If more than one idea is encapsulated in a class, you may reduce the chances for reuse, as well as contravene the laws of encapsulation in object-oriented systems. For example, you may have merged two concepts together so that one can directly access the data of another. This is rarely desirable.

Breaking a class down costs little but may produce major gains in reusability and flexibility. If you find that when you try and separate one class into two or more classes, some of the code needs to be duplicated for each class, then the use of abstract classes can be very helpful. That is, you can place the common code into an abstract superclass to avoid unnecessary duplication.

The following guidelines may help you to decide whether to split the class with which you are working. Look at the comment describing the class (if there is no class comment, this is a bad sign in itself). Consider the following points:

- Is the comment short and clear. If not, is this a reflection on the class? Consider how the comment can be broken down into a series of short clear comments. Base the new classes around those comments.
- If the comment is short and clear, do the class and instance variables make sense within the context of the comment? If they do not, then the class needs to be re-evaluated. It may be that the comment is inappropriate, or the class and instance variables inappropriate.

Look at the instance variable references (i.e. look at where the instance variable access methods are used). Is their use in line with the class comment? If not, then you should take appropriate action.

13.3.3 Overriding Behaviour

As was mentioned at the start of this chapter, a sub type (e.g. a subclass) can override the behaviour defined in a parent class. In fact it is possible to override both methods and fields. It should be noted that in Scala it is also possible to override a parameterless method by a new field or property (this is actually to do with the way in which Scala internally represents data and methods) but can be useful and also confusing.

To override either a field or a method in a parent class you must use the keyword override. You have seen this already with the `toString` method where we had to include the keyword override in order to redefine `toString` to do something more useful then display the fully qualified class name and a hexadecimal number. Of course the default behaviour of `toString` was being inherited into our classes via the class `AnyRef` (which we implicitly extended).

In the following example, the class `Base` overrides `toString` so that the name and age properties of the `Base` class are used to create the string representation of instances of the class. It also defines a method max and a property working.

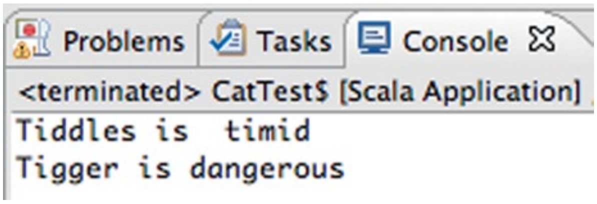
```
class Base(val name: String, var age: Int) {
   def max(x: Int, y: Int): Int = if (x > y) x else y
   val working = false
   override def toString() = name + age
}
```

We can then subclass `Base` with the class `Derived` and override both `max` and `working` if we wish, for example:

```
class Derived(n: String, a: Int) extends Base(n, a) {
  override def max(x: Int, y: Int): Int =
                             if (x > y) y else x
  override val working = true
}
```

In `Derived` we have redefined max to actually return the minimum value for some reason and overridden working to be true.

As another option consider the classes `Cat` and `Tiger` below



```
<terminated> CatTest$ [Scala Application]
Tiddles is  timid
Tigger is dangerous
```

Fig. 13.2 Output from the CatTest program

- Cat has *vals* `dangerous` and `name`.
- Tiger overrides `dangerous` and `name`. However, the value for `name` is now set when the instance is created. Thus the property that is defined as part of the constructor overrides a property used with the `Cat` class, which was not originally part of any construction process.

```
class Cat {
  val dangerous = false
  val name: String = "Tiddles"
  override def toString =
      name + " is " +
         (if (dangerous) "dangerous" else " timid")
}

class Tiger(override val name: String) extends Cat {
  override val dangerous = true
}

object CatTest extends App {
    var c = new Cat()
    println(c)
    c = new Tiger("Tigger")
    println(c)
}
```

The effect of running the `CatTest` program is shown in Fig. 13.2.

13.3.4 Protected Members

By default within Scala all behaviour (methods and functions) as well as data (properties) are public, that is they are visible (can be accessed) anywhere within an application. We have seen that it is possible to mark both behaviour and data as private so that they are only accessible within a single object or class. However, there is another option which has not been mentioned yet. That is, it is possible to make either behaviour or data *protected*.

Protected members of a class are members (methods, functions, properties) that can only be accessed in the current class and in subclasses *and* only in subclasses. They are not visible to other elements of an application.

For example, in the following abstract class `Base` the property age is public, the method `max` is public and the overridden method `toString` is public. However, the property working is only visible within `Base` and any subclasses of `Base`.

```
class Base(val name: String, var age: Int) {
   def max(x: Int, y: Int): Int = if (x > y) x else y
   val working = false
   override def toString() = name + age
}
```

The use of protected properties or behavior helps to explicitly specify the interface between a sub type and its super type.

13.4 Restricting a Subclass

You can restrict the ability of a subclass to change what it inherits from its superclass. Indeed, you can also stop subclasses being created from a class. This is done using the keyword `final`. This keyword has different meanings depending on where it is used. For example in the following example, the keyword final has been applied to the whole classe:

```
final class Employee (n: String ,
                      a: Int,
                      company: String)
                             extends Person(n, a)
```

This means that no element of this class can be extended, so no subclass of `Employee` can be created.

The keyword final can also be applied to a public property. For example:

```
final var maximumMemory = 256
```

This indicates that the property `maximumMemory` cannot be overridden in a subclass. This means that the value of `maximumMemory` is set for this class and for all subclasses wherever they are defined by this class. Using a `val` instead of a `var` means that the value cannot merely be overridden by a subclass it is also only set once and is thus a constant for the hierarchy below the current class:

```
class Employee (n: String ,
                        a: Int,
                        company: String)
                      extends Person(n, a)  {

  final val max = 10
```

The keyword `final` can also be applied to methods. This means that a method cannot be overridden in a subclass, for example:

```
class Employee (n: String ,
                        a: Int,
                        company: String)
                      extends Person(n, a)  {

  final def prettyPrint(): Unit = {
   println("Employee")
   println("\tName: " + name)
   println("\tAge: " + age)
   println("\tCompany: " + company)
  }

}
```

This states that the method `prettyPrint` cannot be overridden in a subclass. That is, a subclass cannot redefine `prettyPrint();` it must use the one that it inherits.

Restricting the ability to overwrite part of, or all of, a class is a very useful feature. It is particularly important where the correct behaviour of the class and its subclasses relies on the correct functioning of particular methods, or the appropriate value of a variable, etc. A class is normally only specified as `final` when it does not make sense to create a subclass of it. These situations need to be analysed carefully to ensure that no unexpected scenarios are likely to occur.

13.5 Abstract Classes

An *abstract* class is a class from which you cannot create an object. It is missing one or more elements required to create a fully functioning instance. In contrast a non-abstract (or concrete) class leaves nothing undefined and can be used to create a working instance. You may wonder what use an abstract class is. The answer is that you can group together elements that are to be shared amongst a number of classes, without providing a complete implementation. In addition, you can force subclasses to provide specific methods ensuring that implementers of a subclass at least supply appropriately named methods. You should therefore use abstract classes when:

- you wish to specify data or behaviour common to a set of classes, but insufficient for a single instance,
- you wish to force subclasses to provide specific behaviour.

In many cases, the two situations go together. Typically, the aspects of the class to be defined as abstract are specific to each class, while what has been implemented is common to all classes. For example, consider the following class. This is a revised version of the Person class we have seen several

```
abstract class Person(val name: String, var age: Int) {
  // Override inherited toString

  override def toString = name + ", " + age;

  //Define an abstract method
  def prettyPrint

  def birthday = age = age + 1
}
```

times before. However we are now making Person an abstract concept. This means that you do not create instances o the Person class itself, but rather you create instances of subclasses of Person such as Employee, Student, Graduate etc. Person brings together the common features of these subclasses, but on its own it is not sufficient to warrant an instance being created. It is only the concrete classes (non abstract classes) which actually make sense as instances:

This abstract class definition means that you cannot create an instance of `Person`. Within the definition of `Person`, we can see that the toString and birthday methods are concrete or defined methods, where as the method `prettyPrint` is not defined (it has no method body). The `prettyPrint` method is what is known as an abstract method. Any class, which has one or more abstract methods, is necessarily abstract (and must therefore have the keywords `abstract class`). However, a class can be abstract without specifying any abstract methods.

An abstract class can also define any number of concrete methods. The method birthday is a concrete method that adds one to the current age of the person.

Any subclass of `Person` must implement the `prettyPrint` method if instances are to be created from it. Each subclass can define how to *pretty print itself* in a different manner. The following `Graduate` class provides a concrete class that builds on `Person`:

```
class Graduate(n: String, a: Int, degree: String, uni:
String) extends Person(n, a) {

  val institution: String = uni

  def this(n: String, a: Int, degree: String) = this(n,
 a, degree, "Oxford")

   override def toString =
   "Graduate [" + super.toString() + ", " + degree +
 "]";

   def prettyPrint = {
     println("Graduate")
     println("\tName: " + name)
     println("\tAge: " + age)
     println("\tDegree: " + degree)
     println("\tUniversity: " + uni)
   }

}
```

This class extends the class `Person` and also provides:

- The four parameter constructor that is used to passing the name and age for the `Person` class's primary constructor and to provide a degree and University for the `Graduate` class.
- A 3 parameter auxiliary constructor that invokes the four parameter primary constructor.
- A concrete version of the `prettyPrint` method.

We can also return to the `Employee` class from earlier and see that it also provides a concrete `prettyPrint` method and invokes the `Person` class's primary constructor:

```
class Employee(n: String, a: Int, company: String)
extends Person(n, a) {

  final def prettyPrint(): Unit = {
    println("Employee")
    println("\tName: " + name)
    println("\tAge: " + age)
    println("\tCompany: " + company)
  }
}
```

13.6 The Super Keyword

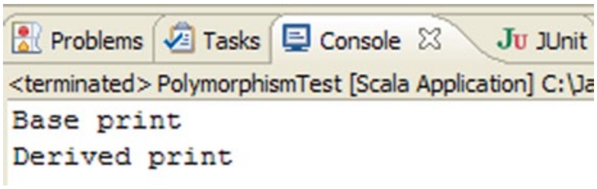
We have already seen that it is possible to override behaviour defined in a parent class so that the version in the current class meets that needs of that class. The method `toString` is a typical example of this. In numerous examples we have redefined `toString` to create a string based on the data held by a class rather than to use the generic version. To do this we used the keyword override and ensured that the method signature (its name, parameters and return matched those define din the parent class).

However, rather than completely override the version of the method define din the parent class we can chose to extend its behaviour. This is done by defining a new version of a method in a subclass and then using the keyword *super* to invoke the version defined higher up the inheritance hierarchy.

For example, in the following example, the abstract class Base defines a method print that prints out a message “Base print”. The subclass Derived extends Base and overrides the method print. However within the body of the method it called `super.print` that causes it to invoke the parent class’s version of print. Note this call could be made anywhere within the body of the method print in Derived, it does *not* need to be the first line of the method.

```
abstract class Base {
  def print = println("Base print")
}

class Derived extends Base {
  override def print {
    super.print
    println("Derived print")
  }
}
```



```
<terminated> PolymorphismTest [Scala Application] C:\Ja
Base print
Derived print
```

Fig. 13.3 Output illustrating inheritance

The effect of the overridden print method in `Derived` is that it calls the parent class's version of print. This means that in effect it extends, rather than replaces, the behaviour of the original version of print. Note that super tells Scala to start searching up the class hierarchy for a version of print defined above the current class in the hierarchy. In this case it is defined in the parent class, but it could have been defined in a parent of `Base`—that is it starts searching Base and will continue search up the class hierarchy until it finds another definition of print to execute.

To illustrate this idea we could create a simple application:

```
object Test extends App {
  var d = new Derived()
  d.print
}
```

If we now run the above application the output would be as shown in Fig. 13.3.

Here you can see that both the original version and the derived version of print have been executed.

13.7 Scala Type Hierarchy

The type hierarchy in Scala is complicated by the presence of traits, but the core types are divided between two types, `AnyVal` and `AnyRef` with the class Any at the root (see Fig. 13.4).

Thus the root of everything in Scala is the abstract class Any. Any has two subclasses, the abstract AnyVal and the concrete AnyRef:

- **AnyVal** this is used to represent Value like types, such as Boolean, Char, Byte, Short, Int, Long, Float, Double. Strictly speaking Scala has no primitive types — these are objects. However, they are a special type of object that are managed by the Scala runtime efficiently.
- **AnyRef** this is used for all reference types such as classes and traits. Examples of AnyRef subtypes include the data structure (or collection) classes such as Array,

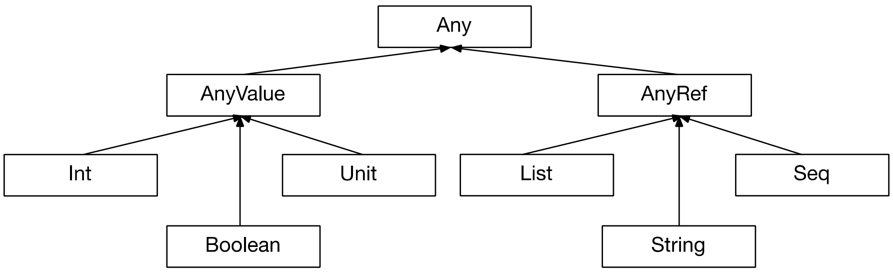


Fig. 13.4 Simplified extract form Scala type hierarchy

List, Seq and String. It is also used as the root for all user defined classes that do not explicitly extend any other class.

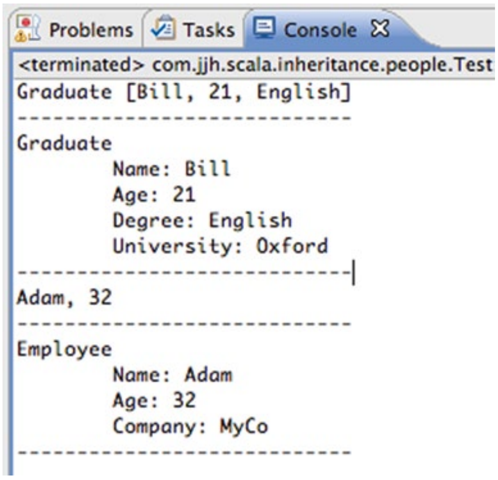
13.8 Polymorphism

Polymorphism was a concept discussed earlier in the book relating to one of the four key concepts in Object Orientation. In terms of Scala programming Polymorphism means that a *val* or *var* local variable or property can actually reference an instance of a particular type or any sub type of that type. Thus a var of type Person can actually hold a reference to a Person (assuming it is not an abstract type) or any subclass of Person (including Student, Employee and graduate etc.).

For example, we can write:

```
object TestPolymorphism extends App {
    var p: Person = new Graduate("Bill", 21, "English")
    println(p)
    println("----------------------------")
    p.prettyPrint
    println("----------------------------")
    p = new Employee("Adam", 32, "MyCo")
    println(p)
    println("----------------------------")
    p.prettyPrint
    println("----------------------------")
}
```

In this test application the variable p is of type `Person`. It can thus reference a `Person`, a `Graduate` or an `Employee`. Initially we are storing a reference to



```
<terminated> com.jjh.scala.inheritance.people.Test
Graduate [Bill, 21, English]
--------------------------
Graduate
        Name: Bill
        Age: 21
        Degree: English
        University: Oxford
--------------------------
Adam, 32
--------------------------
Employee
        Name: Adam
        Age: 32
        Company: MyCo
--------------------------
```

Fig. 13.5 Output from the TestPolymorphism application

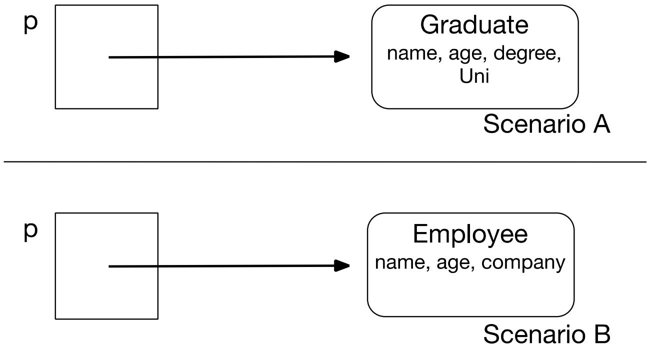


Fig. 13.6 Referencing instances polymorphically in Scala

a `Graduate` in p. We then call `println` on p (which causes the `toString` method to be invoked on the instance reference by p and then call `prettyPrint` on `p`. Both `toString` and `prettyPrint` can be guaranteed to be available in whatever instance p refers to because the functionality in the class Person guarantees it. Any methods defined only in the `Graduate` are not visible via `p` (although they are still present in the instance being referenced—they just cannot be accessed at this point).

After this we create a new instance of the `Employee` class and store a reference to that instance in p, and then use `toString` to print the object out and `prettyPrint` again. However, the behaviour that now executes is whatever behaviour is either defined in `Employee` or inherited into `Employee`.

The output produced by this application is shown in Fig. 13.5.

The key here is that with polymorphism:

1. The type of the variable p acts as a filter—ensuring that only common behaviour is accessible
2. But at runtime the actual definition of, for example, `prettyPrint`, is dynamically bound. That is, the version defined the class that the instance is actually an example of is what is executed.

The illustrate see the following diagram, scenario A indicates the situation when p references a graduate. Thus when the `prettyPrint` method is called on p at that point it is the Graduate version of `prettyPrint` that is run. Scenario B indicates the situation when p references an employee. Thus when `prettyPrint` is called on this instance it is the version in Employee that is `run` (see Fig. 13.6).

To summarise then, polymorphism in Scala is similar to that in languages such as Java and C#, in that:

- A variable of type X can refer to instance of X or any subclass of X
- At runtime method invocations are dynamically bound based on the type of the receiving object (not the type of the variable)

Chapter 14
Objects and Instances

14.1 Introduction

This chapter will discuss the difference between objects in Scala and Instance of a class. This is important as many other object-oriented languages use these terms interchangeably. However, in Scala they are significantly different concepts, defined with different language constructs and used in different ways.

14.2 Singleton Objects

Scala provides another type that can sit along side the class types. It is directly supported by the language construct *object*. A Scala Object is a singleton object that is accessible to any Scala code that has visibility of that object definition. The term singleton here refers to the fact that there is a single instance of the object definition within the virtual machine executing the Scala program. This is guaranteed by the language itself and does not require any additional programmer intervention.

If you have never come across the concept of a Singleton object before it may appear an odd idea. However, it is very widely and commonly used within the object oriented programming world. Examples of the singleton concept can be found in Java, C#, Smalltalk, C++ etc. and have been documented in various ways since it was first popularised in the so-called Gang of Four patterns book. The four authors of this book, Erich Gamma, Richard Helm, Ralph Johnson and John Vlissides (collectively known as the "Gang of Four", or GoF for short) popularized the patterns concepts and ideals.

So what are design patterns? They are essentially useful recurring solutions to problems within designs. For example, "I want to loosely couple a set of objects, how can I do this?", might be a question facing a designer. The Mediator design pattern is one solution to this. If you are familiar with design patterns you can use them to solve problems that occur. Typically early in the design process, the problems are more architectural/structural in nature, while later in the design process they may be more behavioural. Design patterns actually provide different types of patterns some of which are at the architectural/structural level and some of which are more behavioural. They can thus help every stage of the design process.

The Singleton pattern describes a type that can only have one instance constructed for it. That is, unlike other types it should not be possible to obtain more than one instance within the same virtual machine. Thus the Singleton pattern ensures that only one instance of a type is created. All elements that use an instance of that type; use the same instance.

The motivation behind this pattern is that some classes, typically those classes that involve the central management of a resource, should have exactly one instance. For example, a object that managements the reuse of database connections (i.e. a connection pool) could be a singleton.

However, implementing a singleton in some language can be more complex than initially thought, as it is necessary to ensure that it is not possible to have multiple instances of the singleton concept. Scala solves this problem by making the singleton concept part of the language.

You have already seen examples of the syntax used for singletons as that is the syntax we have used for each of our application entry points (whether with an explicit `main` method or by using the `App` trait). The syntax is:

```
object ObjectName { body }
```

Objects can

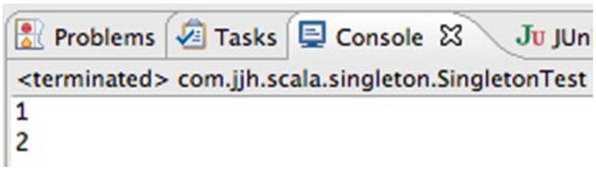
- extend classes,
- mix in traits,
- define methods and functions
- as well as properties (both vals and vars).
- However, m objects cannot define constructors.

A simple singleton object is shown below:

```
object ConnectionPool {
  var count = 0;
  def next = {count = count + 1}
}
```

This simplified *mock* connection pool object defines a count of the number of connections being managed and a method next that adds to the count. This object does not need to be instantiated to be used instead it can be referenced directly by any client code:

Fig. 14.1 Output from SingletonTest application



```
<terminated> com.jjh.scala.singleton.SingletonTest
1
2
```

```
object SingletonTest extends App {
   ConnectionPool.next
   println(ConnectionPool.count)
   ConnectionPool.next
   println(ConnectionPool.count)
}
```

In the above client code we are accessing the functionality in next and the data in count directly by reference to the name of the object (we did not create a new object using the keyword new nor did we run a constructor).

The result of running this simple application is shown in Fig. 14.1, indicating that the same object Is used through out as the count is incremented from 1 to 2:

14.3 Companion Objects

Companion Objects are singleton objects for a class — they can be used to provide utility functions such as factory methods that will support the concept being modelled by the class. As a Companion Object is an object, it is a singleton instance that sits alongside the class.

To define a Companion Object it must:

- Have the same name as the Companion Class.
- Must be defined in the same Source file as the Class.

When used in this way Companion Objects are useful placeholders for static style behaviour (as found in languages such as Java or C#).

From the point of view of the user of the class; the Companion Object and the class appear to be a single concept. For example, consider the following definition of a `Session` class and a Companion Object.

```
/**
 * The Companion class
 */
class Session(var id: Int) {
    override def toString = "Session[" + id + "]"
}

/**
 * Its Companion (singleton) object
 */
object Session {
  private var counter = 0
  private def next = counter = counter + 1
  def create = { next; new Session(counter) }
}
```

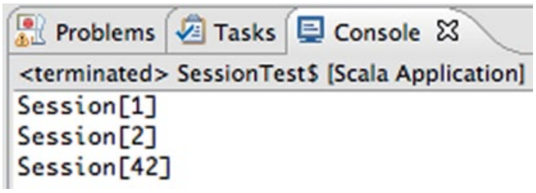
Notice that the object `Session` has a private `counter` (initialised to zero) and a private method `next`. By default all methods and properties are public (accessible anywhere); here we are making the property counter and the method next visible only within the Object Session.

The utility method `create` then uses the method `next` to increment the counter before it creates a new `Session` instance. Note that we are using a ';' here to separate the two statements as they are on the same line and Scala would infer that they were related. I am also surrounding them with curly brackets '{..}' as this is a multiple statement method and thus need to group them.

From a client of the Session concepts point of view they can now create a new session using the `create` (factory) method or by using the keyword *new* and the class name directly:

```
object SessionTest extends App {
    val s1 = Session.create
    println(s1)
    val s2 = Session.create
    println(s2)
    val s3 = new Session(42)
    println(s3)
}
```

Fig. 14.2 Output from SessionTest



```
<terminated> SessionTest$ [Scala Application]
Session[1]
Session[2]
Session[42]
```

The first two session instances above are created using the Session objects Create method and the third session instance is created using the new keyword. From the client programmers point of view there is a single concept here Session which can be instantiated into two ways. The advantage of the Create method is that it handles ensuring an increment of the session ID where as the use of new allows any Session id to be used. The out of this program is shown in Fig. 14.2.

14.3.1 Companion Object Behaviour

It may at first seem unclear what should normally go in a method defined in the class as opposed to what should go in a method defined in a Companion Object when defining a new class. After all, they are both defined in the same file and relate to the same concept. However, it is important to remember that one defines the behaviour of which will be part of an instance and the other the behaviour of which can be shared across the whole concept being implemented.

In order to maintain clarity Companion Object methods, should only perform one of the following roles:

- *Application Entry Point* This role is very important as it is how you can use a Companion Object as the root of an application. It is common to see main methods (or the App trait) which do nothing other than create a new instance the main class of an application and fire off the appropriate behaviour. For example:

```
object Editor extends App {

      def main (args: Array[String]): Unit = {
            val editor = new EditorView()
            editor.startDisplay
      }

}
```

If you define such a method, but the class is not the root of the application, it is ignored. This makes it a very useful way of providing a *test* harness for a given class.

- *Answering enquiries about the class* This role can provide generally useful objects, frequently derived from Companion Object variables. For example, they may return the number of instances of this class that have been created using a factory method.
- *Instance management* In this role, Companion Object methods control the number of instances created. For example, a class only allows a ten instance to be created. Instance management methods may also be used to access an instance (e.g. randomly or in a given state).
- *Examples* Occasionally, Companion Object methods are used to provide helpful examples which explain the operation of a class.
- *Testing* Companion Object methods can be used to support the testing of an instance of a class. You can use them to create an instance, perform an operation and compare the result with a known value. If the values are different, the method can report an error. However, test frameworks are generally a better approach.
- *Support for one of the above roles*

Any other tasks should be performed by a method (of function) defined in the class. Although in general we would use one of the testing frameworks for Scala rather than create multiple main methods.

14.3.2 A Object or an Instance

In some situations, you may only need to create a single instance of a class and reference it wherever it is required. A continuing debate ponders whether it is worth creating such an instance or whether it is better to define the required behaviour in a Companion Object. The answer to this is not straight forward as there are several factors that should be taken into account including:

- The use of an object in Scala guarantees you a singleton instance within the current JVM. This means that it also limits you to a single instance in the current JVM and over time this may be a problem.
- The creation of an instance has a very low overhead. This is a key feature in Scala and it has received extensive attention.
- You may be tempted to treat the object as a global reference. This suggests that the implementation has been poorly thought out.

In deciding whether to use a Scala object or a Scala class to hold data and/or behaviour or functionality you need to consider the context in which it will be used, how you expect to develop the concept and whether there will ever be a need for more than one instance of that concept.

Further Readings

Gang of Four Design Patterns Book
Gamma E, Helm R, Johnson R, Vlissades J (1995) Design patterns: elements of reusable object-oriented software. Addison-Wesley

Quick reference list of design patterns
http://www.oodesign.com/

Introductory descriptions and examples of patterns
http://sourcemaking.com/design_patterns

List of patterns based sites
http://hillside.net/patterns/patterns-catalog

Chapter 15
Value Classes

15.1 Introduction

This chapter introduces another type of class in Scala; Value Classes. A value class is a type where the actual value being represented by the class is held directly by a variable, rather than needing to access that value via a reference (an address in memory). Examples of value types include Booelan, Int and Double which can have the values true, false, 32, 45.7 etc. Such values can be held directly by a variable, rather than accessed via a reference. This can be more efficient for simple types like Int.

Value Classes inherit from AnyVal, rather than AnyRef. However, prior to Scala 2.10 *AnyVal* was actually a type of Trait not a Class. This meant that it was not possible to create user defined value types. However in Scala 2.10 *AnyVal* was redefined as an *abstract* class. As it is normal to subclass abstract classes it is now possible to create *user defined* Value Classes. Thus subclasses of *AnyVal* are user defined Value classes.

15.2 Value Classes

Value classes are treated as special by the Scala compiler. That is, the compiler will determine if it can *inline* the value to be used directly. This avoids the need to allocate runtime objects and is thus more efficient and faster (as no allocation must be made and no reference must be followed).

To ensure that the compiler can treat a value in this way it is necessary for the programmer to ensure that no object allocation is performed within the type. Thus a Value Type cannot hold within itself a reference to a non-Value type (such as an instance of the class Person). It must also ensure that the type being defined:

- must extend AnyVal,
- must be immutable by nature (that is it should not change itself but return a new instance whenever a change in value is required),

- must have a single *public val parameter* for the underlying type (that is the built in Value type being wrapped),
- does not declare any additional fields within itself,
- cannot have any auxiliary constructors,
- cannot define any nested types such as classes, objects or traits,
- are not used in tests used to determine their type or in type based pattern matching,
- must not override the *equals* or *hashcode* methods,
- cannot have any initialization statements.

However, they can have

- any methods or functions as required.

15.3 Simple Value Type Example

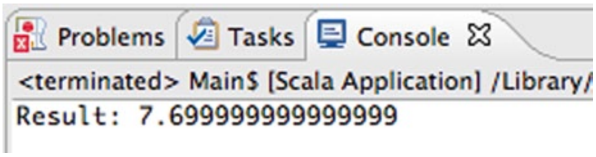
The following ValueType class meets the criteria defined in the last section. That is, the Value Class `Meter` has a single *val* property `value` of type `Double` (which is a built in value type), it extends `AnyVal` directly and provides a method '+'. In addition it exhibits immutability. That is, when the '+' method is invoked it does not change *value* instead it returns a new instance of the `Meter` class representing the new value:

```
class Meter(val value: Double) extends AnyVal {
  def +(m: Meter) : Meter = new Meter(value + m.value)
}
```

The following simple application illustrates how this class may be used:

```
object Main extends App {
  val x = new Meter(3.4)
  val y = new Meter(4.3)
  val z = x + y
  Console.println("Result: " + z.value)
}
```

In this example we create two instances of the `Meter` Value Class and store them in the variables `x` and `y`. We then add them together and store the result in `z`. Note that this line looks very much as it would if `x` and `y` held *Int* or *Doubles* and we added them together. The result is then printed out. The effect of running this application is shown in Fig. 15.1.



```
<terminated> Main$ [Scala Application] /Library/
Result: 7.699999999999999
```

Fig. 15.1 Output from the meter example

Interestingly the compiler actually replaces the references to `Meter` with the primitives held within the Value Class at runtime. Thus there is virtually no overhead in using `Meter` compared to using `Double` directly. This raises the question "Why bother?" The answer is two fold:

- `Meter` is more semantically meaningful than *Double*. That is *Double* is a generic way of representing 54 bit real numbers. The Value class *Meter* represents the concept of a length i.e. a meter.
- `Meter` also allows methods to be defined that allow semantically meaningful operations to be defined that can also indicate what is being done at a higher level of abstraction than the basic type Double would allow.

15.4 Additional Value Class Concepts

Value classes are implicitly treated as final classes, thus ensuring that they cannot be extended by other classes. This is important as it restricts the need for polymorphism and thus allows the compiler to inline the values being represented.

Value classes are implicitly assumed to have structural equality and the same *hashcodes*. That is, their `equals` and *hashcode* methods are taken to be defined as follows (and this is why you must not redefine them):

```
def equals(other: Any) = other match {
  case that: C => this.u == that.u
  case _ => false
}
def hashCode = u.hashCode
```

Where u equates to the underlying (Value type) property (such as Double, or Int). In other words if the underliers have the same value then the value types are equal otherwise they are not equal. In addition the *hashcode* of a value type of the *hashcode* of its underlie.

Value classes can only mix in Universal traits. If you try to mix in a trait which is not a Universal Trait then the class you are defining is not a Value Class but a reference class. A Universal trait is a special trait which extends the Any type rather than the default AnyRef type.

You can make the Value Class a case class that simplifies the syntax and means that you do not need to use the keyword *new*. This often makes for much more readable and semantically clear Value classes. For example, taking the Meter class defined earlier and changing it into a case class:

```
case class Meter(val value: Double) extends AnyVal {
  def +(m: Meter) : Meter = new Meter(value + m.value)
}
```

This now means that we do not need to use the keyword new and thus the test application looks less as if we have created instance of a class and more as if Meter was a built in type:

```
object Main extends App {
  val x = Meter(3.4)
  val y = Meter(4.3)
  val z = x + y
  Console.println("Result: " + z.value)
}
```

15.5 Negating Value Classes

It should be noted that the compiler will not treat a class as a Value Class in some situations. These are presented below:

The compiler will not treat an instance of a Value Class as a value when:

- It is used in an array—it will not inline values into an Array.
- It is used in pattern matching situations such as case statements.
- When used within any polymorphic situation. For example, where the type of the variable relates to a more generic type (such as a trait).

Chapter 16
Scala Constructs

16.1 Introduction

This chapter presents more of the Scala language. It considers the representation and use of numbers, strings and characters. It also discusses assignments, literals and variables. Finally, it considers messages, message types and their precedence.

16.2 Numbers and Numeric Operators

16.2.1 Numeric Values

Just as in most programming languages, a numeric value in Scala is a series of numbers which may or may not have a preceding sign and may contain a decimal point:

```
25   -10   1996    12.45    0.13451345    -3.14
```

Unusually for a programming language, Scala explicitly specifies the number of bytes that must be used for data types such as Short, Int, Long, Float and Double (Table 16.1):

The Scala language designers' purpose in specifying the number of bytes to use for each data type was to enhance the portability of Scala implementations. In C, the number of bytes used for `int` and `long` is at the discretion of the compiler writers. The only constraint placed upon them is that `int` cannot be bigger than `long`. This means that a program that compiles successfully on one machine may prove unreliable and have errors when recompiled on another machine. This can make porting a program from one system to another extremely frustrating (ask anyone who has ever had to port a sizeable C system!).

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Table 16.1 Standard numbers of bytes for numeric data types

Type	Bytes	Stores
Byte	1	Integers
Short	2	Integers
Int	4	Integers
Long	8	Integers
Float	4	32 bit IEEE 754 single precision float
Double	8	64 bit IEEE 754 double-precision float

Table 16.2 Basic numeric operators

+	Addition
-	Subtraction
*	Multiplication
/	Division
%	Remainder
==	Equality
<	Less than
>	Greater than
!=	Inequality
<=	Less than or equal to
>=	Greater than or equal to

Table 16.3 Methods provided by numeric classes

`Equals()`	Equality
`doubleValue()`	Conversion
`toHexString()`	Conversion
`valueOf(aString)`	Conversion (class-side)
`toBinaryString()`	Conversion
`toOctalString()`	Conversion

16.2.2 Arithmetic Operators

In general, the arithmetic operators available in Scala are the same as in any other language. There are also comparison functions and truncation functions (see Table 16.2). Numbers can also be represented by objects which are instances of classes such as `Integer`, `Float`, etc. These classes are all subclasses of the class Number and provide different facilities. However, some of the methods are fairly common (Table 16.3).

A number of the numeric classes also provide class variables, such as `MAX_VALUE` and `MIN_VALUE` (i.e., in `Integer`, `Long`, `Double`, `Float`, etc.), and numbers such as `NEGATIVE_INFINITY` and `POSITIVE_INFINITY` (i.e., in `Double` and `Float`).

In addition, Scala provides a class called `Math`. This class, which is a subclass of `Object`, provides the usual range of mathematical operations (see Table 16.4). All these methods are class (or static) methods available from the class `Math`. You do not have to create an instance of the class to use them.

Table 16.4 Mathematical functions provided by Math

Max	Maximum	Min	Minimum
Ceil	Round up	Floor	Round down
Round	Round to nearest	sqrt	Square root
Abs	Absolute value	exp	Exponential
Pow	Raises one number to the power of the other	Random	Random number generator

It is also interesting to notice that, to enhance the portability of Scala, the language designers have stated that the definitions of many of the numeric methods must produce the same results as a set of published algorithms.

16.3 Characters and Strings

16.3.1 Characters

Characters in Scala are of type Char and are represented by 16 bit unsigned integers. In Scala, a single character is defined by surrounding it with single quotes:

```
'J'    'a'    '@'     '1'     '$'
```

16.3.2 Strings

`Strings` in Scala are represented by the (Java) class String and examples of a string are instances of this class. As such, they are made up of individual elements, similar to strings in C. However, this is the only similarity between strings in C and Scala. A Scala string is not terminated by a null character and should not be treated as an array of characters. It should be treated as an object which responds to an appropriate range of messages (e.g. for manipulating or extracting substrings) (Table 16.5).

A string is defined by one or more characters placed between double quotes (rather than the single quotes used for characters):

```
"John Hunt"     "Tuesday"       "dog"
```

You cannot create a string by generating an array of characters. This can be the source of much confusion and frustration when an apparently correct piece of code does not work. A string containing a single character is not equivalent to that single character:

```
‵a′ != ‶a″
```

Table 16.5 Methods provided by the class string

charAt(index: Int)	Returns the character at position index
compareTo(anOtherString)	Compares two strings lexicographically
equals(String aString)	Compares two strings
equalsIgnoreCase(String aString)	Compares two strings, ignoring the case of the characters
indexOf(char aCharacter)	Returns the first index of the character in the receiving string
substring(int start, int stop)	Creates substring from start to stop (in the receiving string)
toLowerCase()	Returns the receiver in lower case letters
toUpperCase()	Returns the receiver in upper case letters

The string `"a"` and the character `'a'` are, at best, instances of different classes and, at worst, one may be an instance and one a basic type. The fact that the string contains only one character is just a coincidence.

To denote that a variable should take an instance of String, define it as being of type String:

```
val aVariable: String = "John"
```

Of course due to ype inference in most situations Scala can infer that the type of the variableshould be String.

16.4 Assignments

A variable name can refer to different objects at different times. You can make *assignments* to a variable name, using the = operator. It is often read as "becomes equal to" (even though it is not preceded by a colon as in languages such as Ada).

Some examples of assignment statements follow:

```
currentEmployeeIndex = 1;
newIndex = oldIndex;
myName = "John Hunt";
```

Like all Scala operators, the assignment operator returns a value. The result of an assignment is the value of that assignment (thus the value of the expression x = 2 + 2; is 4). This means that several assignments can be made in the same statement:

```
nextObject = newObject = oldObject;
```

The above example also illustrates a feature of Scala style – variable names that indicate their contents. This technique is often used where a more meaningful name

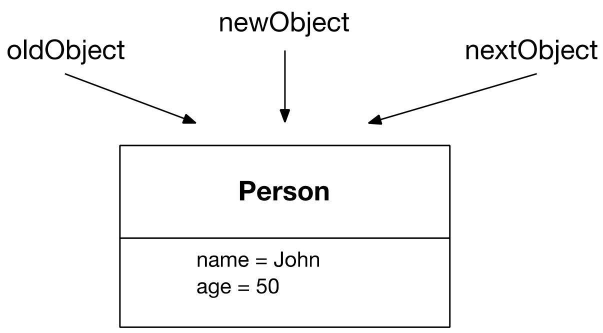


Fig. 16.1 The result of a multiple assignment

(such as `currentEmployeeIndex`) is not available (`temp` might be used in other languages).

Although variables in Scala are strongly typed, this typing is perhaps not as strong as in languages such as Pascal and Ada. You can state that a variable is of type `Any`. As `Any` is a class, such a variable can possess instances of the class Any or *one of its subclasses*! This means that a variable that holds a String may then be assigned a Person or a List (a type of data structure) instance. This is quite legitimate:

```
var temp: Any = new Person()
temp = "John"
temp = List(..)
```

An important point to note is that assignment is by reference when dealing with objects. This means that, in the following example, `nextObject, newObject` and `oldObject` all refer to the *same* object (as illustrated in Fig. 16.1)

```
newObject = oldObject = new Person(..)
nextObject = newObject;
```

As all three variables point to an instance of a class (in this case `Person`), if an update is made to the contents of any one of the properties maintained by the person (such as the age property), it is made for all three!

16.5 Variables

16.5.1 Temporary Variables

These variables exist only for the duration of some activity (e.g. the execution of a method). They can be defined anywhere within a method (as long as they are defined before they are used). The definition takes the form of the type (or class) of the variable and the variable name followed by any initialization required:

```
var aChar: Char;
var anotherChar = 'a';
var anInstance: AnyRef;
var myName = "John Hunt";
```

Note all of these are written as vars but they could equally have been vals. The scope of a temporary variable depends on the context in which it is defined. For example, variables declared at the top level of a method, are in scope from the point at which they are declared. However, block variables only have scope for the block within which they are defined (including nested blocks). Loop variables only have scope for the loop within which they are defined. Thus the scope of each of the following variables is different:

```
def add (a: Int, b: Int): Int = {
 val result = 0                           r
 for (i <- 0 to 5) {                     ir
  if (a < i) {                           ir
    var total = b                       tir
    total = total + c * i               tir
  }                                      ir
 }                                        r
return result                             r
}
```

In the right-hand column, `r` indicates that `result` is in scope, `i` indicates the scope of the loop variable and `t` indicates the scope of the inner block variable, `total`.

16.5.2 Pseudo Variables

A pseudo variable is a special variable, whose value is changed by the system, but which cannot be changed by the programmer. The value of a pseudo variable is determined by the current context and can be referenced within a method.

`this` is a pseudo variable that refers to the receiver of a message itself. The search for the corresponding method starts in the class of the receiver. To ensure that your source code does not become cluttered, Scala assumes you mean `this` object if you just issue a reference to a method. The following statements have the same effect:

```
this.myName()
myName()
```

You can use `this` to pass a reference to the current object to another object:

```
otherObject.addLink(this)
```

16.5.3 Variable Scope

Temporary variables are only available within the method in which they are defined. However, both class variables and instance variables are in scope (or are visible) at a number of levels. An instance variable can be defined to be visible (available) outside the class or the package, only within the package, within subclasses or only within the current class. The scope is specified by modifiers which precede the variable definition:

```
public val myName = "John Hunt"
```

16.5.4 Option, Some and None

Sometimes what we need to represent is that a variable currently does not hold anything. The approach taken in Java was to represent such *values* as *null*. The idea was that the null value is an object that represents nothing or no object. It is not of any type nor it is an instance of any class (including `Object`). It really does means *nothing* or *no value*. However, this has lead to the now much discussed NullPointerException in Java which is generally considered now to be a weakness of the language.

The approach adopted within Scala is to use a type called an Option. An Option can hold any type or can be set to None. None indicates the absence of an actual value but is not the same as Null in Java.

For example, using Option you can indicates that a variable date, should hold a Date type but currently a data has not been specified, for example:

```
val date: Option[Date] = None
```

This declares that the value date as holding an Option wrapper, around a Data but that currently this is initialized to None.

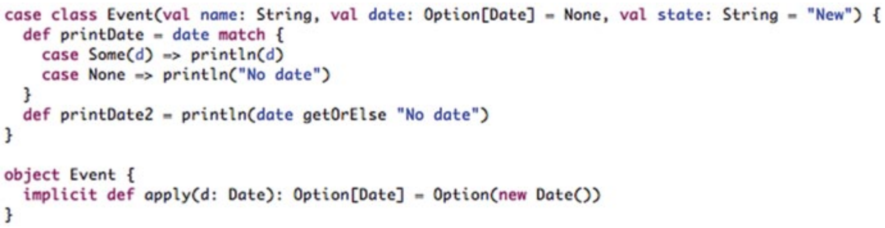
Such values can then be used within a match statement to perform one action if a value is present or another action if there is no value (or None), for example:

```
def printDate = date match {
  case Some(d) => println(d)
  case None => println("No date")
}
```

Although a more a more idiomatic Scala approach would be to use the getOrElse method on Option which indicates that you should retruen the value held by an option or return some default value, for example:

```
def printDate2 = println(date getOrElse "No date")
```

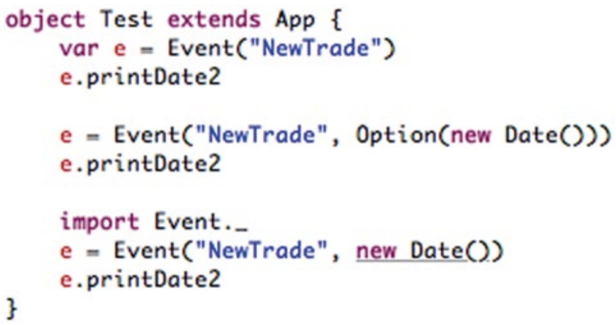
As a more concrete example of using an option consider the following class Event. This class represents some interesting event that has occurred within some system at some point in time.



```
case class Event(val name: String, val date: Option[Date] = None, val state: String = "New") {
  def printDate = date match {
    case Some(d) => println(d)
    case None => println("No date")
  }
  def printDate2 = println(date getOrElse "No date")
}

object Event {
  implicit def apply(d: Date): Option[Date] = Option(new Date())
}
```

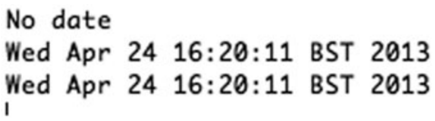
When the data associated with the Event is printed via the printDate method where we either print the date or a string “No date”. Note that the Companion Object Event defines a utility conversion metrhod thaty will take a date and convert it into an Option so that users of the class Event do not have to do this themelves. As the apply is marked as implicit, if the method is in scope, then when Scala is looking for a way to convert a Date into an option it can use this methoud automatically without the programmer explicitly specifying it.

A simple example of using this class is shown below:



```
object Test extends App {
    var e = Event("NewTrade")
    e.printDate2

    e = Event("NewTrade", Option(new Date()))
    e.printDate2

    import Event._
    e = Event("NewTrade", new Date())
    e.printDate2
}
```

Note that the second Event created uses the implicit apply conversion method to convert the new instantiated Date into an option. The output from this application is



```
No date
Wed Apr 24 16:20:11 BST 2013
Wed Apr 24 16:20:11 BST 2013
```

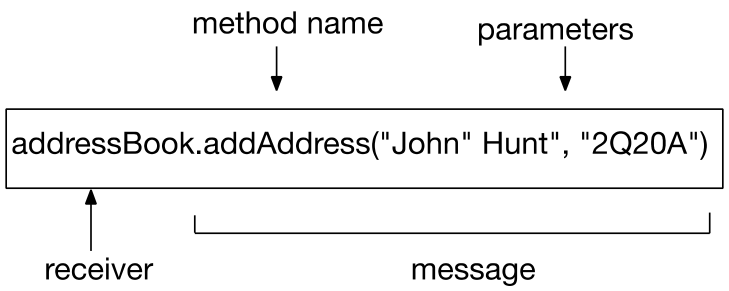


Fig. 16.2 The components of a message expression

16.5.5 Boolean Values

In Scala there is a specific type used to represent truth or falsehood. This is the Boolean type. It has two values true and false which can be written as literals and can be assign to variables and values and used in logical operations.

16.5.6 Literals

All of the preceding types can be written in literal from. That is it is 23 is a literal Int, 23.0 a literal Double, 'A' a Char and "John" a String literal. Scala also supports literals written using:

- hexidecimal preceding the literal with Ox
- Octal preceding the literal with O5=
- Integer ending with L or l is a Long
- Character literals in ' ' e.g. 'A'
- Character literal preceded by\u is a Unicode character e.g. '\u0041'
- Symbol literal is 'aSymbol

16.6 Messages and Message Selectors

16.6.1 Invoking Methods

Invoking a method is often referred to as *sending a message* to the object that owns the method. The expression which invokes a method is composed of a receiving object (the receiver), the method name and zero or more parameters. The combination of method name and parameters is often called the message and it indicates, to the class of the receiving object, which method to execute. Figure 16.2 illustrates the main components of a message expression.

Table 16.6 Operator precedence

Operation	Meaning	Precedence
++x –x	Prefix increment/decrement	16
x++ x--	Postfix increment/decrement	15
−! ~	Arithmetic negation/logical not/flip	14
(typename)	Cast (type conversion)	13
*/%	Multiplication/division/remainder	12
+ −	Addition/subtraction	11
<< >> >>>	Left and right bitwise operators	10
< > <= >=	Relational operators	9
==!=	Equality operators	8
&	Bitwise and	7
^	Bitwise exclusive or	6
|	Bitwise or	5
&&	Conditional and	4
||	Conditional or	3
?:	Conditional operators	2
=	Assignment operator	1

The value of an expression is determined by the definition of the method it invokes. Some methods are defined as returning no value (e.g. `Unit`) while others may return a Value type (such as Int) or instance. In the following code, the result returned by the method `marries` is saved into the variable `newStatus`:

```
newStatus = thisPerson.marries(thatPerson)
```

16.6.2 Precedence

The rules governing precedence in Scala are similar to those in other languages. Precedence refers to the order in which operators are evaluated in an expression. Many languages, such as C, explicitly specify the order of evaluation of expressions such as the following:

```
2 + 5 * 3 - 4 / 2;
```

Scala is no exception. The rules regarding precedence are summarized in Table 16.6. The above expression would be evaluated as:

```
(2 + (5 * 3)) - (4 / 2);
```

Notice that if operators with the same precedence are encountered they are evaluated strictly from left to right.

16.7 Summary

In this chapter and the previous, you have learnt about classes in Scala, how they are defined, how instance variables are specified and how methods are constructed. You have also encountered many of the basic Scala language structures.

Chapter 17
Control and Iteration

17.1 Introduction

This chapter introduces control and iteration in Scala. In Scala, as in many other languages, the mainstay of the control and iteration processes are the `if` and `switch` statements and the `for` and `while` loops.

17.2 Control Structures

17.2.1 The if Statement

The basic format of an `if` statement in Scala is the same as that in languages such as C, Pascal and java. A test is performed and, depending on the result of the test, a statement is performed. A set of statements to be executed can be grouped together in curly brackets {}. For example:

```
if (a == 5)
 println("true")
else
 println("false")


if (a == 5) {
 print("a = 5")
 println("The answer is therefore true")
} else {
 print("a != 5")
 println("The answer is therefore false")
}
```

Of course, the `if` statement need not include the optional `else` construct:

```
if (a == 5) {
 print("a = 5")
 println("The answer is therefore true")
}
```

You must have a *Boolean* in a condition expression, so you cannot make the same equality mistake as in C. The following code always generates a compile time error:

```
if (a = 1) {
 ...
}
```

Unfortunately, assigning a Boolean to a variable results in a boolean (all expressions return a result) and thus the following code is legal, but does not result in the intended behaviour (the string “Hello” is always printed on the console):

```
var a = false
if (a = true)
  println("Hello")
```

You can construct nested `if` statements, as in any other language:

```
if (count < 100)
 if (index < 10)
      {...}
 else
      {...}
else
 {...}
```

However, it is easy to get confused. Scala does not provide an explicit if-then-elseif-else type of structure. In some languages, you can write:

```
if (n < 10)
 print ("less than 10");
else if (n < 100)
 print ("greater than 10 but less than 100");
else if (n < 1000)
 print ("greater than 100 but less then 1000");
else
 print ("greater than 1000");
```

This code is intended to be read as laid out above. However if we write it in Scala, it should be laid out as below:

```
if (n < 10)
 print ("less than 10")
else if (n < 100)
  print ("greater than 10 but less than 100")
 else if (n < 1000)
    print ("> than 100 but < 1000")
  else
    print ("> than 1000")
```

This code clearly has a very different meaning (although it may have the same effect). This can lead to the infamous “dangling else” problem. Another solution is the `switch` statement. However, as you will see the switch statement has significant limitations.

17.2.2 If Returns a Value

Almost all statements in Scala return a result and the if statement is no different. This means that you can use an if statement to determine the value to assign to a value (or pass to a method etc). For example the following code assigns either the string “Dad” or the String “No Data” to the value role defining the the current string referenced by the variable name:

```
val role =
  if (name == "John")
    "Dad"
  else
    "No Data"

println(role)
```

This is a very useful feature of the if statement can be used effectively in many situations.

17.3 Iteration

Iteration in Scala is accomplished using the `for`, `while` and `do-while` statements. Just like their counterparts in other languages, these statements repeat a sequence of instructions a given number of times.

17.3.1 For Loops

A `for` loop in Scala is very similar to a `for` loop in other languages. It is used to step a *variable* through a series of values until a given test is met. Many languages have a very simple for loop, for example:

```
for i = 0 to 10 do
  ...
endfor;
```

In this case a variable I would take the values 0, 1, 2, 3 etc. up to 10. The long hand from of this in Scala is:

```
for (i <- (0).to(10)) {
      print(i)
}
```

Note that in he above *to* is a method call on the Int (integer) type. In practice this is a lower level implementation issue and it would be far more common to write:

```
for (i <- 0 to 10) print(i)
```

This can be done as Scala can infer the brackets and the dot which has the benefit that it will look far more familiar as a language construct to those used to programming languages such as C and Pascal.

One thing to note is that the to operator here includes the value 10 where as in languages such as C and Java it would mean up to but not including 10.

Multiple indexes can be used with a for loop. For example, we could increment I from 1 to 3 and j from 5 to 7:

```
object MultipleForLoopTest extends App {
  for (i <- 1 to 3; j <-5 to 7) {
    print("Value of i: " + i);
    println(" / Value of j: " + j);
  }
}
```

This may not have the effect you expect. This equates to loop the value of I through 1 to 3 for each of the values of j, thus the output is:

```
Value of i: 1 / Value of j: 5
Value of i: 1 / Value of j: 6
Value of i: 1 / Value of j: 7
Value of i: 2 / Value of j: 5
Value of i: 2 / Value of j: 6
Value of i: 2 / Value of j: 7
Value of i: 3 / Value of j: 5
Value of i: 3 / Value of j: 6
Value of i: 3 / Value of j: 7
```

As you can see from this, the value of I remains constant for all values of j and is then incremented for a repeated for the values of j.

17.3.2 For Until

An alternative to the *to* operator is the *until* operator which indicates that a variable i should loop unto but not including the higher bound, thus:

```
for (i <- 1 until 4) println(i)
```

Producers the output:

```
1
2
3
```

But does not include the value 4.

17.3.3 For Loop with a Filter

Another option with the for loop is to include a filter into the looping process. This can be used to *filter* out those elements within a loop that you do not ant to process. A filter is an additional logical test added to the for loop following the iteration values already presented. For example, assuming that the variable files contains some from of list of files, then we can add an extra test to check so that we only print out files where the file name ends with ".txt":

```
for (f <- files if f.getName.endsWith(".txt"))
  println(f)
```

With this loop each file in the list of files is tested such that the name is first obtained (getName) and then the string method endsWith, tests to see if the filename ends with ".txt", if it does then the file is processed by the loop—which in this case involving printing out the file. If the filename does not end with ".txt" then the loop immediately moves onto the name file in the list.

The complete program for this example is shown below:

```
import java.io.File

object FileLoopTest extends App {
   val files = (new File(".")).listFiles
   for (f <- files if f.getName.endsWith(".txt"))
      println(f)
 }
```

Note that any number of if conditions can be added to provide multiple filters on a for loop. Each if condition is separated by a ';', for example:

```
import java.io.File

object FileLoopTest extends App {
   val files = (new File(".")).listFiles
   for (f <- files if f.getName.startsWith("Help");
                if f.getName.endsWith(".txt"))
      println(f)
 }
```

17.3.4 Long Hand for Loop

Although we have looked at a number of different for loops in the preceding sections, they are all subsets of the full for loop which is made up of a generator, an optional definition and a filter. Thus you could write:

```
for (
   p <- persons     ;       // a generator
   n = p.name ;       // a definition
   if (n startsWith "To")     // a filter
) println(n)
```

With the definition being reset each time round a loop

17.3.5 For-Yield Loop

A special for loop is a for-yield loop. It is particular useful for collecting together a set of results from a for loop that can be processed by other code rather then performing the processing directly within the for loop.

That is, the value of the all the previous for loops (from the point of view of the expression being evaluated when the for loop executes) is Unit or nothing. However, using a yield then each time round the loop a *yield* expression can be evaluated and the results of the expression collected together and made available to subsequent lines of code once the for loop has completed.

The general syntax for a for yield loop is:
for (sequence) yield expression
Examples of the use of the for-yield loop are shown below:
val data = for (i <- 1 to 5) yield 10 * i
produces a sequence of values (10, 20, 30, 40, 50) held in the val data
val info = for (n <- List (“one”, “two”, “three”)) yield n.substring (0, 2)
produces a list of values (on, tw, th) held in info

In both cases subsequent code could process either the data variable or the info variable. This is a very powerful construct for creating a collection of data items to be further processed from some loop-based operations.

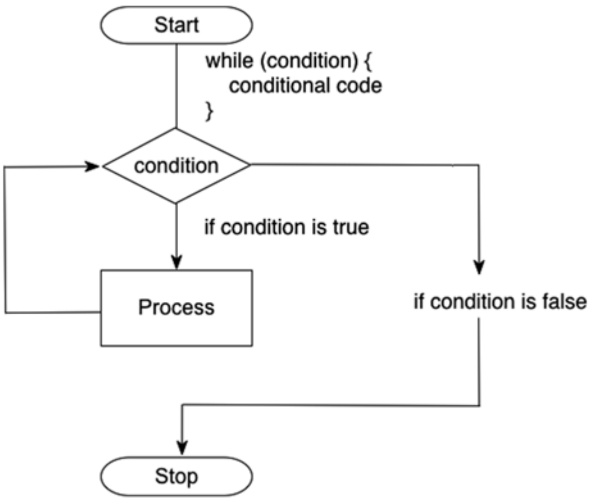


Fig. 17.1 Behaviour of a While loop

17.3.6 While Loops

The while loop exists in almost all programming languages. In most cases, it has a basic form such as:

```
while (test expression)
 statement
```

This is also true for Scala. The `while` expression controls the execution of one or more statements. If more than one statement is to be executed then the statements must be enclosed in curly brackets {}:

```
var i=0;
while (i < 10) {
   println(i)
   i += 1
}
```

The above loop tests to see if the value of *i* is less than or equal to 10, and then prints the current value of *i* before incrementing it by one. This is repeated until the test expression returns false (i.e. `i = 11`).

You must assign *i* an initial value before the condition expression. If you do not provide an initial value for *i,* it defaults to none value and the comparison with a numeric value raises an exception.

The behaviour of the while loop is illustrated in Fig. 17.1.

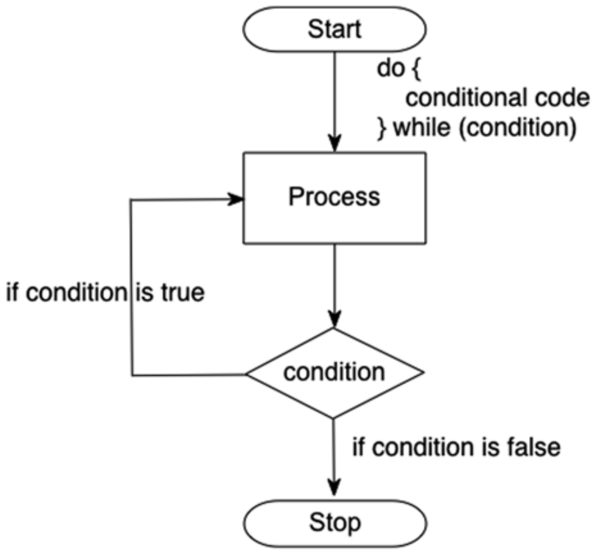


Fig. 17.2 Behaviour of a Do loop

17.3.7 Do Loops

In some cases, we want to execute the body of statements at least once; you can accomplish this with the `do` loop construct:

```
do
 statement
while (test expression);
```

This loop is guaranteed to execute at least once, as the test is only performed after the statement has been evaluated. As with the `while` loop, the `do` loop repeats until the condition is false. You can repeat more than one statement by bracketing a series of statements into a block using curly brackets {}:

```
var n = 10
do {
 println(n)
 n= n - 1
} while (n > 0)
```

The above `do` loop prints the numbers from 10 down to 1 and terminates when n = 0. The logic of the while loop is illustrated in Fig. 17.2.

17.3.8 An Example of Loops

As a concrete example of the `for` and `while` loops, consider the following class. It possesses a method that prints numbers from 0 to the `MaxValue` variable:

```
case class Counter {
  var MaxValue = 10
  def count() = {
    var i = 0
    println("----- For -------------");
    for (i <- 0 to MaxValue) {
      print(" " + i)
    }
    println(" ")
    println("----- While -----------")
    i = 0
    while (i <= MaxValue) {
      print(" " + i)
      i = i + 1
    }
    println(" ")
    println("-----------------------")

  }
}

object Counter extends App {
  val c = Counter()
  c.count
}
```

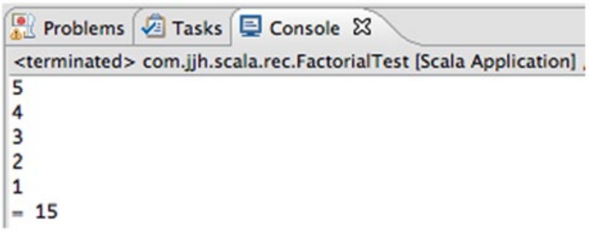
The result of running this application will be:

```
----- For -------------
 0 1 2 3 4 5 6 7 8 9 10
----- While -----------
 0 1 2 3 4 5 6 7 8 9 10
-----------------------
```

17.4 Equality

Two instances may be considered equivalent if their contents is the same. This equivalence is defined by the equals method on a class and is used by the '==' and '!=' operators, where:

== tests for equality
!= tests for not equals



```
<terminated> com.jjh.scala.rec.FactorialTest [Scala Application]
5
4
3
2
1
= 15
```

Fig. 17.3 Running the FactorialTest application

The equality operators are actually invoked on the left hand operand with the right hand operand being passed to the operator as a parameter.

You can compare two instances using == and !=, for example:

- 1 == 2 // false
- 1 != 2 // true
- 1 == 1.0 // true
- List(1, 2, 3) == List(1, 2, 3) // true
- List(1, 2, 3) == "John" // false

Not that there is also a *referential* equality operator in Scala. This is provided by 'eq' method. This method tests that the two instances being compared are literally the same instance rather than just equivalent in value.

17.5 Recursion

Recursion is a very powerful programming idiom found in many languages. Scala is no exception. The following class illustrates how to use recursion to generate the factorial of a number:

```
case class Factorial {
  def factorial(number: Int): Int = {
    println(number)
    if (number == 1)
      return 1
    else
      return { number + factorial(number - 1) }
  }
}

object FactorialTest extends App {
  val f = Factorial()
  println("= " + f.factorial(5))
}
```

The result of running this application is illustrated in Fig. 17.3.

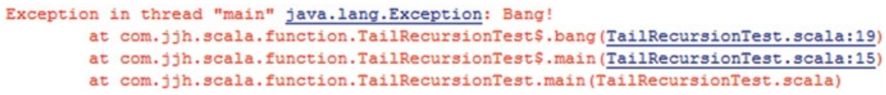
One problem for recursion is that although it is elegant to program it may not be the most efficient rutime solution. However Scala can optimize tail recursive methods such that it can be expressed via recursion in terms of theprogram but optimized into an iterative loop at runtime. Since Scala 2.8 you can now mark a method that you expect to use tail recursion with the annotation @tailrec. An annotation is a piece of metadata that the runtime can use to perform additional processing etc. This allows you to indicate that the method should be optimizable for tail recursion by the compiler. It thus allows the compiler to provide a wanring if the method does not succeed in being tail recursive. For example:

```
package com.jeh.scala.tail

import scala.annotation.tailrec

object Util {
  def factorial(n: Int): Int = {
    @tailrec
    def factorialAcc(acc: Int, n: Int): Int = {
      if (n <= 1) acc
      else factorialAcc(n * acc, n - 1)
    }
    factorialAcc(1, n)
  }
 }
```

To understand why this makes a difference consider the following method:

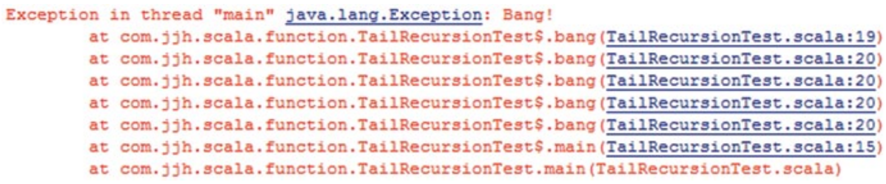
```
package com.jeh.scala.tail

object TailRecursionTest {

  def main(args: Array[String]): Unit = {
    bang(4)
  }

  def bang(x: Int): Int = {
    if (x == 0) throw new Exception("Bang!")
    else bang(x - 1) // +1
  }

}
```

The method bang intentionally throws an Exception (causes an error to occur) when x is Zero. This allows you to see what the compiler has done with the runtime version of the code. With the + 1 element of the else part of the if statement commented out this is a tail recursive method. When we run this program the output is as shown below:



```
Exception in thread "main" java.lang.Exception: Bang!
	at com.jjh.scala.function.TailRecursionTest$.bang(TailRecursionTest.scala:19)
	at com.jjh.scala.function.TailRecursionTest$.main(TailRecursionTest.scala:15)
	at com.jjh.scala.function.TailRecursionTest.main(TailRecursionTest.scala)
```

If we now uncomment the + 1 at the end of the 'if' statement, and rerun this program we now get:



```
Exception in thread "main" java.lang.Exception: Bang!
	at com.jjh.scala.function.TailRecursionTest$.bang(TailRecursionTest.scala:19)
	at com.jjh.scala.function.TailRecursionTest$.bang(TailRecursionTest.scala:20)
	at com.jjh.scala.function.TailRecursionTest$.bang(TailRecursionTest.scala:20)
	at com.jjh.scala.function.TailRecursionTest$.bang(TailRecursionTest.scala:20)
	at com.jjh.scala.function.TailRecursionTest$.bang(TailRecursionTest.scala:20)
	at com.jjh.scala.function.TailRecursionTest$.main(TailRecursionTest.scala:15)
	at com.jjh.scala.function.TailRecursionTest.main(TailRecursionTest.scala)
```

What you can see is that the first version has been converted into a iterative loop which does not need to keep calling itself (which is inefficient at runtime). However, with the second example we have called the same bang method multiple times which has resulted in the need to handle each call separated (set up the call stack for each method invocation) which is far less efficient. Thus knowing whether the recursive method is tail recursive or not is an important consideration.

17.5.1 The Match Expression

Scala's match expression allows for a selection to be made between a number of alternative tests and as such is similar in nature to the case statement in Pascal and C or the Switch statement in java. However, compared to the switch statement in Java is allows much wider pattern matching capability in the case clause of the expression this provides for a far more powerful and flexible construct. Also note that the match expression is an expression (and not just a statement) thus it returns a value and can be used as part of an assignment clause.

The pattern element of the match expression is much more flexible than in languages such as C and Java and can be any one of

- Can be a literal,
- a wildcard (to match anything),
- a type,
- a variable which will be populated,
- of different types,
- tuple patterns etc.

As an example, consider the following simple literal match test:

```
object MatchTest extends App {
    val arg = "John"
    val relationship =
      arg match {
        case "John" => "Dad"
        case "Denise" => "Mum"
        case "Phoebe" => "Daughter"
        case "Adam" => "Son"
          // Default / wildcard
        case _ => "WhoAreYou?"
      }
    println(relationship)
}
```

This example compares the arg varl with the String literals "John", "Denise", "Phoebe" and "Adam". If it is one of these values it returns the string associated with that literal. Thus if arg holds the string "John" then the match expression will return the String "Dad". The result of the match expression is then saved into the relationship val and printed out. If the value held in arg is not one of the strings explicitly mentioned that it will use the default (wildcard) case test. Thus any other string in arg will result in "WhoAreYou?" being returned by the match expression. Note in match expression "_" is being used a s a wildcard that will match any string not mentioned above in the case tests.

However, unlike many other languages the literals used in the individual case tests do not need to be of the same type. For example, the following uses four different types of literal from an Int, to a Boolean, to a String and a empty list (Nil):

```
object MatchTest2 {

  def main(args: Array[String]): Unit = {
    println(describe(5))
    println(describe(true))
    println(describe("hello"))
    println(describe(Nil))
    println(describe(List(1,2,3)))
  }

  def describe(x: Any) = x match {
    case 5 => "five"
    case true => "truth"
    case "hello" => "welcome message"
    case Nil => "The empty list"
    case _ => "something else"
  }

}
```

The type of the parameter x is Any which is the root of everything in Scala and thus x can indeed hold any type of value. We can now use the method *describe* to produce a printed string for any type of value in Scala—although unless it is the value 5, true, "hello" or Nil it will print the description as "something else".

A variable on the last example allows us to use a variable in the case test of the wild card to obtain the actual value passed in and to use that in the expression being evaluated:

```
object MatchTest3 {

 def main(args: Array[String]): Unit = {
    println(describe(5))
    println(describe(true))
    println(describe("hello"))
    println(describe(Nil))
    println(describe(List(1,2,3)))
  }

  def describe(x: Any) = x match {
    case 5 => "five"
    case true => "truth"
    case "hello" => "welcome message"
    case Nil => "The empty list"
    case somethingElseVariable => "something else: " +
somethingElseVariable
  }

}
```

Now when something other than he value 5, true, "hello" or Nil is passed in then the result will be that the string "something else: " concatenated with that thing in string format will be returned by the describe method.

We can also match by type rather than by specific value. For example, in the following example if the type of data passed in is a String then the first case test will pass and the string will be *bound* to the variable s and thus available for processing in the resultant operation associated with that test. In turn if the instance passed in to getSize is a List then it will pass the second test and be bound to the variable l and be available to the operation following this test. If the instance passed to getSize is actually a Map then it will meet the criteria specified by the third case test. The result in each case is that an appropriate method is called to determine the size of the instance passed to getSize. If the instance is not a String, a List or a Map then −1 is returned by default:

```
object MatchTest4 {
  def main(args: Array[String]): Unit = {
    val name = "John"
    println(getSize(name))
    val xxx = List(1, 2, 3)
    println(getSize(xxx))
    val myMap = Map("London" -> 01, "Cardiff" -> 020)
    println(getSize(myMap))
    val otherMap = Map(1 -> "a", 2 -> "b", 3->"c")
    println(getSize(otherMap))
    val lectureMap =
           Map("John" -> "Scala", "Fed" -> "PHP")
    println(getSize(lectureMap))
    val info = (1, 2, 3)
    println(getSize(info))
  }

  def getSize(x: Any) = x match {
    case s: String => s.length()
    case l: List[_] => l.size
    case m: Map[_,_] => m.size
    case _ => -1
  }

}
```

Chapter 18
Traits

18.1 Introduction

In the previous chapters there have already been several references to these things called Traits. For example, we have encountered the App trait numerous times. However we have avoided the question "What are traits?".

In this chapter we will look at the core concepts behind traits and attempt to explain how and why you might want to use them. The next chapter will then explore some more advanced uses and concepts within the area of Traits.

18.2 What are Traits?

Let us start of with what Traits are not:

- They are not Classes or Objects.
- They are not Abstract Classes.
- They are not (Java and C#) Interfaces.
- They cannot be instantiated directly.

However, Traits are part of the type system in Scala. That is a Trait defines a type just as a class defines a type. Thus *vals* and *vars*, properties parameters, return types etc. can all be of a type defined by a Trait and can reference instances (or indeed objects) that mix in a Trait.

They are also a fundamental unit of reuse within the Scala language. If you use Traits appropriately you will find that they allow you to reuse code very elegantly and in a much cleaner way than is possible with Java (or C#) interfaces and abstract classes.

Traits allow you to define methods, functions and properties. They also allow you to define abstract methods, functions and properties. They allow type declarations and can use a self-reference to indicate the types that they expect to be used with. When you define a method, a function or a property they can be made available to the type (Class or Object) that the Trait is used with.

J. Hunt, *A Beginner's Guide to Scala, Object Orientation and Functional Programming,*
DOI 10.1007/978-3-319-06776-6_18, © Springer International Publishing Switzerland 2014

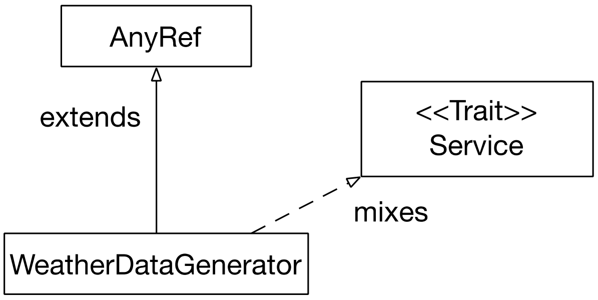


Fig. 18.1 Mixing a Trait into a class

Adding a Trait to a class or object is referred to as *mixing in* a Trait to that type. In fact a class or object can *mix in* any number of traits allowing for a great deal of flexibility and reuse of Traits. This idea is illustrated in Fig. 18.1. In this diagram the class WeatherDataGenerator extends the class AnyRef (the default super class) and mixes in the Trait Service. Thus the WeatherDataGenerator is a reference type and a Service.

You will find many texts refer to a class or object as inheriting form a Trait (partly due to the syntax used with Traits) however I will restrict this terminology to the relationship between one Trait and a sub Trait that directly inherits the features of that Trait. Thus inheritance is possible between Traits and we can use terms such as Super Trait, Trait and Sub Trait to refer to the inheritance relationships between traits. This idea is illustrated in Fig. 18.2.

Note that in Fig. 18.2 the root of the Trait hierarchy is shown as extending *AnyRef*. Prior to Scala 2.10 this was the only option—all traits extended *AnyRef* however, since Scala 2.10 you can also make a Trait extend *AnyVal* that is used for Universal Traits that are discussed later in the chapter.

Also note that a trait can extend one Trait but can mix in any additional traits required using with. This Traits support multiple inheritance rather than single inheritance. It is thus legal to write:

```
trait MyReader extends Immutable with Decorator {
   ...
}
```

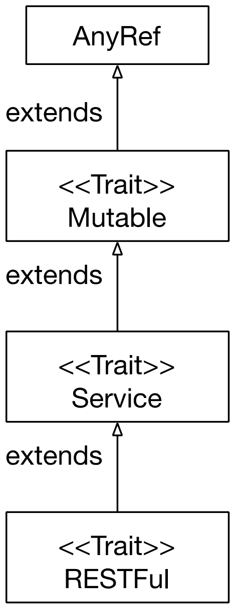
In summary, a Trait is a reuseable type that can be combined with Classes and Objects to provide a very significant form of code reuse in Scala.

18.3 Defining a Trait

A trait is defined by the keyword *trait*, this if followed by the name of the Trait with the body of the trait defined between curly brackets '{.}'.

```
access-modifier trait <name> extends <suber trait> { .. }
```

Fig. 18.2 Trait inheritance hierarchy



Trait definitions can have any number or combination of concrete methods, functions, properties, field, type definitions. It can also have any number or combination of abstract methods, functions and properties. However, Traits do not have constructors (either primary or auxiliary) and may or may not have the extends keyword to indicate inheritance.

A simple example of a trait definition is presented below.

```
trait Model {
  var value: Any

  def printValue() {
    println(value)
  }

  def printer(): Unit
}
```

This trait, called *Model,* defines

- a method *printValue()* that returns *Unit*,
- an abstract property *value* which can hold *Any* type of element but currently is not initialized (and is thus abstract),
- an abstract method *printer()* which returns Unit.

Note that this is not an abstract class (a concept which Scala also supports); it is a Trait that can optionally have concrete (fully defined) methods, functions and properties or abstract methods functions and properties. Any abstract member of the trait will have to be defined either in a sub Trait of this trait, or in a class or object with which this trait is mixed.

Note that in this example all the members (that is the property value and the two methods) are public as this is the default in Scala. However, any member can have either of the encapsulation modifiers applied to them. Thus the methods or the property could be private or protected (and may be qualified).

18.4 Using a Trait

How do you use the trait presented in the last section? You cannot instantiate it directly, you cannot invoke the behaviour defined in it directly; you must mix it into a class or an object.

That is, classes and objects mix in traits such as Model. Any class or object that does this obtains the method *printValue* and must implement the abstract members *value* and *printer*. The key word used to do this differs depending on whether the class or object being used currently extends a named class or not.

If the class or object does not extend a named class then the keyword *extends* is used to indicate the first trait to mix in. If *extends* is already being used to extend a named class then the keyword with is used to indicate the first trait to mix in. Any subsequent traits are always indicated via the keyword *with*.

Thus the generic syntax is actually:

Class <class-name> extends <class or if no class a Trait> with <Trait> with <Trait> …

Object <object-name> extends <class or if no class a Trait> with <Trait> with <Trait> …

The following list illustrates several different combinations:

- `class Course extends Model`—a class with an extends that indicates a trait Model to mix in.
- `class Course extends AnyRef with Model`—a class which explicitly extends the default AnyRef class and mixes in the trait Model.
- `class Course extends Programme with Model`—a class which extends Programme and mixes in the trait Model. Note that without looking at Programme we can not tell whether it is a class or a Trait.
- `class Course extends Model with AwardCeremony`—this is a class with multiple traits. Both Model and AwardCeremony are traits but the first trait is preceeded by extends where as subsequent Traits are preceeded by with.
- `class Course extends Programme with Model with AwardCeremony`. This class extends Programme (a class) and mixes in multiple traits Model and AwardCeremony.

Note that we have used classes above, but the same can be done with Objects. For example:

- `object Course extends Model`—an object that mixes in a single Trait Model.
- `object Course extends Programme with Model`—an object that extends Programme and mixes in Model.
- `object Course extends Model with AwardCeremony`—an object mixing in Model and AwardCeremony.
- `object Course extends Programme with Model with AwardCeremony`—an object that extends Programme and mixes in Model and AwardCeremony.

As a concrete example of this consider the following listing:

```
object Course extends Model {
  var value: Any = "Hello World"
  def printer(): Unit = {println("Hello")}
}
```

This object mixes in the Model trait (even though it uses the extends keyword) and implements the abstract value property and the abstract printer method. It therefore meets the *contract* of the Model trait (which required the two abstract members to be implemented by an *concrete* class or object).

It is now possible to treat the Course object as either a Course or as a Model, for example:

```
object TraitTest extends App {
  val c = Course;
  c.printValue()
  val m: Model = c
  println(m.value)
}
```

This simple test application assigns the Course object to the *val* ‘c’ and then invokes the *printValue* method on ‘c’ (of course we could also have invoked it directly on the Course object). We then assign c to the *val* ‘m’ that is of type Model (we have explicitly stated that in the declaration of m). This is perfectly legal because in terms of the Scala type system, a Course is also a Model.

Of course we are not limited to do this with objects, we could also use a class declaration, for example:

```
class Degree extends Model {
  var value: Any = "B.Sc."
  def printer(): Unit = {println("Degree Award")}
}
```

This class mixes in the Model trait into the class Degree and as before this means that it must implement the value property and the printer method (otherwise we would be defining an *abstract* class which would require us to prefix the class keyword with the keyword abstract and would mean that we could not instantiate the class).

The following listing shows how you can instantiate the *Degree* class and treat it as a *Degree* type or a *Model* type (or indeed an *AnyRef* or *Any* type):

```
object DegreeTest extends App {
   val d = new Degree()
   d.printer
   val m: Model = d
   m.printer
}
```

18.5 Abstract Trait Members

The members of a trait (that is the properties, types, methods and functions defined within a trait) can be abstract (as illustrated in the Model trait. The following Sample trait illustrates an abstract type T, an abstract method transform and two abstract properties; a read only (val) initial and a read-write (var) current.

```
package com.jjh.scala.abs

trait Sample {
  type T
  def transform(x: T): T
  val initial: T
  var current: T
}
```

The implementing class (or object) must provide implementations for all the abstract members:

```
class Car extends Sample {
  type T = String
  def transform(x: T) = x + x
  val initial = "first"
  var current = initial
}
```

This class defines a concrete type String for the type T (which can then be used within the rest of the trait). It also provides an implementation for the transform method that takes a parameter of type T (String) and concatenates it to itself. It also sets initial to the string “first” and current to the value set in initial.

18.6 Dynamic Binding of Traits

There is another way in which you can combine a trait with a class. It is possible to mix in a trait at the point that an instance of a given class is created. For example, given the class Person that contains a *name* property and an override of the *toString* method defined as follows:

```
class Person(val name: String) {
  override def toString = "Person[" + name + "]"
}
```

We can also define a trait Logger that defines a single method log that prints out a “Created” string and runs the Log method whenever anything it is mixed with is instantiated (the invocation of the Log method):

```
trait Logger {
  log
  def log = println("Created")
}
```

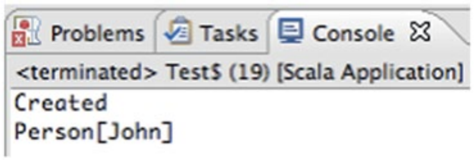
The trait Logger can be mixed into an instance of the class Person dynamically when that instance is created by combining the call to *new* with an additional reference to the trait via the *with* keyword. The syntax for this is:

```
new <classname>(<params>) with <traitname>
```

For example:

```
object Test extends App {
  val p = new Person("John") with Logger
  println(p)
}
```

As you can see form this we are creating a new instance of Person and mixing in Logger at the same time. Thus the instance referenced by the val ‘p’ is both a Person type and a Logger type. It combines the behaviour and data in these types together. The result of running this application is shown below:



```
<terminated> Test$ (19) [Scala Application]
Created
Person[John]
```

From this you can see that when we created the new instance the log method was run as part of the freestanding code executed when the instance was created. This resulted in the String “Created” being printed out. When the method println was invoked on the contents of ‘p’ the resulting version of toString (invoked by println) was that define din the Person class and hence Person[John] was printed out. Thus we have indeed combined to two together at the point of instantiation.

18.7 Sealed Traits

A sealed trait is a trait that can only be used within the file that it is defined within. That is only the classes and objects within the same file as the sealed trait can mix in that trait. It can also only be extended by traits in the same file. For example:

```
package com.jjh.scala.qanda

sealed trait Answer
object Yes extends Answer
object No extends Answer
```

Note that the trait Answer can be used as the type of a variable or a value within other packages—but it cannot be extended or mixed in elsewhere. Therefore in a package com.jjh.scala.test you can reference the type and use it as the type for vars or vals to hold the singleton instances of Yes and No. For example:

```
package com.jjh.scala.test

import com.jjh.scala.qanda.Answer
import com.jjh.scala.qanda.Yes
import com.jjh.scala.qanda.No

object AnswerTest extends App {
   var a: Answer = Yes
   println(a)
   a = No
   println(a)
}
```

18.8 Marker Traits

A marker trait is a trait that declare no methods, functions, types or properties. Instead it is used to indicate additional semantics of a type (class, object or further traits). For example see the scala.Mutable and scala.Immutable traits; these are marker traits indicating the semantics of mutability and immutability.

Marker traits can be used where:

- it is useful to semantically indicate a role or concept that other entities may play with the application. However, these entities may be of varying types (from classes, to objects to further traits) and may inherit behaviour from various different places in the type hierarchy.
- semantically there is a common concept, but there is little or no common behaviour or data representation between the concrete implementations of the generic domain concept.
- client classes may need to know something about the type of an object without actually needing to know the specific type (at least at the interface level).

Using a trait, as the basis of a marker, is particularly convenient in Scala as a type may mix in any number of traits. For example, the following code defines two marker traits, one called Decorator and one called Service.

```
package com.jjh.scala.marker

trait Decorator

trait Service
```

Any type can implement one or more traits, thus any type can implement a marker trait and any other traits as required. For example:

```
trait MyReader extends Immutable with Decorator {
def read: Int
}
```

Semantically this tells us that *MyReader* is a type of Decorator and that it is Immutable.

18.9 Trait Dependencies

When you mix a trait into another type you may want to be able to invoke functionality form the host type. This can be done by defining a *self* reference. A *self reference* ties one type to another type which will be provided at a future point in time. This means that the *this* value can be used to access another types behaviour and data. That is the type it will be mixed into must be of a particular kind and thus the trait you are defining can rely on certain data or behaviour being provided by the host type in the trait.

For example, let us assume that we have defined a class Service:

```
class Service {
  def printer: Unit = println("Service Hello")
}
```

We will then define a class Client that takes an Adaptor type. The method *doWork* invokes the method invoke on the adapter.

```
class Client(adapter: Adaptor) {
  def doWork = adapter.invoke
}
```

Let us assume that we have initially written the Adaptor type as follows:

```
trait Adaptor {
  def invoke: Unit
}
```

However, we would like to use an instance of Service with the Client class. But currently the Service type does not implement an invoke method and the Adapter trait defines an abstract invoke method.

Ideally we want to link the Adaptor to the Service types. There are various ways in which we could do this but the core issue is that currently there is no link between the Service type and the Client type. To solve this problem we will use a self reference in the Adapter type. This allows us to define a trait that can only be used with Service types (and subtypes)

This trait defines a method invoke to use the method printer (provided by the Service type). Thus we can guarantee that the trait Adapter will be used with a Service or a subtype of Service (whether that is a class or an object). Therefore the method printer will be available to wherever the Adapter trait is used.

```
trait Adaptor {
  self: Service =>
  def invoke = printer
}
```

We can then mix this trait into a Service either dynamically at the point of use or statically with the Service in a new type. For example, the following example dynamically binds Adaptor into Service when an instance of the Service class is created. It then passes this to the Client class as a (compatible) parameter. We can then invoke the doWork method.

```
object Test extends App {
  val adpator = new Service() with Adaptor
  val client = new Client(adpator)
  client.doWork
}
```

Alternatively we could have defined a new sub type (AdaptedService) of the class Service that also mixes in the Adapter trait.

```
class AdaptedService extends Service with Adaptor
```

We can now use instances of this type with the client—the only difference to the previous example is that we have statically defined a new type that combines the Service class with the Adaptor trait that can be reused in multiple situations.

```
object Test2 extends App {
  val adpator = new AdaptedService()
  val client = new  Client(adpator)
  client.doWork
}
```

18.10 To Trait or not to Trait

It is worth considering when you should define a trait and when you might define a class. The general set of guidelines on when something should be a trait include:

- If behaviour or data will not be reused—then implement that behaviour or data as a concrete class.
- If behaviour or data might be reused in multiple, unrelated classes, then make it a trait.
- If efficiency is of ultimate importance lean towards a class.
- If it is a reusable concept for a root of a class hierarchy use an abstract class.
- If you want to use it in Java code use an abstract class.
- If you want to model domain concepts to be implemented by different classes in different ways then use Traits.

Chapter 19
Further Traits

19.1 Introduction

This chapter looks at some of the more advanced features associated with the use of traits. The chapter looks at the way in which Traits can be dynamically wrapped around an instance providing a form of Aspect Oriented Programming (AOP) known as stackable traits. We then look at the role Traits can play in developing reusable behaviour that simplifies the development of new types. Universal traits used with Value Types are then discussed. The chapter concludes by considering the way in which traits can be used to define a restricted set of values for a given type.

19.2 Stackable Modifications

Traits can be stacked one on top of another when an instance of a class is created. Each stacked trait can override the behaviour of the trait it is stacked on top of. This allows the trait to either replace some of the behaviour of that trait, or wrap additional behaviour around that trait. This idea is illustrated in Fig. 19.1.

As an example, the following code defines an abstract trait AbstrctProcessor. It is abstract because it defines an abstract method update that takes an Int and returns Unit. This trait is mixed into the class BasicProcessor. This class defines the update method as setting the amount property defined on the class.

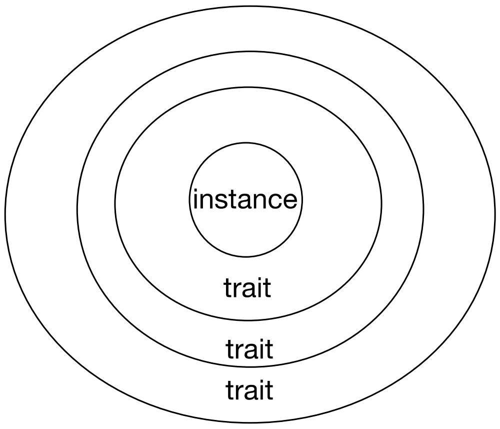


Fig. 19.1 Traits wrapping around an instance

```
package com.jjh.scala.processor

trait AbstractProcessor {
   def update(x: Int)
}

class BasicProcessor(var amount: Int)
                   extends AbstractProcessor {
  def update(x: Int) = amount = x
  override def toString = "BasicProcessor: " + amount
}

object Test extends App {
  val p = new BasicProcessor(0)
  p.update(5)
  println(p)
}
```

The simple test harness class creates a new BasicProcessor using the initial value 0 and then updates it to 5 and prints out the result. The result of executing this program is:

```
BasicProcessor: 5
```

We could new define a Trait *Doubling* that also extends the AbstractProcessor trait. Note that the update method in this trait states that it overrides any other definitions but that it is also abstract. That is, it expects to build on something that it will be mixed into at a later date which is expected to be able to provide the remainder of the behaviour of the update method. This allows it to invoke the super.update

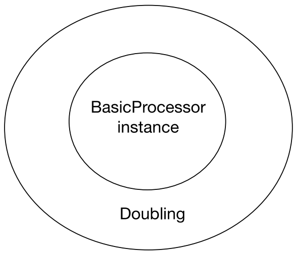


Fig. 19.2 A doubling trait wrapping around a BasicProcessor instance

method. Here super means the next version of update in the stack of traits wrapping the concrete instance of a class (or indeed that concrete instance).

```
trait Doubling extends AbstractProcessor {
  abstract override def update(x: Int) {
    super.update(2 * x)
  }
}
```

Note if the method is not marked as abstract it cannot invoke the super version of the update method.

This trait can be mixed into the BasicProcessor when that BasicProcessor is instantiated, which results in the Doubling Trait wrapping around the BasicProcessor as shown in Fig. 19.2.

The following listing illustrates how the Test application is modified to *stack* the Doubling trait onto the BasicProcessor:

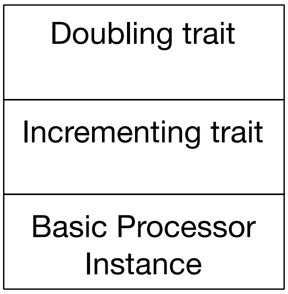
```
object Test extends App {
  val p = new BasicProcessor(0) with Doubling
  p.update(5)
  println(p)
}
```

The result of running this program is:

```
BasicProcessor: 10
```

As you can see from this the value 10 is now being stored in the BasicProcessor—thus the Doubling traits version of update is being invoked which results in the interger being doubled before being passed on down the line to the update method defined on the BasicProcessor instance.

Fig. 19.3 Stacking traits on top of the BasicProcessor instance



This can be taken further, we could define additional traits such as Filtering and Incrementing that either filter the value to be updated or add one to the value being updated. For example:

```
trait Incrementing extends AbstractProcessor {
  abstract override def update(x: Int) {
    super.update(x + 1)
  }
}

trait Filtering extends AbstractProcessor {
  abstract override def update(x: Int) {
    if (x > 0) super.update(x)
  }
}
```

We can now combine these traits in various ways and in different orders. For example:

```
object Test extends App {
  val p = new BasicProcessor(0) with Incrementing with
Doubling
  p.update(5)
  println(p)
}
```

The effect of this is that the Doubling trait is stacked on top of the Incrementing trait, which is stacked on top of the BasicProcessor. This idea is illustrated in figure Fig. 19.3.

The end result of executing the above program is shown below:

```
BasicProcessor: 11
```

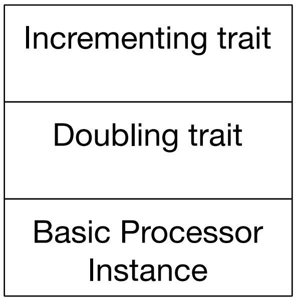


Fig. 19.4 Changing the order in which the traits are stacked

Where as this version results in a different output:

```
object Test extends App {
  val p = new BasicProcessor(0) with Doubling with
Incrementing
  p.update(5)
  println(p)
}
```

The result this time is:

```
BasicProcessor: 12
```

This is because in one example the value is doubled and then incremented by one and in the second example it is incremented first and then doubled. Thus you can see that the order in which the traits are added is significant (with the last trait being the one that is accessed first). Thus the above listing can be represented as shown in figure Fig. 19.4.

Finally, we can also include the filtering Trait to decide if anything is to be done wit a value at all:

```
object Test extends App {
  val p = new BasicProcessor(10) with Doubling with
Incrementing with Filtering
  p.update(0)
  println(p)
}
```

Where the attempt to update the BasicProcessor instance to zero is vetoed by the Filtering trait and thus the output from this program is:

```
BasicProcessor: 10
```

Note that the AbstractProcessor could also have been an abstract class rather than a Trait, however from a design point of view it is cleaner to have the AbstractProcessor as a Trait.

Of course we are not just limited to mixing in stackable traits when a instance of an class I created. We could also have defined a new type with the base class and the stackable traits mixed together. For example:

```
class  DoublingProcessor  extends  BasicProcessor  with
Doubling {..}
```

19.3 Fat versus Thin Interfaces

There is a continual tension in software between the richness of an interface offered by a component or library and implementation and maintenance effort required for such an interface. This is because although 9 in theory) a rich interface is better fro client applications a simpler interface is easier to develop and maintain. Ideally we want the best of both world; minimum effort for the developer of the component and maximum utility for the user of the component. Traits allow methods to be constructed based on existing implementations.

For example, the Ordered Trait defined in the scala.math package is a trait for data that have a single natural ordering. Class or traits that implement this trait inherit a range of concrete method such as <, <=, >, >= etc. which rely on a method compare. However the method compare is an abstract method that is expected to return an integer depending on the value being compared. This method must be provided by a concrete trait, class or object. The definition of the method is:

```
abstract def compare(that: A): Int
```

This method returns the result of comparing the current instance with the operand *that*.

The method returns a value ‘x’ where:

- x < 0 when *this* < *that*
- x == 0 when *this* == *that*
- x > 0 when *this* > *that*

For example, if we wished to create a new Balance class, which supported basic Ordering and comparison type behaviour, we could do this by mixing in the Ordered trait, as shown below.

```
package com.jjh.scala.financial

import scala.math.Ordered

class Balance(val amount: Double) extends
Ordered[Balance] {
   def compare(that: Balance): Int = (this.amount -
that.amount).toInt
}
```

The result is that although the code we have written is quiet light as have obtained a rich interface. For example the range of operations available on the currency instance are shown in:

```
package com.jjh.scala.financial

object Test extends App {
  val b1 = new Balance(20.0)
  val b2 = new Balance(25.0)
  println(b1.<(b2))
  println(b1.<=(b2))
  println(b1.>=(b2))
  println(b1.>(b2))
  println(b1.compare(b2))
}
```

Thus the Balance class has a rich interface but has a simple implementation. The majority of the comparison behaviour is mixed in from the trait (such as the <, > methods) but they build on a concrete implementation of the compare method.

19.4 Universal Traits

Scala's rules for inheritance do not permit value classes to mx in traits that extend from AnyRef. Prior to Scala 2.10 all traits eventually extended AnyRaf, and thus traits could not be mixed into a Value class. However, since Scala 2.10 traits can optionally extend Any instead of AnyRef. This must be specified explicitly when the trait is defined. Such a Trait is known as a Universal trait as it can be mixed into all types of classes from reference types to value classes. This permits value classes to extend traits (as long as they are Universal traits).

When a Universal trait is mixed into a value class then they allow inheritance of methods for the value class but they do not incur the overhead of heap allocation and referencing.

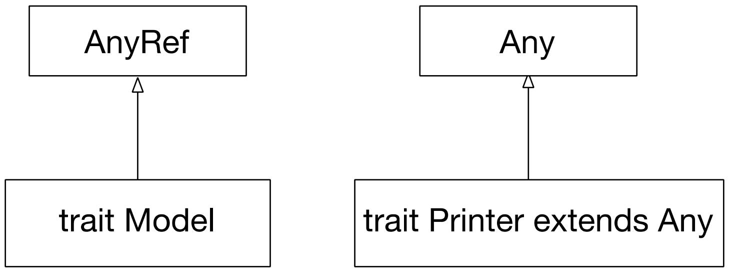


Fig. 19.5 Trait inheritance

The following trait Printable is a Universal trait as it explicitly specifies the parent type as Any. It is then used with the Value class Wrapper (which merely wraps around the underlying type Int) and extends AnyVal and mixes in Printable.

```
package com.jjh.scala.universal

/**
 * Universal Trait - does no allocation
 * and extends Any.
 */
trait Printable extends Any {
  def print(): Unit = println(this)

}

/**
 * Value class that wraps an Int.
 */
class Wrapper(val underlying: Int)
          extends  AnyVal with Printable

/**
 * Test App
 *
 */
object Main extends App {
  val p: Printable = new Wrapper(32)
  p.print()
}
```

Note that if you do not explicitly specify Any as the super type of a Trait then that trait still defaults to extending AnyRef. Thus in figure Fig. 19.5 the trait Model is a Trait as it (by default extends) AnyRef and the trait Printer is a Universal trait as it explicitly extends Any.

This also has some implications for further inheritance. If we have a Universal Trait *Equals* (which explicitly extends Any) and a sub trait Ordered that extends

Equals, then the effect is that the trait Ordered *by default* extends the class AnyRef and *mixes in* the trait Equals. The end result is that this is not a Universal Trait:

```
trait Equals extends Any { … }

trait Ordered extends Equals{ … }
```

To turn Ordered into a Universal Trait then you must explicitly specify that Any is the super class of Ordered as follows:

```
trait Ordered extends Any with Equals { … }
```

The trait Ordered is now explicitly a Universal trait.

19.5 Traits for a Data Type

Although Scala has an enumeration type this implies a specific ordering where as in some cases we merely want to define a set of associated values. For example, if we wished to create a set of values for traffic lights then we might wish to create values for Red, Yellow and Green. However, there is no specific ordering; just these values. We could use a trait to help define the objects used to represent the traffic light colours. For example:

```
package com.jeh.scala.traits

trait TrafficLight

case object Red extends TrafficLight
case object Yellow extends TrafficLight
case object Green extends TrafficLight
```

In this case the trait TrafficLight has been defined but contains no data elements or behaviour (other than the defaults inherited from AnyRef). It is then used to create a set of objects, Red, Yellow and Green. Note that these are case *objects* indicating that all the values associated with TrafficLights are defined in the same file and thus Red, Yellow and Green can be used safely within pattern matching statements with the compiler able to indicate if all conditions are being accounted for.

As an example of using these values the following test harness creates a set of *vals* for each colour and can be used to print out the results and test fro equality etc.

```
object Test extends App {

  val c1 = Red
  val c2 = Yellow
  val c3 = Red

  println(Red)
  println(c1 equals c2)
  println(c1 equals c3)

}
```

This is a commonly recurring idiom in Scala.

Chapter 20
Arrays

20.1 Introduction

This chapter discusses how arrays are represented in Scala. Arrays are (logically) a continuous set of slots that can hold values or references to instances of a specific type.

20.2 Arrays

Arrays in Scala are objects, like most other data types. Like arrays in any other language, they hold elements of data in an order specified by an index. They are zero based arrays, as in C, which means that an array with 10 elements is indexed from 0 to 9.

To create a new array, you must specify the type of array object and the number of elements in the array. The Array type defines *array* like behaviour in Scala. The type of element held in the Array is indicated within a set of square brackets after the Array. The number of elements is specified by an integer between round brackets. As an array is an instance, it is created in the usual way using the new operation:

```
new Array[String](10);
```

This creates an array capable of holding ten String objects. We can assign such an array instance to a variable by specifying that the variable holds an array. You do this by indicating the type of the array to be held by the variable along with the array indicator. Notice that we do not specify the number of array locations that are held by the array variable:

```
val myArray:Array[String]
var names: Array[String]
```

Both of the above define variables which can held a reference to an array of Strings. However, neither state how large the array object being referenced will be. This is

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not a problem as myArray and names will only hold a reference to (or an address of) an array. The reference is the same size whatever the length of array being pointed to.

We now create an array and assign it to our variable:

```
val myArray: Array[String] = new Array[String](3)
```

We could also have used the shorter from relying on type inference for the myArray val:

```
val myArray = new Array[String](3)
```

There is a short cut way to create and initialize an array:

```
val myArray  =  Array("John",  "Denise",  "Phoebe",
"Adam")
```

This relies on both Scala to infer the type of the myArray val and for Scala to use a factory method (called apply) to construct the array. You can use the apply factory method directly if you wish, thus the above is semantically exactly the same as:

```
val myArray2  =  Array.apply  ("John", "Denise",
"Phoebe", "Adam")
```

Both of the above create an array of four elements containing the strings "John", "Denise", "Phoebe" and "Adam". We can change any of these fields by specifying the appropriate index and replacing the existing value with a new string:

```
myArray.update(o) = "Isobel"
```

This causes the zeroth element of the myArray to be updated to the String "Isobel". This is a common enough operation that a short hand from exists that automatically invokes the update method for you:

```
myArray(3) = "Isobel"
```

The above statement replaces the string "Adam" with the string "Isobel". Merely being able to put values into an array would be of little use; we can also access the array locations in a similar manner:

```
myArray.apply(0)
```

This retrieves the current value held in the array referenced by myArray. Once again this is a common enough operation that a short hand (and more commonly used variant) is available:

```
myArray(0)
```

This can be used to retrieve the *zeroth* value in the array. For example:

```
println("The name in position 2 is " + myArray(0));
```

The above statement results in the following string being printed:

```
The name in position 2 is John
```

As arrays are objects we can also obtain information from them. For example, to find out how many elements are in the array we can use the instance variable `length`:

```
myArray.length
```

Arrays are fixed in length when they are created, whereas vectors can change their length. To obtain the size of an array, you can access instance variable, `length`, but you must use a method, `size`, to determine the current size of a vector.

Arrays can be passed into and out of methods very simply by specifying the type of the array, the name of the variable to receive the array and the array indicator.

20.2.1 Arrays of Objects

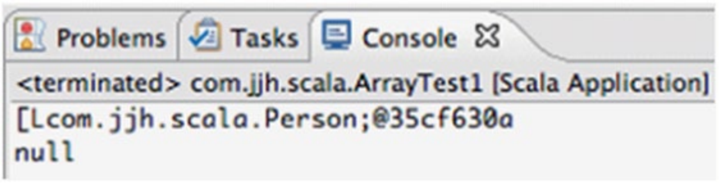
The above examples have focussed on arrays of Strings, however you can also create arrays of any type of object but this process is a little more complicated (it is actually the exactly the same for strings, but some of what is happening is hidden from you). For example, assuming we have a class Person, then we can create an array of Persons:

```
val pa : Array[Person] = new Array[Person](4)
```

Figure 20.1 illustrates the result of creating an array of Person instances. It is important to realize what this gives you. It provides a variable *pa* that can hold a reference to an array object of Persons. At present this array is empty and *does not* hold references to any instances of Person. For example, if you now print out the value of pa and the value of pa(0), that is:

```
println(pa)
println(pa(0))
```

You will get:



```
<terminated> com.jjh.scala.ArrayTest1 [Scala Application]
[Lcom.jjh.scala.Person;@35cf630a
null
```

Note that this indicates that the array is actually an array of references to the instances "held" in the array as opposed to an array of those instances. This illustrated in the first part of Fig. 11.1. To actually make it hold instances of Person we must add each person instance to the appropriate array location. For example:

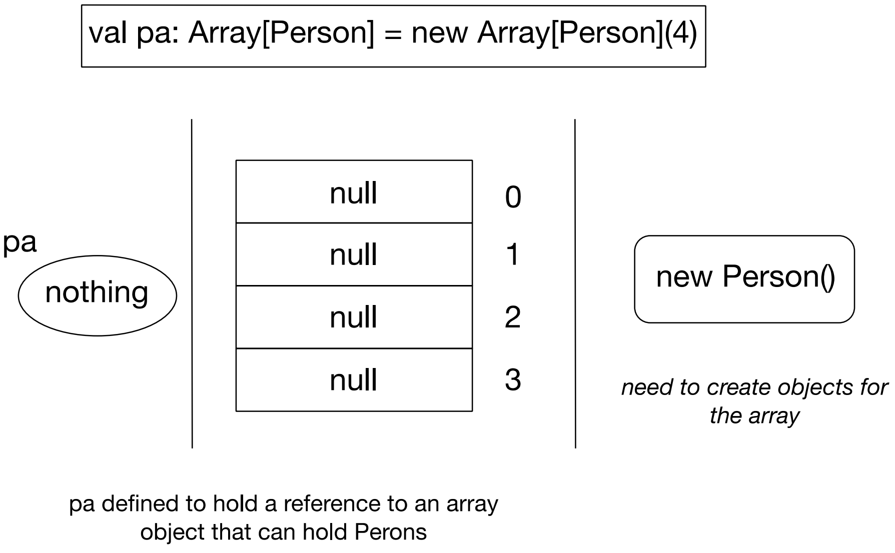

val pa: Array[Person] = new Array[Person](4)
pa
nothing
null
null
null
null
0
1
2
3
new Person()
need to create objects for the array
pa defined to hold a reference to an array object that can hold Perons

Fig. 20.1 Creating an array of objects

```
pa(0) = new Person()
pa(1) = new Person()
pa(2) = new Person()
pa(3) = new Person()
```

This is illustrated in the last part Fig. 20.1 and 20.2. Thus the creation of an array of objects is a three-stage process:

1. Create a variable that can reference an array of the appropriate type of object.
2. Create the array object.
3. Fill the array object with instances of the appropriate type.

20.2.2 Ragged Arrays

As in most high-level languages multi dimensional arrays can be defined in Scala. This is done in the following manner:

```
val fa = Array(Array("John", "Denise", "Phoebe", "Adam"),
               Array("Paul", "Fiona", "Andrew") )
```

Pictorially this can be viewed as shown in Fig. 20.3.

As can be seen from this example, two-dimensional arrays in Scala are actually Array objects holding references to other Array objects. Thus in this case, the first array is an array of two elements (0 and 1). The type of these elements is an Array of Strings. The first array element 0 holds a reference to another array object (one that

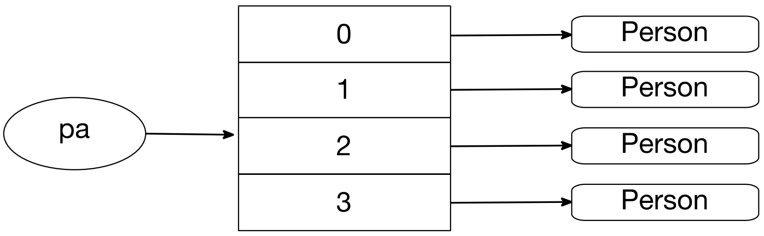


Fig. 20.2 The complete array structure

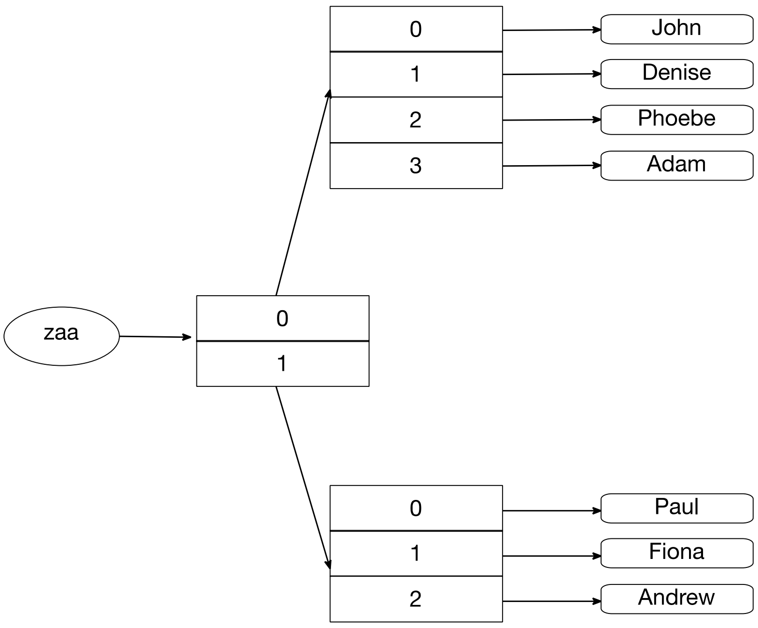


Fig. 20.3 A ragged array

holds Strings) etc. This means that the structure created can be ragged—that is the second dimension in this example is not the same across the two sub arrays—one is of length 4 and one is of length 3.

Thus if you create these arrays and object for the Person class then we would:

1. Define the val *paa* as hold a reference to an array of arrays

```
val paa: Array[Array[Person]]
```

2. Create the multi-dimensional array

```
val paa: Array[Array[Person]] =

                    new Array[Array[Person]](2)
```

Note we have to specify the first dimension as it is necessary to allocate enough space for the required references. We do not have to specify the second dimension as these can be specified in the subsequent array object creation messages.

3. Create the sub arrays:

```
pa(0) = new Array[Person](4)

pa(1) = new Array[Person](3)
```

4. We are now ready to add instances to the two dimensional array, for example:

```
pa(0)(0) = new Person("John")
```

As you can see from this last example, multi-dimensional arrays are accessed in exactly the same way as single dimensional arrays with one indices following another (note each is within its own set of round brackets—()). That is you can access this two dimensional array by specifying a particular position within the array using the same format:

```
println(matrix(2)(2))
```

Note that the way that multi-dimensional arrays are implemented in Scala means that you can easily implement any number of dimensions required, for example:

```
val zaa = Array(
            Array(
              Array("John", "Denise", "Phoebe", "Adam"),
              Array("Paul", "Fiona", "Andrew")),
            Array (
            Array("Darren", "Val")))
```

This defines a three-dimensional array structure containing two 2 dimensional arrays. This is illustrated by Fig. 20.4.

20.3 Creating Square Arrays

Of course, although it is possible to create raged arrays in Scala, it is far more common to create square arrays, for example, a 2 by 2 or a 3 by 3 array. To do this the Array type provides a factory method *ofDim* that can be used to create an array of an appropriate dimensions, for example:

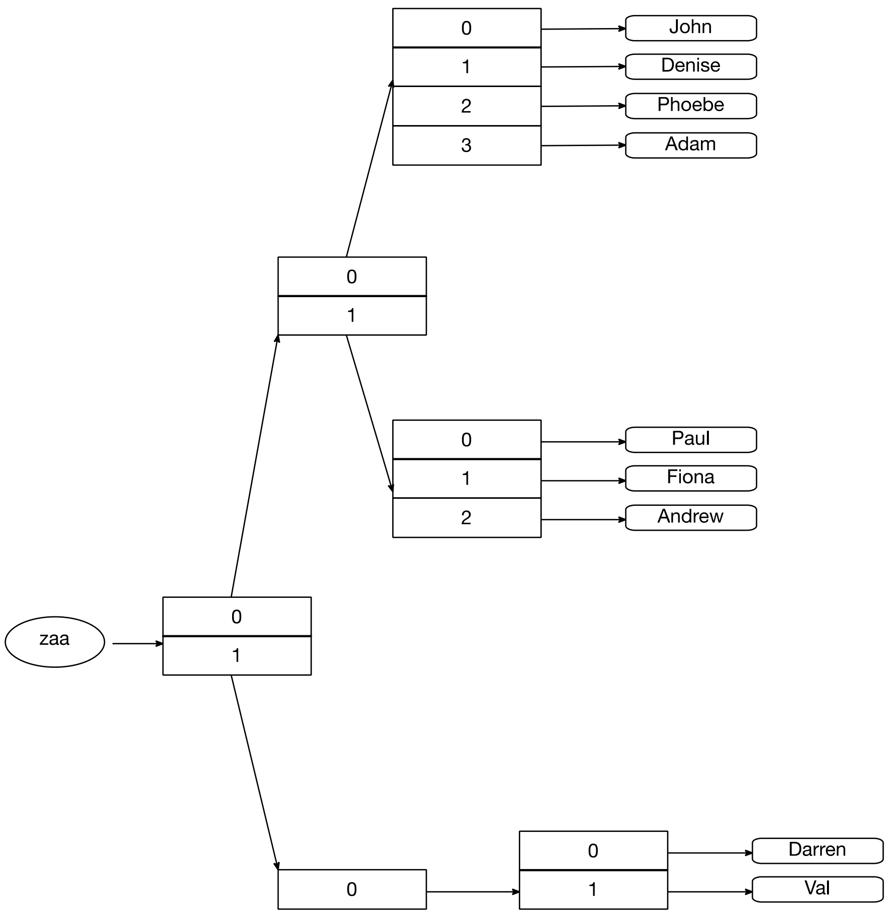


Fig. 20.4 A multi-dimensional ragged array

```
val array = Array.ofDim[Int](3, 2)
```

This creates a two dminesionally array of size 3 by 2 that can hold Int types. This following statements:

```
println(array.length)
println(array(0).length)
println(array(1).length)
println(array(2).length)
```

produce this output

```
3
2
2
2
```

Of course this populates the array of Ints with a set of Zeros. If you wish to initialise such and array with other default values then you can use the fill factory method on the Array type:

```
val myArray = Array.fill(2, 2, 2)(2.0)
println(myArray(0)(0)(0))

produces

2.0
```

This creates a three dimensional array with all the elements of the array populated with the Double value 2.0

20.4 Looping Through Arrays

You can use a loop to process the contents of an array. For example, given an array myArray containing three strings:

```
val myArray = Array("Zero ", "One ", "Two")
```

We can loop through the element sin that array in a number of ways. For example, we can use the length fo the array and an index to access each element in turn, for example:

```
for (i <- 0 to myArray.length -1)
println(myArray(i))
```

In this example the loop variable ‘I’ ranges from 0 to one less than the length of the array. This is because the array contains three strings, with indexes, zero, one and two! This is important if you try and access the element with the index ‘3’ (which is the fourth element in the array) you will get an index out of bounds exception generated—that is your program will generate an error!

The result of running this program is

```
Zero
One
Two
```

However, the problem with this approach is that you must remember to ensure that you loop from zero to one less than the length of the array (otherwise you will not access the elements of the array you expect and you will generate a runtime error). An alternative approach is to loop through each of the elements in turn applying a function to those elements. This is actually an example of functional programming and uses the *foreach* function defined on the Array type. For example:

```
object ArrayTest2 extends App {
  val myArray = Array("Zero ", "One ", "Two")
  myArray.foreach(x =>println(x))
}
```

With this approach the *foreach* function takes element in turn and *binds* it to the variable x above. It then executes the body of the behaviour provided (in this case println(x)). The end result is the same as before:

```
Zero
One
Two
```

However, it is a better (and simpler) abstraction of processing each of the element sin the array.

20.5 The Main Method Revisted

At this point you are ready to review the parameter passed into the main class method. As a reminder, it always has the following format:

```
object MainTest {
   def main(args: Array[String]): Unit = {
     ...
   }
}
```

From this you can see that the parameter passed into the main method is an array of strings. This array holds any command line arguments passed into the program.

We now have enough information to write a simple program that parses the main method command line arguments:

```
object ParseInput {
  def main(args: Array[String]): Unit = {
     println(args.length)
     require (args.length > 0)
     for (i <- args) {
       println("Argument is " + i)
      }
   }
}
```

This is a very simple program but it provides the basics for a command line parser. Do not worry if you do not understand the syntax of the whole program, we cover `if` statements and `for` loops later in the book.

Arrays in Scala are passed into methods by value. However, as parameters only hold a reference to the objects they contain, if those objects are modified internally, the array outside the method is also modified. This can be the cause of extreme frustration when trying to debug programs. Arrays can also be returned from methods:

```
modifiers methodName: type (...)

def returnNames: Array[Person] () {

 ...

}
```

As an example of an array-based application, consider the following application `ArrayDemo`, which calculates the average of an array of numbers. This array is created in the ArrayDemo application and is passed into the `processArray` method as a parameter. This method is defined on the class ArrayProcessor.

Within this method, the values of the array are added together and the total is divided by the number of elements in the array (i.e. its length):

```
class ArrayProcessor {
  def   processArray(myArray: Array[Int]): Unit = {
    var   total = 0
    var   average = 0
    for (i <- myArray) total = total + i
    average = total / myArray.length
    println("The average was: " + average)
  }
}
object ArrayDemo extends App {
    val processor = new ArrayProcessor()
    val intArray = Array(1, 4, 7, 9)
    processor.processArray(intArray)
}
```

Chapter 21
Tuples

21.1 Introduction

In this chapter we introduce Scala tuples, which are a useful (and very simple construct) for grouping instances together.

21.2 Tuples

Tuples are container style objects that can hold multiple types of instances. Examples of some simple tuples are presented below:

- (49, “John”) //a 2 element tuple
- (49, “John”, “Hunt”, 12.75) //a 4 element tuple
- (“John”, 76, Invoice(123)) //a 3 element tuple

As can be seen from these examples, tuples can hold different types of elements (where as an array instance holds a set of the same type such as Strings, Ints, Doubles or Persons etc.). The first example tuple presented here is:

- (49, “John”)

This holds an Int and a String. The first element in the tuple is of type Int and the second is of type String. The second example is a three element tuple:

- (49, “John”, “Hunt”, 12.75)

In this example, the first element is of type Int, the second of type String, the third again of type String and the fourth of type Double. In fact it is possible to define tuples with 1 to 22 elements in them.

21.3 Tuple Characteristics

Tuples exhibit a number of characteristics that are worth noting. Tuples

- Are container style objects
- Are immutable sequences of instances
- Can contain objects of different types (unlike lists and arrays)
- Are useful if you need to return more than one object from a method
- Are not collections as they don't support the *normal* collection style methods
- Allow access to their contents via a dot (.) notation.
- Can be simply created without the need for the new keyword
- Are backed by specific Tuple classes

21.4 Tuple Classes

Each tuple is backed by a class named Tuple followed by the number of elements in the tuple. For example:

(42, "Denise")—is an example of a Tuple2 instance
("John")—is an example of a Tuple1 instance
(49, "John", "Hunt", 12.75)—is an example of a Tuple4 instance

In actual fact there are classes named for all the different combinations of Tuple from 1 to 22, for example:

Tuple1, Tuple2, Tuple3,… Tuple21, Tuple22

Mostly this fact is hidden from you as a programmer but it is worth being aware of. Essentially when you create a new tuple example, an instance of the appropriate type is created with each of the elements used to infer the type to use for those positions. Thus,

("Pete", 21)

Tells Scala to create an instance of the Tuple2 type with the first element set to String and the second element set to Int types.

21.5 Creating a Tuple

There are a number of different ways in which you can create a new Tuple. The long hand from is to create a Tuple of the correct type and use type parameterization to indicate the types to use for each position. For example:

```
val t=new Tuple2[Int, String](1, "John")
```

This creates a new instance of the Tuple2 type with the first element being of type Int and the second element being of type String. The actual values held by the tuple instance are then 1 and "John".

This is a bit long winded for Scala and thus a shorter from of the above allows the types to be inferred by Scala. For example the above can be written without the type parameterization information as:

val t=new Tuple2 (1, “John”)

Now Scala infers that the first element is an Int and the second element is a String from the values being held by the tuple (namely 1 and “John”).

However, this is still a bit repetitive for Scala. Given that we are creating a tuple and there are two elements Scala can infer that what we are creating is a Tuple2 instance. Therefore we do not need to include the name of the type being instantiated. We also do not need to include the keyword *new*. Thus the previous example can be reduced to:

val pair=(1, “John”)

This creates an instance of the Tuple2 class with the first value of type Int and set to 1 and the second element of type String and set to “John”.

Similarly we could write:
val t=(48, “John”, “Hunt”, 12.75)

Which creates an instance of the Tuple4 class with the types being Int, String, String and Double respectively.

The very shorted from of the Tuple syntax is to use the ‘->’ syntax. For example:

val pair2=1 -> “John”

Which again creates a Tuple2 instance containing 1 and “John” with the first element of type Int and the second element of type String.

21.6 Working with Tuples

Once you have created a tuple using one of the forms described in the previous section you can access information about the tuple as well as the information held in the tuple. For example, to access the size of the tuple you can use productArity:

```
val tuple = (47, "John", "Hunt", 12.75)
// Length of a tuple
println(tuple.productArity)
```

The output of this program is 4.

To access the individual elements within a tuple we can use the “._<n>” notation where <n> indicates the position or element to be accessed, for example:

```
val tuple = (47, "John", "Hunt", 12.75)
println(tuple._1)
println(tuple._2)
println(tuple._3)
println(tuple._4)
```

Note that the index used for accessing Tuples is one based (where as that used for Arrays and Lists is Zero based). As Typles are immutable there is no way to update an element within a tuple. However we can make a copy of a tuple and while making a copy change one of the values. For example:

```
val tuple = (47, "John", "Hunt", 12.75)
println(tuple)
println(tuple.copy(_2 = "Bob"))
```

The output of this program is:

```
(47,John,Hunt,12.75)
(47,Bob,Hunt,12.75)
```

21.7 Iterating over a Tuple

If you want to iterate over a tuple then you can obtain a product iterator built on top of your tuple. A product iterator provides a wrapper that can access each element in a tuple in turn. A function can then be applied to each element in turn. Thus we can write a simple tuple iterator that will print out the value sin our tuple one at a time.

```
tuple.productIterator.foreach{x => println(x)}
```

This states that we want to create an iterator over the contents of the tuple and then for each of the elements produced apply the function that takes a single parameter (x) and applies the println(x) method. A shorthand from of this can imply the parameter as it is only used to temporarily pass a given element in the tuple to the *println* method. We can therefore infer this in Scala and write the following (where the under bar '_' represents a placeholder for the parameter x):

```
tuple.productIterator.foreach{ println _ }
```

The output of either of the above versions of the *foreach* operation is:

```
47
John
Hunt
12.75
```

21.8 Element Extraction

It is also possible to extract the values held in a tuple using simple matching variables. For example, given a tuple t1 containing two elements an Int and a String we can extract them as follows:

```
val t1 = (1, "John")
val (a, b) = pair
println(a + ": " + b)
```

Here the *val* ‘a’ is of type *Int* and the *val* ‘b’ is of type *String*. The *val* ‘a’ will hold 1 and the *val* ‘b’ will hold a reference to the string “John”. The output of this program is thus:

```
47: John
```

Chapter 22
Functional Programming in Scala

22.1 Introduction

This chapter examines the functional programming features of Scala and looks at how they can be used while the next chapter will look at concepts such as Currying and Partially Applied functions.

22.2 Scala as a Functional Language

In Scala Functions are *first class* language constructs just as Classes and Objects and Value Classes are first class language types. That is Functions are part of the type system in Scala, a variable can be defined to hold a reference to a function and functions can be assigned to *vals* and *vars*. They can be passed into methods, constructors and other functions as parameters etc. They are top-level entities that act as independent units or entities within the language. They can of course be evaluated in which case they are executed and will take in some data as parameters and return a result etc.

That is, functions are like instances or values, and can be:

- Assigned to variables,
- Passed as parameters to functions,
- Returned as results of functions
- Written as function literals

In addition they can be evaluated which results in the function being executed.

Functions should have *referential integrity* and this is true of Scala functions just as much as it is true of functions in pure functional languages. Given the same set of inputs, a function should produce the same set of outputs every time. It should thus be possible to replace the function call with the result (at least in theory).

Thus a Scala function should only transform its inputs into its outputs and should have no (hidden) side effects. That is, it should not change the state of the system nor should it be involved in any state based behaviour.

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22.3 Defining Scala Functions

A function definition can be anonymous as it defines a type and this it is an entity in its own right. For example, the syntax for a anonymous function definition is:

```
(parameter list) => {func body}
```

An example of a function definition (or functional literal) is:

```
(x: Int) => { x * x}
```

This defines a function that takes an Int and returns and int where the body of the function is defined as x * x. The signature of this function (sand thus its type) is

- (Int): Int

That is, it takes a single parameter of type Int and returns an Int.

Note that this function definition matches the criteria we specified for functions—the function takes in a single Int and returns a value derived purely based on this parameter (it multiples itself by itself). We could thus replace it by its result.

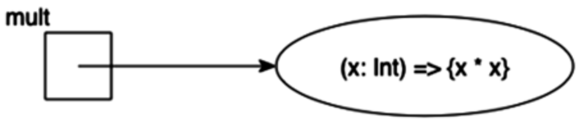
As it stands it is of limited value as the function merely defines a new function. However we can assign this to a local variable or to a property. Once we have done this we can invoke the function via that variable or property. As a very simple example consider the following same application:

```
object FunctionTest1 extends App {

  val mult = (x: Int) => { x * x}

  println(mult(2))
  println(mult(4))

}
```

The result of running this simple application is:

```
4
16
```

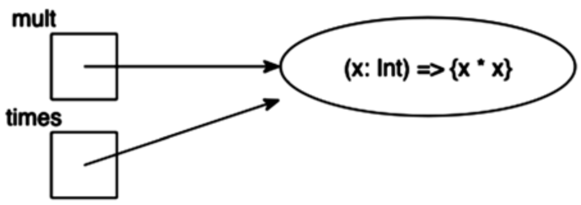
In this example within the object FunctionTest1 we have defined a finction (x:Int) => {x * x} and assigned that function to mult. In essence we have the following:



This illustrates that a function is an entity within the language rather than just some code held within an object (as is the case for methods). This means we can also assign the function referenced by mult to another variable, thus we could write:

```
val mult = (x: Int) => {x * x}
val times = mult
```

We could now have:



We can thus access the function via either mult or times.

In the earlier example application we accessed the function via the val mult, for example:

```
println(mult(2))
```

The result of this expression is that the function referenced by mult is evaluated by passing in the value 2. This value is bound to the variable x and the body of the function is executed. Which results in the expression 2 * 2 being processed resulting in 4 being returned by the function. This is then passed to the println method and printed out to the console.

Notice that we could now also have written

```
println(times(2))
```

And the same function would have been evaluated. Although in reality mult and times reference the same function definition, the effect is that mult and times are aliases for the same functionality.

As another example, consider the following lines of code.

```
var increase = (x: Int) => x + 1
var y = 1
println("Initial value of y: " + y)
y = increase(y)
println("Increased y: " + y)
```

In this block of code a variable *increase* is defined that references a function. This function takes an Int and adds one to whatever value is passed into it. As the '+' operator returns a result this is used as the value returned by the function. In this case a variable y has an initial value 1 assigned to it. The result generated by the function referenced by the *increase* variable is then assigned to y.

Note that as *increase* is a var we can reassign to it—thus we can change the function referenced by *increase*, for example:

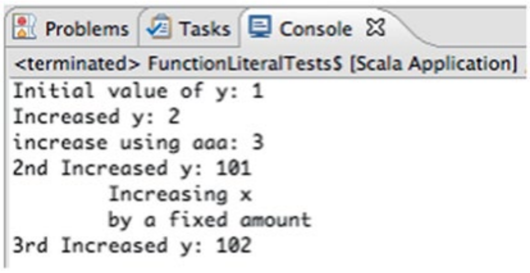
```
increase = (x: Int) => x + 99
y = increase(y)
```

The variable increase now references a function that adds 99 to the integer passed to it. Thus if we invoke *increase* it now appears that its functionality has changed. Be careful of do this indiscriminately as it can make programmes harder to understand and debug.

The above samples are grouped together in the following listing as a set of worked examples:

```
object FunctionLiteralTests extends App {

    // Functional literals can be assigned to variables
    // Note last value assigned is returned as result of
    // function - return type inferred
    var increase = (x: Int) => x + 1
    var y = 1
    println("Initial value of y: " + y)
    y = increase(y)
    println("Increased y: " + y)
    // Can also assign to another identifier
    val aaa = increase
    println("increase using aaa: " + aaa(2))
    // Because increase is a var you can re-assign it
    increase = (x: Int) => x + 99
    y = increase(y)
    println("2nd Increased y: " + y)
    // Can also fundamental change what it is
    // Note can't assign to the parameter X they are vals
    increase = (x: Int) => {
      println("\tIncreasing x")
      println("\tby a fixed amount")
      x + 1
    }
    y = increase(y)
    println("3rd Increased y: " + y)

}
```

The result of executing this simple application is shown below:



```
<terminated> FunctionLiteralTests$ [Scala Application]
Initial value of y: 1
Increased y: 2
increase using aaa: 3
2nd Increased y: 101
        Increasing x
        by a fixed amount
3rd Increased y: 102
```

22.4 Class, Objects and Methods

Classes and Objects can define both methods and functions. In many cases you can ignore the difference between the two, they are just parts or members of the class or object, however the differences can be summarized as:

- A method defines behaviour which is tied to the class or object and which can be invoked via the dotation and
- A function defines an operation held by the class or object that can be invoked via the dot notation.

For example:

```
class Calculator {

  def max(x: Int, y: Int): Int = {
    if (x > y) x else y
  }

  val increment = (x: Int) => x + 1

}

object Test1 extends App {
  val c = new Calculator()
  val a = c.max(2, 3)
  println(a)
  val b = c.increment(3)
  println(b)
}
```

In the above listing we have defined a class Calculator that defines both a method `max` and a function `increment`. From the client of the class Calculator they look the same. They can both be both invoked via the dot natation, for example:

```
val a = c.max(2, 3)
val b = c.increment(3)
```

However, the way in which they were defined gives a hint to the differences. The method is an integral part of the definition of the class Calculator. The method is literally part of the fabric of that class. In contrast `increment` is a read-only val property which holds a reference to the function (x: int) => x + 1. This means that the function referenced by the property could be assigned to another variable, for example:

```
 val alias = c.increment
println(alias(4))
```

When we execute these lines the result is

```
5
```

Such assignment of functionality is not available for methods (as they are not separate entities in the way that functions are). This also means that functions can be passed as parameters into other functions or `method` etc.

The above example uses a class to define the method `max` and the function `increment`. We could also have defined them within an object, for example:

```
object Math {

  def max(x: Int, y: Int): Int = {
    if (x > y) x else y
  }

  val increment = (x: Int) => x + 1
}

object FunctionTest extends App {
  // Can invoke methods
  println(Math.max(2, 3))
  // Can invoke functions
  println(Math.increment(3))
  // Can use named parameters
  println(Math.max(x = 2, y = 3))
  println(Math.max(y = 3, x = 2))
}
```

Although this is now an object, everything that was said about methods and functions for classes is also true for methods within an Object. Thus the max method is an integral part of the object Math, where as increment is a read-only property holding a reference to a function, that increments the value passed to it.

22.5 Closure

One question that might well be on your mind now is what-happens when a function references some data that is in scope where it is defined but is no longer available when it is evaluated? This question is answered by the implementation of a concept known as closure.

Within Computer Science (and programming languages in particular) a closure (or a lexical closure or function closure) is a function (or more strictly a reference to a function) together with a referencing environment. This referencing environment records the context within which the function was originally defined and if necessary a reference to each of the non-local variables of that function. These non-local or free variables allow the function body to reference variables that are external to the function but which are utilised by that function. This referencing environment is one of the distinguishing features between a functional language and a language that supports function pointers (such as C).

The general concept of a lexical closure was first developed during the 1960s but was first fully implemented in the lanacgue Sceme in the 1970s. It has since been used within many functional programming languages including LISP, ML and Scala.

At the conceptual level, closure allows a function to reference a variable available in the scope where the function is originally but not available by default in the scope where it is executed.

For example, in the following simple programme, the variable more is defined outside the body of the function referenced by increase. This is permissible as the variable is defined within the body of the main method of the ClosuresTest object, as is the function. Thus the variable more is *within scope* at the point of definition.

```
object ClosuresTest {

  def main(args: Array[String]): Unit = {
     var more = 100;
     val increase = (x: Int) => x + more
     println(increase(10))
     more = 50
     println(increase(10))
  }

}
```

Within the main method we then invoke the *increase* method by passing in the value 10. This is done twice with the variable more being reset to 50 between the two. The output from this program is shown below:

```
110
60
```

Note that it is the *current* value of more that is being used with the function executes and not the value of more present at the point that the function was defined. Hence the out is 110 and 60 that is 100 + 10 and then 50 + 10.

This might seem obvious as the variable more is still in scope within the same method as the invocations of the function referenced by *increase*. However, consider the following example:

```
object ClosureTest2 {

  var increment = (x: Int) => x + 1

  def main(args: Array[String]): Unit = {
    println(increment(5))
    resetFunc()
    println(increment(5))
  }
  def resetFunc() {
    // Local variable is bound and stored on the heap
    // as it is used within the function body
    var addition = 50;
    increment = (a: Int) => { a + addition }
  }

}
```

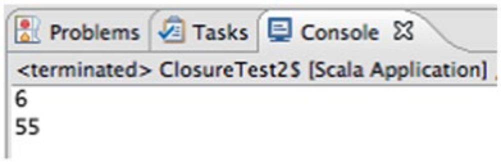
In the above listing a property *increment* holds a reference to a function. Initially the function being referenced adds 1 to whatever value has been passed to it. In the main method this function is called with the value 5 and the result returned by the function is printed. This will be the value 6.

However, after this a second method, resetFunc() is invoked. This method has variable that is local to the method. That is, *normally* it would only be available within the method resetFunc. This variable is called addition and has the value 50.

The variable *addition* is however, used within the method body of a new function definition. This function takes an integer and adds the value of addition to that integer and returns this as the result of the function. This new function is then assigned to the property *increment*.

Now, when the second invocation of increment occurs, back in the main method, the resetFunc() method has terminated and *normally* the variable addition would no longer even be in existence. However when this program runs the value 55 is printed out from the second invocation of increment. That is the function being referenced by *increment* when it is called the second time in the main method is the one defined within resetFunc() and which uses the variable addition.

The actual output is shown below:



```
<terminated> ClosureTest2$ [Scala Application]
6
55
```

So what has happened here? It should be noted that the value 50 was not copied into the second function body. Rather it is a concrete example of the use of a reference environment used with the closure concept. Scala ensures that the variable addition is available to the function, even if the invocation of the function is somewhere different to where it was defined by binding any free variables (those defined outside the scope of the function) and storing them so that they can be accessed fro the functions context (in effect moving the variable from the local stack to the heap).

Chapter 23
Higher Order Functions

23.1 Introduction

Functions in Scala are part of the type system. That is, they are part of the system of entities that comprise the types that variables and parameters can reference. Thus just as a parameter can be of type Int, or Boolean, or Person a parameter to a method or a function can be another functions. A function that takes a function as a parameter is referred to as a *Higher-Order* Function. This chapter discusses Higher-Order Functions and how they can be used and provides some examples taken from the collection classes in Scala.

23.2 Higher Order Function Concepts

In Scala Higher-Order Functions are functions that do at least one of the following (and may do both):

- Take as a parameter one or more functions
- Return as output a function

All other functions in Scala are first-order functions.

Many of the functions found in the collection classes such as *map*, *foldLeft*, *foldRight* and *forEach* are higher order functions. It is a common enough pattern that once you are aware of it you will recognise it in many different classes and objects.

As an abstract example, consider the following higher order function *apply*. This function (written in pseudo code) takes an integer and a function. Within the body of the function being defined the function passed in as a parameter is applied to the integer parameter. The parameter function takes an integer and returns a Double. The result of the function being defined is then returned:

```
define apply(x: Int, func: (Int)=>Double): Double
begin
  result = func(x)
return result
end
```

The function *apply* is a higher order function because its behaviour (and its result) will depend on the behaviour defined by another function—the one passed into it.

We could also define a function that multiplies an integer by 10.0, for example:

```
define mult(y: Int): Double
begin
  return y * 10.0
end
```

Now we can use the function *mult* with the function *apply*, for example:

```
apply(5, mult)
```

This would return the value 50.0

23.3 Scala Higher Order Functions

The key to understanding how higher order functions are defined is to understand that a function definition defines a function type. That is a type that takes zero or a set of parameters (of given types) and returns a result. Thus the function:

```
(x:Int)=>x*2
```

Is a one parameter function that takes an Int and returns a Int—that is its type. Thus the

```
(Parameter type list)=>return type
```

Defines a new Function type.

Thus a parameter that expects to be given a reference to a function that takes an Int and returns an Int can be given a reference to any function that takes an Int and returns an Int. Thus all of the following functions meet that criteria

```
(x: Int) => 1
(y: Int) => y
(a: Int) => a * 2
(x: Int) => x * x
```

All of the above could be used with the following higher order function:

```
object Processor {
  val apply = (n: Int, f: Int => Int) => f(n)
}
```

For example:

```
println(Processor.apply (10, f1))
```

This is actually also true for methods. For example the following is a higher order method, where the second parameter is a function:

```
object Processor {
  def apply(n: Int, f: Int => Int) = f(n)
}
```

For example:

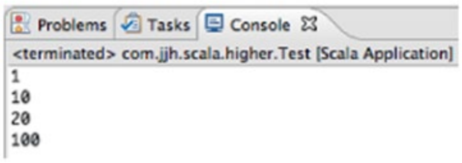
```
println(Processor.apply(10, f1))
```

Notice that as previously mentioned, from the invoking clients point of view there is little different between a function and a method.

The following listing provides a complete set of the earlier sample functions and how they may be used with the apply function:

```
object Processor {
  val apply = (n: Int, f: Int => Int) => f(n)
}
object Test extends App {

    val f1 = (x: Int) => 1
    val f2 = (y: Int) => y
    val f3 = (a: Int) => a * 2
    val f4 = (x: Int) => x * x

    println(Processor.apply(10, f1))
    println(Processor.apply(10, f2))
    println(Processor.apply(10, f3))
    println(Processor.apply(10, f4))

  }
```

The output from this program is:



```
<terminated> com.jjh.scala.higher.Test [Scala Application]
1
10
20
100
```

23.4 Using Higher Order Functions

Looking at the previous section you may be wondering why you would want to use a higher-order function or indeed why define one. After all could you not have called one of the functions (f1 to f4) directly by passing in the integer to used? Yes we could have, for example we could have done:

```
f4(10)
```

And this would have exactly the same effect as calling:

```
Processor.apply(10, f4)
```

The first approach would seem to be both simpler and more efficient.

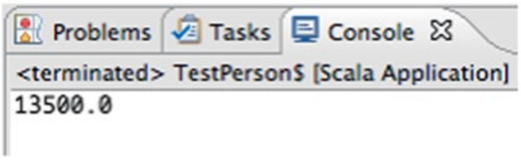
The key to why higher-order functions are so powerful is to consider what would happen if we know that some function should be applied to the value 10 but we do not yet know what it is. The actual function will be provided at some point in the future. Now we are creating a reusable piece of code that will be able to apply an appropriate function to the data we have when that function is known.

For example, let us assume that we have a Person class. This person class has a salary property. However, we do not know how to calculate the tax that this person must pay as it is dependent on external factors. The `calculateTax` method could take an appropriate function that performs that calculation and provides the appropriate tax value to be stored.

The following listing implements this approach. The class Person itself does not have a way of calculating the tax, this must be provided as a parameter to the `calculateTax` method. The function passed in takes a Double and returns a Double. It is used with the salary property to determine the `taxToPay` property.

```
class Person(val salary: Double) {
    var taxToPay = 0.0
    def calcuateTax(calculator: (Double) => Double) {
      taxToPay = calculator(salary)
    }
}

object TestPerson extends App {
  val taxCalculator = (x: Double) => Math.ceil(x * 0.3)
  val p = new Person(45000.0)
  p.calcuateTax(taxCalculator)
  println(p.taxToPay)
}
```

The TestPerson object defines a new function that takes a double and multiplies it by 0.3 and then uses the Math.ceil function to round it up to a whole number. This function is stored into the taxCalculator local val variable. It then creates a new instance of the Person class specifying a salary of 45,000. The calculateTax method is called passing in the taxCalculator function. Finally it prints out the tax calculated for the person. The result of running this program is:



```
<terminated> TestPerson$ [Scala Application]
13500.0
```

Thus the class Person is a reusable class that can have different tax calculation strategies defined for it.

23.5 Higher-Order Functions in Scala Collections

The place that you are most likely to encounter higher-order functions in Scala, at least when learning Scala, is within the Scala collection classes. Two examples are the filter method and the foreach method. These are both higher-order functions defined on the Class List. A List is an ordered sequence of values (and will be discussed in greater detail later in this book).

The definition of the filter method is:

```
def filter(p: (A) => Boolean): List[A]
```

That is, the method takes a single parameter. This parameter is a type of function that takes a single parameter and returns a Boolean. The whole method (filter) itself returns a new List. The ‘A’ in the above is a placeholder for the type held by the List to which filter will be applied (for example a list of Strings, or a List of Ints etc.).

The filter method selects all elements of the list that satisfy the predicate function p. The function p is used to test all the elements in the List. Those that return *true* are included in the list of values returned. The result returned is a new list consisting of all elements of this list that satisfy the given predicate p. The order of the elements is preserved.

The definition of the `foreach` method is:

```
def foreach(f: (A) => Unit): Unit
```

The `foreach` method applies a function ‘f’ to all elements of the list in turn. Any result generated by the function ‘f’ is discarded.

The following listing illustrates creating a list and applying simple functions to `filter` and `foreach`. Note the examples illustrate the different ways in which the functions to be applied can be defined:

```
object HigherOrderFunctionTests extends App {
  // Can use as function literals with various Scala
  // libraries that provide higher-order functions
  var list = List(1, 2, 3, 4)
  // Filter is a higher order function that takes the
  // function to be used to filter the contents of a list
  var list2 = list.filter((x: Int) => x > 2)
  println(list2)
  // Short hand forms for function literals
  // e.g. 'target typing' this allows parameter type to be
  // inferred here because it is being applied to a
  // list of integers
  list2 = list.filter((x) => x > 2)
  println(list2)
  // Can also write this without the parentheses
  list2 = list.filter(x => x > 2)
  println(list2)
  // Place holder syntax - allows for the variable
  // x itself to be implied
  list2 = list.filter(_ > 2)
  println(list2)
  // Place holder extreme!
  list.foreach(x => println(x))
  // Can replace whole parameter list and
  // expression with underscore
  list.foreach(println _)
  // But Scala can imply the underscore so can
  // just write
  list.foreach(println)
}
```

Chapter 24
Partially Applied Functions and Currying

24.1 Introduction

This chapter looks at two ways in which functions (and in fact methods) in Scala can comprise components of reuse within a software system. These two approaches are partial application of functions and Currying. The two approaches represent variations on a theme. In both cases they allow a function with one or more parameters to be have one or more of those parameters bound to a specific value to create a new function with one or more fewer variables.

At an abstract level, consider having a function that takes two parameters. These two parameters, x and y are used within the function body with the multiply operator in the form x * y. For example, we might have:

```
operation = (x, y) => x * y
```

This operation might then be used as follows

```
total = operation(2, 5)
```

Which would result in 5 being multiplied by 2 to give 10. Or it could be used:

```
total = operation(10, 5)
```

Which would result in 5 being multiplied by 10 to give 50.

If we needed to double a number we could thus reuse operation many times, for example:

```
operation(2, 5)
operation(2, 10)
operation(2, 6)
operation(2, 151)
```

All of the above would double the second number. However, we have had to remember to provide the 2 so that the number can be doubled. However, the number

2 has not changed between any of the invocations of operation. What if we fixed the first parameter to always be 2, thus would mean that we could create a new function that apparently only takes one parameter (the number to double). For example, let us say we could write something like:

double = operation(2, *)

Such that we could now write:

double(5)

double(151)

In essence double is an alias for operation, but an alias that provides the value 2 for the first parameter and leaves the second parameter to be filled in by the future invocation of the double function.

This is essentially what Scala provides, although it has two mechanisms through which this style of parameter binding can be implemented. The two approaches are Partially Applied functions and Currying.

Note that what is said in the rest of this chapter for functions is also true for methods. The only difference is that methods are always part of the class or object in which they are defined. However it is possible to partially apply and currying both functions and methods.

24.2 Partially Applied Functions

A Partially Applied function in Scala is a function where one or more of its parameters have been *applied or bound* to a value, resulting in the creation of a new function one fewer parameters than the original. For example, let us create a function operation based on the example presented above in Scala.

```
val operation = (x:Int, y: Int) => x * y
```

This operation does exactly what the previous example did. It takes two parameters and multiples them together. We can thus invoke it in the normal manner:

```
println(operation(2, 5))
```

The result of executing this statement is:

```
10
```

However, we can bind the first parameter to 2 so that it will always double the second parameter and store the resulting function reference into a property double. For example:

```
val double = operation(2, _: Int)
```

Double now references a function that takes one parameter an Int. Note that the '_' underbar indicates that this is a placeholder for future values and that the type that will be used with this placeholder is Int. This allows for overloading of functions and distinguishing between such overloading (overloading relates to functions with the same names but different parameter types).

To invoke this function we merely need to provide the parameter value to be double, for example:

```
println(double(5))
```

The result of executing this line is once again:

```
10
```

It is also possible to have more than one parameter bound and more than one parameter left unbound. These parameters can be inter mixed with any parameter in any position being bound or unbound as required.

The following listing shows a simple summation function that takes three integered and adds them together. It also shows a situation where the first and the third parameter are bound and the resulting function assigned to the val partialSum. The function referenced by partialSum takes a single int and adds the value passed in to the values 1 and 3.

```
 var sum = (a: Int, b: Int, c: Int) => a + b + c
println(sum(1, 2, 3))

val partialSum = sum(1, _: Int, 3)
println(partialSum(2))
```

The result of executing this listing is:

```
6
6
```

Partially Applied functions are very useful for creating new functions from existing functions. The other approach is Currying which is described below.

24.3 Currying

24.3.1 Introduction to Currying

An alternative approach to partially applied functions is to use a technique/pattern known as Currying in the Scala/Functional world. The name Currying may seem obscure but the technique is named after Haskell Curry (for whom the Haskell programming language is named).

Currying allows new *language* structures to be created. The language features can resemble normal function invocations or can resemble language constructs. This allows the constructs developed to be presented to client code as if they are merely an extension to Scala (which in many ways they are). For example, structures such as:

```
transaction {
  …
}
```

can be created where transaction is a function that has been curried such that it is linked to an appropriated database etc.

A curried function is a function that is applied to *multiple* argument lists (in contrast a Partially applied function have one argument list). Note that functions can have one or more parameter lists.

24.3.2 Defining Multiple Parameter List Functions

All the function examples we have seen so far have used a single argument list with multiple parameters. For example this function takes two parameters (x and y) and multiplies them together. It is used with println in this example to print out eh result of multiplying 2 and 3:

```
class Basic {
  def basicSum(x: Int, y: Int) = x + y
}

object BasicTest extends App {
  val test = new Basic
  println(test.sum(2, 3))
}
```

In Scala we can re-write this function as a multiple argument function, on which case each argument list takes a single argument. The arguments can still both be used in the body of the function (and thus we can still multiple x and y together):

```
package com.jjh.scala.curry

class CurryTest {
  def sum(x: Int)(y: Int) = x + y
}

object CurryTest extends App {
  val test = new CurryTest
  println(test.sum(2)(3))
}
```

Both of these functions return the value 6 and both allow you to pass in two parameters to the function. However, in effect the second version results in two functions invocations back to back. It is a bit like chaining two functions together. The first function invocation takes a single Int parameter x and returns a function value for the second function. The second function takes the Int parameter Y and applies it to the first functions result.

24.3.3 Using Curried Functions

Why is this useful? It is because we can provide a value to use for the *first* function before we wish to provide a value for the *second* function. As the result of providing the value for the first function is to return a function value to use with the second we can essentially *store* that functions and its subsequent invocation for later use. For example, given the following function definition in the class CurryTest:

```
package com.jjh.scala.curry

class CurryTest {
  def sum(x: Int)(y: Int) = x + y
}
```

This function has multiple argument lists and could be called directly as shown above.

However we could *curry* the function such that we provide the first argument but not the second. Note that in comparison with Partially Applied Functions where any argument can be applied, when Currying it is only the left hand side arguments that can be applied. Thus in this case we could not supply the second argument rather than the first. Also note that because of this currying doe not require that you specify the types of the omitted parameters.

The approach used with multiple argument lists is to provide the arguments from the left and to use '_' to indicate that the remainder of the function invocation has been left out:

```
val plusOne = test.sum(1)_
println(plusOne(10))
```

The plusOne function is now a curried function that takes the y argument and adds it to the value 1 which was provide for the x argument when the plusOne val was defined. Note that as far as the client code of plusOne is concerned this is just a normal single parameter function.

The definition of plusOne used above is actually a short hand from for the definition of the curried function. All of the following are also variations on the definition of the curried function:

```
def plusTwoLL(y:Int):Int = sum(2)(y: Int)
def plusTwoL(y:Int) = sum(2)(y: Int)
def plusTwo(y: Int) = sum(2)(y)
def plusTwoS(y: Int) = sum(2)_
def plusTwoRS = sum(2)_
```

The explanation for of the variations on the plusTwo function are provided below:

- The function definition plusTwoLL is the *longest longhand* from of the function where we specify the parameter and the return type of the newly created function as well as the binding of the first parameter to 2.
- The plusTwoL function is a *longhand* from which infers the return type.
- The plusTwo method allows the type of the second parameter in the second parameter list to be inferred (this is allowed in Currying—specifying the type is optional here; this was not the case for Partially Applied functions).
- The plusTwoS definition is a *shorthand* from where the second parameter list is replaced by the underbar (‘_’) placeholder.
- The plusTwoRS is the *really shorthand* from where the parameter type of the newly created function is also inferred.

24.3.4 Building Domain Specific Languages

If you need to create a framework to be used by Scala programmers, but want to provide a flexible way to configure that framework and allow the developers to view the end results as merely part of the Scala environment then Currying has many advantages.

For example, the use of currying allows you to build new language structures based on multiple argument lists. For example you can then exploit the ‘{}’ syntax for a single parameter. If this parameter is itself a function the end result is a construct that looks like a language feature:

```
write (file) {
  writer => writer.println(new Date)
}
```

The above is a function *write* that has two argument lists; one that takes a file and one that takes a function. The round bracket syntax could be used for both parameters. However, by using the ‘{}’ syntax for the last parameter this looks more like a language structure! This is an alternative syntax for parameters that can be used for the last set of parameters lists.

We can create the write example presented earlier by implementing a function or a method with multiple parameters. In this example, we are using a method write:

```
object Printer {
   def write(file: File)(op: PrintWriter => Unit) {
     val writer = new PrintWriter(file)
     try {
       op(writer)
     } finally {
       writer.close
     }
   }
}
```

This method has two parameter lists defined; one parameter list that takes a file and one parameter list that takes a function. This function takes a PrintWriter and returns Unit.

This could then be used as follows:

```
val file = new File("data.txt")
write (file) (writer => writer.println(new Date))
```

Note that the second parameter lists contains a function definition that takes a parameter of type PrintWriter and calls the method println on that print writing. The result is that the current Date is written into whatever writer is passed to this function. Inside the write method, the function is passed a PrintWriter that is bound to the file passed in within the first parameter list.

With each parameter now having its own argument list. Of course we could also exploit the '{}' syntax which means that we could also write:

```
val file = new File("data.txt")
write (file) {
  writer => writer.println(new Date)
}
```

Which makes the write function appear more of a language construct than a straight function or method call.

However, we could take this further. If we are creating a logging system in which we always want client code to write to the same log file we could use currying to create a fileWriter function that is guaranteed to write the file we wish to specify:

```
val fileWriter = write(file)_
fileWriter {
  writer => writer.println(new Date)
}
```

Client code can now invoke the fileWriter merely providing the function that will determine the actual value to write. If this is return to client code via a factory or explicitly imported, they will merely see this as a part of the language.

In fact this can be written more concisely yet using the implicit parameter syntax in which an underbar is used to represent a parameter passed into the function and used within that function:

```
fileWriter {
  _ println new Date
}
```

Which is very clean and simple to present to client code.

The advantages of Currying are:

- It allows new *language* constructs to be created.
- It allows constructs to be bound at run time to specific objects etc. If this approach is combined with the Factory pattern then the details can be hidden from client code.

The drawbacks of Currying include:

- Partially applied functions are more flexible in terms of which parameters are applied and which are not yet applied.

Chapter 25
Scala Collections Framework

25.1 Introduction

The Collections framework is one of the main categories within the set of Scala libraries that you will work with. It provides types (Traits, Objects and Classes) that support various types of data structures (such as lists and maps) and ways to process elements within those structures. This chapter introduces the Scala Collections framework.

25.2 What are Collections?

A *collection* is a single object representing a group of objects (such as a list or dictionary). That is they are a *collection* of other objects. Collections may also be referred to as containers (as they contain other objects). These collection classes are often used as the basis for data structures and abstract data types. In general a collection should be used wherever some significant behaviour is associated with the data in the collection (arrays can be used elsewhere). For example, a `SortedList` may need to support the idea of adding and removing elements from the list but also maintaining some *sort* order etc. Collections are thus the Scala mechanism for building data structures of various sorts; it is therefore important to become familiar with the collection API and its functionality.

Some of the collection classes, for example, `ListBuffer`, provide functionality similar to existing data structure classes such as Arrays, but are more flexible to use (at a small performance cost). For example, `ListBuffers` are growable, that is they can grow in size as new elements are added to them, where as Scala Arrays are of fixed size.

25.3 Scala Collections

The Scala collections framework is defined within the `scala.collection` package and the subpackages associated with it. This package provides a collections framework for holding references to objects, instances and values.

The Collection types incorporate higher order functions, such as the Scala List type that includes a `foreach` function that can be used to apply an operation to each of the elements held in a collection.

The Scala collection framework is split into Mutable and Immutable structures that are defined in the `scala.collection.mutable` and the `scala.collection.immutable` packages. Thus all the collections in the mutable package can be updated, added to, removed from etc. In practice this means that you can change the contents of the mutable collection after it has been created. All immutable collections however, once created cannot change their content. Thus when you create an immutable list then the element that comprised that list cannot be removed, added to etc. This does not mean that these collections do not include operations that appear to add, remove or otherwise alter their contents; rather that these operations produce a copy of the original collection which reflects the changes being made.

Note that by default the contents of the `scala.collection.immutable` package is imported into all Scala source files and thus you need to explicitly import the collection types in the `scala.collection.mutable` package.

All Scala collections have type parameters which can be used to specify the type contained within the collection. For example:

```
val myList = List[String]("One", "Two", "Three")
```

This specifies that we wish to create a new List that will hold references to Strings and is initialised with the strings “One”, “Two” and “Three”. We can often get Scala to infer the type of the collection for us but such type parameterization of collections is very common.

The Scala collections framework was heavily revised in Scala 2.8 to provide a common, uniform framework for collection types. A number of key design principles underpin the framework, these are:

- **Ease of Use**. Most problems can be solved with just a couple of operations, which are common across the framework.
- **Concise**. Due to the presence of higher order functions within the framework, such as the *foreach* function, activities that would have taken several statements in other collection frameworks can be achieved in a single statement.
- **Safe**. The presumption of immutability and the avoidance of side effects makes the use of Collection types much safer in Scala.
- **Fast**. The operations within the collections framework have been heavily tuned and optimized to maximise performance.

- **Universal**. A common set of operation exists across all the Collection types. Thus one collection type has similar operations to another collection type that is similar in nature. This means that developers only need to learn a fairly small vocabulary to be able to use a wide range of types.
- **Expressive**. The vocabulary that is used is expressive and semantically meaningful helping developers to clearly express the intent of their code. For example, val (minors, adults) = people.partition(_.age < 18)

The packages that comprise the Scala Collection framework are:

- `scala.collection.` This package contains the root collection types. These root types may be mutable or immutable. For example, scala.collection.IndexedSeq is a parent of both collection.immutable.IndexedSeq and of scala.collection.mutable.IndexedSeq. In general the operations define don the type in the scala.collection package are repeated in the immutable type and extended on in the mutable type.
- `scala.collection.mutable.` This package contains the mutable versions of the collection types.
- `scala.collection.immutable.` This package contains the immutable versions of the collection types.
- `scala.collection.generic.` This package provides building blocks for constructing collection types; you would not normally need to work the this package.

25.3.1 Package Scala.Collection

There is a relatively small set of collection types in the scala.collection package. Some of these types are presented in Fig. 25.1 and described briefly below. The major of the types are traits although some also have objects that support utility type operations such as the Map object with methods such as apply, empty etc.

- **Traversable**. This trait is the root trait of all traversable collections. It is the base trait for all kinds of Scala collections. It provides the common behaviour common to all collections (such as the foreach method). Thus all collection types that mix in this trait must implement a foreach operation.
- **Iterable**. A base trait for iterable collections. An iterable collection is one that it is possible to iterate over. This means that it is possible to process each element in an Iterable collection on-by-one. Implementations of this trait need to provide a concrete method with the signature def iterator: Iterator[A].
- **Seq**. This is a base trait for all sequence like collections. A sequence is a collection in which there is a specific order to the elements it holds. Sequences provide an apply method for indexing, operations such as indexOf, lastIndexOf, startsWith, endsWith and reverse.
- **IndexedSeq**. This is a base trait for indexed sequences. An indexed sequence is a sequence where each element is accessible by an index and where element access is supported in constant time (or near constant time) for elements across

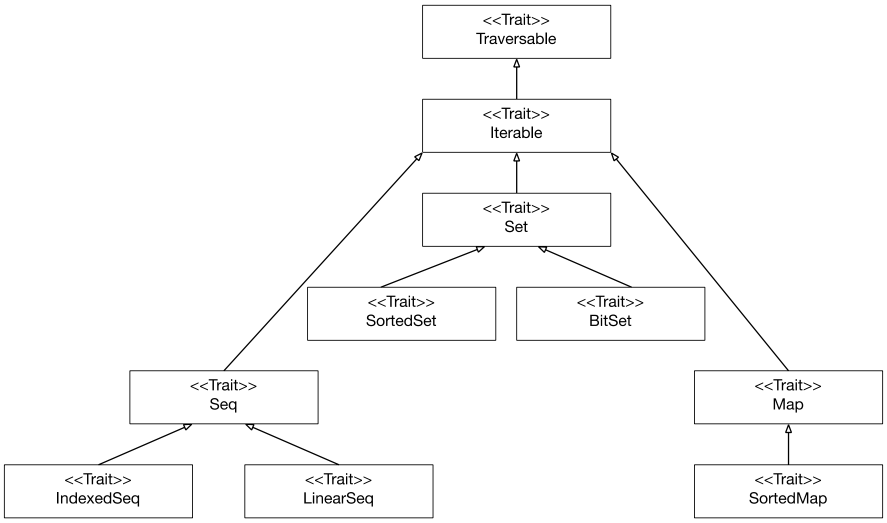


Fig. 25.1 Key Scala Collection types

the collection. An IndexedSeq provides fast random access to elements and a fast length operation.

- **LinearSeq**. The base trait for linear sequences such as Lists and Streams. A LinearSeq provides fast access only to the firs element, via the head, but also fast tail operation.
- **Set**. The base trait for all sets (both mutable and immutable). A Set does not allow a duplicate of en element.
- **SortedSet**. The SortedSet trait represents a Set that has been sorted.
- **BitSet**. A base trait for BitSets. BitSets are sets of non-negative integers that can be used to represent variable-size arrays of bits packed into 64-bit words.
- **Map**. This is a trait represent the key concepts implemented by all Maps. A map is a collection that maintains relationships between keys and values.
- **SortedMap**. A SortedMap trait is a Map whose keys are sorted.

25.3.2 Common Seq Behaviour

The following lists some of the common behaviour shared by all Seq types.

- seq(n) Return the element n in the sequence seq. Note that Scala collections are zero based and therefore the first element in the sequence will be the element ‘0’. This means that if the sequence holds 5 elements they will be accessed by the indexes 0 to 4.
- seq.length Return the length of the sequence

- seq.lengthCompare(s2) returns −1 if seq is shorter than s2 and +1 it is longer, with zero indicating that they have the same length
- seq.indexOf(x) The index of the first element in seq equal to x
- seq.lastIndexOf(x) Return the index of the last element in seq that equals x
- seq.indexOfSlice(s2) The first index of seq such that the successive elements starting from that index from the sequence s2
- seq +: x A new sequence that consists of x prepended to seq
- seq:+ x A new sequence that consists of x appended to seq.
- seq.padTo(length, x) The sequence resulting from appending the value x to seq until the length is reached.
- seq(i) = x Changes the element of seq at index I to be x.
- seq.sorted A new sequence obtained by sorting the elements of seq using the standard ordering of the element type containe dwihtin seq.
- seq.sortWith(test) A new sequence obtained by sorting the elements of seq using the 'test' as the comparison operation.
- seq.reverse Returns a sequence with the elements of seq in reverse order.
- seq.iterator Returns an iterator yielding each of the elements of seq in order.
- seq.reverseiterator Returns an iterator yielding each fo the elements of seq in reverse order.
- seq.contains(x) Tests whether seq contains an element equal to x
- seq.startsWith(s2) Returns true if seq starts with the sequence contained in s2.
- seq.endsWith(s2) Returns true if seq ends with the sequence contained in s2.
- seq.intersect(s2) The multi-set intersection of sequences seq and s2 that preserves the order of the elements in seq.
- seq.diff(s2) The multi-set difference of sequences seq and s2 that preserves the order of the elements in seq.

25.3.3 Common Set Behaviour

The following lists some of the common behaviour shared by all Set types.

- set.contains(x) Tests whether set contains an element equal to x
- set(x) Same as set.contains(x)
- set.subsetOf(s2) Tests whether set is a subset of s2.
- set+x returns the set containing all the elements of set plus x
- set ++ s2 A set containing the union of all the elements of set and s2.
- set − x A set containing all the elements of set except x.
- set − s2 A set containing all the elements of set except those elements also in s2
- set.empty Test to see fi the set is empty.
- Set interest s2 The set intersection of set and s2
- Set diff s2 The set difference between set and s2.

25.3.4 Common Map Behaviour

The following lists some of the common behaviour shared by all Map types.

- m.contains(k) Tests whether m contains a mapping for key k.
- m.get(k) Retrieves the value associated with the key k as an Option or None if there is no mapping.
- m(k) Retrieves the value associated with the key k or an exception if not mapping is present.
- m.getOrElse(k, d) Retrieves the value associated with the key k or the default value d if no key is found.
- m + (k -> v) Add the mapping k -> v to the map.
- m − k Remove the key k (and its associated value) from the map m.
- m.keys Return an iterable containing each of the keys in the map m.
- m.keySet Return a set containing all the keys in the map m.
- m.keyIterator Return an iterator for each of the keys in the map m.
- m.values An iterable containing each of the values in the map m.
- m.valuesIterator An iterator over the values in the map m.

Chapter 26
Immutable Lists and Maps

26.1 Introduction

This chapter focuses on the List and Map types from the `scala.collection.immutable` package.

26.2 The Immutable List Collection

As a common approach is applied across all the collection classes in Scala we will first use the `scala.collection.immutable.List` class as a detailed case study to look at the facilities it provides and the operations that can be performed on it.

A `List` is an immutable (fixed) sequence of elements that provides for constant-time access to the first element and to the tail (remaining) elements. Many other operations takes linear time. Lists are a very widely used collection as they provide all the core sequence like behaviours.

26.2.1 List Creation

The following listing illustrates some of the list creation options available:

```
// List creation options
val myList0: List[String] = List[String]("One", "Two",
"Three")
val myList1 = List[String]("One", "Two", "Three")
val myList2 = List("One", "Two", "Three")
```

The first option illustrated by `myList0` creates a list containing strings initialied to “One”, “Two” and “Three”. This is saved into a val `myList0` which is specified to be of type `List[String]`. The second example illustrates how Scala can infer the type of the val `myList1` for us, and the third indicates that Scala can determine the type of the contents of the list so that it is not necessary to explicitly state that the list will contain Strings.

26.2.2 List Concatenation

We can concatenate strings together using the ‘`:::`’ operator. This creates a new list based on two existing lists, for example:

```
// The list concatenation method that creates a new list
// based on existing lists
val longList = myList0 ::: myList1
```

This results in `longList` now containing the list:

```
List(One, Two, Three, One, Two, Three)
```

Note that in the lastest version of Scala the ‘`:::`’ operator has been replaced by the ‘`++`’ operator to bring it into line with other collection classes, so that it would now be more normal to write:

```
val longList = myList0 ++ myList1
```

However, the effect will be the same which ever operation you select to use.

It is also possible to use the *cons* operator (‘`::`’)to prepend an element to the front of a list (which takes constant time), for example:

```
// The cons method that prepends a new element
// to the beginning of a list - takes constant time
val newList = "Zero" :: myList2
```

Note that this of course produces a new list referenced by `newList` as Lists are immutable. The contents of `newList` is:

```
List(Zero, One, Two, Three)
```

The cons operator can also be used to construct a list from a set of existing values. For example:

```
val myList3 = "One" :: "Two" :: "Three" :: Nil
```

This example may look a little strange. This is because the value `Nil` at the end of the statement represents an empty list. It is thus to this list that the strings “One”, “Two” and “Three” are being added. This raises the question, why is Nil at the end of the statement and not at the start? This is because any method or operation that ends with a ‘:’ is right associative. Thus the expression:

```
"Three" :: Nil
```

must be read from the right to the left (and not from the more traditional left to right). Thus the String “Three” is being prepended to the empty list represented by `Nil`. This expression then returns the new list containing the String “Three”. The String “Two” is then prepended to that list by the next ‘::’ cons operation. This result sin a new List containing “Two” and “Three”. The string “One is then prepended to that List to create the final list containing “One”, “Two” and “Three”. As prepending is done in constant time is the preferred way to add an element to the List.

There is also the ‘+:’ operator which again prepends an element to the front of the list return a new copy of the list.

We could also append an element to the contents of the existing list using the ‘`:+`’ operator. However, this is rarely used as the time it takes to append to the list grows linearly as the size of the list grows:

```
val endList = myList2 :+ "End"
```

The val `endList` would now hold a reference to the following list:

```
List(One, Two, Three, End)
```

26.2.3 List Operations

Other operations of interest on the List class are illustrated in the following listing and discussed below:

```
object Test2 extends App {
  // Create a list of numbers
  val numbers = List(1, 2, 3, 4, 5)
  println(numbers)
  // Determine the length of the list
  println("length of the list: " + numbers.length)
  // Reverse the list
  val rv = numbers.reverse
  println("Reversed: " + rv)
  // returns the list without its first 2 objects
  println("Drop first two objects: " + numbers.drop(2))
  // Returns the first element
  println("The first element: " + numbers.head)
  // Returns the last element
  println("The last Element: " + numbers.last)
  // Returns the list minus the first element
  println("The tailed list: " + numbers.tail)
  // Returns the list minus the last element
  println("The init part of the list: " + numbers.init)
  // Tests to see if the list is empty
  println("Is the list Empty: " + numbers.isEmpty)
  // Convert the list into a String
  val s = numbers.mkString(",")
  println("String format of list: " + s)
}
```

The method `length` returns the length of the list while the method `reverse` returns the list in reverse order. The `head` of the list returns the first element in the list and the method `last` returns the last element in the list. The method `tail` returns all the elements in the list bar the first element. The method `isEmpty` returns a Boolean `true` of `false` depending upon whether the list is empty or not and the `.mkString` method converts the contents of the list into a string with each element in the list separated by the string passed into the method. The result of executing `Test2` are shown below:

```
List(1, 2, 3, 4, 5)
length of the list: 5
Reversed: List(5, 4, 3, 2, 1)
Drop first two objects: List(3, 4, 5)
The first element: 1
The last Element: 5
The tailed list: List(2, 3, 4, 5)
The init part of the list: List(1, 2, 3, 4)
Is the list Empty: false
String format of list: 1,2,3,4,5
```

26.2.4 List Processing

You can also process all the elements in the list. This can be done in a number of ways. For example, Lists are iterable collections and thus you can iterate over the elements in the list as follows:

However, many of the collection classes also provide the `foreach` higher order function that can take a function to apply to each of the elements in the List in turn. Therefore you can also write:

```
myList.foreach((x: String) => {println(x)})
```

Of course in Scala this can be written in a number of different (and shorter) ways, including:

```
// More Scala oriented equivalent
myList.foreach((e) => {println(e)})
myList.foreach(e => {println(e)})
myList.foreach(e => println(e))
myList.foreach(println (_))
// Shortest form of above
myList.foreach(println)
```

Where we gradually rely in Scala to infer more and more of what is being defined.

26.2.5 Further List Processing

As well as the `foreach` operation, there is a whole range of higher order functions that you can use with Lists. These include `filter`, `map`, `foldLeft` and `foldRight`, `flatMap` etc.

For example, if you wish to select only certain elements in a list, that meet a specific criteria, you can do that using the filter higher order function. For example:

```
// Create a list of numbers
val numbers = List(1, 2, 3, 4, 5)
println(numbers)
// Apply a function used to filter the members
// of the list and create a new list
val f = numbers.filter(n => n < 3)
println("Filtered: " + f)
```

This would result in the following output:

```
List(1, 2, 3, 4, 5)
Filtered: List(1, 2)
```

As you can see from this example, the result of applying the function literal passed into the filter is that only elements less than 3 have been included in the filter list 'f'.

We can also apply a function to each of the elements in a list and create a new list of the same size, based on the result returned by the function we applied. For example:

```
// Create a list of numbers
val numbers = List(1, 2, 3, 4, 5)
// Apply a function to each of the members of the list
// and create a new list of the same size
val m = numbers.map(n => n + 10)
println("Modified list: " + m)
```

The output from this is

```
Modified list: List(11, 12, 13, 14, 15)
```

Thus the modified list has 5 elements, and these elements are each 10 greater than the elements in the original list. Thus the function:

```
n => N + 10
```

has added 10 to each of the elements and collated the results into a new list referenced by 'm'.

We could have written this in a short from as:

```
// Short hand form of the above.
// That is {n=>n+10} can be rewritten as (_+10) which means
// you do not need to declare the input param
val m2 = numbers.map(_ + 10);
println("Modified List (alternative form): " + m2)
```

Which would also result in a list being created containing 5 elements, where each element is 10 greater than that in the original list:

```
Modified List (alternative form): List(11, 12, 13, 14, 15)
```

We can also apply a function to all the elements in the list and gather up the results into a single value. This can be done using either the `foldLeft` or the `foldRight` methods. The `foldLeft` operation takes an initial value (or state) and propagates that state from one element to the next, with the result of one evaluation being passed as input to the next. It starts from the left most element and processes right towards the end of the list. For example, given our list of numbers we could add them all up using the foldLeft operation:

```
// Create a list of numbers
val numbers = List(1, 2, 3, 4, 5)
val sum = numbers.foldLeft(0)((total, element) => total +
  element)
println("Sum of List " + sum)
```

The result of this is:

```
Sum of List 15
```

Note that foldLeft is a multi argument list operation, thus the first argument takes the initial value to use (in this case zero) and the second argument list takes the function to apply. This function is a 2 parameter function, one which takes the total already calculated and one parameter that is the current element to process. The result return from this function is then passed to the next invocation of the function. Note due to the alternative syntax available for single parameter lists the above could also be written as the following with the second parameter list being represented by the curly braces '{..}':

```
// Create a list of numbers
val numbers = List(1, 2, 3, 4, 5)
val sum = numbers.foldLeft(0){(total, element) => total +
  element}
println("Sum of List " + sum)
```

There is also a foldRight operation which starts at the end of the list with the last element and processes towards the start of the list. For example:

```
// Also an option to start from the right
// and process towards the start
val alternativeSum = numbers.foldRight(0)
      {(total, element) => total + element }
println("Alternative Sum of List " + alternativeSum)
```

The result (in this case) is exactly the same, alternativeSum contains the value 15:

```
Alternative Sum of List 15
```

However, there are some issues with `foldRight` when it comes to processing very large lists and thus it is often better to reverse a list and then call `foldLeft`, for example:

```
myList.reverse.foldLeft(0){(t, e) => t + e}
```

Another operation `flatten` can be used to flatten a list. That is, given a list of lists it can return a single list constructed from the contents of the original sublists. For example:

```
scala> val nested = List(List(1, 2, 3), List(4, 5))
nested: List[List[Int]] = List(List(1, 2, 3), List(4, 5))

scala> nested flatten
res0: List[Int] = List(1, 2, 3, 4, 5)
```

In the above example, the first sublist containing 1, 2 and 3, and the second sublist containing 4 and 5 have been flattened into a single list containing 1, 2, 3, 4 and 5.

The operation `flatMap` is essentially map plus `flattern` combined together. The function given to the `flatMap` is expected to return a list of values. The resultant list of lists is then flattened into a single list. For example, given a val 'contents' containing a list of Arrays of Integers. In the following example, we use `flatMap` to convert the array to a list and then to flattern the two lists into a single list:

```
val contents = List(Array(1, 2, 3), Array(4, 5, 6))
val result = contents.flatMap(x => x.toList)
println(result)
```

The output from this program is:

```
List(1, 2, 3, 4, 5, 6)
```

26.2.6 Pattern Matching

It is possible to extract the contents of a list into a set of variables as follows:

```
val myList = List("a", "b", "c")
val List(x, y, z) = myList
```

with the result that `x`, `y` and `z` are variables containing the contents of the `myList` (rather than being the members of a new list):

```
x: java.lang.String = a
y: java.lang.String = b
z: java.lang.String = c
```

However, this has limited utility unless you know the number of elements in the list. A generally more useful approach is to extract the head and the tail of a list in this way:

```
val hd :: tl = myList
```

which results in two vals being created one called `hd` and containing the string "a" and one called `tl` containing the list of strings ("b" and "c"):

```
hd: java.lang.String = a
tl: List[java.lang.String] = List(b, c)
```

26.2.7 Converting to a List

There are numerous ways in which you can convert other sequence like constructs into lists. For example, you can convert an array to a list:

```
scala> Array(1, 2, 3, 4) toList
List[Int] = List(1, 2, 3, 4)
```

Or a string to a list (which results in a list of characters);

```
scala> "abc" toList
List[Char] = List(a, b, c)
```

Or a generated sequence into a list

```
var shortList = 1 to 10 toList
```

And indeed other collection types into a list, such as a Set or a Map:

```
scala> Set("abc", 123) toList
List[Any] = List(abc, 123)

scala> Map("apple" -> "red", "banana" -> "yellow") toList
List((apple,red), (banana,yellow))
```

Of course the reverse is also true. That is it is possible to convert a List to a range of sequence like structures using various to<Type> methods, such as `toArray`, `toString`, `toSet`, `toMap`.

26.2.8 Lists of User Defined Types

All of the examples we have looked at so far with Lists have used strings or Integers. We can of course also make lists of user defiend types. For example, given the class `Person` as can create lists which hold `Person` types:

```
val dad = new Person("John", 49)
val mum = new Person("Denise", 46)
var adam = new Person("Adam", 14)
var phoebe = new Person("Phoebe", 16)

val family = List[Person](dad, mum, adam, phoebe)
```

This defines four vals holding references to four istances of a class Person. These four vals are then used to initialise a List of Persons referenced by the val `family`. We have explicitly stated the type of the contents of the List as `Person` in this case but that is of course optional and we could also have written:

```
val family = List(dad, mum, adam, phoebe)
```

In the above example, Scala will infer that this is a list of Person types.

We can now apply the operations discussed earlier in this section with this list of persons. Of course we can now access the properties and methods defined on the class `Person` within the functions we apply to the elements of the list. Thus assuming the class `Person` is defined as follows:

```
case class Person (var name: String, var age:Int)
```

We can write:

```
val family = List(dad, mum, adam, phoebe)

// Note Scala can infer the parameter:
family.foreach{println("Family Member: " + _) }

// get everyone over the age of 21
val over21 = family.filter { _.age > 21 }
println(over21)

// Extract the ages and find the average
val ages = family.map(_.age)
println(ages)
val averageAge = ages.sum / ages.size
println("Average age: " + averageAge)
```

The examples illustrate the use of `foreach`, `filter` and `map`. The `foreach` example prints out each member of the family with a prefix of “Family member:”. The second filters the family members to find those over 21 using the age property. The final example uses the map function to obtain a list containing the ages of each of the members of the family which is then used to calculate the average of all the ages. The output of this program is:

```
Family Member: Person(John,49)
Family Member: Person(Denise,46)
Family Member: Person(Adam,14)
Family Member: Person(Phoebe,16)
List(Person(John,49), Person(Denise,46))
List(49, 46, 14, 16)
Average age: 31
```

26.3 The Immutable Map Type

A Map is a set of associations, each representing a key-value pair. The elements in a `Map` may be unordered, but each has a definite name or *key*. Although the values may be duplicated, keys cannot. In turn a key can *map* to at most one value. Some Map implementations, like `TreeMap` and `ArrayMap`, make specific guarantees as to their order; others, like `HashMap`, do not. The `Map` protocol allows either the keys to be viewed, the values to be viewed or for the keys to be used to access the values.

A Concrete implementation of the `Map` trait is the `scala.collection.immutable.HashMap` class. It provides an immutable implementation of a Map based on the use of a hashing trie. A hash trie is a standard way to implement immutable sets and maps efficiently within Scala. To find a given key in a map, the code first takes the hash code of the key and based on information held in the hash find the appropriate *bucket* into which the key value pair will have been placed. The advantage of hash tries are that they strike a balance between reasonably fast lookup and reasonably efficient inserts and deletions.

The following listing illustrates some of the operations available on the `Map` trait that is implemented by the `HashMap` class.

```
import scala.collection.immutable.HashMap

object HashMapTest extends App {
   val capitalCitys =
            HashMap("UK" -> "London",
                    "FRANCE" -> "Paris",
                    "Spain" -> "Madrid",
                    "USA" -> "Wasington. DC")
   println(capitalCitys.size)
   println(capitalCitys.keys)
   println(capitalCitys.values)
   println(capitalCitys.isEmpty)
   println(capitalCitys.get("UK"))
   println(capitalCitys("UK"))
   println(capitalCitys.contains("UK"))
   println(capitalCitys.getOrElse("Ireland",
                                 "Not known"))
   val newCapitalCitys =
             capitalCitys +("Ireland" -> "Dublin")
   println(newCapitalCitys("Ireland"))
}
```

The result of executing this program is shown below:

```
4
Set(USA, Spain, UK, FRANCE)
MapLike(Wasington. DC, Madrid, London, Paris)
false
Some(London)
London
true
Not known
Dublin
```

The points to note about this listing include that a map contains key to value pairs. Thus the size of the map is 4 elements just after it is instantiated. Also note that you can obtain the keys and values in the map separately should you need to do so. The keys are returned as a `Set` as they will be unique. The Values are returned as a type of sequence as there may be duplicates amongst them. You can also test a map to see if it is empty. The method `get` and the access (nth) are often treat as synonymous but they actually have different return types, for example:

```
println(capitalCitys.get("UK"))
```

Returns

```
Some(London)
```

Where as

```
println(capitalCitys("UK"))
```

Returns

```
London
```

The difference being that get will return None if the key does not exist in the `HashMap` were as the *accessor* will throw an exception if the key is not present.

An alternative is to use the `getOrElse` method:

```
println(capitalCitys.getOrElse("Ireland", "Not known"))
```

This will return the value associated with the specified key (in this case Ireland) or if the key is not present it will return the value passed to the method as the second parameter.

Finally note that act of adding a new key-value pair to the map results in a new map being created containing the same set of key-value pairs as the original map with the addition of the new key-value pair (the original map is unaffected):

```
val newCapitalCitys = capitalCitys +("Ireland" -> "Dublin")
```

Chapter 27
Immutable and Mutable Collection Packages

27.1 Introduction

This chapter discusses the contents of the Scala collection framework packages for immutable and mutable collections.

27.2 Package scala.collection.immutable

The key classes and traits in the `scala.collection.immutable` package. Are shown in Fig. 27.1 and described in the rest of this section.

27.2.1 Sequences

There are a number of different types of Sequences including:

- **Vector**. This is a general-purpose immutable indexed sequence. As a general rule you might choose to use a `Vector` over a `List` as it provides faster access. An example of using the `Vector` class is given below:

```
object VectorTest extends App {
  val v1 = Vector(3, 2, 1)
  println(v1)
  println(v1(0))
  println(v1.length)
  val v2 = 4 +: v1
  println(v2)
}
```

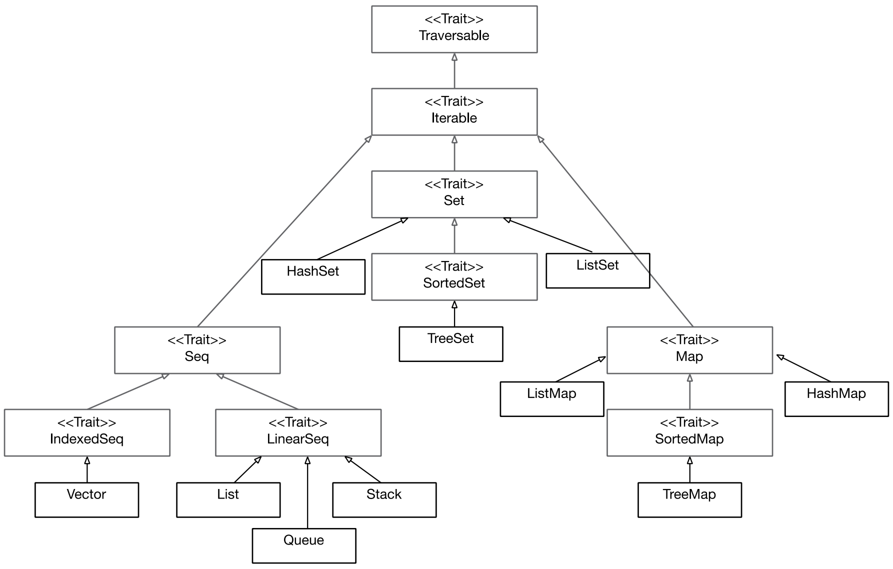


Fig. 27.1 Key classes and traits in the scala.collection.immutable package

The result of running this program is shown below:

```
Vector(3, 2, 1)
3
3
Vector(4, 3, 2, 1)
```

- **List**. The List class has been discussed extensively earlier in this chapter. However, it is worth noting that it is probably the most widely used type in the `sca-la.collection.immutable package.`
- **Queue**. A Queue is a first in first out (FIFO) type of collection. That is elements can be added to a queue and removed from the queue in the same order. The primary methods on a Queue are the `enqueue` method for adding an element to the `queue, dequeue` for removing an object from the queue. This type might at first seem a strange choice for the immutable a package, After all once you create an immutable Queue you cannot modify it. This is true, but there operations such as `enqueue` and `dequeue` that return a copy of the original queue with a new element added or an element removed respectively. This is particularly useful in concurrent processing environments where this avoids the need to worry about multiple processes updating a common data structure such as a `Queue`. An example of using the `Queue` class is shown below:

```
import scala.collection.immutable.Queue

object QueueTest extends App {
  val q1 = Queue[Int]()
  val q2 = q1.enqueue(1)
  println(q2)
  val q3 =q2 .enqueue(List(2, 3))
  println(q3)
  val (r, q4) = q3.dequeue
  println(r)
  println(q4)
}
```

The result of executing this program is:

```
Queue(1)
Queue(1, 2, 3)
1
Queue(2, 3)
```

Points to note about this example, are that each of the operations to add or remove elements from the `queue` generated a new Queue instance. Also note that `de-queue` returned both the result of removing the first element from the queue and the newly generated queue instance containing all the elements of ‘q3’ minus the value removed. Finally, also note that we had to import the `Queue` type.

- **Stack**. A `Stack` provides a last-in first-out behaviour (LIFO). As with the `Queue` any operations that add elements to the stack or remove elements from the stack actually result in a new `Stack` instance being created. A simple example is shown below:

```
import scala.collection.immutable.Stack

object StackTest extends App {
      val s1 = Stack[Int]()
      val s2 = s1.push(1)
      println(s2)
      val s3 = s2.push(2)
      println(s3)
      println(s3.top)
      val q4 = s3.pop
      println(q4)
}
```

The result of executing this program is given below:

```
Stack(1)
Stack(2, 1)
2
Stack(1)
```

Note that we have again imported the `scala.collection.immutable.Stack` class. Also note that the top method returns the value at the top of the stack but does not remove it. Pop on the other hand removes the tope value and returns a copy of the original stack without the top element.

27.2.2 Sets

There are a number of different types of Sets including:

- **HashSet** is an immutable `Set` implementation based on a hashing function. A Set only allows a single instance of an element in the Set—the `equals` method is used to determine equality. For example:

```
// Create an immutable Set
var teams =
     HashSet("Liverpool", "West Ham",
        "Newcastle", "Everton", "West Ham")
println(teams)
```

This results in the following output:

```
HashSet(Liverpool, West Ham, Newcastle, Everton)
```

Note that there is only one occurrence of the String "West Ham" in this set.

- **TreeSet**. This class implements the `Set` concept based on a tree structure. Specifically on a Red-Black Tree structure. Red-black trees are a form of balanced binary tree where some nodes are designed *red* and some nodes are designated *black*. As with any balanced tree structure the operations applied to the tree complete in time logarithmic to the size of the tree.
- **ListSet**. A `ListSet` is an immutable set using a list-based structure internally. It can be viewed as a List that restricts the occurrences of some element to one within the list. For example:

```
var t2 = ListSet("Liverpool", "West Ham",
"Newcastle", "Everton", "West Ham")
  println(t2)
```

Which results in the following output;

```
ListSet(Everton, Newcastle, West Ham, Liverpool)
```

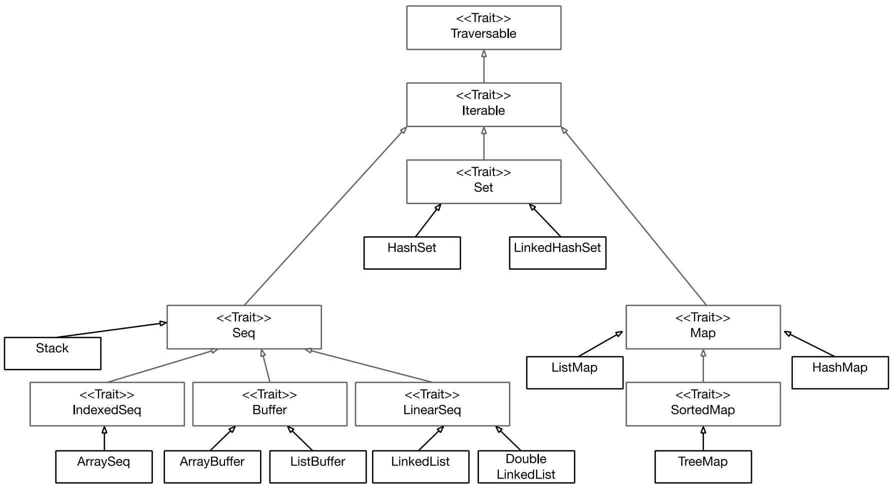


Fig. 27.2 Key types in the scala.collection.mutable package

27.2.3 Maps

There are a number of different types of Maps including

- **ListMap**. A `ListMap` is a map that uses a linked list based structure to internally represent the key-value pairs in the Map. Operations on a list map take linear time relative to the size of the map. Due to this there is little benefit in using a ListMap and a `HashMap` is almost always a better choice.
- **HashMap**. Represents a collection of associated keys and values that are organized based on the hash code of the key.
- **TreeMap**. This class implements the Map as a tree structure.

27.3 Package scala.collection.mutable

The key types in the `scala.collection.mutable` package are presented in Fig. 27.2. You will notice that many of the names are the same as those in the immutable collection described earlier. This can make it very confusing for someone working with the collection classes to understand the impact of the operations being performed. For example, an operation on an immutable collection may generate a new instance of that collection containing the new element, where as the mutable version will merely add that element to the collection (and both collections are called `HashMap`!). Therefore ensuring that you know which type of collection you are working with is an important issue. In this section we will look at the `ArrayBuffer`, `ListBuffer`, `Stack` and `HashMap` classes.

27.3.1 *ArrayBuffer*

An `ArrayBuffer` is a growable collection that is backed by an array and has a current size (it is similar in nature to the ArrayList class in Java). The majority of operations on an array buffer have the same speed as for an array as the operations simply access and modify the underlying array, ArrayBuffers can therefore be used for efficiently building up a large collection whenever new items are added to the end of the array (for example as a result of reasoning data from a file or a database). The following example illustrates how they are used (remember elements in a collection such as `ArrayBuffer` are indexed from Zero not one):

```
import scala.collection.mutable.ArrayBuffer

object ArrayBufferTest extends App {
  val data = ArrayBuffer[Int]()
  data += 1
  println(data)
  data += 5
  data += 6
  println(data)
  println(data(2))
  val array = data.toArray
  println(array)
}
```

The result of executing this program is shown below:

```
ArrayBuffer(1)
ArrayBuffer(1, 5, 6)
6
[I@3d5b5376
```

As you can from this example it is the `ArrayBuffer` data which is updated when we add an element using the '+=' operator. Thus we can see that data is a mutable collection as opposed to the immutable collections we looked at earlier. We have also included how an `ArrayBuffer` can be converted into an Array using the `toArray` (other options include `toList` and `toSet`).

27.3.2 *ListBuffer*

A `ListBuffer` is like an `ArrayBuffer` except that it uses a linked list as its underlying structure (rather than an array). This means that insertion may be faster than for an `ArrayBuffer`. Also if you intend to convert your structure to a List once you have added all the elements to the buffer, then a `ListBuffer` is a more efficient option. Here is an example of working with a `ListBuffer`:

```
import scala.collection.mutable.ListBuffer

object ListBufferTest extends App {
  val data = ListBuffer[Int]()
  data += 1
  println(data)
  data += 5
  data += 6
  println(data)
  println(data(2))
  val array = data.toList
  println(array)
}
```

The output from this program is given below:

```
ListBuffer(1)
ListBuffer(1, 5, 6)
6
List(1, 5, 6)
```

27.3.3 LinkedList

Linked lists are mutable sequences that consist of nodes that are linked together via pointers. That is the first node has a reference to the second node. The second node has a reference to the third etc. with next pointers.

27.3.4 Stack

The mutable `Stack` provides similar functionality to the immutable Stack with the primary difference being that when an element is added to the stack or removed from the stack it affects that stack (rather than creating a copy of the stack modified as appropriate). The following listing illustrates typical mutable stack behaviour:

```
import scala.collection.mutable.Stack

object StackTest extends App {
  val stack = Stack[Int]()
  stack.push(1)
  stack.push(2)
  stack.push(3)
  println(stack)
  println("top: " + stack.top)
  println("pop: " + stack.pop)
  println("pop: " + stack.pop)
  println(stack)
}
```

The result of running this program is:

```
Stack(3, 2, 1)
top: 3
pop: 3
pop: 2
Stack(1)
```

Note that the push operation updates the stack directly as the pop option. Note that for the mutable stack pop returns the item popped where as for the immutable version it returned the state of the stack after the pop.

27.3.5 HashMap

The mutable `HashMap` class is very similar to the immutable `HashMap` except that modifications are made to the receiver of the operation rather than to a copy. The following listing illustrates `HashMap` usage:

```
import scala.collection.mutable.HashMap

object HashMapTest extends App {
  val map = HashMap[String,String]()
  map += ("UK" ->"London")
  map += ("FRANCE" ->"Paris")
  map += ("Spain" ->"Madrid")
  map += ("USA" ->"Wasington. DC")
  println(map)
  println(map.size)
  println(map.keys)
  println(map.values)
  println(map.isEmpty)
  println(map.get("UK"))
  println(map("UK"))
  println(map.contains("UK"))
  println(map.getOrElse("Ireland", "Not known"))
}
```

The result of executing this program is given below:

```
Map(FRANCE -> Paris, UK -> London, Spain -> Madrid, USA ->
Wasington. DC)
4
Set(FRANCE, UK, Spain, USA)
HashMap(Paris, London, Madrid, Wasington. DC)
false
Some(London)
London
true
Not known
```

27.4 Generic Collections

One interesting area is to look at what happens if you create one of the scala. collection core collections such as Set or Map. The following programme uses the Map type from the scala.collection.

```
object Test3 extends App {
  var flights = Map[Int, String]()
  println(flights.getClass())
  flights += (121 ->"Miami")
  println(flights.getClass())
  flights += (231 ->"Dublin")
  println(flights.getClass())
  flights += (456 ->"Paris")
  println(flights.getClass())
  println(flights)
  println(flights(231))
}
```

Now consider the output from this programme:

```
class scala.collection.immutable.Map$EmptyMap$
class scala.collection.immutable.Map$Map1
class scala.collection.immutable.Map$Map2
class scala.collection.immutable.Map$Map3
Map(121 -> Miami, 231 -> Dublin, 456 -> Paris)
Dublin
```

There is something strange happening here. The class name retrieved from the getClass method appears to be different!

This is because by default the core Map type uses the immutable Map from the scala.collection.immutable package. However, because our program then adds a series of key-value pairs to that map it must create new instances of the Map class to represent the new map and bind those to the variable flights. It does this as flights actually references a wrapper around an immutable Map and it is this inner map that is replaced.

If we add an import to this program to import the scala.collection. mutable.Map, for example:

```
import scala.collection.mutable.Map
```

We can now use the same immutable HashMap through out the application:

```
class scala.collection.mutable.HashMap
class scala.collection.mutable.HashMap
class scala.collection.mutable.HashMap
class scala.collection.mutable.HashMap
Map(456 -> Paris, 121 -> Miami, 231 -> Dublin)
Dublin
```

27.5 Summary

It is likely that, just as in C# and Java, these classes will become some of the most used classes in Scala. The various collection API interfaces and classes will form the basis of the data structures you build and will be the corner stone of most of your implementations. Stick with them, try them out, implement some simple programs using them and you will soon find that they are easy to use and extremely useful. You will very quickly come to wonder why every language doesn't have the same facilities!

Chapter 28
Type Parameterization

28.1 Introduction

This chapter introduces type parameterization. We have already seen examples of type parameterization in the collection types where a List can be parameterized to hold only Strings, Person objects or integers etc. In this chapter we will look at how you can create your own parameterized types and the options available for controlling the types that can be used with those parameterizations.

28.2 The Set class

As a concrete example of type parameterization we will explore the Set class. The Set class allows the type of element that it will hold to be specified between square brackets '[…]' after the name of the class and before any parameters passed to the Set constructor. For example:

```
object SetTest extends App {

  val s =
     Set[String]("John", "Denise", "Phoebe", "Adam")
  println(s)

}
```

In the above listing, the Set class is being parameterized to only hold items of type String (hence the Set[String]). If we wanted it to be limited to only holding integers then we would use Set[Int] and to only hold Person types then we would use Set[Person]. The type parameterization is the application of [String] or [Int] to the type Set. Of course this is Scala, so Scala is quiet capable of inferring this from the contents of the Set, thus

```
val s2 = Set("John", "Denise", "Phoebe", "Adam")
```

s2 also referecnes a Set that has been parameterized to only hold Strings.

In both cases the class Set is referred to as a *generic* class. If you look at the definition of Set in the Scaladoc then you will see that it is defined as being:

```
Set[T]
```

Which indicates that Sets can hold elements of a type T where T is a placeholder for the type to be defined. Thus in Set[String] and Set[Int] the placeholder T has been replaced by String and Int respectively. The result of applying a type to a Set is a *parameterized* Set.

28.3 Adding Type Parameterization

28.3.1 The MyQueue Mutable Class

You can create your own types that are generic types and that can be parameterized by a concrete type. For example, the mutable collection class MyQueue, presented in the following listing, is a programmer defined generic type. It defines a placeholder T that will be used to represent various concrete types. Note by convention the letter T is used to indicate a type to specify (but we could use any letter or sequence of letters thus if the types for a key and a value were being specified we might use K and V).

```
package com.jjh.scala.collection

import scala.collection.mutable.ListBuffer

class MyQueue[T] {
  private val content: ListBuffer[T] = new
ListBuffer[T]

  def head: T = content.head
  def size = content.size

  def enqueue(x: T) = content :: x :: Nil

  def dequeue: T = {
    content.remove(0)
  }

  override def toString =
           "[" + content.mkString("| ") +"]"

}
```

The class MyQueue uses T as if it were an actual type in the body of the class. Thus the type of element held by the ListBuffer is T, the type of element that can be enqueued using the enqueue method is T and the result returned by the dequeue method is T. The type of the head element is also T.

This class is used in exactly the same way as one of the built in collection classes as shown below:

```
package com.jjh.scala.collection

object MyQueueTest extends App {
  val q = new MyQueue[String]()
  q.enqueue("John")
  q.enqueue("Denise")
  q.enqueue("Phoebe")
  q.enqueue("Adam")
  println(q.head)
  val name = q.dequeue
  println(name)
  println(q.head)
  q.enqueue("Paul")
  println(q.head)
  println(q)
}
```

In this example the type String is used to parameterize MyQueue such that it now holds Strings. The effect is that the latter T is replaced by the type String throughout the instance of the MyQueue class referenced by the variable ‘q’. This the effect is that the type of head is String, the type used as a parameter to enqueue is String and the type returned by dequeue is String. Thus it is the same as writing:

```
def head: String = content.head
...
def enqueue(x: String) = content += x

def dequeue: String = {
  content.remove(0)
}
```

However, we can also create a MyQueue of Ints, for example:

```
val q2 = new MyQueue[Int]()
```

This is now the equivalent of writing:

```
def head: Int = content.head
...
def enqueue(x: Int) = content += x

def dequeue: Int = {
  content.remove(0)
}
```

As well as String and Int any type can be used as the concrete type including Double, Boolean as well as user defined types such as the class Person or the Trait Model.

Thus generic class and type parameterization provides a powerful construct for creating type safe, reusable code.

Note that you can create generic Classes and Traits as both can be instantiated with a concrete type. You cannot create generic Objects as you do not instantiate an Object (this is handled for you by the Scala runtime).

The output from the Queue test program is shown below:

```
[John| Denise| Phoebe| Adam]
John
        John
Denise
Denise
[Denise| Phoebe| Adam| Paul]
```

28.3.2 The Queue Immutable Class

We can also create generic types that are immutable and that take parameters into the primary constructor. Note that the types used in the primary constructor can also refer to the type T. Thus the head passed into the Queue is of type T and the tail is a List of type T. Also note that as this is an immutable Queue when you add something to this queue a new copy of the queue is created containing the existing data plus the new element. Of course the type of the push method is T.

```
package com.jjh.scala.collection

class Queue[T](val head: T, val tail: List[T]){

   def enqueue(x: T) = new Queue(x, head :: tail)
   def peek = head
   def dequeue = new Queue(tail.head, tail.tail)

   override def toString =
              head + " : " + (tail mkString ",")

}
```

The Queue class creates a new Queue when a value is added to the Queue, returns a new Queue class (with the current head removed) in response to a dequeue and provides a peek operation to see what is currently at the head of the queue.

To use this class we can specify the concrete type such as String when we create an instance. For example:

```
val q =
   new Queue[String]("John", List("Denise", "Phoebe"))
```

This is used in the following program listing to create a Queue which is then processed using *peek* and *dequeue*.

```
object QueueTest extends App {
  val q =
     new Queue[String]("John", List("Denise",
"Phoebe"))
  println("q = " + q)
  println("q.peek = " + q.peek)
  val q2 = q.dequeue
  println("q2 = " + q2)
  println("q = " + q)
}
```

Again the result is that the placeholder ‘T’ has been replaced within the instance of the Queue class by the concrete type String. Thus the type of the head property is String, the type of the tail is List[String] and the type of the parameter ‘x’ in the enqueue method is String as is the type returned by the dequeue method.

Note that Scala could have inferred the type being used with the myQueue class, thus we could also have written:

```
val q = new Queue("John", List("Denise", "Phoebe"))
```

This would also have been a Queue instance parameterized by the type String.

We can actually create a Queue parameterized by Int, Boolean, Double or any user defined type such as Person. For example:

```
val q = new Queue[Person](Person("John", 49), List(new
Person("Denise", 46), Person("Phoebe", 16),
Person("Adam", 14)))
```

The result of running the earlier QueueTest is:

```
q = John : Denise,Phoebe
q.peek = John
q2 = Denise : Phoebe
q = John : Denise,Phoebe
```

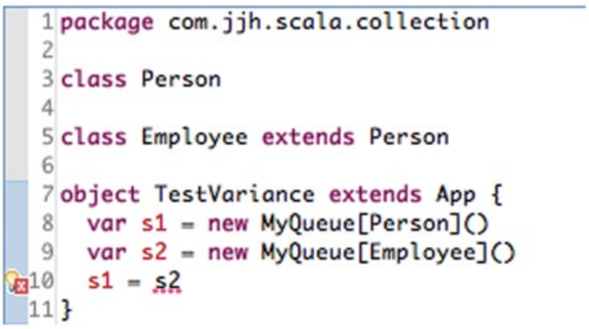
28.4 Variance

An important question to consider when looking at generic types is how are subtypes (such as sub classes or sub traits) treated with respect to classes that have been parameterized by a parent type. For example, if we have a Set that can hold Persons, should it be able to hold references to instances of the class Employee if it is a subtype of Person? This subject is referred to as variance and within a type system within a programming language a type rule is

- **Covariant** if it preserves the ordering of types from more specific ones to more generic ones.
- **Contravariant** if it reverses the ordering.
- **Invariant** if neither of these applies.

In Scala the default for generic types is invariance—that is given a type Person and a subtype Employee MyQueue[Employee] is not a subtype of MyQueue[Employee] and thus it is not possible to assign a reference to a variable of type MyQueue[Employee] to a variable of type MyQueue[Person]. For example, Fig. 28.1 illustrates an attempt to do just that. However, the IDE indicates that there is a compilation problem at line 10 when we try and assign s2 to s1. This would still be true if we used a built in type such as ListBuffer or ArrayBuffer.

However, you can override this limitation with what are known as *variance annotations*. When we define our generic types we can indicate whether we would



```
package com.jjh.scala.collection

class Person

class Employee extends Person

object TestVariance extends App {
  var s1 = new MyQueue[Person]()
  var s2 = new MyQueue[Employee]()
  s1 = s2
}
```

Fig. 28.1 Invariance in scala

like them to be covariant or contravariant using either a '+' or a '−' before the type placeholder. For example:

- Queue[+T](…){…}—indicates covariant where Queue[String] is considered a subtype of Queue[AnyRef]
- Queue[−T](…){…}—indicates contravariance where Queue[AnyRef] would be considered a super type of Queue[String]

Using these we can control whether we wish MyQueue[Employee] to be a subtype of MyQueue[Person] or not.

28.5 Lower and Upper Bounds

If you want to limit the types that can be used for T or any supertype of T then you can use a *lower* bound on the type specification. For example:

```
def enqueue[U >: T](x: U) =
               new Queue(x, _head :: tail)
```

In this case if we try to enqueue an item then the type of this item must be of type T or a super type of T. Thus if we have a queue of Employees this would allow us to enqueue a Person to the Queue (although the resulting Queue only guarantee that it holds references to Person objects or subtypes of Person).

If you want to limit the types that can be used with T or any subclass of T then you can use an *upper* bound. For example:

```
def enqeue[U <: T](x: U) =
               new Queue(x, _head :: tail)
```

28.6 Combining Variance and Bounds

We can combine variable and bounds together to create flexible containers, for example:

```
case class FlexiQueue[+T](head: T, tail: List[T]) {
   def enqueue[U >: T](x: U) = new FlexiQueue(x, head
:: tail)
   def peek = head
   def dequeue[U >: T] = new FlexiQueue[U](tail.head,
tail.tail)
}
```

This class, the FlexiQueue class indicates that the type T will be treated covariantly and that the methods enqueue and dequeue have lower bounds indicating that the type T and its super types may be used with these methods. Thus if we create a FlexiQueue of Employees and then subsequently enqueue a Person this will return a FlexiQueue of Person types. This scenario is represented by the following listing:

```
object FlexiQueueTest extends App {
  val q1 = FlexiQueue[Employee](
             new Employee("John"),
             List(new Employee("Denise"),
                    new Employee("Phoebe")))
  println(q1)
  val q2 = q1.enqueue(new Person("Adam"))
  println(q2)
}
```

The interesting thing to note is that type inferred by Scala for q1 and q2:

- q1 holds a reference to a FlexiQueue[Employee] type of instance
- q2 holds a reference to a FlexiQueue[Person] type of instance.

This of course makes sense because when we first created the FlexiQueue we could guarantee that all the elements in the queue were Employees. However once we added a Person to the FlexiQueue, the only thing we could now guarantee is that the contents of the queue were now at least Person instance (although others may be Employee instances).

You can also combine lower or upper bounds with specific types and covariance or contravariance. For example, if you wish to indicate that the type to be used should be a Person or a subtype of Person then you can do so using the Upper bound limit and the type Person with a covariant annotation, for example:

```
class Queue[+T <: Person]() {...}
```

Chapter 29
Further Language Constructs

29.1 Introduction

This chapter introduces a number of new concepts. The first is the use of *implicit*. Implicit facilities are a range of language facilities that provide *implicit* conversions between one type and another (typically in order to access some functionality or to provide compatibility between types). The chapter then introduces Scala annotations (a form of meta data for types), Enumerations and lazy evaluation.

29.2 Implicit Conversions

Explicit conversions are achieved programmatically using conversion methods and functions. An example of an explicit conversion is the way in which a string can be converted to an *Int* using the *toInt* function. For example:

```
package com.jeh.scala.convert

object TestStringConversion extends App {

  val s = "32"
  val i:Int = s.toInt
  println(i)

}
```

The val *s* holds a reference to a String containing the characters '3' and '2'. Using the *toInt* operation we can convert it into the integer 32, which is stored in the val 'i' (which we have explicitly declared as an Int although this is not actually necessary as Scala can infer the type of i). The result of this program is that the integer 32 is printed out.

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Implicit conversions, by contrast, are conversions from one type to another type that happen automatically. Scala supports the idea of implicit conversions by looking for any available, appropriate conversion functions when it finds that the type made available does not match the type required. For example, if a function or method required an integer and the programmer provided a string, Scala would look to see if there was an appropriate conversion method available (within scope) that could be used to convert a string into an integer.

For a method or function to be used in this way it must be marked with the keyword *implicit*. This means that only those methods marked by the developer as being suitable to be used with an implicit conversion can be used in this way.

Implicit conversion methods and functions are a very useful way of extending the types that a library of code can work with. For example, you cannot extend the class String, but in Scala you can extend the concept of a String. For example, what if you want to be able to use the '*' operator to replicate a string a given number of times. There is no support in the current String class for this, but we can add it. This can be done by creating a new class, the *StringRepeated* class and providing an implicit converter that converts from a standard string into a *StringRepeated* class. For example:

```
class StringRepeated(original: String) {
  def mult(times: Int) = {
    def multiply(times: Int, accumulated: String):
String = {
      if (times > 1)
           multiply(times - 1, accumulated + original)
      else
           original + accumulated
    }
    multiply(times, "")
  }
}
 object Util {
 implicit def string2repeated(x: String) =
                                    new StringRepeated(x)
}
```

The key here is that the *string2repeated* method is marked as being implicit and thus can be used when an implicit conversion is required.

At one level we have defined a new class that builds on a string and allows that string to be repeated a number of times. It also provides a method that allows a string to be converted into a *StringRepeated* instance. This code could be used as shown below:

```
val repeated = (new StringRepeated("=")) mult 10
println(repeated)
```

Thus would result in the following output:

```
==========
```

However, this does not meet the proposed aim described earlier. We have not extended the concept of a String. However, the following example appears to suggest that we have done exactly that:

```
import Util._
val result = "=" mult 10
println(result)
```

In this case the String "=" does not have an operation '*' defined for it. However, Scala looks to see if there is an implicit method available that can convert a String into a type that does support the '*' operation. If the string2repeated method is in scope (for example because it has been imported) then Scala can use that method to convert the "+" string into a *StringRepeated* instance and then invoke the '*' operator on it. As the return type of the '*' method is a String the val *result* holds a String. Thus it appears that Strings now support the '*' operator. The result of printing out result is again:

```
==========
```

Implicit conversions can be very powerful however, you should be careful how and when you use implicit conversions as there can be unintended consequences. It is therefore important to manage the visibility of your implicit conversion methods appropriately.

29.3 Implicit Parameters

An implicit parameter is a parameter to a method, function or constructor that is marked as implicit. Such a parameter does not need to have been provided by the called. Instead, if an implicit parameter is missing when the method is invoked, Scala will attempt to provide an appropriate value. It does this by local at the set of variables currently in scope and attempts to fund one that has been marked as implicit and is of the right type (or that can be implicitly converted to the right type).

Note that this is not the same as providing a default value for a parameter, Rather it provides a way for Scala to fund suitable parameters from those that are currently in scope. That is, the compiler will search for an implicit value defined within the current scope (according to the resolution rules). Implicit parameters are very good for simplifying an API by providing values that can be imported and used when the programmer does not want (or need) to provide them.

The following method defines two parameter lists with the second parameter list containing a single implicit parameter ‘I’:

```
def printer(content: String)(implicit i:Int): Unit = {
    for (i <- 0 until i) print(content)
}
```

The printer method can now be called within 1 or 2 arguments (as long as an implicit variable is available to provide the second parameter). Thus we can call the printer function in the following ways:

```
printer("John")(4)
println("\n-----------------")
printer("John")
```

The first invocation of printer passes in the string “John” and the integer 4. The output of this is

```
JohnJohnJohnJohn
```

The second invocations again passes in the string “John” but Scala looks for an implicit argument to provide t=for the second parameter list. If none is available a compilation error will be generated. In this case a definition of an implicit val integer ‘v’ is in scope:

```
implicit val v=2
```

Thus Scala uses the value in ‘v’ as the value to use for the second parameter which means that the second invocation of printer is the same as writing (printer(“John”)(2)), with the result that the output generated is:

```
JohnJohn
```

Defining a *val* or *var* (or indeed a method that will supply an appropriate value) as *implicit* means that the value held will be considered during any *implicit resolution*. However, you should note that an explicit invocation would always override an implicit value.

There are some restrictions on implicit parameters, including:

- There can only be a single implicit keyword per method
- The implicit parameter must be at the start of a parameter list (although there can be multiple parameter lists)
- When the implicit keyword is used with a parameter list then it makes all values of that parameter list implicit.
- If there are multiple parameter lists, then only the last one may be implicit.

29.4 Implicit Objects

It is also possible to have a companion object that contains appropriate implicit values or implicit conversion method. Scala will search companion objects for implicit values or conversion methods/functions. This is a very useful feature and can be used for building implicit adapters that convert form one type to another.

For example in the following listing a trait LabelMaker has a companion object LabelMaker. This companion object defines two things. The first is an AddressLabelMaker inner object. This AddressLabelMaker is a subtype of the LabelMaker trait. It defines a method output that takes an Adddress instance and returns a string representing the Address as a Label. It is also marked as an *implicit* object and thus can be used whenever an implicit value is required.

```
package com.jeh.scala.label

case class Address(street: String, number: Int)

 // Defines a trait to convert things into labels
trait LabelMaker[T] {
  def output(t: T): String
}

object LabelMaker {
  // Adapter class that converts Address to labels
  // and an instance created from it for use
  // with implicit params
  implicit object AddressLabelMaker extends
LabelMaker[Address] {
    def output(address: Address): String = {
       address.number + " @ " + address.street
    }
  }
  // label method that uses an implicit param
def label[T](t: T)(implicit lm: LabelMaker[T]) =
                                          lm.output(t)

}
```

The other method defined by the companion object LabelMaker is *label*. This method is a generic method which defines the generic type ‘T’ as the parameter type for the single parameter in the first parameter list. It then specifies an implicit parameter in the second parameter list. This second parameter requires a instance of r object that is a type of LabelMaker. This label maker is used as to convert the parameter ‘t’ into a label. Any client of the Label Maker can either call the printLabel using the two parameter lists, for example:

```
  label(address)(myLabelMaker)
```

or they can call it with a single parameter list, for example:

```
label(address)
```

In this latter case, Scala will look within the current context to see if there is an implicit value that can be used for the required second parameter. If there is it will use it, if there is not then the code will not compile.

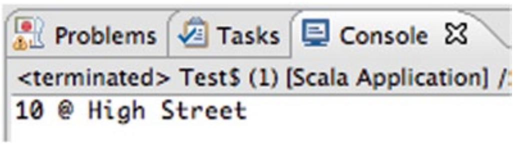
In the test application presented below, we are importing the LabelMaker definitions into the Test object. Note that we have used the import statement within the body of the Test object. This means that the properties, methods and functions defined on the LabelMaker concept will only be directly accessible within Test. Also note that the LabelMaker *concept* is comprised of the LabelMaker Trait and the LabelMaker *companion* object and thus the contents of both are imported at this point. The Test object creates an Address to use and then calls the *println* function passing in the result returned from the label method. Note that it is the single parameter list version that is being invoked here and thus Scala looks for an implicit value to use for the second parameter list for the LabelMaker. As the LabelMaker object has been imported it finds an implicit object AddressLabelMaker that it can use and thus the second parameter is bound to the AddressLabelMaker.

```
package com.jeh.scala.label

object Test extends App {
  import LabelMaker._
  val a = Address("High Street", 10)
  // method label uses Label maker to convert to labels
  // implicitly uses the object instance of
  // AddressLabelMaker
  println(label(a))
}
```

The result of executing this program is shown in Fig. 29.1.

29.5 Implicit Classes

Implicit classes (which were introduced in Scala 2.10) can be used to automatically provide a factory conversion function that will convert a given type into the implicit class type. That is, using the implicit keyword in front of the class definition causes Scala to create a factory method that will convert another type of object into an instance of the implicit class.



```
<terminated> Test$ (1) [Scala Application] /
10 @ High Street
```

Fig. 29.1 Output from the LabelMaker Test Application

Classes annotated with the implicit keyword are referred to as implicit classes. There are a set of restrictions on implicit class that must be met, these are:

1. All *implicit* classes must have a primary constructor with *exactly* one argument in its first parameter list (although it can have additional parameter lists that may include additional implicit parameters).
2. Implicit class cannot be top-level classes, they must be contained within another type (but may be defined within an object, a trait or another class).
3. There cannot be any method, member or object in scope with the same name as the implicit class.

For example, in the following listing the implicit inner class RIchString makes its primary constructor available for implicit conversions. Thus if we need to convert a string into a RichString in order to invoke the times method, then the RichString will be invoked by creating a new instance of the RichString based on the original string (which is passed in as the value required by the single parameter constructor).

```
package com.jeh.scala

object Util {
  implicit class RichString(value: String) {
      def times(i: Int): String = {
        var result = ""
        for (i <- 0 until i) result = result + value
        return result
      }
  }
}
```

The compiler effectively converts this into the following:

```
package com.jeh.scala

object Util {
   class RichString(value: String) {
      def times(i: Int): String = {
        var result = ""
        for (i <- 0 until i) result = result + value
        return result
      }
  }

  implicit final def RichString(value: String):
RichString = new RichString(value)

}
```

The above has the same behaviour as the implicit class—although the implicit class is both more concise and simpler to understand.

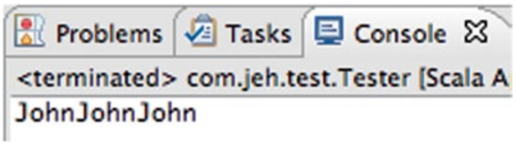
This Util class and its implicit inner class RichString can be used in the following way:

```
package com.jeh.test

import com.jeh.scala.Util

object Tester extends App {
    import Util._
    println("John" times 3)
     }
```

Note that again although the Util object is imported at the top of the file the RichString implicit class is only imported (without qualification) within the Tester object. This means that the string "John" is implicitly converted into a RichString using the RichString constructor so that the times method can be invoke don that instance. The integer 3 is passed into the *times* method and the string "John" is replicated 3 times. The end result is that the String "John" is printed out three times, as illustrated by Fig. 29.2.

29.6 Scala Annotations

Annotations are meta data about program code, that is they provide additional information about a class, object, trait, method, function, parameter etc. to the compiler and to the runtime environment within which the code executes. Scala is not the



```
<terminated> com.jeh.test.Tester [Scala A
JohnJohnJohn
```

Fig. 29.2 Using the Implicit class

only programming language to have annotations (or annotation like constructs). Both Java and C# support annotation style constructs.

In general annotations are used to provide:

- Directives to the compiler
- Generating additional material—Scaladoc
- Pretty printing
- Checking for common errors
- Information to third party frameworks

In Scala annotations can be applied to:

- vals, vars, defs, classes, objects, traits, types and expressions

Basic Scala annotations have the format:

```
@<annotation-name>
```

For example:

```
@deprecated
class Author {}
```

Annotations with parameters have round brackets '(..)' and can take a comma separated list of expressions, for example:

```
@SerialVersionUID(1L)
```

Currently there is a range of annotations that can be used as shown in Table 29.1.

The following listing illustrates a single class which has a number of annotations applied to it. Note that more than one annotation can be applied to a particular program element. In this case the class Person has two annotations applied, @SerialVersionUID and @deprecated. In addition the method toString has been marked with the @inline annotation.

Table 29.1 Annotations in Scala

Annotation	Meaning
`scala.SerialVersionUID`	Indicates serial version UID value. A serial version unique ID is used to determine whether a serialized instance is compatible with the class that will used when the instance is deserialized. If the number associated with the class is the same as that stored with the instance then they are compatible. If they are not the same then a Serialization exception is thrown
`scala.cloneable`	Indicates the instance of the associated type can be cloned (copied)
`scala.deprecated`	Indicates that the associated type or construct is deprecated. This means that the type or construct should no longer be used and (typically) alternative shave been provided
`scala.inline`	Indicates compiler should try to inline annotated method
`scala.native`	Type checking is present but implementation will be native
`scala.remote`	Indicates can be accessed remotely
`scala.throws`	Indicates that a method throws a checked exception
`scala.transient`	Indicates field is transient
`scala.reflect.BeanProperty`	Adds setter and getter methods to a field

```
package com.jjh.scala.anno
import scala.Serializable

@SerialVersionUID(1L)
@deprecated
class Person(name : String, var age : Int) extends
Serializable {
  @inline
  override def toString() = name + ": " + age;
}
```

29.7 Type Declarations

A type declaration can be used to create a new type or provide an alias to an existing type. It can also be used as a way of defining an abstract type that must be provided at a later date. It is particularly useful as a way of proving a more semantically meaningful name for a generic type. Types are defined using the key word *type*, for example a type can be defined based on an existing type as follows:

```
type T:=String
```

Alternatively a type declaration can be based on a function signature:

```
type F=Int=>String
```

Which is a very useful way of specifying a meaningful name for such a signature.
A type can also be an abstract declaration:

```
type T    // actual type to be supplied in sub type
```

In which case the concrete type used with T must be provided in a sub type (for classes) or in the class (or object) that the trait is being mixed into.

An abstract type may also have a bound that is used to restrict the range of concrete types that can be used with it. For example:

```
type T<: Transport
```

Thus the abstract type 'T' has an upper bound of Transport. This means that the concrete type used in a class or object must either be of type Transport or a subtype of Transport.

Examples of the above are shown in the following listing:

```
class Transport

class Test {
  type T = String
  type F = Int => String
  type X                        // abstract type
  type Y <: Transport           // Upper Bounds
  type Z >: Transport           // Lower Bounds
}
```

29.8 Enumerations

There is a type *Enumeration* in Scala. This type is a trait that defines the core concepts of an Enumeration. An enumeration is a collection of entities that represent a complete, ordered set of all of the entities in that set. For example, the days of the week could be represented by an Enumeration as there is a finite set of days in the (working) week.

In Scala an enumerated set is an object that mixes in the trait Enumeration and defines the vals that will from the set of values that comprise that enumeration. For example, the days of the (working) week enumeration could be defined as follows:

```
package days

object DaysOfWeek extends Enumeration {
  val Monday = Value
  val Tuesday = Value
  val Wednesday = Value
  val Thursday = Value
  val Friday = Value
}
```

Note that each of the *val* in the enumeration is of type Value and is represented by a Value instance. Because all of the values in the enumeration are of the same type a short hand from can be used to define them, as follows:

```
object Weekend extends Enumeration {
          val Saturday, Sunday = Value
 }
```

Here both Saturday and Sunday are values of the enumeration Weekend and both are represented by instances of Value.

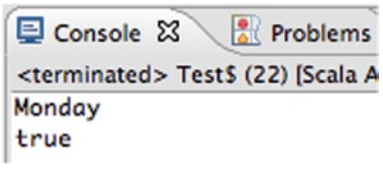
The Value of an enumeration entry is actually an inner class of the Enumeration trait. The Value inner class:

- has an id—the value for this element of the enumeration. Note that enumerations are zero based by default and thus the first element in an enumeration has the *value* 1.
- provides numerous methods +, <, equals etc.
- defines a number of *implicit* methods.

Each call to a Value method adds a new unique value to the enumeration set where the id (or value) is incremented by one. Thus in the above example, Monday has id0, Tuesday the id1, Wednesday the id 2 etc.

Once we have defined the enumeration it can be imported into other code using the import statement. Once it is imported then it can be used to provide values for variables etc. For example:

```
import days.DaysOfWeek

object Test1 extends App {
  val today = DaysOfWeek.Monday
  println(today)
  println(today < DaysOfWeek.Friday)
}
```



```
<terminated> Test$ (22) [Scala A
Monday
true
```

Fig. 29.3 Output from Enumeration

In the above code the DaysOfWeek enumeration has been imported and the enumeration element Monday has been used for the value of the *val* today. We then compare the value of today to see if it less than the value for Friday. As an enumeration is an ordered set there is an ordering to the element in the set and thus we can perform such comparisons. The result of executing this program is shown in Fig. 29.3. As you can see the value of today is printed as Monday—this the string representation of an element of an enumeration is the name of the element (and not the underlying id).

In Scala is it also possible to import the values defined within an enumeration so that they can be used directly (without the need to prefix them with the name of the Enumeration). This can be done by directly importing the contents of the enumeration. For example:

```
import days.DaysOfWeek._
```

It is now possible to use the Enumeration values directly, for example:

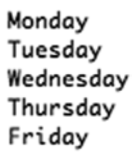
```
object Test1 extends App {
  import DaysOfWeek._
  val today = Monday
  println(today)
  println(today < Friday)
}
```

Note that we have imported the enumeration inside the definition of Test1 and thus the enumerated values are only directly visible within the scope of Test1.

It is also possible to obtain all of the values in an Enumeration using the *values* property of the enumeration. For example, to print out all of the values in the DaysOfWeek enumeration we can:

```
object Test2 extends App {
  DaysOfWeek.values.foreach(println(_))
}
```

This results in the output presented in Fig. 29.4.



```
Monday
Tuesday
Wednesday
Thursday
Friday
```

Fig. 29.4 Output from the Test2 program

If you wish to you can of course get hold of the underlying id of each of the values in an Enumeration. This is done by access in the readonly id property of any value within the enumeration. For example, to obtain the id of Monday we can:

```
object Test3 extends App {
  val today = DaysOfWeek.Monday
  println(today.id)
}
```

This also means that it is possible to access a specific value of an enumeration using the id. Referencing the Enumeration and specifying the index to use as a parameter to a factory function that returns the appropriate value do this. For example:

```
object Test4 extends App {
  val d = Weekend(0)
  println(d)
}
```

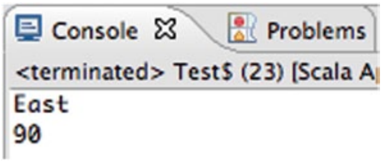
In the above code we access the value *Saturday* using the index '0'.

It is also possible to define your own ids for the values in the enumeration (that is they do not need to start zero and be incremented by one). For example, in the following listing the Direction enumeration contains four values for North, South, East and West with the degrees used to represent these compass points used as the *value* of each element in the enumeration. Note that the value to use as the id is used with the factory constructor for the Value inner class.

```
object Direction extends Enumeration {
   val North = Value(0)
   val East =  Value(90)
   val South = Value(180)
   val West =  Value(270)
}
```

As before it is possible to access the id of the value as well as the value itself:

Fig. 29.5 Using a custom value



```
<terminated> Test$ (23) [Scala A
East
90
```

```
object Test extends App {
  val d = Direction.East
  println(d)
  println(d.id)
}
```

The result of running this program is shown in Fig. 29.5. In this figure you can see that the result of printing the enumerated value is East but the id of this value is now 90.

Note that you can access the custom values in exactly the same way as you can access the default index values. Thus you can specify the enumerated element using a values such as 0, 90, 180 and 270:

```
val d1 = Direction(90)
println(d1)
```

However, values are not restricted to integers as indexes. It is also possible to define values based on Strings. These are referred to as named values. In the following example the strings “n”, “e”, “s” and “e” are used to uniquely name (or identify) the individual members of the Enumeration.

```
object StringDirection extends Enumeration {
   val North = Value("n")
   val East =  Value("e")
   val South = Value("s")
   val West =  Value("e")
}
```

As before we can access the members of the enumeration using North, East. West and South or using their names such as “n”. However to do this we use an access or function on the enumeration called *withName.* For example:

```
val d3 = Direction.withName("n")
println(d3)
```

One issue with the examples we have looked at so far is that the type of the members of the enumeration is Value. Thus if we wish to create properties or functions that work with the values of the enumeration the specified type will be Value. For example, the type of the parameter today is *Value*:

```
val today = DaysOfWeek.Monday
println(today)
```

Thus if we wrote a method to take this value and print it we would write:

```
def printDay(d: Value) = println(d)
```

Whilst this is legal Scala, it is not very meaningful to a human reader of the code. There is some semantic meaning that has been lost from the Enumeration to the inner Value. It is thus common to find that a recurring idiom is present within an Enumeration. This idiom defines a new type with a more meaningful alias for Value that can be used with clients of the enumeration. This type is defined within the scope of the Enumeration and thus does not pollute the namespace of a system. For example within the Enumeration *DaysOfWorkingWeek* we have defined a new type called Day that is an alias for Value. Monday, Tuesday, Wednesday etc. are still instances of the inner class Value. However, we can refer to this type either through the name Value or the name Day.

Thus given the definition of the Enumeration *DaysOfWorkingWeek*:

```
object DaysOfWorkingWeek extends Enumeration {
  type Day = Value
  val Monday, Tueday, Wednesday, Thursday, Friday = Value
}
```

We can now import the contents of the Enumeration and directly refer to the type Day as well as the values Monday, Tuesday, Wednesday etc. Thus the parameter to the function *printDay* can now be Day (rather than Value):

```
import DaysOfWorkingWeek._
def printDay(d: Day) = println(d)
```

29.9 Lazy Evaluation

Scala possesses the ability to mark a *val* or *var* as lazy, for example the following standard definition of *val* is evaluated immediately:

```
val x=15
```

However, you can use the prefix *lazy* to indicate that the *val* should only be evaluated the first time it is accessed:

```
lazy val x=15
```

This can be used to improve the performance of a system where some resource is expensive to create (either in terms of time and/or resources) but is only infrequently required.

Chapter 30
Exception Handling

30.1 Introduction

This chapter considers exception handling and how it is implemented in Scala. You are introduced to the object model of exception handling, to the throwing and catching of exceptions, and how to define new exceptions and exception-specific constructs.

30.2 What Is an Exception?

In Scala, everything is an instance of a class, although we have Value Classes and Reference Classes. Exceptions and exception handling relate to reference types that is exceptions are instances of Reference Classes.

All exceptions in Scala must extend the (Java) class `Throwable` or one of its subclasses, which allows an exception to be thrown or raised. Figure 30.1 presents the Exception class hierarchy.

The `Throwable` class has two subclasses: `Error` and `Exception`. Errors are exceptions generated at runtime from which it is unlikely that a program can recover (such as out of memory errors). Where as Exceptions are issues that your program should be able to deal with (such as attempting to read form the wrong file).

Unlike Java which has two types of `Exception` subclass (one for checked or managed exceptions and one for unchecked or runtime exceptions) Scala only has one type of Exception. These are in Java terminology unchecked exceptions—meaning that you can handle them if you wish but the compiler will not check to see that you have handled them.

An exception can be thrown explicitly by your code or implicitly by the operations you perform. In either case, an exception is an object, and you must instantiate it before you do anything with it. You do this by using the `throw` operator. This is

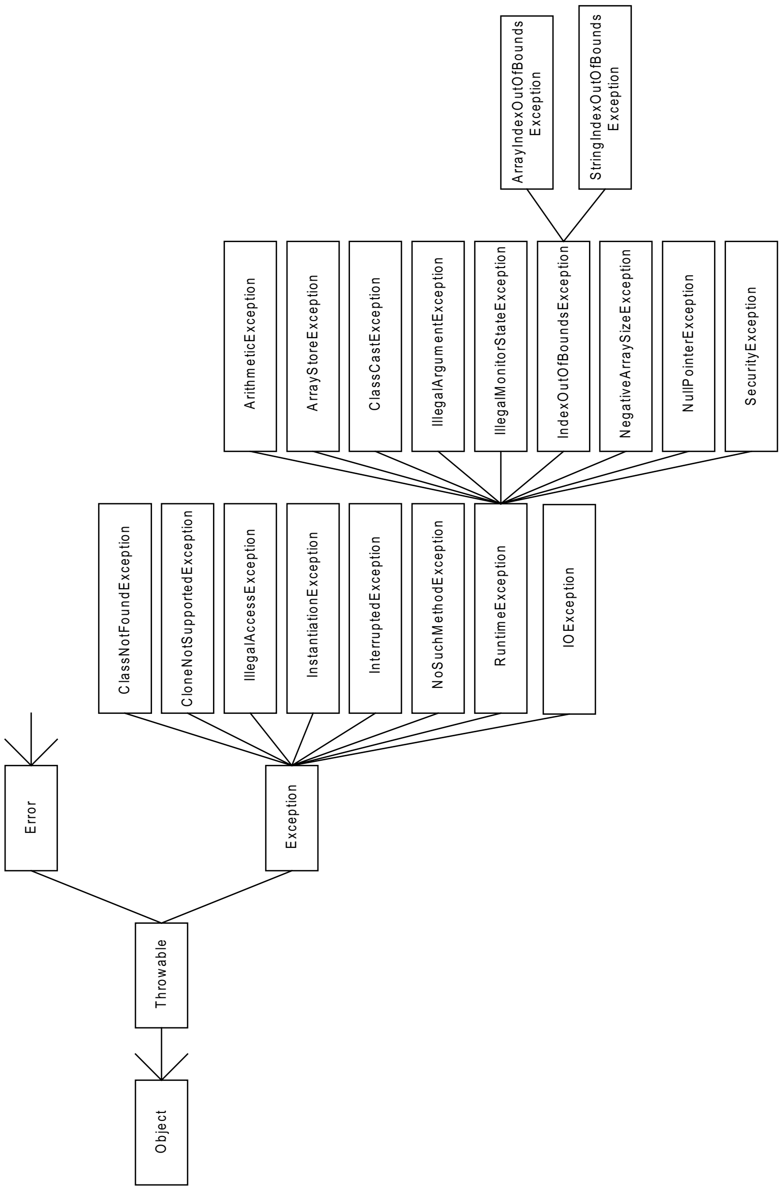


Fig. 30.1 Part of the Exception class hierarchy

Table 30.1 Terms used in exception handling

Exception	An error that is generated at runtime
Raising an exception	Generating a new exception
Throwing an exception	Triggering a generated exception
Handling an exception	Processing code that deals with the error
Handler	The code that deals with the error (referred to as the `catch` block)
Signal	A particular type of exception (such as *out of bounds* or *divide by zero*)

used to throw an instance of the appropriate exception. For example, to raise (and then throw) an `ArithmeticException` for a divide by zero error, we write:

```
throw new ArithmeticException("Division By Zero")
```

The exception is caught by the first handler (`try` block) that is defined on the `ArithmeticException` (or one of its parent exception types).

We can also define new exceptions based on existing Exception classes. For example:

```
class RottenEggException extends Exception
…
throw new RottenEggException
```

The class `RottenEggException` directly extends the `java.lang.Exception` class. It thus inherits all the behavior of an exception and can be instantiated using the keyword *new* and thrown using the keyword *throw* in exactly the same way as any built in exception class.

30.3 What Is Exception Handling?

An exception moves the flow of control from one place to another. In most situations, this is because a problem occurs which cannot be handled locally, but can be handled in another part of the system. The problem is usually some sort of error (such as dividing by zero), although it can be any problem (for example, identifying that the post code specified with an address does not match). The purpose of an exception, therefore, is to handle an error condition when it happens at run time (Table 30.1).

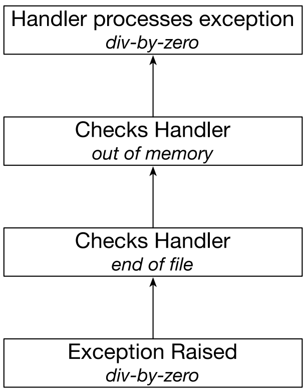


Fig. 30.2 Searching through the execution stack

It is worth considering why you should wish to handle an exception; after all, the system does not allow an error to go unnoticed. For example, if we try to *divide by zero*, then the system generates an error. This may mean that the user has entered an incorrect value, and we do not want users to be presented with a dialog suggesting that they enter the system debugger. We can use exceptions to force the user to correct the mistake and rerun the calculation.

Different types of error produce different types of exception. For example, if the error is caused by dividing an integer by zero, then the exception is a *divide by zero* exception. The type of exception is identified by objects called signals which possess exception handlers. Each handler can deal with exceptions associated with its class of signal (and its subclasses).

An exception is initiated when it is thrown. The system searches back up the execution stack until it finds a handler which can deal with the exception (i.e. it searches for a try block of the appropriate type). The associated handler then processes the exception. This may involve performing some remedial action or terminating the current execution in a controlled manner. In some cases, it may be possible to restart executing the code.

As a handler can only deal with an exception of a specified class (or subclass), an exception may pass through a number of other blocks before it finds one that can process it.

Figure 30.2 illustrates a situation in which a *divide by zero* exception is raised. This exception is passed up the execution stack where it encounters an exception handler defined for an *End of File* exception. This handler cannot handle the *divide by zero* exception and so it is passed further up the execution stack. It then encounters a handler for an *out of memory* exception. Again, it cannot deal with a *divide by zero* exception and the exception is passed further up the execution stack until it finds a handler defined for the *divide by zero* exception. This handler then processes the exception.

30.4 Throwing an Exception

Unlike Java, Scala methods and functions do not need to specify whether they throw exceptions nor not. Thus any type of operation could throw an exception if a problem occurs. When an exception is thrown there are three things that can be done:

- Let the exception propagate back/pass back up the call chain.
- Catch the exception and handle it within the method.
- Catch the exception and map it onto your own exceptions by throwing a new exception.

Passing the exception back up the execution stack is acceptable as long as you know that it will be dealt with sensibly at some point. Scala does not force you either to handle the exception locally or to pass it back up the execution stack explicitly. Instead you must decide how to handle an exception and document which methods throw which exceptions. In general you must consider carefully whether to throw or handle the exception and such handling of exceptions should be part of the design of your software and not an after thought.

30.5 Catching an Exception

You can catch an exception by implementing the try-catch-finally construct. This construct is broken into three parts:

- Try block

The `try` block indicates the code that is to be monitored for the exceptions listed in the `catch` expressions.

- Catch expressions

You can use an *optional* `catch` expression to indicate what to do when certain classes of exception occur (e.g. resolve the problem or generate a warning message).

- Finally block

The *optional* `finally` block runs after the `try` block exits (whether or not this is due to an exception being raised). You can use it to clean up any resources, close files, etc.

This construct may at first seem confusing, however once you have worked with it for a while you will find it less daunting. Typically, you use the same incantation of the construct; concentrate on the details of the code within the `try` block and do not worry about the exception handling mechanism.

The basic construct is illustrated below:

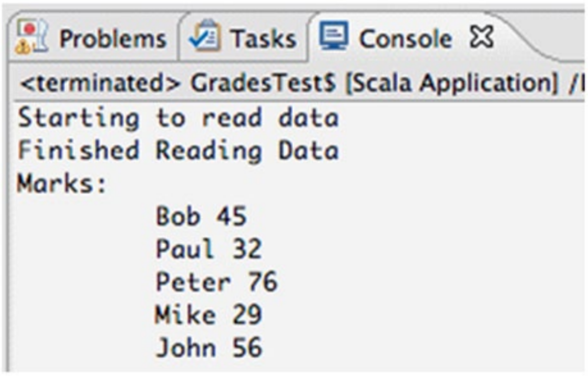
```
  try {
    println("Start Cooking")
    makeAnOmlet
    println("Omlette Made")
} catch {
    case ex: RottenEggException => println("#$%&#@")
    case ex: Exception =>
                      println("What went wrong?")
} finally {
    println("Finished Cooking")
}
```

In the above we try and make an omlette. The first thing we do when we enter the try block is print out the message "Start Cooking". We then invoke the `makeAnOmlet` method. However if something goes wrong while invoking the `makeAnOmlet` method then we will move straight to the catch block (and do not execute the rest of the `makeAnOmlet` method and the second `println` statement. If no problem occurs then we will print out the "Omlette Made" string. In both cases once processing of the try (and optionally catch) blocks finishes we execute the finally block (which is always run) and print out the "Finished Cooking" string.

If a problem does occur in the main try block and processing moves to the catch block we then use pattern matching to compare the type of exception raised with the types listed in the order they are defined in. Thus the first comparison is with the `RottenEggException` type. If what we have is a type of `RottenEggException` (or a subclass of `RottenEggException`) then the behaviour associated with that check is performed. Note that the actual exception is available in the variable ex (although you can call this variable any name you like). If the type of exception is not a `RottenEggException` then we move onto the next test and check to see if what we have is an `Exception` or a subclass of `Exception`. If it is then we process the associated behaviour. Due to the fact that consideration is given to subclass of the type of exception listed, more specific Exceptions need to come before more generic exceptions.

The following example uses the try-catch-finally construct to read data from a file and process it. The `try` block incorporates the file access code, and the code in the catch block states what should happen if an `FileNotFoundException` is raised. In this case, it prints a message. The message in the `finally` block is always printed. It brings together many of the aspects of the Scala language. It includes a `ListBuffer`, a `match` statement, the use of the `Option` wrapper and `for` loops. It also uses a Scala `Source` to read information from a file.

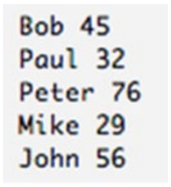
```
    package com.jjh.scala.file

    import scala.collection.mutable.ListBuffer
    import scala.io.Source
    import java.io.FileNotFoundException

    class Grades {
      var marks = ListBuffer[String]()

    def calculateGrades: Unit = {
      loadData("input.data")
      println("Marks:")
      for (i <- 0 until marks.size) {
        println("\t " + marks(i))
      }
    }

    def loadData(filename: String) = {
      var source: Option[Source] = None
      try {
        println("Starting to read data")
        source = Some(Source.fromFile(filename))
        source.get.getLines.foreach {
          e => marks += e
        }
      } catch {
        case ex: FileNotFoundException => println(
                    "Whoops we have a problem")
      } finally {
        println("Finished Reading Data")
        source match {
          case Some(x) => source.get.close()
          case None => println("Problem with source")
        }
      }
    }
  }

  object GradesTest extends App {
    val grades = new Grades()
    grades.calculateGrades
  }
```



```
<terminated> GradesTest$ [Scala Application] /l
Starting to read data
Finished Reading Data
Marks:
        Bob 45
        Paul 32
        Peter 76
        Mike 29
        John 56
```

Fig. 30.3 Running the Grades application

The Grades application reads data from a file called `input.data` that has the following format:



```
Bob 45
Paul 32
Peter 76
Mike 29
John 56
```

The `loadData` method uses the `scala.io.Source` object to access the file indicated by the filename parameter. A factory style method, (`fromFile`) is used to create an appropriate source instance. This instance is then used to obtain the contents of the file (using getLines) and then a `foreach` loop is used to process each line read in turn. This is processed within the function specified in the body of the `foreach` where each line is added to the `ListBuffer` marks.

This code is wrapped up in a `try` block. If this code raises an `FileNotFoundException`, the message "Whoops we have a problem" is printed. Once the `try` block is processed, the `finally` block prints out "Finished Reading Data". It then checks to see if the source has been set or not. If it has been set then it closes the source. If it was not set then it prints out a message stating that there was a problem with the source.

The `calculateGrades` method loads in the data file (using `loadData`) and prints out the data in the marks `ListBuffer`. Figure 30.3 shows the result of executing the Grades application.

30.6 Try Block Returns a Value

In Scala most statements are actually expressions that return a value. The try-catch-finally expression is no different. You can assign the value returned by the try block (or the catch block if an error occurs) to a value. For example, the following listing reads the contents of a file into the *val* content or throws an appropriate exception. If an exception is thrown then the value assigned is determined by which exception it is. If the `FileNotFoundException` is thrown then the string "No file" is return by the try-catch construct. If it is the `IOException` which is thrown then it is the string "General IO issue" which is return. In all cases the string returned is assigned to the val `contents` and is then printed out:

```
import scala.io.Source
import java.io.IOException
import java.io.FileNotFoundException

object TestAssign1 extends App {
 val content =
    try {
        Source.fromFile("test.txt")
                          .getLines.mkString("\n")
    } catch {
         case ex: FileNotFoundException => "No file"
         case ex: IOException => "General IO issue"
    }
    println(content)
}
```

Note that the `FileNotFoundException` is a subtype of the `IOException` and thus must come before the `FileNotFoundException`. Also note that the `mkString` method converts an array of strings into a single string (and in this case uses '\n' (or carriage return) to separate the lines within the String.

30.7 Defining an Exception

As mentioned earlier in this chapter, you can define your own exceptions, which can give you more control over what happens in particular circumstances. To define an exception, you create a subclass of the `Exception` class or one of its subclasses. For example, to define a `DivideByZeroException`, we can extend the Exception class and generate an appropriate message:

```
class DivideByZeroException(val source: Any)
    extends Exception("Divide By Zero in " + source)
```

This class explicitly handles divide by zero exceptions. We could have made it a subclass of `ArithmeticException`, however we have decided to extend `Exception` here to illustrate that it is the programmer's choice which exception should be extended.

The following code is an example of how we might use `DivideByZeroException`:

```
class Example(val x: Int, val y : Int) {
  def test = {
    if (y == 0)
      throw new DivideByZeroException(this)
    else
      println(x / y)
  }
}

object ExampleTest extends App {
  val e = new Example(5, 0)
  try {
    e.test
  } catch {
    case ex: DivideByZeroException => println("Opps")
  }
}
```

In this example, we check to see if the divisor is zero. If it is, we create a new instance of the `DivideByZeroException` class and throw it. The test method delegates responsibility for this exception to the calling method (in this case, the main method). The `main` method catches the exception and prints a message.

30.8 A More Functional Approach

For those of you who are familiar with exception handling in other languages such as Java, C# etc. you will see that Scala's try-catch-finally construct is very similar. However, it is not without its drawbacks. The need to work with some resources (such as source, database connections or connections to a file) in multiple places can result in some awkward programming solutions. In general there are two key problems with this approach:

- The syntax results in scoping issues leading to unnecessarily complicated constructs as well as the need to nest try-catch block within either the try, catch or finally part of the top level construct!
- Multi-threaded code can be difficult to deal with using the try-catch-finally construct. For example, how should you react to an exception which occurs in a

separate thread but which impacts the data being accessed? In fact the try-catch-finally construct primarily assumes that the exception is handle din the current thread (that is the exception is completely handled within the thread in which it occurred). This is not ideal for a concurrent program and seems at odds with the Actor model implemented by Akka.

It can also be argued that the try-catch-finally approach is not particularly functional and is more procedural in nature. As Scala is a hybrid language this is not necessarily an issue in its own right, but it does high light that alternative approaches can be developed based on the functional programing model.

An alternative approach is based on the

- `scala.util.control.Exception` singleton object and associated Catch class

This singleton object provides the catching method for handling exceptions that does not require the use of the try-catch-finally construct. In addition the associated `Catch` class provides the `withApply` method and the `apply` method. To see how the methods associated with `scala.util.control.Exception` can be used let us consider a simple try-catch-finally example:

```
import scala.io.Source
import java.io.IOException
import java.io.FileNotFoundException

object TestAssign1 extends App {
 val content =
    try {
        Source.fromFile("test.txt")
                          .getLines.mkString("\n")
    } catch {
          case ex: FileNotFoundException => "No file"
          case ex: IOException => "General IO issue"
    }
    println(content)
}
```

The above example reads the contents of the file text.txt into the val `contents` (or stores the string “No file” or “General IO issue” into content if an exception is thrown.

We could rewrite this using the `scala.util.control.Exception` object method `catching` as follows:

```
import scala.util.control.Exception
import java.io.IOException
import java.io.FileNotFoundException
import scala.io.Source

object TestCatching extends App {
    val fileCatch =
      Exception.catching(classOf[FileNotFoundException],
                         classOf[IOException])
                           .withApply{
                              e => "File Problem"}
    val content =
       fileCatch{
         Source.fromFile("test.txt")
                    .getLines.mkString("\n")}
    println(content)
}
```

The `catching` method returns a instance of the `Catch` class (the Catch class is a (nested) member class of the `scala.util.control.Exception` class. Every object of this class captures the exception handling logic usually represented by the catch (and the optional finally) parts of the try-catch-finally construct. The the `fileCatch` val is of type Catch and can be used to execute behaviour which we want to wrap in try-catch style processing. In the above example, the `fileCatch` val is used to execute the process of reading the contents of the file test.txt. The strings in the val `content` are wither the string lines in the file test.txt or the string "File Problem" if a `FileNotFoundException` or a IOException are thrown. In either case the string(s) in `content` are printed out.

Note that we can import the catching method directly from the Exception object by importing:

```
import scala.util.control.Exception.catching
```

Which means that in the main body of the application we would not need to repeat `Exception.catching`; instead we only need to use catching, for example:

```
val fileCatch =
        catching(classOf[FileNotFoundException],
                 classOf[IOException])
            .withApply{e => "File Problem"}
```

Another variation on the processing of the Catch instance is to use the `opt` method. This method takes a code block as parameter and executes the code as we have seen before. However, the result is an `Option` wrapper that either wraps a value or returns `None`. This may be more appropriate where we do not want to provide a default value in the catching specification. We can the use standard `Option` functionality to obtain the value or retrieve a default value etc. For example

```
import scala.util.control.Exception.catching
import java.io.IOException
import java.io.FileNotFoundException
import scala.io.Source

object TestCatchingWithOpt extends App {
  val fileCatch =
        catching(classOf[FileNotFoundException])
            .withApply(
            e =>
              throw new RuntimeException("problem", e))

    val content =
      fileCatch.opt{Source.fromFile(test.txt)
                                .getLines.mkString("\n")}

    println(content.getOrElse("File Not Found"))
  }
```

30.9 The Try Type

Scala 2.10 added a new type to the facilities available for processing exception. This is the `scala.util.Try` type. The `Try` type is intended to further enhance the handling of exceptions in a functional style in Scala. The `Try` type is a container that has one of two possible values; one of type `Success` and one of type `Failure`. The `Failure` instance holds the `Throwable` instance (the exception) that caused the code that was run to fail.

For example:

```
import scala.util.Try

object TestTry extends App {
   val i = Try ( "123".toInt )
   println(i)
   val j = Try ( "John".toInt )
   println(j)
}
```

This example attempts to convert a string to an integer for the val *i* and the val *j*. The string used for *i* can be converted to an *Int* (the Int 123) but the string used for *j* cannot be converted into an integer. Thus the first expression should succeed, but the second should fail. The output of this program is:

```
Success(123)
Failure(java.lang.NumberFormatException: For input
string: "John")
```

As you can see from this the value held in ‘i’ is a Success type but the value held in ‘j’ is a Failure type. The Failure also contains information about the problem that occurred and the value associated with it. To obtain the actual value from the Success wrapper you can use the method get, for example:

```
val i = Try ( "123".toInt )
println(i.get)
```

Which would print the Int 123.

There are a number of useful features associated with the Try type. One of the most useful is the recover method. The recover method allows us to include logic to identify and recover from the exception that caused the `failure` of the `Try` behaviour. For example:

```
import scala.util.Try

object TryWithRecoverTest extends App {
    val i = Try ( "John".toInt ) recover {
        case e: NumberFormatException => 0
     }
    println(i)
}
```

In this case we are mimicking the try-catch behaviour where the catch behaviour provides an alternative value to use. Thus in this case if the string to be converted to an `Int` cannot be represented as an `Int` we will default to the value Zero.

Chapter 31
Scala and JDBC Database Access

31.1 Introduction

In this chapter we will primarily look at how Scala can use a database connectivity API referred to as JDBC. Strictly speaking this is available to Scala when run on a JVM due to its relationship to the byte code environment of the JVM. Officially JDBC is not an acronym, however to all intents and purposes it stands for **J**ava **D**ata**B**ase **C**onnectivity. This is the mechanism by which relational databases are accessed in Java. As Scala runs in the same environment as Java Scala programs also have access to JDBC. At the time of writing it is the simplest and most stable approach to database access in Scala; however it is not the only approach and we will look at some of the more Scalaesque approaches in the next chapter.

31.2 Why JDBC?

Although there are some object-oriented databases available, many database systems presently in commercial use are relational (although NoSQL databases are gaining in interest it is still the case that relational database systems are the most prevalent). It is therefore necessary for any object-oriented language that is to be used for commercial development to provide an interface to such databases.

For many technologies, each database vendor provides their own proprietary (and different) API that can be used to access their (and only their own) database system. These libraries are commonly used by other languages such as Pascal and C. In many cases they are little more than variations on a theme, however they tend to be incompatible. This means that if you were to write a program that was designed to interface with one database system, it is unlikely that it would automatically work with another.

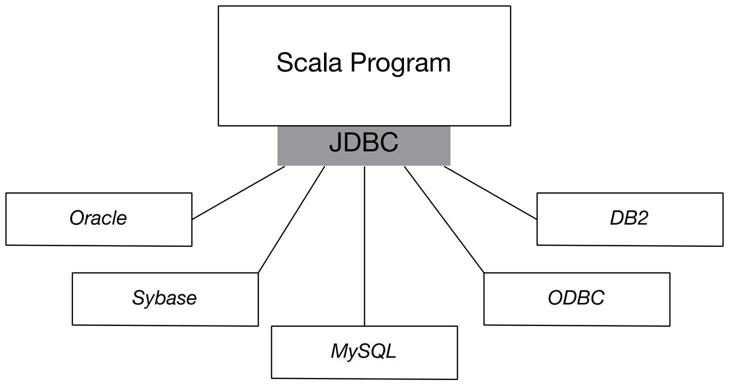


Fig. 31.1 The relationship between Scala, JDBC and Relational Database Systems

One of the philosophies of Java (and by implication Scala) is "*write once, run anywhere*". This means we do not want to have to re-write our Scala code just because it is using a different database on a different platform (or even the same platform). JDBC was Sun's (and now Oracle's) attempt to provide a vendor independent interface to any relational database system. That is, a single interface (JDBC) is provided to any relational database. A programmer therefore only needs to program to the JDBC interface, while behind the scenes the differences between database systems is managed by JDBC. This is illustrated in Fig. 31.1.

This is possible as most vendors implement most (if not all) of the standard SQL, thus allowing a common denominator. SQL stands for Standard Query Language and is used for obtaining information from relational databases. SQL is a large topic in its own right and is beyond the scope of this book.

One potential problem with such an approach is that although the developers interface is the same, different implementations of the framework would be needed to link to different databases. In the JDBC this is overcome by providing different back end drivers. The developer is now insulated from the details of the various relational database systems that they may be using and has a greater chance of producing portable code.

31.3 What is JDBC?

The JDBC allows a Java or Scala developer to connect to a database, to interact with that database via SQL, and of course to use those results within a Scala application. The combination of Scala and JDBC allows information held in databases to be easily and quickly accessed. It also provides a bridge that supports the Open Database Connectivity (ODBC) standard. The first version of the JDBC was released in the summer of 1996 and since then it has been enhanced with numerous additions. It is

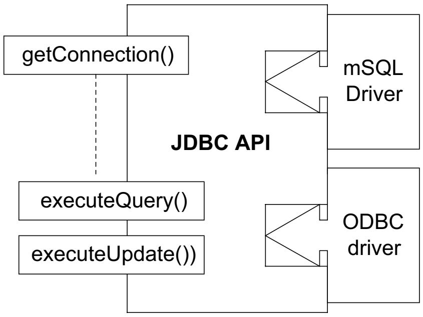


Fig. 31.2 The structure of the JDBC

an important addition to Scala's armoury, as the JDBC provides programmers with a language and environment that is platform and database vendor independent.

ODBC is a database access standard developed by Microsoft. This standard has been widely adopted not only by the vendors of Windows based databases but by others as well. For example, a number of databases more normally associated with Unix based systems or IBM mainframes now offer an ODBC interface. Essentially, ODBC is a basic SQL interface to a database system that assumes only "standard" SQL features. Thus specialist facilities provided by different database vendors cannot be accessed. In many ways JDBC has similar aims to ODBC. However, one major difference is that JDBC allows different database drivers (interfaces) to be used; one of which is the ODBC driver.

The JDBC is able to connect to any database by using different (back-end) drivers. These act as the interfaces between the JDBC and databases such as Oracle, Sybase, Microsoft Access and open source systems such as MySQL.

The idea is that the front end presented to the developer is the same whatever the database system, while the appropriate back-end is loaded as required. The JDBC then passes the programmer's SQL to the database via the back end. JDBC is not the first system to adopt this approach, however a novel feature of the JDBC is that more than one driver can be loaded at a time. The system will then try each driver until one is found that is compatible with the database system being used. Thus multiple drivers can be provided and at runtime the appropriate one is identified and used. This is illustrated in Fig. 31.2.

Figure 31.2 illustrates some of the most commonly used methods provided by the JDBC along with two database drivers (namely the My SQL driver and the ODBC driver; not that any number could have been provided). Such a set up would allow a Java program to connect to a mSQL database via the mSQL driver and to any database that supports the ODBC standard through the ODBC driver. The `getConnection()`, `executeQuery()` and `executeUpdate()` methods will be looked at in more detail later in this article.

There are a number of database drivers available for JDBC. At present databases such as Oracle, Sybase and Ingres all have their own drivers. This allows features of those databases to be exploited. However, even databases that are not directly supported can be accessed via the ODBC driver thus making a huge range of databases available to the Java developer.

To summarise JDBC – Java DataBase Connectivity:

- It is available to all JVM Languages including Java and Scala.
- It provides common front end for different databases.
- It relies on database specific drivers for the back end connection to the actual database.
- It provides an ODBC bridge (which is essentially a default back end driver).
- It is implemented within the java.sql and javax.sql packages as it is a core part of the Java libraries on which Scala builds.

31.4 Working with JDBC

There are a common series of steps that must be performed by any JDBC program. These involve loading an appropriate driver, connecting to a database, executing SQL statements and closing the connection made. These are discussed in more detail later in this chapter. However for reference they are illustrated graphically in Fig. 31.3. This illustrates the key elements that comprise the JDBC API (Application Programmers Interface):

In Fig. 31.3 you can see that the Driver Manager can have multiple drivers associated with it. Currently this runtime has three drivers; the Oracle Driver, the DB2 Driver and the MySQL Driver. When the program asks the Driver Manager for a Connection, each driver is prompted in turn for a connection. In this case it is the MySQL driver that returns a connection instance from the `getConnection` request.

Using the connection the program can get metadata about the database it is connected to use the `getMetaData` method. This returns a `DatabaseMetaData` instance.

Also using the connection instance the program can obtain a statement instance using the `createStatement` method. This returns an instance that can be used to execute a query or execute an update against the database. In this case we are using an `executeQuery` method with some SQL (such as `SELECT * from <table name>`). This method returns a `ResultSet` instance. A `ResultSet` instance can provide metadata about the data held in the result set via the `getMetaData` method. This returns a `ResultSetMetaData` instance (containing the number of columns and their names etc.).

It is also possible to loop through each of the rows in the `ResultSet` using the next method that moves the *cursor* on a row at a time (note it starts before the first row). Once the *cursor* (a pointer to the current row in the result set) is referencing a row various get methods can be used to retrieve the data. For example `getString`(name) will return the value associated with the column called *name*

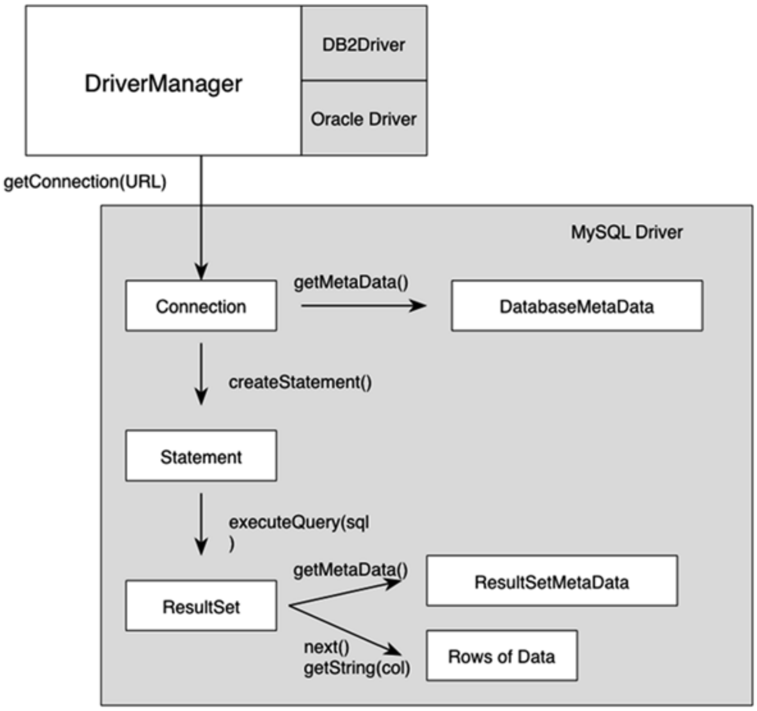


Fig. 31.3 Working with JDBC

as a string. Alternatively you can use `getString`(2) which will return the value held in the second column as a String. There are appropriate get methods for all of the fundamental types in Scala.

Note if something goes wrong in connecting to the database, running some SQL, retrieving a value etc. then an `SQLException` is thrown.

31.5 The Database Driver

What actually is a driver? In practice it provides the concrete implementation for a number of interfaces defined in the SQL package. In particular it defines implementations for the types (such as `Driver`, `Connection`, `Statement` and `ResultSet`) which form a major part of the `sql` API. Each of these will be considered in more detail later. However, essentially they comprise the way to connect to a database, to pass SQL statements to be executed to that database and to examine the results returned. Note that, unlike some object to relational database interfaces, JDBC does not try to objectify the results of querying a relational database. Instead the results are returned in a table like format within a results set. It is then up to the developer to decide how to handle the information retrieved.

31.6 Registering Drivers

As part of the JDBC API a JDBC driver manager is provided. This is the part of the JDBC that handles the drivers currently available to a JDBC application. It is therefore necessary to "register" a driver with the driver manager. There are a number of ways of doing this however for the moment we will focus on doing this programmically. A JDBC Driver can be loaded by referencing the class that is the root of the Driver's implementation. JDBC requires a JDBC Driver to register itself with a central DriverManager when it is loaded. Within Scala there is a feature that allows a class to be loaded without an instance of it being created. This features uses a construct called classof. Thus to load a JDBC Driver programmatically all you have to do is to mention the drivers root class via a classOf statement, for example:

```
 // Load the driver
classOf[com.mysql.jdbc.Driver]
```

This will cause the associated class (in this case the MySQL JDBC Driver) to be loaded into the running application.

As was mentioned earlier you can install more than one driver in your JDBC program. For example you could write:

```
 // Load the driver
classOf[com.mysql.jdbc.Driver]
classOf[sun.jdbc.odbc.JdbcOdbcDriver]
```

When a request is made to make a connection to a database each one will be tried in .turn until one accepts that request. However, using more than one driver will slow down both system start up (as each must be loaded) as well as your runtime (as each may need to be tried in turn). For this reason, it may be best to select the most appropriate driver and stick with that one.

The JDBC ODBC driver is provided as part of the underlying (Java derived) runtime used with Scala. However, other drivers can be obtained and used with the JDBC. For example, the mySQL driver mentioned above was downloaded from the web and installed in an appropriate directory. In this way database vendors can supply their own proprietary database drivers that developers can then utilize in their own applications.

31.7 Opening a Connection

Listing 1 presents a simple class that uses the MySQL driver to connect to a MySQL database. We must first make the JDBC API available, this is done by importing the SQL package. Next the application loads the JDBC MySQL driver and then requests that the `DriverManager` makes a connection with the database `employee`. Note that to make this connection a string (called `url`) is passed to the driver manager along with the user id and the password.

Listing 1: TestConnect.java

```
import java.sql.DriverManager
import java.sql.Connection

object TestConnect extends App {

    // Change to Your Database Config
  val url =
"jdbc:mysql://localhost:3306/employees?user=user&pass-
word=user123"

                var conn: Option[Connection] = None
  try {
    // Load the driver
    classOf[com.mysql.jdbc.Driver]
    // Setup the connection
    conn = Some(DriverManager.getConnection(url))
   } catch {
    case ex: Exception => {
      ex.printStackTrace()
    }
  } finally {
    conn match {
      case Some(c) => c.close
    }
  }
}
```

The string specifying the database to connect to is formed from a JDBC URL. This is a URL that is comprised of three parts:

1. The JDBC protocol indicator (`jdbc:`)
2. The appropriate sub-protocol such as `mysql:`
3. The driver specific components (in this case server, followed by port and then database information and user name etc.)

URLs are used as the program accessing the database may be running as a stand-alone application or may be running in an application server (such as WebLogic, WebSphere or Tomcat) and may need to connect to the database via the internet. Note that different database drivers will require different driver specific components.

Once a connection has successfully been made to the database, the program then does nothing other than to close that connection. This is important as some database drivers require the program to close the connection while others leave it as optional. If you are using multiple drivers it is best to close the connection.

Note that the attempt to load the driver and make the connection we placed within a `try{} catch{}` block. This is because both operations can raise exceptions and these must be caught and handled (as they are not runtime exceptions). The `classOf[…]` operation raises the `ClassNotFoundException` if it can't find the class which represents the specified driver. In turn the `getConnection()` method of the `DriverManager` raises the `SQLException` if the specified database cannot be found.

The `try{} catch {}` block works by trapping any exceptions raised in the try part within the catch part (assuming the exception raised is an instance of the specified class of exception or one of its subclasses).

Another thing to note about this application is that we are using the Scala Option wrapper to hold the Connection. A variable of type Option can either hold a value within the Option or can have the value None. None can be used to indicate that the value is currently empty (but is not abstract), This is important for a Connection as when we try and make a connection it may fail and thus no connection will exist. However as the code that creates the connection is within one block scope (the try block) and the code which is guaranteed to run even if a problem occurs is within the finally block scope we cannot be sure if a connection was made or not. Thus the finally block must protect against situations whether the connection failed to be made by testing to see if the connection currently holds a value (i.e. there is *Some*-thing there or whether it is None. As we are only interested in the situation where there is a value present we do not test for None. This

```
conn match {
case Some(c)=>c.close
}
```

Will only try and close the connection if conn matches the situation where there is something present that can be bound to the variable c.

31.8 Obtaining Data from a Database

Having made a connection with a database we are now in a position to obtain information from it. Listing 2 builds on the application in listing 1 by querying the database for some information. This is done by obtaining a `Statement` object from the `Connection` object. SQL statements without parameters are normally executed using Statement objects. However, if the same SQL statement is executed many times, it is more efficient to use a `PreparedStatement`. In this example we will stick with the `Statement` object.

Listing 2: TestQuery.java

```
package com.jeh.scala.jdbc

import java.sql.{ Connection, DriverManager, ResultSet
}

object TestDbQuery extends App {
  // Change to Your Database Config
  val url =
"jdbc:mysql://localhost:3306/employees?user=user&passw
ord=user123"
  var conn: Option[Connection] = None
  try {
    // Load the driver
    classOf[com.mysql.jdbc.Driver]
    // Setup the connection
    conn = Some(DriverManager.getConnection(url))
    // Obtain a statement
    val statement = conn.get.createStatement()
    // Execute Query
    val rs = statement.executeQuery("SELECT * FROM
employee")
    // Iterate Over ResultSet
    while (rs.next)
      println(rs.getString("id") + ": " +
rs.getString("name"))
  } catch {
    case ex: Exception => ex.printStackTrace()
  } finally conn match {
      case Some(c) => c.close
  }
}
```

Having obtained the statement object we are now ready to pass it some SQL. This is done as a string within which the actual SQL statements are specified. In this case the SQL statement is:

```
SELECT * FROM employee
```

This is pure SQL. The SELECT statement allows data to be obtained from the tables in the database. In this case the SQL states that all columns from the table *employee* should be retrieved for all rows in the table.

This string is passed to the `statement` object via the `executeQuery()` method. This method also generates an `SQLException` if a problem occurs. The method passes the SQL to the driver previously selected by the driver manager. The driver in turn passes the SQL onto the database system. The result is then returned to the driver that in turn returns it to the users program as an instance of `Results-Set`. A results set is a table of data within which each row contains the data that matched the SQL statement. Within the row, the columns contain the fields specified by the SQL. A `ResultSet` maintains a cursor pointing to its current row of data. Initially the cursor is positioned before the first row. The `next()` method moves the cursor to the next row.

The `ResultsSet` class defines a variety of get methods for obtain information out of the `ResultsSet` table. For example, `getBoolean()`, `getByte()`, `getString()`, `getDate()` etc. These methods are provided by the JDBC driver and attempt to convert the underlying data to the specified Java or Scala type and return a suitable Scala value. In listing 2 we merely print out each address in turn using the `next()` method to move the table cursor on.

Finally, the `statement` and the `connection` are closed. In many cases it is desirable to immediately release a `statement's` database and JDBC resources instead of waiting for this to happen when it is automatically closed; the `close` method provides this immediate release.

31.9 Inserting into a Table

As well as query an existing table for values, it is also possible within JDBC to insert new rows into tables. This is done using the executeUpdate method. Essentially the same process is adopted as that shown in the previous section. However, the values to be inserted must be provided via an SQL INSERT statement. This could be constructed using String manipulation, however it is common to use a Prepared statement for this.

A prepared statement is again obtained from a connection instance (and is actually a sub type of the more generic Statement). However, it is oriented around multiple executions. Thus it is created with SQL that is sent to DBMS immediately to be compiled. The statement instance can then be used with parameters in SQL, indicated via '?'. For example:

```
INSERT INTO addresses (name, address) VALUES(?, ?)
```

Use the setXXX(pos, value) methods to set values for the insert

```
st.setString(1, "Phoebe")
st.setString(2, "B50")
```

Note if you wish to make a set of insertions together as a database transaction (that is all the changes are treated as one or are not made) then you can indicate this to the driver managed by setting autocmmit to false on the connection, for example:

```
conn.setAutoCommit(false)
```

And then when you wish the changes to be made as a group setAutoCommit to true:

```
conn.setAutoCommit(true)
```

or alternatively call the commit method on the connection:

```
con.commit()
```

The difference is that commit allows you to restart building up a set of changes until the next commit where as setAutoCommit(true) reverts to immediately updating the database.

If for some reason you decide not to commit (record) the changes then you can call rollback on the connection instance:

```
conn.rollback()
```

The following is an example of a series of changes made as part of a single database transaction,:

```
con.setAutoCommit(false)
valsql   =   "INSERT   INTO   addresses   (name,   address)
VALUES(?, ?)"
valst = con.prepareStatement(sql)
st.setString(1, "Adam")
st.setString(2, "A8")
st.executeUpdate
st.setString(1, "Denise")
st.setString(2, "B56")
st.executeUpdate
con.commit
con.setAutoCommit(true)
```

An example of a simple but complete insert program in Scala is shown below. This program inserts a new row for Jocelyn into the employee table.

```
package com.jeh.scala.jdbc

import java.sql.{ Connection, DriverManager,
ResultSet };

object TestDbInsert extends App {
  // Change to Your Database Config
  val url =
"jdbc:mysql://localhost:3306/employees?user=user&pass
word=user123"
   try {
     // Load the driver
     classOf[com.mysql.jdbc.Driver]
     // Setup the connection
     valconn = DriverManager.getConnection(url)
     valstatement = conn.createStatement
     // do database insert
     val prep = conn.prepareStatement("INSERT INTO
employee
     (id, name) VALUES (?, ?) ")
     prep.setString(1, "5")
     prep.setString(2, "Jocelyn")
     prep.executeUpdate
     conn.close
     println("Success")
   } catch {
case ex: Exception => ex.printStackTrace()
   }
```

31.10 Update an existing Row

Updates are performed in a similar manner to inserts. In the following example, rather than use a prepared statement, we are using the generic statement and passing the UPDATE SQL statement and the values to use with it to the executeUpdate method:

```
package com.jeh.scala.jdbc

import java.sql.{ Connection, DriverManager,
ResultSet}

object TestDbUpdate extends App {
  valurl =
"jdbc:mysql://localhost:3306/employees?user=user&pass
word=user123"
  varconn: Option[Connection] = None
  try {
    // Load the driver
    classOf[com.mysql.jdbc.Driver]
    // Setup the connection
    conn = Some(DriverManager.getConnection(url))
    // Obtain a statement
    valstatement = conn.get.createStatement()
    // Execute Query
    val rs = statement.executeUpdate("UPDATE employee SET
name='James' WHERE id='5'")
  } catch {
case ex: Exception =>ex.printStackTrace()
  } finally {
conn match {
case Some(c) => c.close
    }
  }
```

31.11 Deleting from a Table

Completing the set is the ability to delete a row (or rows) of data from a database. Again this uses the executeUpdate method but now with an SQL DELETE statatement. For example:

```
package com.jeh.scala.jdbc

import java.sql.{ Connection, DriverManager, ResultSet}

object TestDbDelete extends App {
 val url =
"jdbc:mysql://localhost:3306/employees?user=user&passw
ord=user123"
  var conn: Option[Connection] = None
  try {
    // Load the driver
    classOf[com.mysql.jdbc.Driver]
    // Setup the connection and statement
    conn = Some(DriverManager.getConnection(url))
    val statement = conn.get.createStatement()
    // Execute update
    val rs = statement.executeUpdate("DELETE FROM
employee WHERE id='5'")
   } catch {
case ex: Exception => ex.printStackTrace()
   } finally {
     conn match {
       case Some(c) => c.close
     }
   }
  }
```

31.12 Creating a Table

So far we have examined how to connect to a database and how to query that database for information. However we have not considered how that database is created. Obviously the database may not be created by a Scala application, for example it could be generated by a legacy system, by a tool such as Toad or MySQLWorkbench etc.. However, in many situations it is necessary for the tables in the database to be updated (if not created) by a JDBC program. Listing 3 presents a modified version of Listing 2. This listing shows how a statement object can be used to create a table and how information can be inserted into that table. Again the strings passed to the statement are pure SQL, however this time we have used the `executeUpdate()` method of the `Statement` class.

Listing 3: TestCreate.java

```
    package com.jeh.scala.jdbc

    import java.sql.Connection
    import java.sql.DriverManager

    import com.mysql.jdbc.Driver

    object TestDbCreate extends App {
      val url =
    "jdbc:mysql://localhost:3306/employees?user=user&passw
    ord=user123"
      var conn: Option[Connection] = None
      try {
        // Load the driver
        classOf[com.mysql.jdbc.Driver]
        // Setup the connection
        conn = Some(DriverManager.getConnection(url))

        // Configure to be Read Only
        valstatement = conn.get.createStatement()

        statement.executeUpdate(
          "CREATE TABLE addresses (name char(15), address
    char(3))")

        statement.executeUpdate(
          "INSERT INTO addresses (name, address)
    VALUES('John', 'C46')")
        statement.executeUpdate(
          "INSERT INTO addresses (name, address)
    VALUES('Denise', 'C40')");

    statement.close();
      } catch {
        case ex: Exception => ex.printStackTrace()
      } finally {
        conn match {
          case Some(c) => c.close
        }
    }

  }
```

The `executeUpdate()` is intended for SQL statements which will change the state of the database, such as INSERT, DELETE and CREATE. It does not return a result set, rather it returns an integer indicating the row count of the executed SQL. You can either use this value or ignore it (as in listing 3).

31.13 Stored Procedures

Stored procedures in a database are procedural code written in database specific languages that run within the database. They can be invoked from Scala via JDBC. This is done obtaining a statement instance from a connection and then executing an appropriate invocation. For example:

```
val storedProc = "…"
val st = con.createStatement
st.executeUpdate(storedProc)
val cst =
                con.prepareCall("{call …}")
val rs = cst.executeQuery
```

The result of the call to execute the stored procedure will depending on what the stored procedure actually does.

31.14 JDBC Data Sources

Although all the examples so far in this chapter have used a DriverManager as the basis for obtaining a connection to a database, DriverManagers are not without their own limitations. For example, a DriverManager requires the Driver classes to be available on all JVMs in which the driver will be used. Thus it will need to be available to all clients of the database. Then to use the Driver with the DriverManager you must:

1. Load the Driver class
2. Connect to the database using a URL like string

This URL might contain driver protocol, machine name, port number etc. All of which can easily become difficult to maintain even with the use of properties files etc.

However with JDBC 2.0 DataSources were introduced. This allows JNDI (The Java Naming and Directory Interface) to be used to map a *logical name* to the actual data source. Thus in client (to the database) program the logical name can map to whatever data source is held in a naming service accessed via JNDI. This is easier to main as the client program does not need to be changed if something changes in with the location or port used to access the database. Instead a separate program that is used to configure the data source will need to be modified.

Thus the process of providing a connection between a database and the program accessing the database is broken down into two steps:

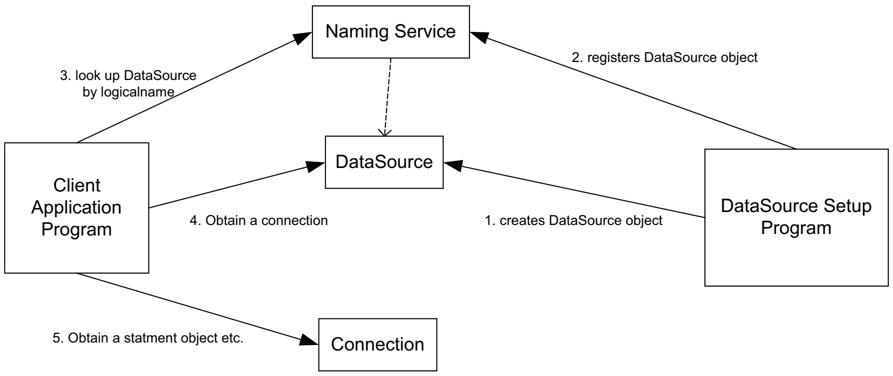

Naming Service
2. registers DataSource object
3. look up DataSource by logicalname
DataSource
Client Application Program
4. Obtain a connection
1. creates DataSource object
DataSource Setup Program
5. Obtain a statment object etc.
Connection

Fig. 31.4 The steps taken to use a DataSource

1. Set up a data source with an appropriate driver and register with a naming service via JNDI
2. In the client application program access the data source form the naming service again via JNDI
3. The client application program can then obtain a connection from the Data-Source object.
4. The DataSource object in turn acts as a factory for connection objects.
5. The connection obtained form the data source is then used in exactly the same way as a connection obtained form a DriverManager. The following code snippet illustrates this idea:

```
val ctx = new InitialContext()
val ds = (DataSource)ctx.lookup("jdbc/Personnel")
val con = ds.getConnection()
```

This code snippet connects up to the current naming service (defined by the properties in a file called jdbc.properties). It will then look in this naming service for a DataSource object bound to the name “jdbc/Personnel”.

These steps are illustrated graphically in Fig. 31.4.

In many situations step 1 will be performed by some form of application server such as JBOSS or WebSphere. However it is by no means the only way in which a DataSource could be registered with a naming service. For example, a separate set up program could be written to create a data source object and register it, for example:

```
DataSource ds = new OracleDataSource()
ds.setServerName("thor")
ds.setDatabaseName("employees")
Contact ctx = new InitialContext()
ctx.bind("jdbc/Personnel", ds)
```

The above snippet creates an OracleDataSource object that will provide connections to a database called employees, running on the server thor. It can be accessed from the naming service being used via the name jdbc/Personnel.

It is interesting to note that originally it was expected that the use of DataSources would replace the use of DriverManagers. However what seems to have happened is that for simple single or two tier applications the DriverManager approach is still being used. However for EJB based applications the DataSource approach is used.

The methods defined by the DataSource interface are presented below:

`Connection` **getConnection**`()`
Attempt to establish a database connection.
`Connection` **getConnection**`(username: String, password: String)`
Attempt to establish a database connection.
`Int` **getLoginTimeout**`()`
Gets the maximum time in seconds that this data source can wait while attempting to connect to a database.
`PrintWriter` **getLogWriter**`()`
Get the log writer for this data source.
`Unit` **setLoginTimeout**`(seconds: Int)`
Sets the maximum time in seconds that this data source will wait while attempting to connect to a database.
`Unit` **setLogWriter**`(out: PrintWriter)`
Set the log writer for this data source.

The example code illustrated in Fig. 31.5 defines a test harness client illustrating how a client may access a data source and obtain a connection in Scala.

31.15 Connection Pooling

The basic idea behind connection pooling is that a "pool" of connections is maintained and shared amongst several users. Why would this be a useful strategy? The answer is to do with both the overheads of creating a connection in the first place and the limit on the number of connections allowed by a database. We shall start with the first issue.

Although in many cases it may not be apparent, but the creation of objects is both time consuming and expensive in terms of memory, which may need to be garbage

Fig. 31.5 Testing a Data Source

```
package com.jeh.scala.jdbc

import javax.sql.DataSource
import javax.naming.InitialContext

object TestDataSource extends App {
  val ctx = new InitialContext()
  val source = ctx.lookup("jdbc/testDS")
  val ds: DataSource =
source.asInstanceOf[DataSource]

  if (ds != null) {
    val con = ds.getConnection()
    val st = con.createStatement()
    val rs = st.executeQuery("SELECT * FROM
employee")
    while (rs.next) {
      println(rs.getString("id") + ": " +
rs.getString("name"))
    }
  }
}
```

collected at a later date. In the case of connections this is exacerbated by the need to make an external connection to the database, to authenticate the user and verify their password etc. in addition to the allocation of memory by the JVM for the connection. It is not uncommon for this operation alone to take one, two or more seconds in heavily used applications. When we take into account that what we are looking at are server applications, that service many clients (possibly thousands of clients) we can see that this overhead is very expensive for the system.

An additional concern is that it many cases there is some limit on the number of connections that are either allowed on a database system or that are in some way optimal. If we are considering a web application being accessed world-wide we may be taking about thousands of concurrent user. However in most cases most users are not using the connection all the time. Rather they will perform some task and then need to read, consider and digest the information they receive. Thus one connection could be shared amongst several users, each getting a slice of the connection while the others are busy doing other things. In this way fewer connections can support a large number of concurrent users.

The two points discussed above are the basis for the need for connection pooling. In connection pooling a pool of connections is maintained. When a client needs to connect to the database they obtain a connection (temporarily) from the pool. They perform whatever operations they require and then return the connection back to the pool. When they need to perform further database operations they will return to the connection pool and obtain another connection. If no connections are available (there is usually a limit on the number of connections held in the pool) then they are queued until such time as a connection is free.

There are some constraints on connection pooling. Firstly users who access the database must do so either through a single account or through a small set of common accounts. This is necessary as each connection is instantiated for a particular account. Thus it is not possible for each user to access the database with a separate account. If they do this then connection pooling is not appropriate. This is not as strict a restriction as it may seem. For example, internet search engines do not require a user to log in, if they use a database a common account can be used to perform the search etc. Secondly although users may log into an application via their own user id this does not mean that they have to access the database behind the application with that id. Rather the application can perform some authentication operation and once logged in the users can be allocated an appropriate (but shared) database account etc.

The second constraint is that the application does not need to hold on to the connections for long periods of time. That is, the application can perform some operation and release the connection. if a permanent connection to the database is required then connection pooling will not work. However, again the application can be designed around this. For example, in the next section two types of RowSet are described a JdbcRowSet and a CachedRowSet. The JdbcRowSet requires a permanent connection to the database where as the CachedRowSet does not. Thus by choosing an appropriate RowSet we can work around the need for permanent database connections.

The javax.sql package provides for connection pooling in such a way as to hide the details of this from the application programmer. That is the application server (such as JBOSS or WebSphere) and the database Driver handle the connection pooling behaviour internally. This however will only work if we use DataSource objects. In most cases it is necessary to configure the application server so that it will use connection pooling, however this is in general done externally to any Scala (or indeed Java) program. This means that from the developers point of view, their programs do not need to change to use connection pooling and the hard work is done by the application server. This means that we can modify the diagram in Fig. 31.4 to show the use of a connection pool. This modified diagram is illustrated in Fig. 31.6. The changes from the earlier diagram are hi-lighted in bold.

Exactly how the application server is configured will differ from one server to another (e.g. from WebLogic to Websphere to JBOSS). However in general they will need to specify:

- The class implementing the javax.sql.ConnectionPoolDataSource interface
- The class implementing the java.sql.Driver interface
- The size of the connection pool (usually minimum and maximum size)
- The timeout period for a connection
- Authentication for the database

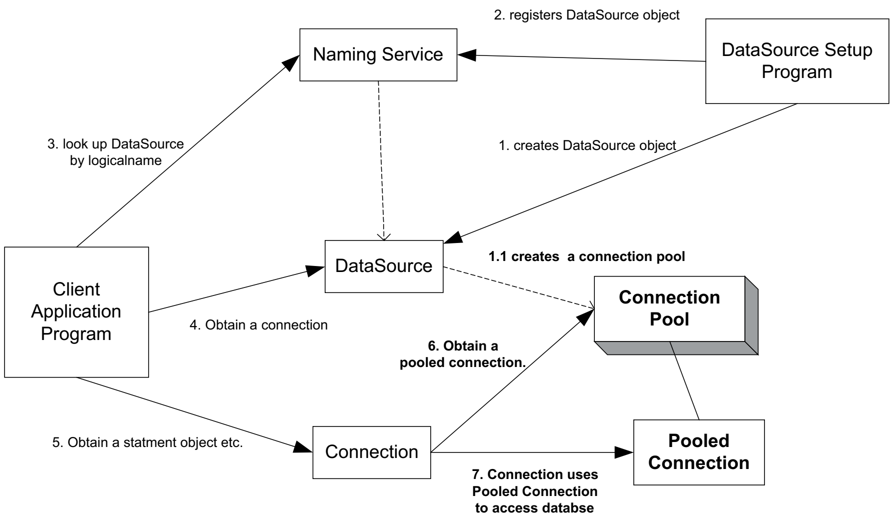

2. registers DataSource object
Naming Service
DataSource Setup Program
3. look up DataSource by logicalname
1. creates DataSource object
DataSource
1.1 creates a connection pool
Client Application Program
Connection Pool
4. Obtain a connection
6. Obtain a pooled connection.
5. Obtain a statment object etc.
Connection
Pooled Connection
7. Connection uses Pooled Connection to access databse

Fig. 31.6 Using PooledConnections with a DataSource

31.16 JDBC MetaData

MetaData is data about data, with respect to databases that means that it is data about the database or results obtained from the database. For example, the tables in a database, rows and columns in a table or results set. This can be very useful information if you need additional flexibility in your application or if you need to dynamically adjust to the contents of a database or results set. For example, MetaData can be used to create a Database-aware JTable. Such a table could be given a database to connect to, login details and a select statement to be used to populate itself. It could then configure itself as appropriate given the results obtained (for example the number of columns and their titles, the type of each column etc.). Note it is up to the database driver to implement the metadata objects. However not all drivers will provide all the information indicates via the various metadata interfaces.

31.16.1 DatabaseMetaData

The DatabaseMetaData object can provide information about the structure of a particular database. This metadata object is obtained from the connection to that database. For example:

```
con.getMetaData()
```

The DatabaseMetaData object is very comprehensive and provides over 130 methods. These are organised (loosely) into 4 categories:

- Methods that return a String
- Methods that return an Int
- Methods that return a Boolean
- Methods that return a ResultSet

String returning methods provide Information about the database such as the user name, product name, version, driver name etc. They also provide Information about database specifics such as:

- terms used for schema, procedure
- that actual Database product name

The string returning methods can also provide information on the SQL understood by the database and the escape character used etc.

The int returning methods usually provide information on limits such as the maximum length allowed for a column name. They are generally of the form getMaxXXX for example getMaxColumnNameLength() or getMaxColumnsInTable().

The methods that return a Boolean are the largest category (with well over 70 methods in all) and allow you to test for compliance with standards or for support for various features. They are usually of the form supportsXXX such as supportsANSI92FullSQL, supportsFullOuterJoins(), supportsSelectForUpdate() etc.

The final category are methods that themselves return a ResultSet. This is the most complex category of methods and need careful examination of the methods to determine how to use them. For example, it is possible to obtain a description of the stored procedures in a database using the getProcedures method:

```
getProcedures(catalog: String,
               schemaPattern: String,
               procedureNamePattern: String)
```

However the ResultSets retrieved by these methods may themselves be large and need analysis and processing in their own right.

31.16.2 ResultSetMetaData

It is possible to obtain a MetaData object from a ResultSet (or RowSet). This is obtained from a ResultSet using the getMetaData() method. For example:

```
val md = resultsSet.getMetaData()
```

Thus the ResultSetMetaData object contains information about the ResultSet form which it was derived.

As an example of using the metadata object look at the following code snippet:

```
val md = rs.getMetaData
int cols = md.getColumnCount
for (i <- 1 to cols)
    println(md.getColumnName(i));

// Note from 1 to cols not 0 to cols-1
```

In this example we obtain the meta data for a result set and then print out the name of each of the columns in that result set using the getColumnCount() method and the getColumnName() method. Note that the columns are number from 1 rather then 0.

Chapter 32
Scala Style Database Access

32.1 Introduction

The last chapter introduced how Scala can use JDBC to access a database. However, there a number of different Scala based approaches being developed to explore more Scala like ways of interacting with a database than JDBC. Although JDBC works very well it is far more Java like than Scala like and actually provides a very low level of abstraction (witness the many Object Relational Mapping, or ORM, tools within the Java world such as Hibernate).

The list of possible approaches includes

- SLICK (previously Scalaquery)
- Querulous
- Squeryl
- O/R Broker

We will look at each of these briefly in the remainder of this chapter.

32.2 SLICK

SLICK (Scala Language-Integrated Connection Kit) provides database query and access facilities for Scala. It attempts to treat data stored in the database as if it was just another Scala collection. This means that using Slick can be (almost) as easy as working with standard Scala collections.

The aim of SLICK is that it abstracts (hides) the lower level JDBC or SQL calls. Thus an object of a specific type can extend the concept of a Table (and indicate the name of the table in the underlying database). Methods on this object can then be used to add rows to the table, search the table etc.

The following simple code snippet illustrates these ideas:

```
object Coffees extends Table[(String, Int,
Double)]("COFFEES") {
 def name = column[String]("COF_NAME", O.PrimaryKey)
 def supID = column[Int]("SUP_ID")
 def price = column[Double]("PRICE")
}
```

The object Coffee relates to a table called COFFEES in a database. This table has three columns (COF_NAME, SUP_ID and PRICE). Based on these columns four methods are provided called name, supID and price which act as accessors. This object can now be used to insert new rows:

```
Coffees.insertAll(
  ("Colombian", 101, 7.99),
  ("Colombian_Decaf", 101, 8.99),
  ("French_Roast_Decaf", 49, 9.99)
)
```

And to query for values currently held by the table

```
val q = for {
   c <- Coffees if c.supID === 101
} yield (c.name, c.price)
```

32.3 Querulus

Querulus is a open source Scala project from Twitter. Querulus still provides direct access to SQL but avoids a number of the basic frustrations of using JDBC. For example, the basic usage of Querulus is very simple. Having imported the core QueryEvaluator class from Querulus you can write:

```
val queryEvaluator = QueryEvaluator("host", "username",
"password")
```

Once you have a queryEvaluator you can then use this to run a select statement:

```
val users = queryEvaluator.select("SELECT * FROM employee")
{ row =>   new User(row.getInt("id"),
row.getString("name")) }
```

or to insert or update values in the database:

```
queryEvaluator.execute("INSERT INTO users VALUES (?, ?)",
1, "Jacques")
```

You can also group database operations into transactional units:

```
queryEvaluator.transaction { transaction =>
  transaction.select("SELECT ... FOR UPDATE", ...)
  transaction.execute(
       "INSERT INTO users VALUES (?, ?)", 1, " John")
  transaction.execute(
       "INSERT INTO users VALUES (?, ?)", 2, " Denise") }
```

32.4 Squeryl

Style-wise, Squeryl sits midway between SLICK, which hides SQL behind Scala comprehensions as much as possible, and Querulous which uses SQL strings directly.

Squeryl provides an SQL-like DSL (Domain Specific Language), which gives you type safety and aims to ensure that if a statement will compile then it will not fail at runtime.

To illustrate the core concepts let us look at another example. Here we have two classes Author and Book that map to information in tables in the database. For the class Book an annotation @Column is being used to map AUTHOR_ID to the field authorId.

```
    import org.squeryl.PrimitiveTypeMode._

    class Author(var id: Long,
                 var firstName: String,
                 var lastName: String)
    class Book(var id: Long,
               var title: String,
            @Column("AUTHOR_ID") var authorId: Long,
            var coAuthorId: Option[Long]) {
      def this() = this(0,"",0,Some(0L))
  }
```

The object Library maps these classes to the appropriate database tables. In this case the Author class is being mapped to the table Authors and the Book class is mapped to a table called Book (not if the names are the same they do not need to be repeated.

```
object Library extends Schema {
   //When the table name doesn't match the class name, it
is specified here :
    val authors = table[Authors]("AUTHORS")
    val books = table[Book]
}
```

The following provides a basic example of the use of Squeryl to insert some values into the books table. All interaction is via a session instance with a `using` block. The authors are added to the books table. A query is then run to retrieve all authors called hunt.

```
classOf["org.postgresql.Driver")]

val conn =
   java.sql.DriverManager.getConnection("jdbc:postgresql:/
   /localhost:5432/squeryl", "squeryl", "squeryl")

val session = Session.create(conn, new PostgreSqlAdapter)

//Squeryl database interaction is within a 'using' block :
import Library._

using(session) {
    books.insert(new Author(1, "Michel","Folco"))
    val a = from(authors)(a=> where(a.lastName === "Hunt")
                              select(a))
}
```

32.5 O/R Broker

The final approach we will look at is called O/R Broker. It is not an Object Relational mapping tool (although the name might imply this). Instead it is a JDBC library for Scala that aims to hide most of the JDBC API and wrap it up into a more Scala like interface.

Extractors are used to *extract* information from the database. Extractors are declarative, written in Scala. They can be reused in other queries that fit the expectation of the extractor. A very simple extractor is shown below:

```
object CustomerExtractor extends RowExtractor[Customer] {

  // Construct object from row.
  def extract(row: Row) = {
    val id = row.integer("ID").get
    val name = row.string("NAME").get
    new Customer(id, name)
  }
}
```

This is then connected to a query by declaring a named Token:

```
val SelectCustomer =
       Token('selectCustomer, CustomerExtractor)
```

This can then be executed via the broker:

```
val customer = broker.readOnly() { session =>
  session.selectOne(SelectCustomer, "custID"->1234)
}
```

Further Reading

SLICK, from typesafe
http://slick.typesafe.com/

Squeryl
http://squeryl.org/

Querulous
https://github.com/twitter/querulous

O/R broker
http://code.google.com/p/orbroker/

Chapter 33
Scala and MySQL Database Example

33.1 Introduction

In this chapter we will be writing some simple functions to run some queries against a simple database. The chapter uses MySQL. This is an open source database management system that can be, and is used, for commercial systems.

33.2 Obtaining MySQL

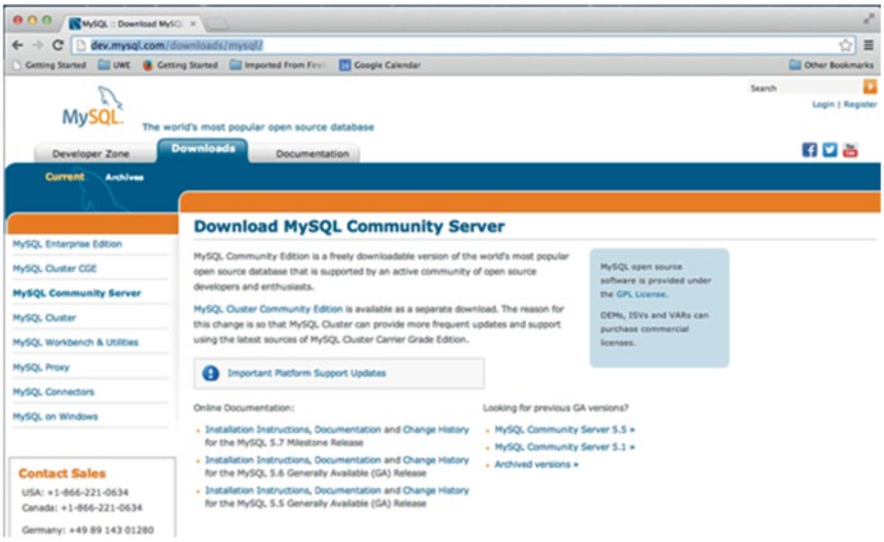
MySQL is available for free download from http://dev.mysql.com/downloads/mysql/

This version is known as the MySQL Community Server (the current release at the time of writing was 5.6.14). The download site for MySQL is illustrated in Fig. 33.1. To download MySQL you should select the version appropriate to your platform and then from the list of options available select an appropriate download. Note that when you do that it will look as if you need an Oracle Web Account—you do not! There is a link at the bottom of the page that says 'No thanks, just start my download'. Your download should then start.

You should then follow the appropriate instructions for your platform to install MySQL.

33.2.1 Starting/Stopping/Connecting to MySQL

You should use the information provided by MySQL with regard to your platform and the best way of running MySQL for a Windows machine, a Mac or a Linux box etc. For example, if you are on a windows machine then open a command window and cd into the bin directory of the location you installed MySQL in. You can then enter the command



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MySQL Cluster Community Edition is available as a separate download. The reason for this change is so that MySQL Cluster can provide more frequent updates and support using the latest sources of MySQL Cluster Carrier Grade Edition.

MySQL open source software is provided under the GPL License.

OEMs, ISVs and VARs can purchase commercial licenses.

Important Platform Support Updates

Online Documentation:

- Installation Instructions, Documentation and Change History for the MySQL 5.7 Milestone Release
- Installation Instructions, Documentation and Change History for the MySQL 5.6 Generally Available (GA) Release
- Installation Instructions, Documentation and Change History for the MySQL 5.5 Generally Available (GA) Release

Looking for previous GA versions?

- MySQL Community Server 5.5 »
- MySQL Community Server 5.1 »
- Archived versions »

Contact Sales
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Canada: +1-866-221-0634
Germany: +49 89 143 01280

Fig. 33.1 MySQL download site

```
mysqld -console
```

This will start MySQL if it is not already running. However, if you are on a Mac then you will need to issue a command such as

```
sudo/Library/StartupItems/MySQLCOM/MySQLCOM start
```

The same is true for suttign MySQL down. For example, on a windows box you can use

mysqld –stop
Where as on a Mac you can use
sudo/usr/local/mysql/support-files/mysql.server stop

33.3 Creating a Database

To access MySQL you may wish to use the command line client (mysql) or a tool such as Toad or MySQLWorkbench. In the following we will assume that we have started the command line client for MySQL. On windows this can be done by changing into the bin directory of MySQL within a command window and issuing the following command (assuming the root user has no password):

```
mysql -u root
```

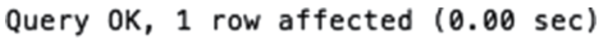
While on a Mac you will need to open a terminal and issue the command:

```
/usr/local/mysql/bin/mysql -u root
```

You can now create any databases that you will need to work with. For example, to create the database *employees* from the lecture notes, issue the following command:

CREATE DATABASE employees;

If this is successful you will see a prompt back from MySQL confirming the creation:



```
Query OK, 1 row affected (0.00 sec)
```

33.3.1 Adding a User

You can now add a user to the DMBS who will be allowed to access and work with the employees database:

```
GRANT ALL on employees.* to 'user'@'localhost'
IDENTIFIED by 'user123';
```

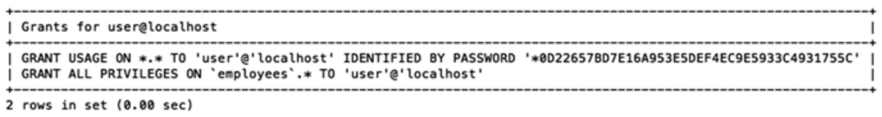
Again if you are successful you should see a confirmatory message form MySQL:

```
Query OK, 0 rows affected (0.00 sec)
```

You can also confirm that the user has appropriate rights using the command

```
SHOW GRANTS FOR 'user'@'localhost';
```

This should display the information related to the user:



```
+------------------------------------------------------------------------------------------------------+
| Grants for user@localhost                                                                            |
+------------------------------------------------------------------------------------------------------+
| GRANT USAGE ON *.* TO 'user'@'localhost' IDENTIFIED BY PASSWORD '*0D22657BD7E16A953E5DEF4EC9E5933C4931755C' |
| GRANT ALL PRIVILEGES ON `employees`.* TO 'user'@'localhost'                                          |
+------------------------------------------------------------------------------------------------------+
2 rows in set (0.00 sec)
```

33.3.2 Selecting to Work with a Database

In MySQL you can *move into* a database so that all commands you issue are by default associated with that database. You do that by issuing the command

```
use <database name>
```

For example

```
use employees
```

You should get a confirmatory ‘Database changed’ message form MySQL.

33.3.3 Creating a Table

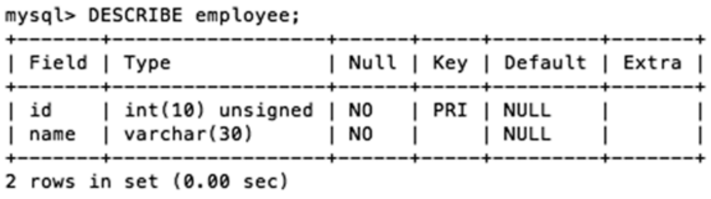
The easiest way to create and manage tables is to use an appropriate tool such as Toad (see http://www.quest.com/toad-for-mysql/) however you can do the same thing form the MySQL command line prompt.

To create a table such as that presented in the lectures you can issue a create command such as:

```
CREATE TABLE employee (id INT UNSIGNED NOT NULL,
PRIMARY KEY (id), name VARCHAR(30) NOT NULL);
```

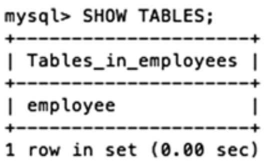
If this is successful you will obtain a confirmatory message from MySQL.

However, you can also check that the table is as expected using the *describe* table command:



```
mysql> DESCRIBE employee;
+-------+------------------+------+-----+---------+-------+
| Field | Type             | Null | Key | Default | Extra |
+-------+------------------+------+-----+---------+-------+
| id    | int(10) unsigned | NO   | PRI | NULL    |       |
| name  | varchar(30)      | NO   |     | NULL    |       |
+-------+------------------+------+-----+---------+-------+
2 rows in set (0.00 sec)
```

Alternatively you can enter a show tables command:



```
mysql> SHOW TABLES;
+---------------------+
| Tables_in_employees |
+---------------------+
| employee            |
+---------------------+
1 row in set (0.00 sec)
```

33.3.4 *Adding Data to a Table*

Again using a tool such as Toad will make this much easier, but you can still issue SQL insert and update statements from the MySQL command line. For example, given the employee table in the employees database we could issue:

```
mysql> INSERT into employee(id, name) VALUES (1, 'John'), (2, 'Denise'), (3, 'Phoebe'), (4, 'Adam');
Query OK, 4 rows affected (0.00 sec)
Records: 4  Duplicates: 0  Warnings: 0
```

As usual MySQL provides a confirmatory response. However you could check that the data you expected has been added by running a SELECT statement against it:

```
mysql> select * from employee;
+----+--------+
| id | name   |
+----+--------+
|  1 | John   |
|  2 | Denise |
|  3 | Phoebe |
|  4 | Adam   |
+----+--------+
4 rows in set (0.01 sec)
```

33.4 Creating the Scala Project

As usual a new project can be created from the File menu under New -> Scala Project. Although you do not need to do this if you do not wish to. This will cause the 'New Scala Project' wizard to be displayed allowing you to enter the name of your project. You can choose any name that seems appropriate. In this case the name of the project will be practical6. Now click finish.

33.5 Create a New Package

As before we will create a package for our code to go in. Use the same name as we have previously used. To create a new package select your project and from the right mouse menu selection New -> Package. This will display the new Package Wizard.

As always you can use whatever name you wish although you should note that a Scala package is a series of names separated by '.'s which are typically prefixed

Fig. 33.2 Selecting the Navigator View

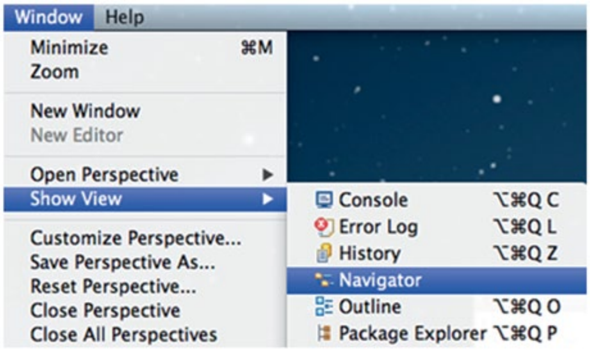
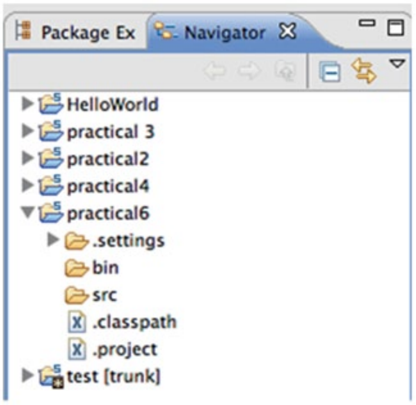


Fig. 33.3 The Scala IDE Navigator View



by the domain of the organization creating the code, for example: uk.ac.uwe.scala. Once you have provided a package name click 'Finish'.

You will now see a new package provided for you in the Package Explorer view of the IDE.

For this example I am also going to suggest that you open the Navigator view. This can be done by going to the Window menu and selecting the Show View -> Navigator option (Fig. 33.2).

The Navigator view will then be added to your Eclipse Perspective. You may find that this is displayed in the lower area of the IDE, personally I prefer to move it to the left hand area as another tab along side the Package Explorer. An example of the Navigator view is shown in Fig. 33.3.

33.6 Obtaining the JDBC Libraries

In order to access the MySQL database we will need the JDBC MySQL driver library. This is a jar file that must be added to the classpath of the Scala application we are developing. The Classpath is a set of locations or files that Scala (actually

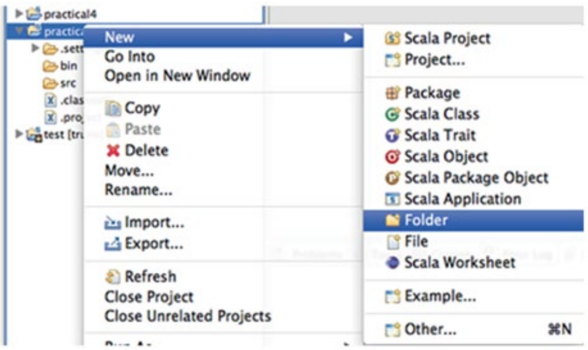


Fig. 33.4 Selecting the new Folder menu option

the Java Virtual Machine) looks in at runtime to find your code and the libraries you are using. A JAR file is essentially a ZIP file with some additional information in a manifest file.

You can download the MySQL JDBC drive from (http://dev.mysql.com/downloads/connector/j/#downloads) or access it from resources provided with the course.

Once you have a copy of the driver file you need to add it to your Scala project within the IDE. To do this first create a new folder called lib under the root of the project. This can be done by selecting the project in the Navigator view and form the right mouse menu selecting the New -> Folder menu items (selecting this menu option is shown in Fig. 33.4).

This will display the New Folder dialog (see Fig. 33.5). You should ensure that the correct project is selected and then enter the name of the folder you wish to create. In this case the folder should be called *lib* and click on 'Finish'.

You should now see a new folder/directory under the practical6 project as shown in Fig. 33.6.

You can now copy the jar file into this directory. The easiest way to do this is to select it in your file explorer and select Copy form the right mouse menu. Then select the lib directory inside the IDE and select the Paste menu form the right mouse menu—see Fig. 33.7.

If this is successful you should find that your lib directory now contains a single jar file, as shown in Fig. 33.8.

We have now made the jar file part of the project, but we need to tell Eclipse to use the contents of the jar file when looking for libraries. This is done by modifying the project properties.

33.7 Modifying the Project Properties

To update the project properties, from the Properties menu select the Properties menu item (see Fig. 33.9).

This will cause the properties dialog to be displayed for this project. The project properties dialog has a lot of option on it as shown in Fig. 33.10.

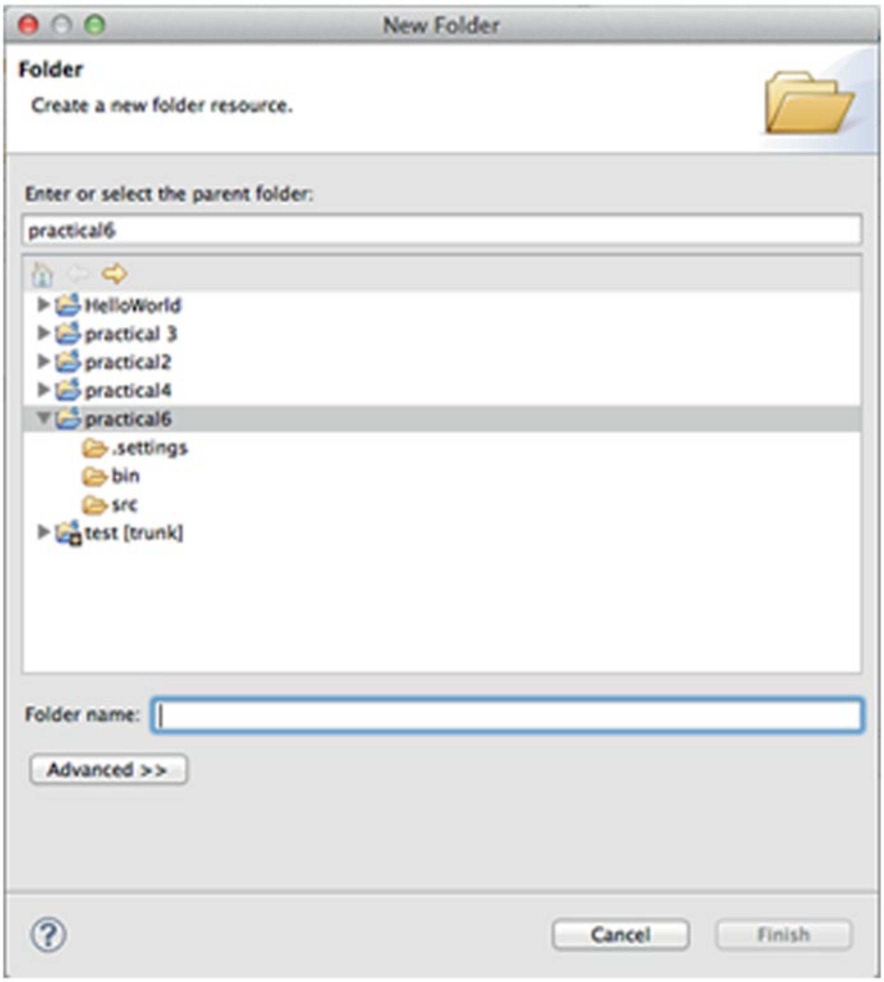


Fig. 33.5 The New Folder wizard

On the left hand side select the 'Java Build Path' option—although this is Scala at runtime we use the Java Virtual Machine (JVM) and this the references here to Java really relate to the JVM.

You should now see the dialog shown in Fig. 33.11.

Next select the Libraries Table (if it is not already selected) as shown in Fig. 33.12.

This indicates that currently the core Java and Scala libraries are available to the project—but no other libraries. To update this click on the 'Add Jars…' button on the right hand side of the dialog. You will now see the 'Jar Selection' dialog. Expand the practical6 node and the *lib* node and select the mysql jar file, as shown in Fig. 33.13.

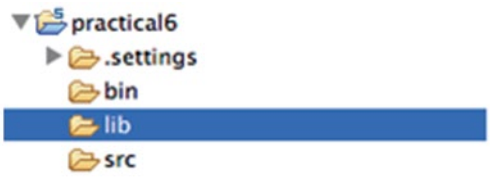


Fig. 33.6 The folders in the project including 'lib'

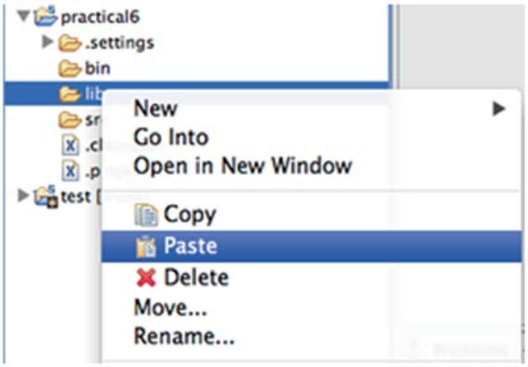


Fig. 33.7 Selecting the Paste Menu option

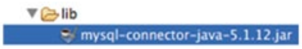


Fig. 33.8 lib folder containing database driver

Now click on 'OK'.

You will then be taken back to the Properties dialog and should now see that the mysql jar file has been added to the libraries available as illustrated in Fig. 33.14.

Click 'OK'. You have now added the MySQL driver to your project.

33.8 Accessing the Database

We will now look at what we need to do to retrieve this information using Scala. To do this we will create a simple application that makes a connection to the database, obtains a statement and runs a simple SQL query against the database using the statement.

The first step is to create a new application object. As before we will do this using the right mouse menu and selecting the New -> Scala Application menu items. As previously seen this will display the 'New Scala Application' dialog.

We will use EmployeeQuery for the Object name and select Finish. You will now create a new object EmployeeQuery with mixes in the App trait—this will be displayed within the code area of your IDE:

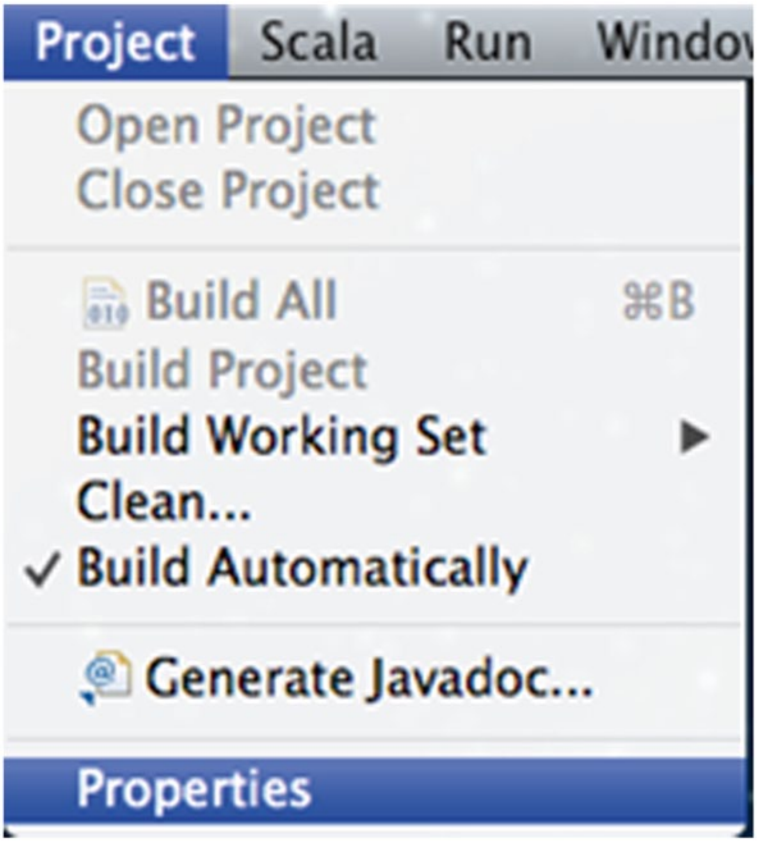
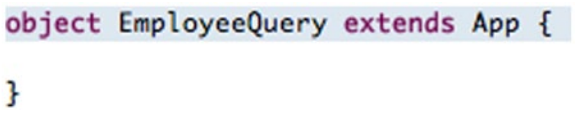


Fig. 33.9 Selecting the project Properties option

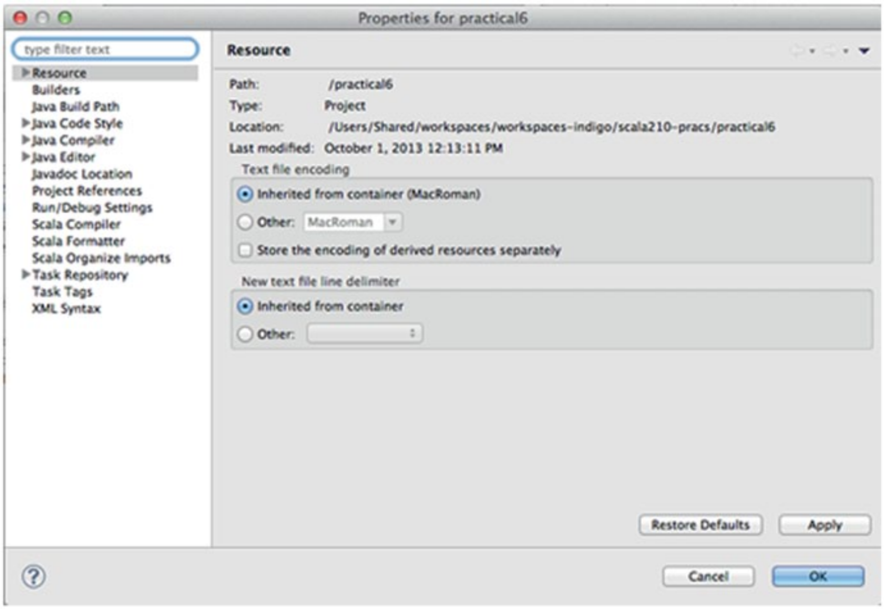


```
object EmployeeQuery extends App {

}
```

Next wee need to add the code from the libraries that we will be using within the application. The libraries to be used are the JDBC libraries which are all in the java.sql package, thus all you need to do is to add the following line above the object definition:

```
import java.sql._
```

This makes all the JDBC facilities in this library available for this file.



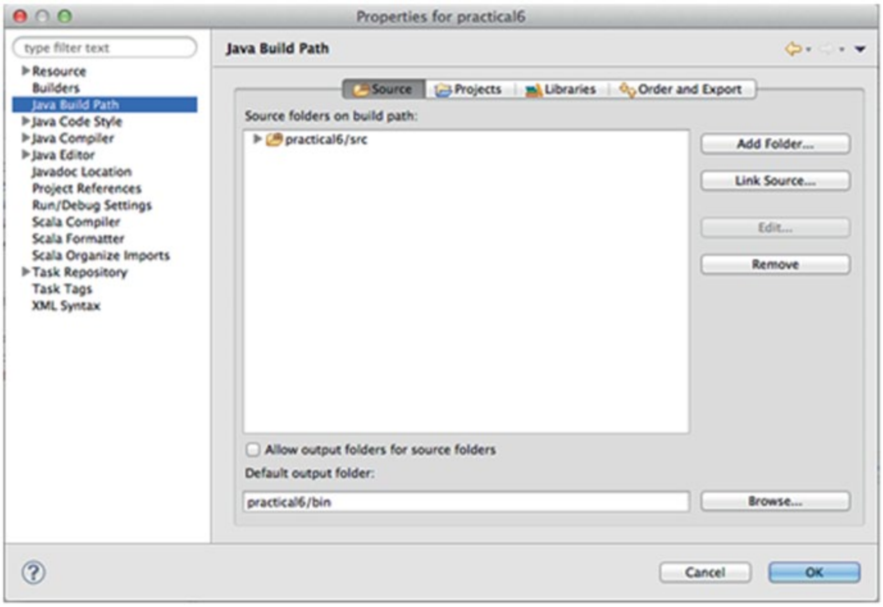
Resource

Path: /practical6
Type: Project
Location: /Users/Shared/workspaces/workspaces-indigo/scala210-pracs/practical6
Last modified: October 1, 2013 12:13:11 PM

Text file encoding
[✓ Inherited from container (MacRoman)]
Other: MacRoman
Store the encoding of derived resources separately

New text file line delimiter
[✓ Inherited from container]
Other:

Fig. 33.10 Projects properties dialog

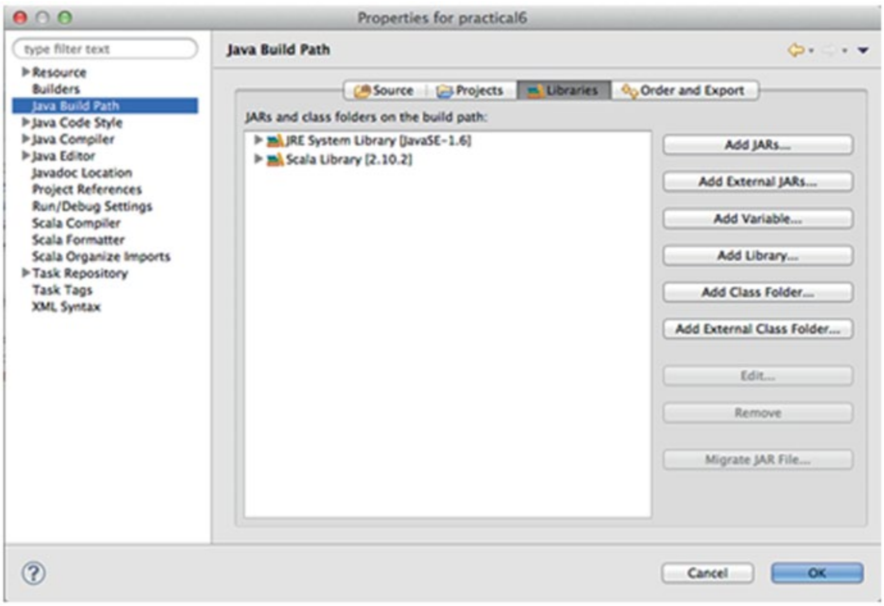


Java Build Path

Source folders on build path:
practical6/src

Allow output folders for source folders
Default output folder:
practical6/bin

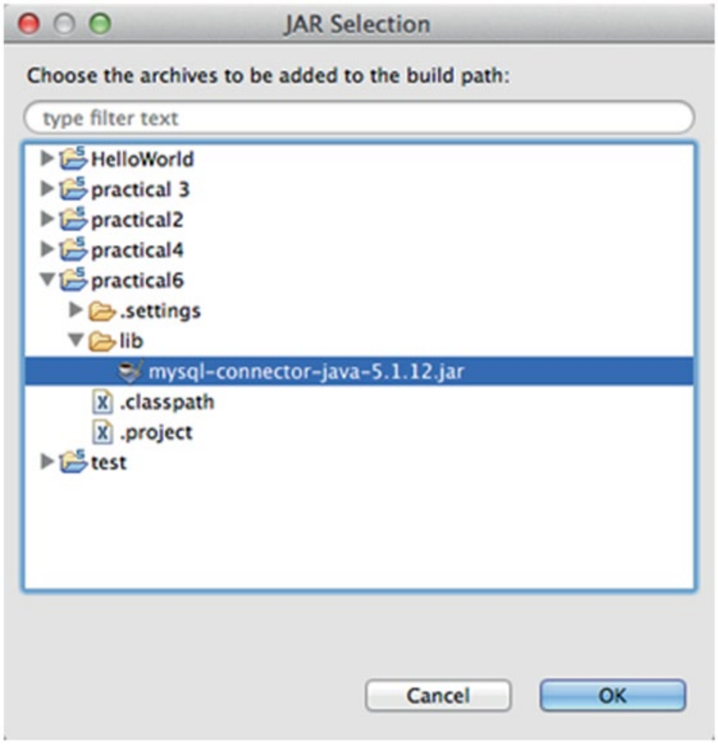
Fig. 33.11 Selecting the Java Build Path option



JARs and class folders on the build path:

JRE System Library [JavaSE-1.6]
Scala Library [2.10.2]

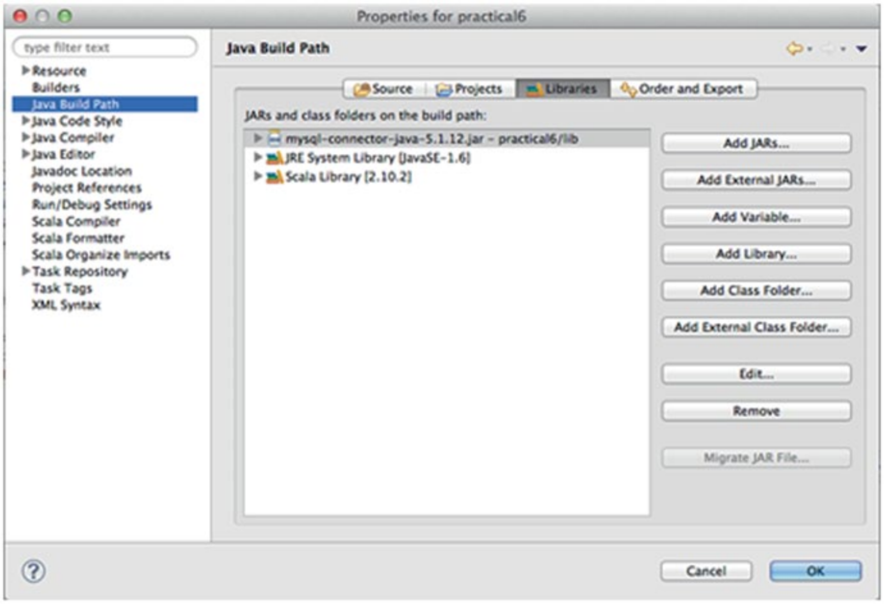
Fig. 33.12 Selecting the Libraries Tab



Choose the archives to be added to the build path:

HelloWorld
practical 3
practical2
practical4
practical6
.settings
lib
mysql-connector-java-5.1.12.jar
.classpath
.project
test

Fig. 33.13 Selecting the JDBC MySQL driver jar file

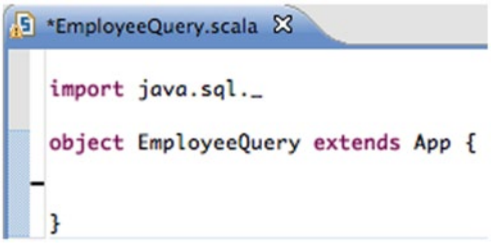

Properties for practical6

Java Build Path

JARs and class folders on the build path:

- mysql-connector-java-5.1.12.jar - practical6/lib
- JRE System Library [JavaSE-1.6]
- Scala Library [2.10.2]

Fig. 33.14 The MySQL driver is on the project classpath


*EmployeeQuery.scala

```
import java.sql._

object EmployeeQuery extends App {

}
```

The next thing to do is to define the URL used to connect to your database. Assuming that you have followed all the defaults in the previous practical then your URL should be:

val url = "jdbc:mysql://localhost:3306/employees?user=user&password=user123"

We can now use this URL when making a connection object:

However we will first define the connection variable to be used outside of our try-catch-finally block:

```
var conn: Option[Connection] = None
```

This allows it to be referenced in both the try block and the finally block.

We now need to create the try-catch-finally block structure. This can be done as follows:

```
try {

}catch {

}finally {

}
```

We will now populate the try part. This section will load the JDBC driver (if it is not already loaded), make a connection and create a statement, for example:

```
 // Load the driver
classOf[com.mysql.jdbc.Driver]
// Setup the connection
conn = Some(DriverManager.getConnection(url))
// Obtain a statement
val statement = conn.get.createStatement()
```

Once we have done this we can then use the statement to run a query against the MySQL database. The SQL will be ‘SELECT * FORM employee’ and will be used as the parameter to the executeQuery method. This method returns a ResultSet object:

```
// Execute Query
val rs = statement.executeQuery("SELECT * FROM employee")
```

We can now loop through the result set obtaining each value in turn:

```
// Iterate Over ResultSet
while (rs.next)
      println(rs.getString("id") +
                      ": " +rs.getString("name"))
```

Thus the contents of the try block is thus:

```
try {
    // Load the driver
    classOf[com.mysql.jdbc.Driver]
    // Setup the connection
    conn = Some(DriverManager.getConnection(url))
    // Obtain a statement
    val statement = conn.get.createStatement()
    // Execute Query
    val rs = statement.executeQuery("SELECT * FROM
employee")
    // Iterate Over ResultSet
    while (rs.next)
      println(rs.getString("id") + ": " +
rs.getString("name"))
  }
```

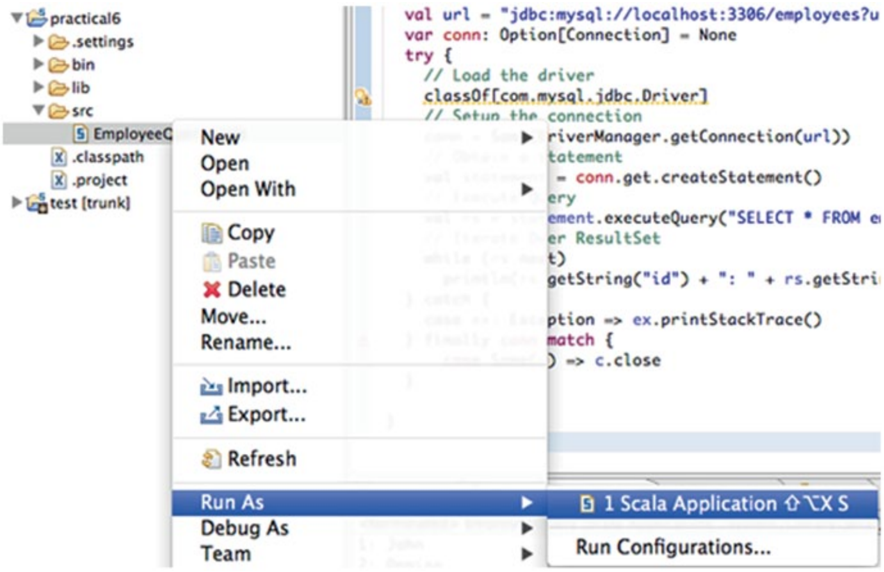
Next we need to define what happens within the catch block if an error or exception occurs (such as might happen if the database is not running). In our case we will merely print out the exception:

```
catch {
    case ex: Exception => ex.printStackTrace()
}
```

The last thing is to define what happens in the finally block. In this block we want to see if the connection was actually made. If it was we need to close the connection (which will also close the statement).

```
finally conn match {
      case Some(c) => c.close
}
```

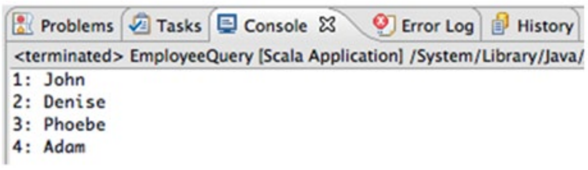
Thus the complete listing for the test application is:



```
val url = "jdbc:mysql://localhost:3306/employees?u
var conn: Option[Connection] = None
try {
  // Load the driver
  classOf[com.mysql.jdbc.Driver]
  // Setup the connection
```

Fig. 33.15 Running the Scala Application

```
import java.sql.DriverManager
import java.sql.Connection

object EmployeeQuery extends App {
  // Change to Your Database Config
  val url =
"jdbc:mysql://localhost:3306/employees?user=user&pass
word=user123"
  var conn: Option[Connection] = None
  try {
    // Load the driver
    classOf[com.mysql.jdbc.Driver]
    // Setup the connection
    conn = Some(DriverManager.getConnection(url))
    // Obtain a statement
    val statement = conn.get.createStatement()
    // Execute Query
    val rs = statement.executeQuery(
                      "SELECT * FROM employee")
    // Iterate Over ResultSet
    while (rs.next)
      println(rs.getString("id") +
              ": " + rs.getString("name"))
  } catch {
    case ex: Exception => ex.printStackTrace()
  } finally conn match {
    case Some(c) => c.close
  }
}
```



```
<terminated> EmployeeQuery [Scala Application] /System/Library/Java/
1: John
2: Denise
3: Phoebe
4: Adam
```

Fig. 33.16 Running the Test EmployeeQuery Application

33.9 Running the Application

You can run the application by selecting the EmployeeQuery.scala file and selecting the Run As -> Scala Application option from the right mouse menu (see Fig. 33.15).

The result of running this application will then be displayed in the console. The exact results will depend upon the data you inserted into the table in the last practical, for example the output from my database query is shown in Fig. 33.16.

Chapter 34
Testing

34.1 Introduction

This chapter considers the different types of tests that you might want to perform with the systems you develop in Scala. It also introduces Test Driven Development.

34.2 Types of Testing

There are at least two ways of thinking about testing:

1. It is the process of executing a program with the intent of finding errors/ bugs (see Glenford Myers, The Art of Software Testing).
2. It is a process used to establish that software components fulfil the requirements identified for them, that is that they do what they are supposed to do.

These two aspects of testing tend to been emphasised at different points in the software lifecycle. Error Testing is an intrinsic part of the development process, and an increasing emphasis is being placed on making unit testing a central part of software development.

It should be noted that it is extremely difficult—and in many cases impossible—to prove that software "works" and is error free. The fact that a set of tests finds no defects does not prove that the software is error-free. 'Absence of evidence is not evidence of absence!'. This was discussed in the late 1960s and early 1970s by Dijkstra and can be summarized as:

Testing shows the presence, not the absence of bugs

Testing to establish that software components fulfil their contract involves checking operations against their requirements. Although this does happen at development time, it forms a major part of QA and User Acceptance testing. It should be noted that with the advent of Test Driven Development, the emphasis on testing against requirements during development has become significantly higher.

There are of course many other aspects to testing, for example, Performance Testing helps identify how a systems will perform as various factors that affect that system change. For example, as the number of concurrent requests increase, as the number of processors used by the underlying hardware changes, as the size of the database grows etc.

However you view testing, the more testing applied to a system the higher the level of confidence that the system will work as required, and therefore the lower the risk of building a business around that system.

34.3 What should be Tested?

What aspects of your software system should be subject to testing? In general anything that is repeatable should be subject to formal (and ideally automated) testing. This includes (but is not limited to):

- The build process for all technologies involved.
- The deployment process to all platforms under consideration.
- The installation process for all runtime environments.
- The upgrade process for all supported versions (if appropriate).
- The performance of the system/ servers as loads increase.
- The stability for systems that must run for any period of time (e.g. 24×7 systems).
- The backup process.
- The security of the system.
- The recovery ability of the system on failure.
- The functionality of the system.
- The integrity of the system.

Notice that only the last two of the above list might be what is commonly considered areas that would be subject to testing. However, to ensure the quality of the system under consideration, all of the above are relevant. In fact, testing should cover all aspects of the software development lifecycle and not just the QA phase. During requirements gathering testing is the process of looking for missing or ambiguous requirements. During this phase consideration should also me made with regard to how the overall requirements will be tested, in final software system. Test planning should also look at all aspects of the software to test for functionality, usability, legal compliance, conformance to regulatory constraints, security, performance, availability, resilience, etc. Testing should be driven by the need to identify and reduce risk.

34.4 Types of Testing

As indicated in Fig. 34.1 there are a number of different types of testing that are commonly used within industry. These types are:

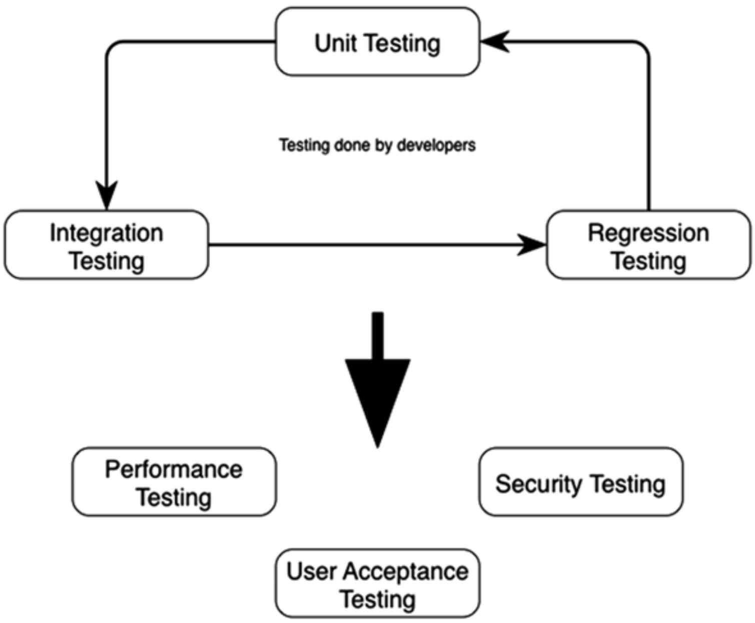


Fig. 34.1 Types of Testing

- **Unit Testing**, which is used to verify the behaviour of individual components.
- **Integration Testing** that tests that when individual components are combined together to provide higher-level functional units, that the combination of the units operates appropriately.
- **Regression Testing**. When new components are added to a system, or existing components are changed, it is necessary to verify that the new functionality does not break any existing functionality. Such testing is known as Regression Testing.
- **Performance Testing** is used to ensure that the systems' performance is as required and, within the design requirements, is able to scale as utilization increases.
- **Security Testing** ensures that access to the system is controlled appropriately given the requirements. For example, for an online shopping system there may be different security requirements depending upon whether you are browsing the store, purchasing some products or maintaining the product catalogue.
- **Usability Testing** which may be performed by a specialist usability group and may involved filming of users while they use the system.
- **User Acceptance Testing** validates that the system actually meets the user requirements and conforms to required application integrity.

Key testing approaches are discussed in the remainder of this section.

34.4.1 Unit Testing

A unit can be as small as a single function or as large as a subsystem but typically is a class, object, self-contained library (API) or web page.

By looking at a small self contained component an extensive set of tests can be developed to exercise the defined requirements and functionality of the unit.

Unit testing typically follows a *white box* approach, (also called *Glass Box* or *Structural* testing), where the testing utilizes knowledge and understanding of the code and its structure, rather than just its interface (which is known as the *black box* approach).

In *white box* testing, test coverage is measured by the number of code paths that have been tested. The goal in unit testing is to provide 100 % coverage: to exercise every instruction, all sides of each logical branch, all called objects, handling of all data structures and files, (including the absence of a file) normal and abnormal termination of all loops etc. Of course this may not always be possible but it is a goal that should be aimed for. Many automated test tools will include a code coverage measure so that you are aware of how much of your code has been exercised by any given set of tests.

Unit Testing is almost always automated—there are many tools to help with this, perhaps the best known being JUnit for Java and ScalaTest for Scala (with similar tools being available for other languages). Developers write test and stubs, allowing us to:

- focus on testing the unit
- simulate data or results from calling another unit (representative good and bad results.)
- try to create data driven tests for maximum flexibility and repeatability.
- Often rely on *mock* objects that represent elements outside the unit that it must interact with.

Having the tests automated means they can be run frequently, at the very least after initial development and after each change that affects the unit.

Once confidence is established in the correct functioning of one unit, developers can then use it to help test other units with which it interfaces, forming larger units that can also be unit tested or, as the scale gets larger, put through integration testing.

34.4.2 Integration Testing

Integration testing is where several units (or modules) are brought together to be tested as an entity in their own right. Typically integration testing aims to ensure that modules interact correctly and the individual unit developers have interpreted the requirements in a consistent manner.

An integrated set of modules can be treated as a unit and unit tested in much the same way as the constituent modules but usually working at a "higher" level of functionality. Integration testing is the intermediate stage between unit testing and full system testing.

Thus integration testing focuses on the interaction between two or more units to make sure that those units work together successfully and appropriately. Such testing is typically conducted from the bottom up but may also be conducted top down using mocks or stubs to represented called or calling functions. An important point to note is that you should not aim to test everything together at one (so called *Big Bang* testing) as it is more difficult to isolate bugs so that they can be rectified. This is why it is more common to find that integration testing has been performed in a bottom up style.

34.4.3 System Testing

System Testing aims to validate that the combination of all the modules, units, data, installation, configuration etc. operates appropriately and meets the requirements specified for the whole system. Testing the system has a whole typically involves testing the top most functionality or behaviours of the system. Such Behaviour Based testing often involves end users and other stake holders who are less technical. To support such tests a range of technologies have evolved that allow a more *English* style for test descriptions. Cucumber is one example of a Behaviour Driven Development system and ScalaTest has a behavioural aspect to its testing styles.

34.4.4 Installation Testing

Installation testing is the testing of full, partial or upgrade install processes. It also validates that the installation and transition software needed to move to the new release for the product is functioning properly. Typically, it

- verifies that the software may be completely uninstalled through its back-out process.
- determines what files are added, changed or deleted on the hardware on which the program was installed.
- determines whether any other programs on the hardware are affected by the new software that has been installed.
- determines whether the software installs and operates properly on all hardware platforms and operating systems that it is supposed to work on

34.4.5 Smoke Tests

A smoke test is a test or suite of tests designed to verify that the *fundamentals* of the system work. Smoke tests may be run against a new deployment or a patched deployment in order to verify that the installation performs well enough to justify further testing. Failure to pass a smoke test would halt any further testing until the smoke tests pass. The name derives from the early days of electronics: If a device began to smoke after it was powered on, testers knew that there was no point in testing it further. For software technologies the advantages of performing smoke tests include:

- Smoke tests are often automated and standardized from one build to another.
- Because smoke tests test things that one expects to work, when they fail, one might suspect that the program may have been built with a wrong file, or that the new build introduced a new bug.
- If a system is built daily, it should be smoke tested daily.
- It will be necessary to periodically add to the smoke tests as new functionality is added to the system.

34.5 Automating Testing

The actual way in which tests are written and executed needs careful consideration. In general we wish to automated as much of the testing process as is possible as this makes it easy to run the tests and also ensures not only that all tests are run but that they are run in the same way each time. In addition once an automated test is set up it will typically be quicker to re-run that automated test than to manually repeat a series of tests. However, not all of the features of a system can be easily tested via an automated test tool and in some cases the physically environment may make it harder to automated tests.

Typically most unit testing is automated and most acceptance testing is manual. You will also need to decide which forms of testing must take place. Most software projects should have unit testing, functional testing and acceptance testing as a necessary requirement. Not all projects will implement performance or regression testing, but you should be careful about omitting any stage of testing and be sure it is not applicable.

Chapter 35
Scala Testing

35.1 Introduction

This chapter examines the various facilities available within Scala to perform a range of tests.

35.2 Scala Runtime Test Facilities

35.2.1 Validation Checks

Scala provides three language facilities that can be used for validation. These are:

- *Assert*—this operation is used to validate the sate of some property and throws a java.lang.AssertionError if the condition it defines is not met.
- *Require*—this is intended as a pre-condition for a class, method or function. It can be used to validate parameters and throws an IllegalArgumentException if the condition specified is not met.
- *Assume*—this is essentially an alias for assert—it can therefore be used to validate the state of an instance of an object and also throws the AssertionError if the condition specified is not met. However, static analysis tools could decide to treat assume as being different. For example, it could be that assume is used to represent a concept which has already been verified and thus it can be assumed to be correct.

None of the above operations uses the Java framework assertion and are always evaluated unless turned off at compile time. In fact if you examine the Predef.scala source file you will find that the three validation type assertions are all very similar and differ only in the exceptions that they throw. An except illustrating the definitions of the assert, assume and require methods is shown below:

```
  def assert(assertion: Boolean) {
    if (!assertion)
      throw new java.lang.AssertionError(
                               "assertion failed")
  }
  def assume(assumption: Boolean) {
    if (!assumption)
      throw new java.lang.AssertionError(
                               "assumption failed")
  }
  def require(requirement: Boolean) {
    if (!requirement)
           throw new IllegalArgumentException(
                             "requirement failed")
  }
```

35.2.2 Using Require and Assert

The following simple listing illustrates how the *require* and the *assert* operations can be used:

```
package com.jjh.scala.validate

object AssertionTests {

  def main(args: Array[String]): Unit = {
    var count = 0
    // Try require
    require(count == 0)
    require (count == 0,
          {println("Require called should be 0")})
    // Assert
    assert(count == 0)
    assert(count == 0,
             {println("Assert called is not 0")})
  }

}
```

Note that the operations, require, assert and assume can all take a condition that returns true or false and an operation to perform if the condition is not met. Thus:

```
require(count == 0)
```

validates that count is currently set to Zero, while

```
require(count == 0,
        {println("Require called should be 0")})
```

also validates that count is zero but evaluated the behaviour passed in as the second parameter if the Boolean test fails. In this case we merely print a message out to the console. The same is true for the assert example above.

35.3 Test Libraries in Scala

There are several libraries in Scala which extend the basic facilities available within the language itself to provide a richer way to represent and express tests. At the time of writing the three leading libraries are:

- ScalaTest
- Spec
- ScalaCheck

Each of these is briefly described below, while ScalaTest will be discussed in more detail in the next section.

35.3.1 ScalaTest

ScalaTest (see http://www.scalatest.org) provides a number of different testing options from Unit tests, through functional testing to behaviour-based testing.

35.3.2 Spec

Spec is a Behaviour Driven Development testing framework for Scala (see http://code.google.com/p/specs).

35.3.3 ScalaCheck

ScalaCheck (see http://www.scalacheck.org) is a testing framework developed from the Haskell library QuickCheck but has now extended beyond this. It is a property based testing framework which means that each test is associated with a property that you wish to ensure for the elements being tested and how that property is verified. For example:

```
import org.scalacheck.Properties
import org.scalacheck.Prop.forAll

object StringSpecification extends Properties("String")
{
    property("startsWith") = forAll { (a: String, b:
String) =>     (a+b).startsWith(a)
}
    property("concatenate") = forAll { (a: String, b:
String) =>     (a+b).length > a.length && (a+b).length >
b.length
   }
    property("substring") = forAll { (a: String, b:
String, c: String) =>     (a+b+c).substring(a.length,
a.length+b.length) == b
   }
}
```

35.4 ScalaTest Testing Framework

The most established Scala test framework in use is ScalaTest. This framework actually allows several different testing styles to be adopted. The simplest of which is the unit testing approach based on direct integration between JUnit (originally a Java Unit test framework) and Scala. Essentially, using ScalaTest around JUnit, a developer writes a simple unit test using Scala idioms that is then run through the JUnit infrastructure. This means that if a development project is using a mixture of Java and Scala code then can write JUnit tests in either Java or Scala and run them through the same tool sets.

35.4.1 Setting up your Scala Project

The first thing you will need to do if you are going to use ScalaTest and JUnit is to make them available to your applications. That is, to write test that will utilize the ScalaTest to JUnit bridge you will need to have both the ScalaTest Library and the JUnit library on your *classpath*. Note that you must ensure that you are using compatible versions of JUnit and ScalaTest. If the versions are not compatible you may find that you get unexpected results

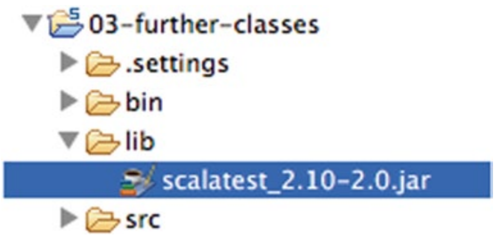


Fig. 35.1 Adding the ScalaTest jar to the project

To set up your environment in Eclipse you will need to add the JUnit jar and the ScalaTest jar to your project.

First let us obtain the ScalaTest jar. This can be done from the *downloads* page of the main ScalaTest web site (see http://www.scalatest.org/download). The current release at the time of writing is the ScalaTest 2.0 release. As previously done create a lib folder in your project and download the ScalaTest 2.0 jar file into this folder as illustrated in Fig. 35.1.

At this point all we have done is to add a file to a folder within the project. We will now add the JUnit jar and the ScalaTest jars to our classpath so that they are accessible to our applications.

The easiest way to add the *jUnit* jar is to use the version of JUnit that comes with your Eclipse. To do this go to your project properties and from the Properties dialog presented to you select the Java Build Path option on the left hand side of the window. This will cause the Java Build Path view to be displayed in the right hand side of the dialog, as illustrated in Fig. 35.2.

If the Libraries tab is not selected, then you should select it. You should now see that there are two sets of libraries currently included with the project. These are in fact the default Scala runtime libraries and include the Scala Library and the underlying Java Library. Now select the 'Add Library…' button on the right side of the display:

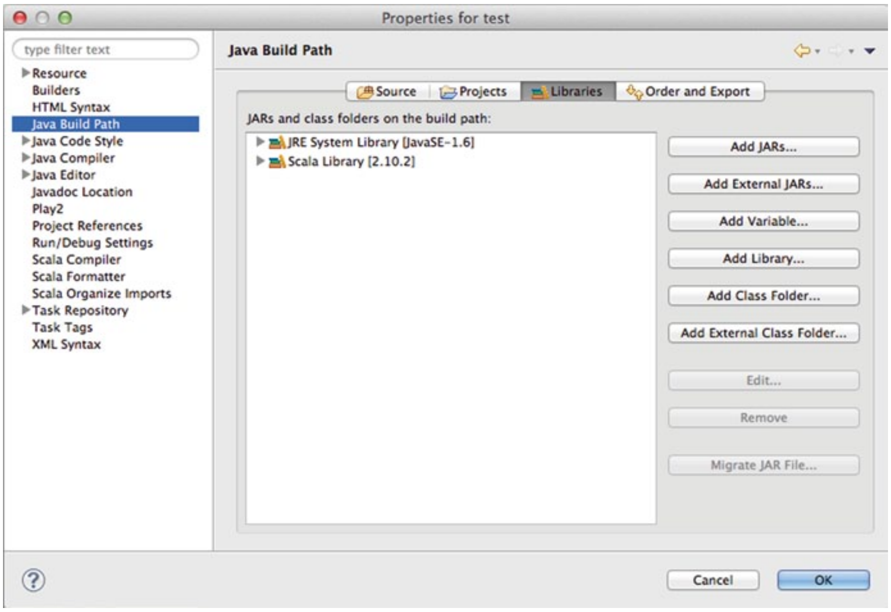
This will result in the *Add Library* dialog being displayed as shown in Fig. 35.3. Select the JUnit library.

Now select the button 'Next >' which will display the JUnit Library selection dialog, as shown in Fig. 35.4. Select JUnit 4 (note JUnit 3 is not compatible with the ScalaTest library).

In the figure the version of JUnit being selected in JUnit 4.8.2 which is compatible with the version of ScalaTest we will be using. Now select 'Finish'.

You should now be returned to the Java Build Path dialog that now shows JUnit 4 as one of the libraries (as illustrated in Fig. 35.5).

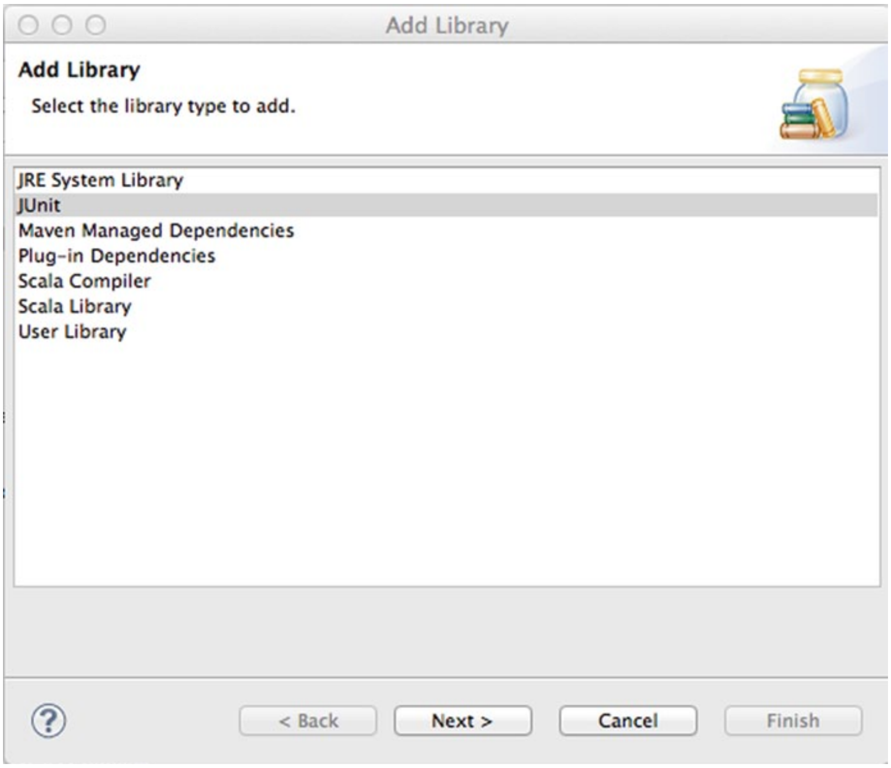
We can now add the ScalaTest jar file that we placed into the lib folder of our project, to our classpath. This is done by selecting the 'Add Jar…' button on the right hand side of the dialog:



JARs and class folders on the build path:

- JRE System Library [JavaSE-1.6]
- Scala Library [2.10.2]

Fig. 35.2 The Eclipse Project Properties Dialog

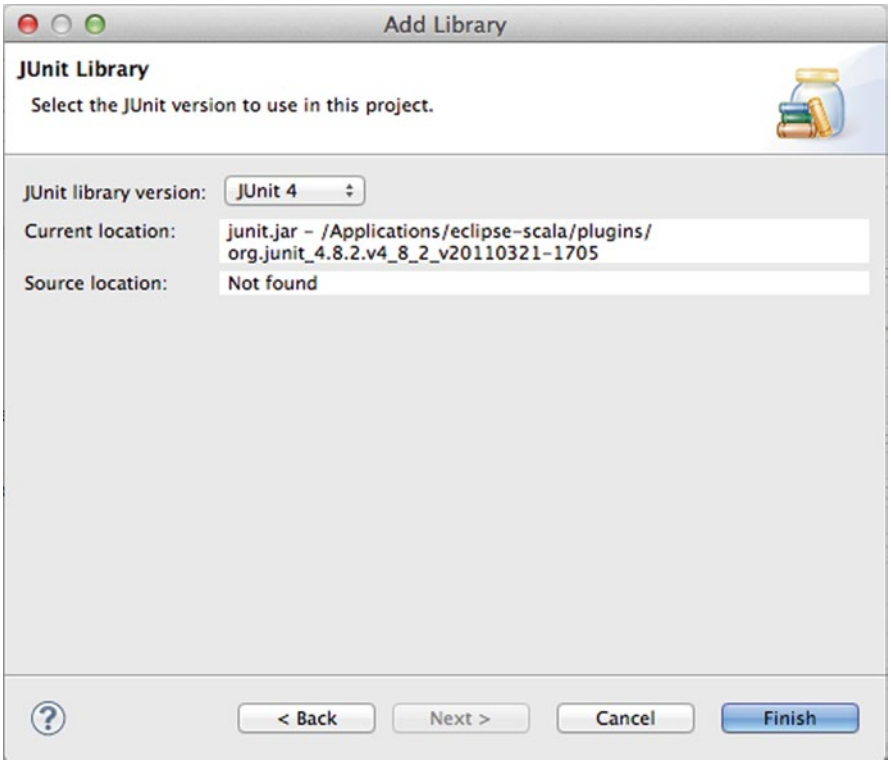


Add Library

Select the library type to add.

JRE System Library
JUnit
Maven Managed Dependencies
Plug-in Dependencies
Scala Compiler
Scala Library
User Library

Fig. 35.3 Add Library Dialog



JUnit Library

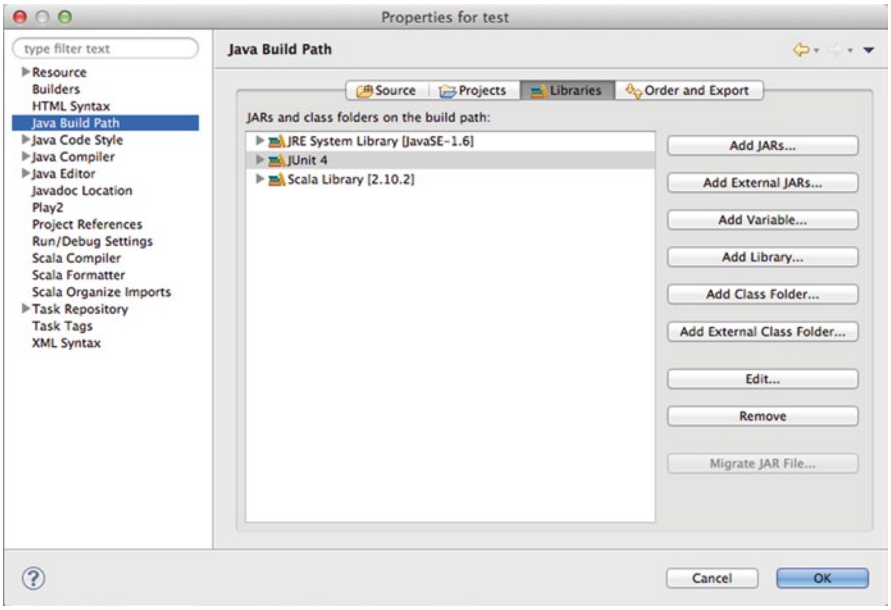
Select the JUnit version to use in this project.

JUnit library version: JUnit 4

Current location: junit.jar - /Applications/eclipse-scala/plugins/org.junit_4.8.2.v4_8_2_v20110321-1705

Source location: Not found

Fig. 35.4 Selecting JUnit 4



Java Build Path

JARs and class folders on the build path:

- JRE System Library [JavaSE-1.6]
- JUnit 4
- Scala Library [2.10.2]

Fig. 35.5 JUnit library added to Eclipse

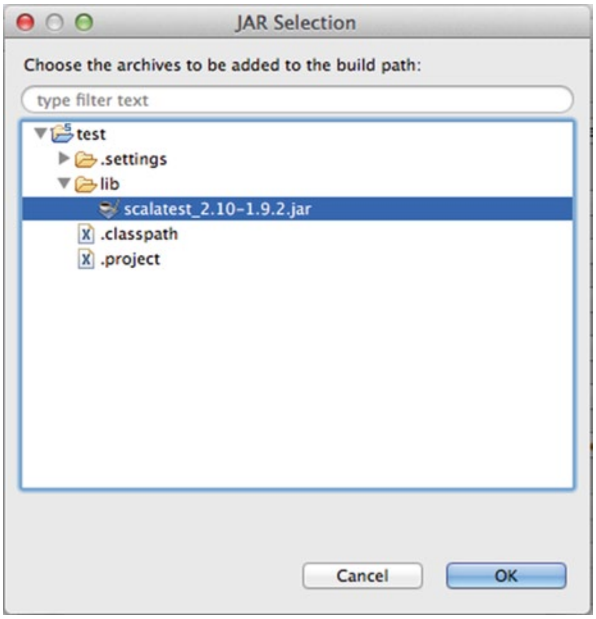


Fig. 35.6 Selecting the ScalaTest jar

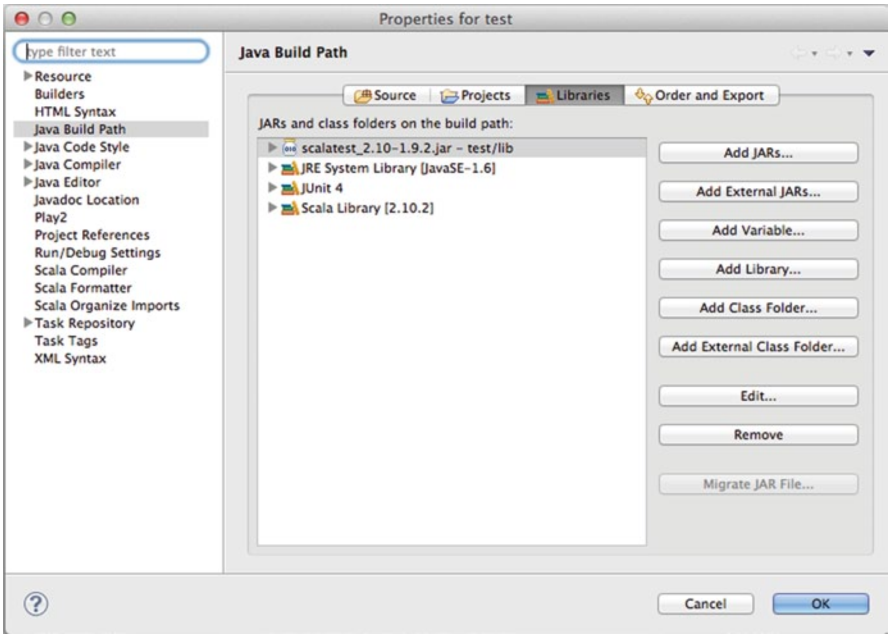
This displays the *Jar Selection* dialog. In this dialog expand the selection tree to find your lib project within your project and select the ScalaTest jar file as shown in Fig. 35.6.

Now select 'OK'. You should now find that the ScalaTest jar file has been added to the list of libraries available for the current project (see Fig. 35.7).

35.4.2 ScalaTest and JUnit

In this section we will look at how you can write simple unit tests in ScalaTest. A ScalaTest test mixes in the trait `org.scalatest.Suite` and can mix in one or more additional traits that allow you to control the behaviour of the tests. In general we will call our test classes <something>Test or Test<something> where *something* is an appropriately descriptive name. Therefore we might write a class called PersonTest (which indicates that it provides one or more test methods associated with the class Person. To illustrate the idea let us assume that we have a simple class Person as shown in the following listing:

```
package com.jjh.scala

class Person(val name: String, var age: Int) {
  override def toString() = name + " is " + age
}
```



JARs and class folders on the build path:

- scalatest_2.10-1.9.2.jar - test/lib
- JRE System Library [JavaSE-1.6]
- JUnit 4
- Scala Library [2.10.2]

Fig. 35.7 JUnit and ScalaTest both on the classpath of an Eclipse project

A simple test class for this Person class might thus be:

```
package com.jjh.scala

import org.junit.runner.RunWith
import org.scalatest.Suite
import org.scalatest.junit.JUnitRunner
import org.junit.Assert._

@RunWith(classOf[JUnitRunner])
class PersonTest extends Suite {
  def testPersonCreation() = {
    val p = new Person("John", 49)
    assertEquals("Age incorrect", 49, p.age)
  }
}
```

There are a number of points to note about this simple test class.

The package The first is that both the Person class and the PersonTest class are defined within the package com.jjh.scala. However, this does not mean that they are both defined in the same source location. I have created a second location that will contain all my tests. I thus have a route folder main/scala/src and a root folder test/

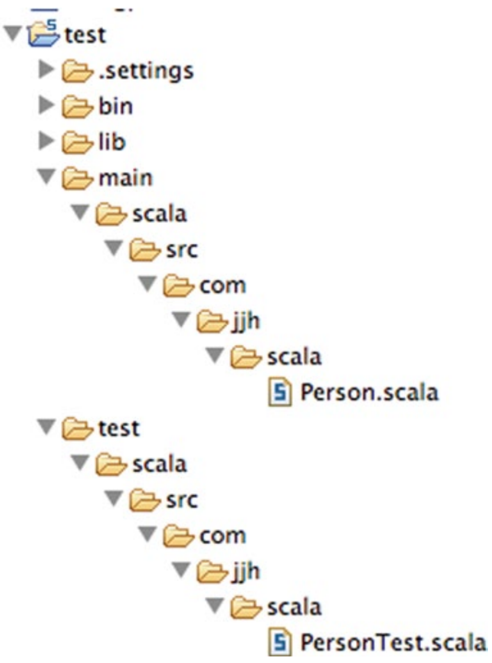


Fig. 35.8 Two source folders in an Eclipse project

scla/src that can both contain Scala source code. The main path indicates the main body of the system and the test path the location of test code. This means that I can ensure that no test code is accidently included in the deployed system as the deployed system should not contain anything under the test root. However, for testing purposes I would like to allow the test class to have at least package visibility of all data and methods as this can make setting up test scenarios easier. In Scala it does not matter that Person and PersonTest are in different source locations, the important point is that they are both part of the package com.jjh.scala. This is illustrated in Fig. 35.8.

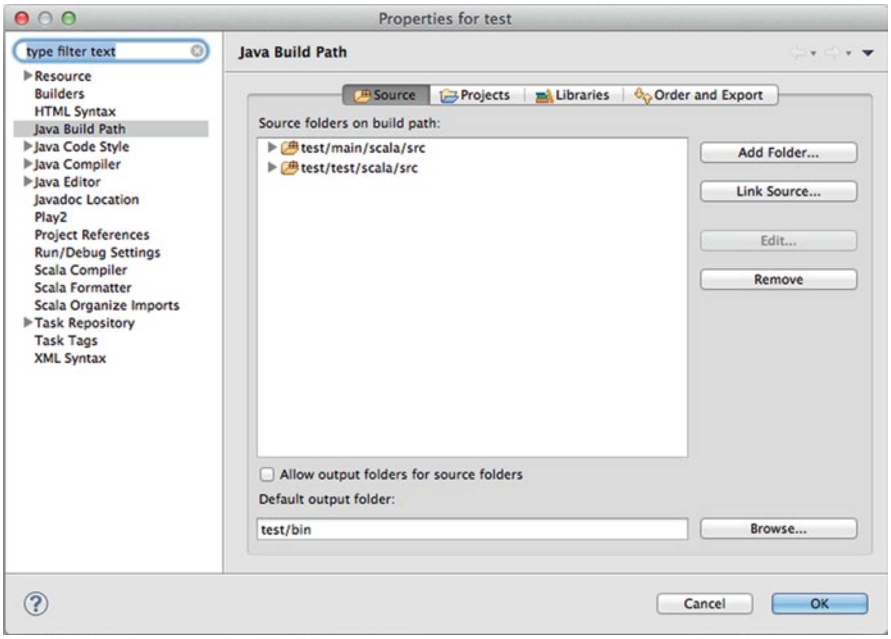
However Eclipse must be told that the two folders contain source code. This is done from the project properties dialog. Open the project properties and select the *Source* tab. Using the 'Add Folder…' button add the two folders to the project and remove any folders that do not hold source code. The end result in my project is shown in Fig. 35.9.

RunWith Annotation Secondly the class is *annotated* with a

```
@RunWith(classOf[JUnitRunner])
```

This indicates that when this class is run it is not run as a standard Scala application. Instead it should be run through the JUnit framework via the JUnitRunner.

Naming Conventions The third point to note is that the method within the PersonTest class is called test <something>. This is important; ScalaTest and JUnit look for methods that start test in order to find an appropriate set of tests to execute.



Source folders on build path:
test/main/scala/src
test/test/scala/src

Allow output folders for source folders

Default output folder:
test/bin

Fig. 35.9 Two source folders in Eclipse properties

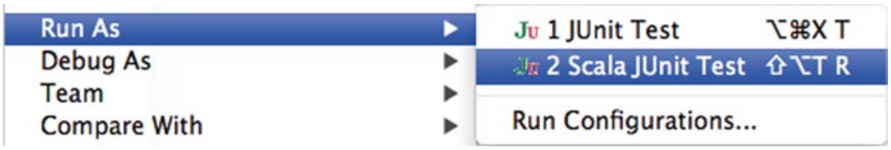


Fig. 35.10 Run As Scala Test

A Method called Test is not the same as a method called test and thus if you use a capital letter as the start of the test method it will not be found.

Finally, within the *testPerson* method, having created an instance of the Person class we validate the test using an Assert.assertEquals method. In fact the Assert class of the org.junit package provides many different assertion methods. We could have used the Assert.assert.Equals but this is quiet long winded and Assert.assert seems a bit repetitive. To avoid this we imported the methods on the Assert class into this file using:

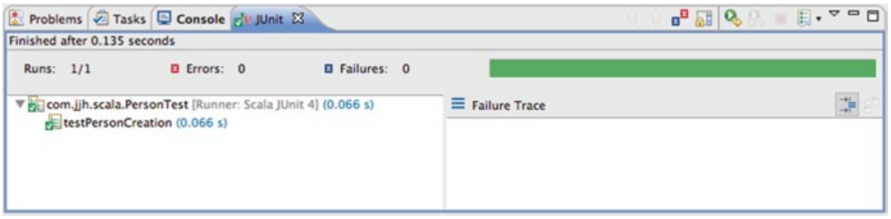
```
import org.junit.Assert._
```

We can now run this simple test. This is done using the right mouse menu option Run As -> Scala JUnit Test as illustrated in Fig. 35.10.

This will result in Eclipse displaying the JUnit view which provides feedback on how many tests were run, how many were successful, how many failed and how many exceptions were thrown (as Errors). A Green bar indicates that all the tests passed, where as a red bar indicates one or more tests failed. This is shown in Fig. 35.11.

There is a range of options that can be applied to these tests. For example, if you wish to define some behaviour that will be run before each test, referred to as test fixtures you can mix in the *BeforeAndAfter* trait. This provides the ability to define a *before* and *after* expression. The following listing illustrates a test suite for a class Stack that has two tests and a before fixture and an after fixture:

```
import scala.collection.mutable.Stack
import org.scalatest.junit.JUnitRunner
import org.junit.runner.RunWith
import org.scalatest.Suite
import org.scalatest.BeforeAndAfter
import org.junit.Assert._

@RunWith(classOf[JUnitRunner])
class SuiteTest extends Suite with
BeforeAndAfter {

  before {
    println("Before behaviour")
  }

  after {
    println("After behaviour")
  }

  def testStackPush() {
    val stack = new Stack[Int]
    stack.push(52)
    assertEquals(1, stack.size)
  }

  def testStackPop() {
    val stack = new Stack[Int]
    stack.push(32)
    val x = stack.pop()
    assertEquals(32, x)
  }
  }
```



Finished after 0.135 seconds
Runs: 1/1 Errors: 0 Failures: 0

com.jjh.scala.PersonTest [Runner: Scala JUnit 4] (0.066 s)
testPersonCreation (0.066 s)

Fig. 35.11 JUnit runtime view in Eclipse

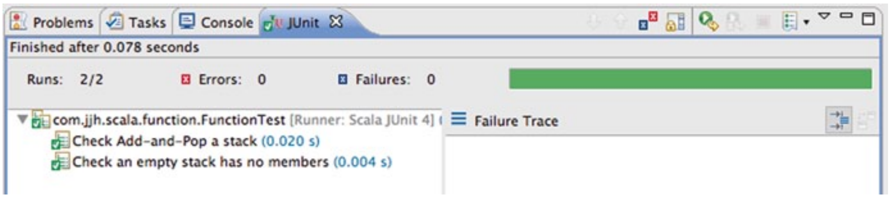
The result of executing this test is that both tests pass and the console contains the output shown below:

```
Before behaviour
After behaviour
Before behaviour
After behaviour
```

As you can see from this example, the *before* and *after* behaviours have been run before (and after) each test.

35.4.3 Scala Test and Functional Test Suites

The functional test suite facilities available in ScalaTest are aimed at supporting TDD style development. In a function style test each test is a *named* function within the test suite. A developer's class extends the FunSuite (which stands for Function Suite) and can use BeforeAndAfter fixtures for setup and tear down style behaviour. In the function suite tests, names can be more description as the name of test are strings and can have spaces within them. However, at runtime they are presented as normal JUnit tests.



Finished after 0.078 seconds

Runs: 2/2 Errors: 0 Failures: 0

com.jjh.scala.function.FunctionTest [Runner: Scala JUnit 4]
Check Add-and-Pop a stack (0.020 s)
Check an empty stack has no members (0.004 s)

Fig. 35.12 Running a Function style test

The following listing illustrates a Function Test Suite:

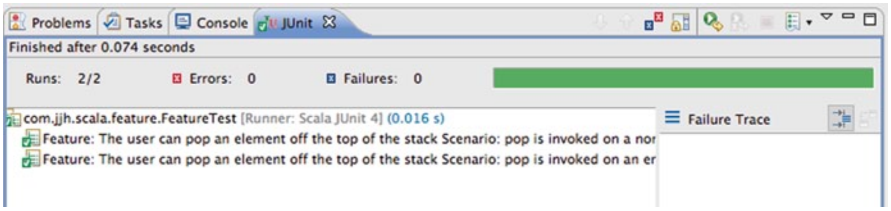
```
import org.scalatest.junit.JUnitRunner
import org.junit.runner.RunWith
import org.scalatest.FunSuite
import scala.collection.mutable.Stack

@RunWith(classOf[JUnitRunner])
class FunctionTest extends FunSuite {

  test("Check Add-and-Pop a stack") {
    val stack = new Stack[Int]
    stack.push(1)
    assert(stack.pop() === 1)
  }

  test("Check an empty stack has no members") {
    val emptyStack = new Stack[Int]
    assert(emptyStack.length == 0)
  }

}
```

The results of running this FunctionTest within Eclipse are presented via the JUnit view as shown in Fig. 35.12.

35.5 ScalaTest and Feature Tests

Another test style supported by ScalaTest is that of the *feature test*. A Feature is typically a very high level concept that would be meaningful to a user. As such features are primarily those things that might be tested at the user acceptance testing level. ScalaTest provides the FeatureSpec trait that can be used to represent these very high level concepts. The aim is to provide a structure that allows developers to work along side non-programmers to define the acceptance criteria. The following listing illustrates a ScalaTest Feature Specification test:

```
import org.scalatest.FeatureSpec
import org.scalatest.GivenWhenThen
import scala.collection.mutable.Stack

import org.scalatest.junit.JUnitRunner
import org.junit.runner.RunWith

@RunWith(classOf[JUnitRunner])
class FeatureTest extends FeatureSpec with
GivenWhenThen {

  feature("The user can pop an element off the top of the
stack") {

    info("As a programmer")
    info("I want to be able to pop items off the stack")
    info("So that I can get them in last-in-first-out
order")

    scenario("pop is invoked on a non-empty stack") {

      given("a non-empty stack")
      val stack = new Stack[Int]
      stack.push(1)
      stack.push(2)
      val oldSize = stack.size

      when("when pop is invoked on the stack")
      val result = stack.pop()

      then("the most recently pushed element should be
returned")
      assert(result === 2)

      and("the stack should have one less item than
before")
      assert(stack.size === oldSize - 1)
    }

    scenario("pop is invoked on an empty stack") {

      given("an empty stack")
      val emptyStack = new Stack[Int]

      when("when pop is invoked on the stack")
      then("NoSuchElementException should be thrown")
      intercept[NoSuchElementException] {
        emptyStack.pop()
      }

      and("the stack should still be empty")
      assert(emptyStack.isEmpty)
    }
  }
```



```
Finished after 0.074 seconds
Runs: 2/2    Errors: 0    Failures: 0
com.jjh.scala.feature.FeatureTest [Runner: Scala JUnit 4] (0.016 s)
  Feature: The user can pop an element off the top of the stack Scenario: pop is invoked on a nor
  Feature: The user can pop an element off the top of the stack Scenario: pop is invoked on an er
```

Fig. 35.13 A Feature Style Test

The result of running this as a Scala JUnit test in Eclipse is shown in Fig. 35.13.

35.6 Test Driven Development

Test Driven Development (of TDD) is a development technique whereby developers write test cases *before* they write any implementation code. The tests thus drive or dictate the code that is developed. The implementation only provides as much functionality as is required to pass the test and thus the tests act as a specification of *what* the code does (and some argue that the test are thus part of the that specification and provide documentation of what the system is capable of).

TDD has the benefit that as tests must be written first, there are always a set of tests available to perform unit, integration, regression testing etc. This is good as developers can find that writing tests and maintaining tests is boring and of less interest than the actual code itself and this put less emphasis into the testing regime than might be desirable. TDD encourages, and indeed requires, that developers maintain an exhaustive set of repeatable tests and that those tests are developed to the same quality and standards as the main body of code.

There are three rules of TDD as defined by Robert Martin for TDD, these are:

1. You are not allowed to write any production code unless it is to make a failing unit test pass
2. You are not allowed to write any more of a unit test than is sufficient to fail; and compilation failures are failures
3. You are not allowed to write any more production code than is sufficient to pass the one failing unit test.

This leads to the TDD cycle described in the next section.

35.6.1 The TDD Cycle

There is a cycle to development when working in a TDD manner. The shortest form of this cycle is the TDD mantra:

```
Red /Green/ Refactor
```

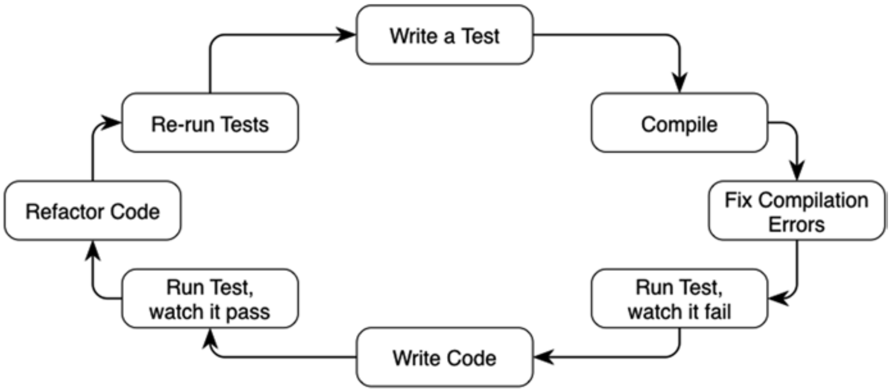


Fig. 35.14 TDD Cycle

Which relates to the JUnit suite of tools where it is possible to write a JUnit based test. Within tools such as Eclipse, when you run a JUnit test a JUnit view is shown with Red indicating that a test failed, Green indicating that the test passed. Hence Red/Green, in other words write the test and let it fail, then implement the code to ensure it passes. The last mart of this mantra is *Refactor* which indicates once you have it working make the code cleaner, better, fitter by Refactoring it. Refactoring is the process by which the behaviour of the system is not changed but the implementation is alter to improve it.

The TDD mantra can be seen in the TDD cycle that is shown in Fig. 35.14 and described in more detail below:

1. Write a single test
2. Compile it. It shouldn't compile because you've not written the implementation code
3. Implement just enough code to get the test to compile
4. Run the test and see it **fail**
5. Implement *just enough* code to get the test to pass
6. Run the test and see it **pass**
7. **Refactor** for clarity and deal with any issue of reuse etc.
8. Repeat for next test.

35.6.2 Test Complexity

The aim is to strive for simplicity in all that you do within TDD. Thus you write a test that fails, then do just enough to make that test pass (but no more). Then you refactor the implementation code (that is change the internals of the unit under test) to improve the code base. You continue to do this until all the functionality for a unit has been completed. In terms of each test, you should again strive for simplicity with each test only testing one thing with only a single assertion per test (although this is the subject of a lot of debate within the TDD world).

35.6.3 Refactoring

The emphasis on refactoring with TDD makes it more than just testing or Test First Development. This focus on refactoring is really a focus on (re)design and incremental improvement. The tests provide the specification of what is needed as well as the verification that existing behaviour is maintained, but refactoring leads to better design software. Thus with refactoring TDD is not TDD!

References

Dave A (2003) Test-driven development: a practical guide. Prentice-Hall/Pearson Education, ISBN 0-13-101649-0

Kent B (2003) Test-driven development: by example. Addison-Wesley, ISBN 0-321-14653-0

Dijkstra EW (1970) Notes on structured programming, Technical University of Eindhoven, The Netherlands, Department of Mathematics, Technical Report 70-WSK-03, April 1970 (see http://www.cs.utexas.edu/users/EWD/ewd02xx/EWD249.PDF)

Glenford M, Badgett T, Sandler C (2011) The art of software testing, 3rd edn. Wiley, 1118031962

Martin F (1999) Refactoring: improving the design of existing code. Addison-Wesley, 0201485672

Further Reading

Cucumber behaviour driven development, see http://cukes.info/
ScalaTest see http://www.scalatest.org
ScalaCheck see http://www.scalacheck.org
Robert C. Martin (aka Uncle Bob)
http://butunclebob.com/ArticleS.UncleBob.TheThreeRulesOfTdd
http://www.testdriven.com

testdrivendevelopment group (Yahoo):
http://groups.yahoo.com/group/testdrivendevelopment

xUnit implementations:
http://www.xprogramming.com/software.htm
http://www.junit.org

Refactoring.com
http://www.refactoring.com/Further Reading

Chapter 36
Introduction to Akka Actors

36.1 Introduction

This chapter introduces the concept of an *Actor* as an approach to the development of concurrent programs. In particular we focus on the Scala *Akka* implementation of the Actor model based on release 2.2.3 (the current release at the time of writing). Note that Scala 2.10 also has its own *scala.actor* implementation of the Actor model however the Akka approach is more sophisticated and is likely to migrate into Scala.

36.2 The Actor Model

The Actor model of concurrency (which dates from 1973) is based on the idea of having independent concurrent *Actors* that receive and send asynchronous messages and that perform some behaviour based on these message requests. These actors can hold their own state and behaviour. However, ideally only immutable data is exchanged between them. Thus each actor is independent of all other actors and only performs some computation or processing based on a message sent to it. This is illustrated in Fig. 36.1.

The key idea underpinning the Actor model is that most of the problems with concurrency; from deadlocks to data corruption; result from having shared state. Thus in the Actor world there is no shared state (such as a concurrent producer-consumer queue). Instead, messages are sent between actors and these messages are queued in an *inbox* in a similar manner to email messages. The actors then respond to the messages as they get to them.

The Actor model has been used as the basis of a number of implementations including those in Erlang, the scala.actor framework and the Scala and Java Akka libraries. It is also used with the education system Scratch.

The actor model consists of a few key principles:

- No shared state.
- Lightweight processes.

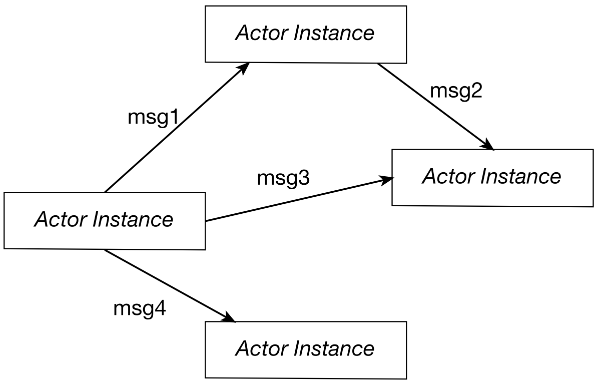


Fig. 36.1 Actors communicating via asynchronous messages

- Asynchronous message-passing.
- Buffering for incoming messages via an a *inbox* in which it receives messages
- Message processing with pattern matching with each message being processed one at a time.
- No shared mutable data.
- No blocking operations.
- Any process can send a message to an actor.
- An actor doesn't do anything unless/until it receives a message.

Thus an actor is an independent flow of control running in its own thread or process. In many ways you can think of an actor as a *thread of execution* with extra features.

The fact that Actors do not share state means that you implement an actor as if it was a simple sequential process. This avoids a large number of the problems that result from shared state. It should be noted that in most Actor implementations it is actually possible to share state; it's just a very bad idea!

Within Scala there are actually two distinct implementations of the Actor model, these are the *scala.actor* framework and the *akka.actor* framework. In the rest of this chapter we will look at the latter of these two.

36.3 Some Terminology

The world of concurrent programming is full of terminology that you may not be familiar with. Some of those terms and concepts are outlined below:

- *Asynchronous versus synchronous invocations*. Most of the method, function or procedure invocations you will have seen in programming represent synchronous invocations. A synchronous method or function call is one which blocks the calling code from executing until it returns. Such calls are typically within a single thread of execution. Asynchronous calls are ones where the flow of control immediately returns to the *callee* and the *caller* is able to execute in its own thread of execution. Allowing both the caller and the call to continue processing.

- *Non-Blocking versus Blocking code*. Blocking code is a term used to describe the code running in one thread of execution, waiting for some activity to complete which causes one of more separate threads of execution to also be delayed. For example, if one thread is the producer of some data and other threads are the consumers of that data, then the consumer treads cannot continue until the producer generates the data for them to consume. In contrast, non-blocking means that no thread is able to indefinitely delay others.
- *Concurrent versus parallel code*. Concurrent code and parallel code are similar, but different in one significant aspect. Concurrency indicates that two or more activities are both making progress even though they might not be executing at the same point in time. This is typically achieved by continuously swapping competing processes between execution and non-execution. This process is repeated until at least one of the threads of execution (Threads) has completed their task. This may occur because two threads are sharing the same physical processor with each is being given a short time period in which to progress before the other gets a short time period to progress. The two threads are said to be sharing the processing time using a technique known as time slicing. Parallelism on the other hand implies that there are multiple processors available allowing each thread to execute on their own processor simultaneously.

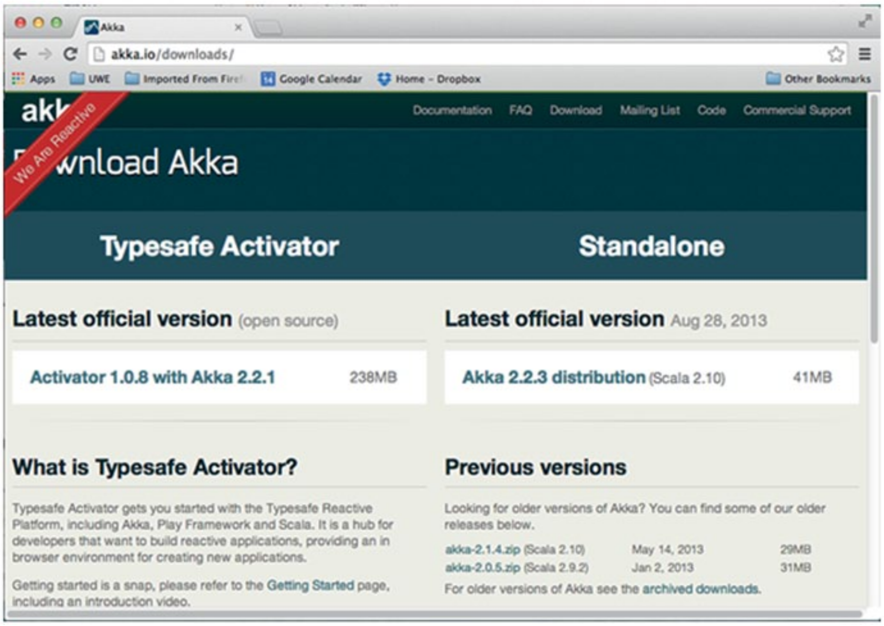
36.4 Scala Threads

Under pining the *Akka* Actor model is the notation of a Thread. A Scala Thread is a pre-emptive lightweight process. Every thread (process) has an associated priority and a Scala thread runs to completion unless a higher priority process attempts to gain control. Scala does not necessarily share the processor time amongst processes of the same priority (as this is the responsibility of the underlying JVM). Threads with a higher priority are executed before threads with a lower priority. A thread with a higher priority may interrupt a thread with a lower priority. By default, a process inherits the same priority as the process that spawned it.

A thread is a "lightweight" process because it does not possess its own address space and it may not be treated as a separate entity by the host operating system. Instead, it typically exists within a single virtual machine process using the same address space.

It is useful to get a clear idea of the difference between a thread (running within a single virtual machine process) and a multi-process system. The thread that is currently executing is termed the active thread. A thread can also be suspended (i.e. waiting to use the processor) or stopped (waiting for some resource).

You will find when reading about Akka Actors this term *thread* is used when considering how an Actor manages the requests it receives. For example, an Actor utilizes a single thread thus allowing it to process a single request at a time, to completion, before processing the next request. Alternatively, multiple Actors may use a pool of threads, so that they can process multiple requests via the multiple underling threads managed in the pool.



akka.io/downloads/

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What is Typesafe Activator?

Typesafe Activator gets you started with the Typesafe Reactive Platform, including Akka, Play Framework and Scala. It is a hub for developers that want to build reactive applications, providing an in browser environment for creating new applications.

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Previous versions

Looking for older versions of Akka? You can find some of our older releases below.

akka-2.1.4.zip (Scala 2.10)	May 14, 2013	29MB
akka-2.0.5.zip (Scala 2.9.2)	Jan 2, 2013	31MB

For older versions of Akka see the archived downloads.

Fig. 36.2 Obtaining the Scala Akka library

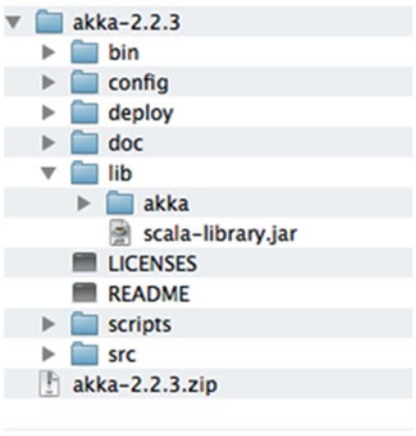
36.5 Akka Scala Actor library

The Akka Actor library is a implementation of the Actor model. Note that there is both a version of this library for Java and for Scala. You therefore need to be careful if you are researching this library on the web that you are looking at material for the Scala version.

At the time of writing the current version of this library is the Akka 2.2.3 release. Note that the 2.2 family of distributions are significantly different to those that pre-date them and you therefore also need to be careful that you are not looking at documentation related, for example, to the 2.1 release of the Akka library.

The Akka library is open source and is available under the Apache 2 license. You can obtain it from the Akka home page (http://akka.io). If you wish to download the Akka library then you can do so from the Download page, which is shown in Fig. 36.2.

Note that there are two downloads available; one is the Typesafe Activator distribution which includes the Akka library, the Play Framework discussed elsewhere in this book, Scala as well as other resources and templates. You can also down load the core Akka distribution as a zip file. As we are not using the Typesafe Reactive Platform nor any of the templates provided with the Activator, this chapter assumes that you have downloaded the Akka distribution zip file.



```
▼ akka-2.2.3
    ▶ bin
    ▶ config
    ▶ deploy
    ▶ doc
    ▼ lib
        ▶ akka
          scala-library.jar
      LICENSES
      README
    ▶ scripts
    ▶ src
  akka-2.2.3.zip
```

Fig. 36.3 The Scala Akka distribution

The Akka distribution zip file will need to be extracted into a suitable location. The contents of this zip file is more than just a set of library Jar files Fig. 36.3 illustrates the contents of the Akka zip file).

The Akka distribution contains the jar files making up the library in the lib/akka directory. The remainder of the distribution provides a standalone microkernel into which you can place Akka based applications. This may be particularly useful if what you are creating is a multiple thread (multi actor) service. However, for our purposes we will focus on the library as this can be used by any application, including web application, by adding the jar files to the classpath of your application.

The Akka library is actually a very modular library. This is because it is comprised of different library jar files representing different features of the Akka system. If you are not using those features then you do not need to incorporate those library files. Some of the modules you might decide to use are presented below:

- akka-actor—Classic Actors, Typed Actors, IO Actor etc.
- config—Used to handle configuration type tasks within the framework
- akka-cluster—Cluster membership management, elastic routers.
- akka-mailboxes-common—common infrastructure for implementing durable mailboxes

The two parts of the library that we will be working with are the akka-actor and the config jars. It is these two jars that you need to find and add to your projects. Note that the names of the files are derived from the release of Scala that is targeted and the release number of Akka, for example in Fig. 36.4 the akka-actor file is actually called akka-actor_2.10-2.2.3.jar, that is it applies to Scala 2.10 and is release 2.2.3 of Akka.

If you are using Eclipse Scala IDE then these Jars must be added to the build path of your project as shown in Fig. 36.5.

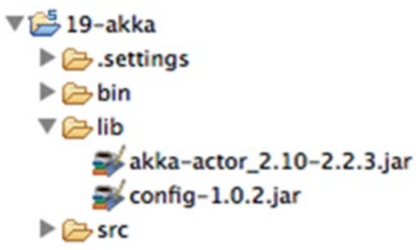
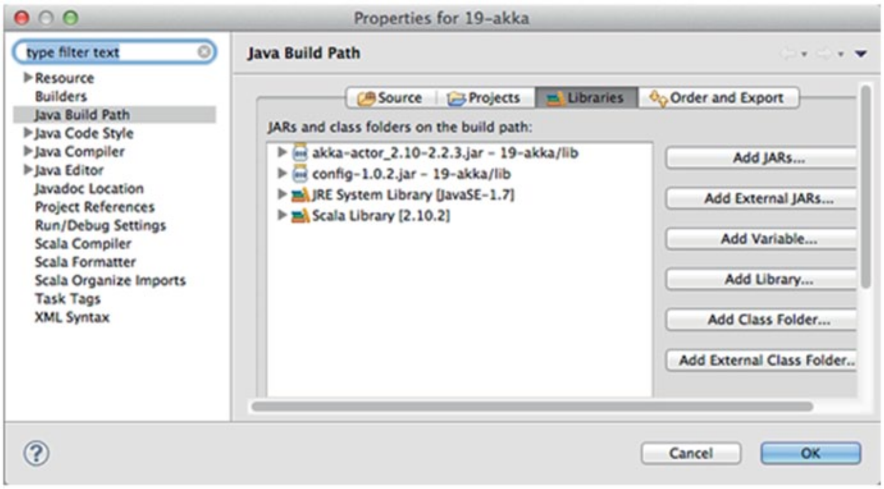


Fig. 36.4 The Akka library jar files


Properties for 19-akka

Java Build Path

Source | Projects | Libraries | Order and Export

JARs and class folders on the build path:

- akka-actor_2.10-2.2.3.jar - 19-akka/lib
- config-1.0.2.jar - 19-akka/lib
- JRE System Library [JavaSE-1.7]
- Scala Library [2.10.2]

Fig. 36.5 Setting the classpath properties for an Akka project in the Scala IDE

36.6 Concurrent Hello World

In this section we will look at two simple Akka based programs. The first of these programs creates a simple Actor that can be sent messages. If the message sent is the string “Hello” then it will print out the message “Hello World”, if anything else (of any type) is sent to the actor then it will print out the string “Hello Whoever”.

To implement an Actor you must mix in the `Actor` trait. This trait requires that a single method `receive` is implemented. This method will be called when a message is available to be processed in the actor’s inbox. Locally the inbox is queue in which messages are added to the back of the queue and taken from the front of the queue. Each message is processed to completion before the next message is taken. This is shown in Fig. 36.6.

The import statements for the example being discussed here are:

```
import akka.actor.Actor
import akka.actor.Props
import akka.actor.ActorSystem
```

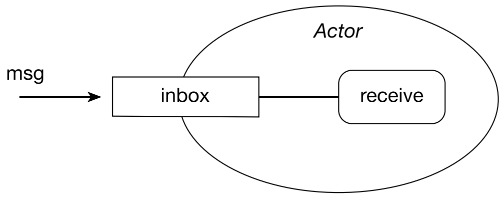


Fig. 36.6 Actor with an inbox and a receive method

It is important to take note of the package names as there is also an Actor type in the `scala.actor` package. If you import that type you will get compilation problems as it is not compatible with the Akka library

The following listing illustrates how a simple actor called `Greeter` can be implemented:

```
class Greeter extends Actor {
  def receive = {
    case "hello" => println("Hello World")
    case _ => println("Hello Whoever")
  }
}
```

In this case, when the string "hello": is received it will printout "Hello World", while anything else (as indicated by the wild card '_') will print out "Hello Whoever". Notice that the `receive` method is implemented using *case pattern matching*, thus the Actor can handle different messages, different message types etc. in different ways. If you want to be able to handle unknown messages then you need to have a default case as in the example above.

The test application that uses this `Greeter` actor is shown below:

```
object HelloworldAkkaTest extends App {
  val props = Props[Greeter]
  val system = ActorSystem("mysystem")
  val actor1 = system.actorOf(props)
  actor1 ! "hello"
  actor1 ! "Goodbye"
  actor1 ! 42
  actor1 ! true
}
```

This test application goes through three steps in order to obtain a reference to the actor held in the val `actor1`. The steps are:

1. **Create a Props instance**. `Props` is a configuration class used to specify the options to be used to create an actor. In this case it is specifying the class that

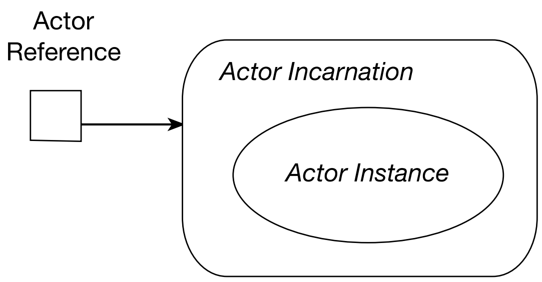


Fig. 36.7 The role of the actor reference

defines the Actor (i.e. the `Greeter class`). This Props type can also be used to pass data to any constructor defined on the class (we will see this later).

2. **Access the ActorSystem**. The Actor system is the element within the Akka framework that is responsible for creating top-level actors. These actors can create child actors, can respond to messages and can be stopped, restarted, etc. The `ActorSystem` is given a name so that multiple such systems can be created if required. However, note that the `ActorSystem` is a heavy weight object and you should try to only create one per application unless absolutely necessary.
3. **Create a new actor using actorOf**. Using the actor system reference obtained in the previous step, the application creates a new actor based on the properties in props. The `actorOf` method is a factory method that creates new actors of the type specified by the props object. The type returned by the `actorOf` method is an `ActorRef`.

Once it has successfully created a new actor a series of message are sent to the actor. These mix strings, within an `Int` and a `Boolean`. They are handled by the `receive` method in turn. The method decides what to do with each message based on the pattern matching case statements defined within it.

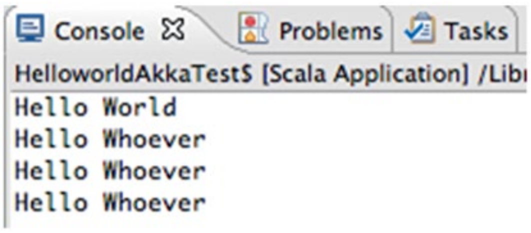
It should be noted that actor1 does not hold a reference to the actual actor instance. Instead it holds a reference to the *Actor Incarnation*. This is a wrapper around the current *Actor Instance*. For the most part this is transparent to the programmer. This structure is used to allow an actor that has exited its own underlying thread (or process) to resume processing. This is done within the Akka library by creating a new Actor instance and *restarting* it. However, as this is hidden inside the Actor Incarnation the programmer is not affected by this (Fig. 36.7.).

The output generated by running the HelloworldAkkaTest is shown in Fig. 36.8.

36.7 Concurrent Actors

The example discussed in the previous section illustrates how an Akka Actor can be defined and how messages can be sent to an actor. However, it does not really capture the concurrency inherent in Actors. To illustrates this idea see the following

Fig. 36.8 Output form the HelloworldAkkaTest application



```
HelloworldAkkaTest$ [Scala Application] /Libı
Hello World
Hello Whoever
Hello Whoever
Hello Whoever
```

listing presenting the `Printer` Actor. This Actor prints out different strings depending upon the messages it receives. However, it does each string 500 times. This means that if we have multiple instances of the `Printer` running concurrently, we should be able to observe a mixture of A, B, C and _ being printed out.

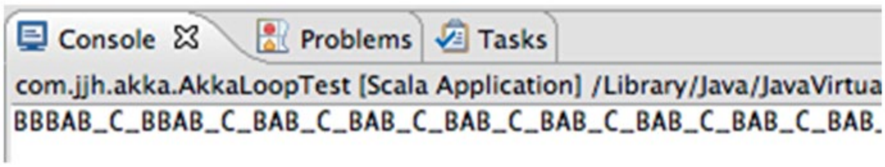
```
class Printer extends Actor {
  def receive = {
    case "A" => for (i <- 1 to 500) print("A")
    case "B" => for (i <- 1 to 500) print("B")
    case "C" => for (i <- 1 to 500) print("C")
    case _ => for (i <- 1 to 500) print("_")
  }
}
```

The sample program that uses this `Printer` Actor is shown below:

```
object AkkaPrinterTest extends App {
  val props = Props[Printer]
  val system = ActorSystem("mysystem")
  val actor1 = system.actorOf(props, "actor1")
  val actor2 = system.actorOf(props, "actor2")
  val actor3 = system.actorOf(props, "actor3")
  val actor4 = system.actorOf(props, "actor4")
  actor1 ! "A"
  actor2 ! "B"
  actor3 ! "C"
  actor4 ! "X"
}
```

In this program we again obtain a `Props` instance but this time for the class `Printer`. We then obtain the `ActorSystem` and then use this to crate the actors. In this case we create four actors. Each actor is an independent instance of the Printer Actor.

As you can see the version of `actorOf` used here takes the *Props* instance and a name string. The *name* parameter is optional. However as the name is used with log messages it may helpful during debugging. Note if a given name is already in use then an exception will be thrown.



```
com.jjh.akka.AkkaLoopTest [Scala Application] /Library/Java/JavaVirtua
BBBAB_C_BBAB_C_BAB_C_BAB_C_BAB_C_BAB_C_BAB_C_BAB_C_BAB_C_BAB.
```

Fig. 36.9 Output from multiple concurrent Akka Actors

Once we have created the four actors each is sent a message. As the main application will run concurrently to the actors themselves, all four messages should be sent before the first actor has a chance to complete the printout 500 strings. We should therefore see a mixture of different strings being output. This is shown in Fig. 36.9.

From this we can see that the four Actors due run concurrently, sharing the available processor, with output coming from Actors 1, 2 and 3 clearly marked by the "A's, "B" and "C"s. The output from actor 4 is indicated by the "_"s.

36.8 The Akka Actor API

The `Actor` trait we looked at in the last couple of sections only defines a single abstract method, `receive`, which must be implemented to define the behaviour of the Actor. However, several other facilities are provided by the trait which are presented below:

- **self**—a reference to the `ActorRef` of the actor.
- **sender**—a reference to the sender of the message currently being processed by the Actor. Useful for returning results.
- **context**—a reference to the actors execution context. This allows access to various facilities including the ability to create child actors (actors that execute under the control of the parent actor) and lifecycle operations.
- **supervisorStrategy** this is used to allow a strategy to be defined that will control what should happen to child actors when various situations occur. This is discussed in the next chapter.

36.9 Actor Lifecycle

Each Actor can go through a number of states during its lifetime. This is illustrated in Fig. 36.10.

An actor goes through the following states during its lifetime:

- Does Not Exist—initially an actor does not exist.
- Actor is Incarnated. When the `actorOf` method is called it assigns an incarnation of the actor described by the Props to a given path. A Path represents a route from the top-level location, via any parents, to the actor being created. If the

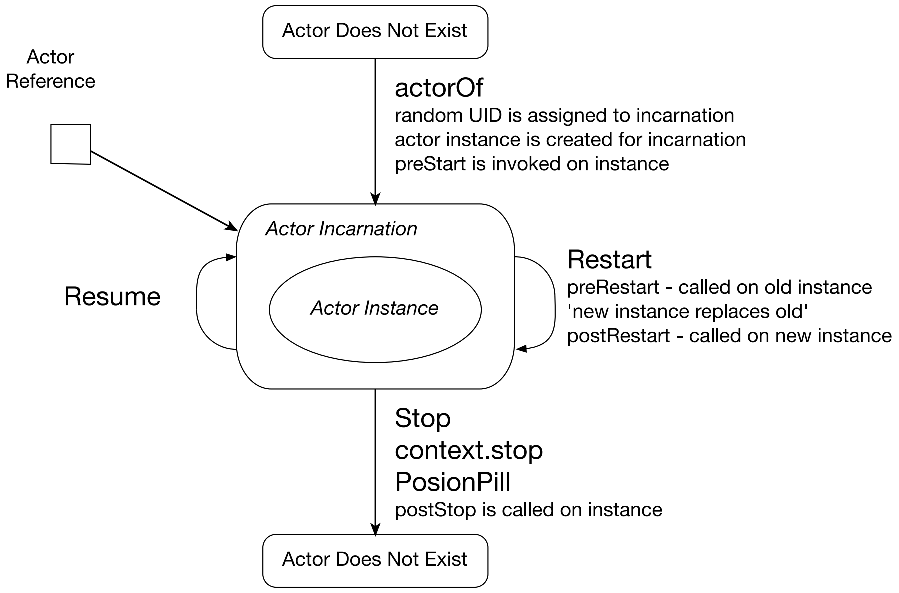

Actor Does Not Exist
Actor Reference
actorOf
random UID is assigned to incarnation
actor instance is created for incarnation
preStart is invoked on instance
Actor Incarnation
Actor Instance
Resume
Restart
preRestart - called on old instance
'new instance replaces old'
postRestart - called on new instance
Stop
context.stop
PosionPill
postStop is called on instance
Actor Does Not Exist

Fig. 36.10 The lifecycle of an Actor

actor is being created by the `ActorSystem` then it is a top level actor. If it is being created by another actor then it is a child of that actor and its path is relative to the parent. An actor incarnation has a unique ID (a UID) and holds a reference to the current Actor Instance. Once the Actor Instance has been created from the actor incarnation then the `prestart` method is called on the actor instance. Note the fact that the Actor incarnation wraps the actor instance, allows different actor instances to be used without the external references being ware of this.

- The lifecycle of the Actor incarnation ends when the actor is stopped. This can be done by called the `stop` method on the context. At that point the `postStop` method is called on the actor instance allows for any clean up operations to be performed. Once the actor has been stopped the name of the actor can be reused.
- If an actor throws an exception it can be restarted if the exception scenario can be handled. The restart involves creating a new Actor instance to run the concurrent behaviour wrapped inside the same Actor incarnation. The lifecycle methods `preRestart` and `postRestart` are available to handle suitable processing of this scenario. However, you should note that `preRestart` is called on the old actor instance and the `postRestart` is called on the new actor instance.
- Resume is an alternative to Restart. That is, where as Restart is used to restart a clean internal actor instance, Resume can be used to continue with the internal Actor Instance (as long as the internal state of the actor is stable).

To illustrate some of these ideas the following simple `LifecycleGreeter` actor defines overrides for the `preStart` and `postStop` lifecycle methods. These methods merely print out a string in this example.

The Actor's `receive` method is defined such that it will print out a message "Hello World" is sent the message "hello". It will also print out "Hello Whoever" if sent any other string the "stop". However, if sent the message string "stop", it will use the context property of the actor to stop itself.

The associated `LifecycleTest1` application then sends three messages to the actor, "hello", "Welcome" and "stop":

```
import akka.actor.Actor
import akka.actor.Props
import akka.actor.ActorSystem

class LifecycleGreeter extends Actor {

  override def preStart(): Unit =
                 { println("preStart") }
  override def postStop(): Unit =
                 { println("postStop") }

  def receive = {
    case "hello" => println("Hello World")
    case "stop" => context.stop(self)
    case _ => println("Hello Whoever")
  }
}

object LifecycleTest1 extends App {
  val props = Props[LifecycleGreeter]
  val system = ActorSystem("mysystem")
  val actor = system.actorOf(props)
  actor ! "hello"
  actor ! "Welcome"
  actor ! "stop"
}
```

The output from this program is shown below:

```
preStart
Hello World
Hello Whoever
postStop
```

As you can see from this the `prestart` method is called before the actor starts processing the messages sent to it. It then processes each of the messages in turn. The final message causes the actor to stop and thus the `postStop` method is called.

36.10 Akka Configuration

The Akka system is configured via the `ActorSystem`. That is, all configuration information is provided to the `ActorSystem` object. This can be done by specifying a `Config` object or by relying on the default locations used by Akka. If you wish to use the default configuration files, then you have a choice of the following files:

- application.conf
- application.json
- application.properties

These files are found in the root of the classpath. The Actor system merges information from these locations together to determine the default configuration information. An example of a custom application.conf file is shown below. This example configures the default logging information and a default actor dispatcher. A dispatcher determines how to handle messages received by the actor.

```
akka {

   loggers = ["akka.event.slf4j.Slf4jLogger"]

   # Options: OFF, ERROR, WARNING, INFO, DEBUG

   loglevel = "DEBUG"

   # Log level for the basic Akka logger

   # Options: OFF, ERROR, WARNING, INFO, DEBUG

   stdout-loglevel = "DEBUG"

   actor {

      default-dispatcher {

         # Throughput for default Dispatcher, set to 1
         # for as fair a policy as possible

         throughput = 10

      }

   }
}
```

Notice that the default-dispatcher has a throughput property. This defines thread distribution "fairness" in your dispatcher—telling the actors how many messages to handle in their mailboxes before relinquishing the thread so that other actors do not starve. However, a context switch in CPU caches is likely each time actors are assigned threads, and warmed caches are one of your biggest friends for high performance. Therefore in general it is better to be less fair so that you can handle quite a few messages consecutively before releasing it (hence why our example sets this value to 10).

Alternatively you can use a config object. This is very flexible and allows you to load or specify any configuration information in any form. There are numerous factory methods that allow you to create config objects in different ways defined on the ConfigFactory object. For example, you can use the parseString method to create a config object based on the content of a string, for example:

```
Config config =

   ConfigFactory.parseString("something=somethingElse");

ActorSystem system =

   ActorSystem.create("myname", config);
```

36.11 Actor DSL

To make it easier to create simple Actors, the Akka library provides a Domain Specific Language (or DSL) specifically for their creation. For example, one off workers can be created very concisely using the Act trait. The Act trait is defined by the akka.actor.ActorDSL._ type and includes supporting objects.

The *implicit* actor system serves as the ActorRefFactory required by the actor function when using the Act trait to create the actor. The actor function essentially uses the ActorOf functionality of the ActorSystem (or ActorContent if used inside an Actor) to create the new actor based on the Act trait. This is done by overriding the default behaviour of the Act traits become method. The overridden version of become essentially swaps the created Actors' receive method with that defined in the Act trait at runtime.

The following listing provides a simple example of creating a worker Actor:

```
import akka.actor.ActorDSL._
import akka.actor.ActorSystem

object TestWorker extends App {
  implicit val system = ActorSystem("demo")

  val a = actor(new Act {
    become {
      case "A" => println("hello")
    }
  })

  a ! "A"

}
```

In this example the new `Act` instance defines the behaviour which will be used for the resulting actors `receive` method in the `become` function. Here if the string "A" is received, the actor will print out the string "hello". After defining this actor the message "A" is sent to the reference held to that actor.

The output from this program is:

```
Hello
```

The DSL also supports defining lifecycle behaviours. This is done using the `whenStarting`, `whenStopping`, `whenFailing` and `whenRestarted` fucntions, as shown below:

```
import akka.actor.ActorDSL.Act
import akka.actor.ActorDSL.actor
import akka.actor.ActorSystem

object LifecycleTest2 extends App {

  implicit val system = ActorSystem("demo")

  val a = actor(new Act {
    become {
      case "hello" => println("hello World")
      case "stop" => context.stop(self)
      case _ => println("Hello Whoever")
    }
    whenStarting { println("starting") }
    whenStopping { println("stopping") }
    whenFailing {case m@(cause, msg) =>
println("Error") }
    whenRestarted { cause => println("whenRestarted")
}
  })

  a ! "hello"
  a ! "Goodbye"
  a ! "stop"

}
```

The output from this program is:

```
starting
hello World
Hello Whoever
stopping
```

This is because the starting and stopping behaviours have been invoked but the failing and restarted ones have not.

Chapter 37
Further Akka Actors

37.1 Introduction

The previous chapter introduced the basic Akka Actor concepts and constructs. This chapter takes these concepts further looking at how a result can be returned by (obtained from) an Actor. It also looks at Actor hierarchies and Actor supervision.

37.2 Generating a Result from an Actor

So far all our examples have received a message and then performed some operation. This operation has not returned a result and thus this has not been an issue. However, there are may situations where we do require a result. If you look at the specification for `receive` you will see that it is actually a `PartialFunction` which returns `Unit`. Thus the `receive` method cannot return a value.

To return a result from an actor when it has finished processing a message, you can use the `sender` property to send a result back to the requesting actor. Note this assumes that the requester is also an Actor itself, however the next section on Futures will look at how we can retrieve a result when the sender is not an actor.

In this example we are using a companion object to act as a factory for the generation of the `Props` object associated with the Actors. Thus the `Calculator` Actor has a `Calculator` companion object with a method props that returns the `Props` instance configured as appropriate for the actor. The calculator actor is listed below:

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```
object Calculator {
 def props = Props[Calculator]
}

class Calculator extends Actor {
 def receive = {
   case x: Int => {
    println("Calculator received: " + x)
    var total = x
    for (i <- 1 to x) {total = total * i}
    println(
   "Calculator processing completed, returning result" )
sender ! total
    }
  }
}
```

The key element of interest here is the `receive` method. This has a case pattern matcher that will handle Ints. Within the body of the associated behaviour a calculation is performed based on the integer received. Once this calculation is completed the result (total) is sent back to the Actor that initialled the request using the `sender` which is always bound to the actor that issued the request (if the message sender was indeed an Actor). Thus:

```
sender ! total
```

results in a new message being sent from the calculator actor to whatever actor issued the initial request.

The invoking actor, the `Controller` Actor, also has a companion object with a `props` factory method. In this case a string is passed in as a parameter to the constructor on the `Controller`. Thus the `Props` construction process requires a different syntax. This syntax allows information to be passed to the actors constructor. To do this we use an alternative `Props` factory method. This version of the Props factory takes the type of class to configure (the actor class) and the parameters to pass into the constructor of that class. Note any number of parameters can be passed here, as this is a variable length parameter list.

```
object Controller {
  // String controller passed as a parameter to the
  // contructor of the controller class
  def props = Props(classOf[Controller], "Controller")
}

class Controller(name: String) extends Actor {
  def receive = {
    case"start" => {
      println(name + ": starting calculator")
      context.actorOf(Calculator.props) ! 4
      println(name + ": message set")
    }
    case result: Int => {
      println(name + " received: " + result)
      context.stop(self)
    }
  }
}
```

The Controller actor itself has two case statements in its receive method. One matches the string “start” which obtains a reference to the Calculator actor and sends it a message containing the integer ‘4’. The other case condition matches an Int which is assumed to be the result of the calculators calculations and is printed out. In this case, once it has done that it stops itself (and as the Calculator was created by the Controller as a child of the controller) it also stops the Calculator actor.

The simple application that exercises these actors is shown below:

```
object ReplyTest extends App {
  println("Starting ReplyTest application")
  val system = ActorSystem("mysystem")
  val controller = system.actorOf(Controller.props)
  controller ! "start"
  println("End of ReplyTest body")
}
```

This program obtains a reference to the Controller actor from the ActorSystem and sends it the message string “start”.

Note that the three imports for these three elements are the usual:

```
import akka.actor.Actor
import akka.actor.Props
import akka.actor.ActorSystem
```

The output of this program is:

```
Starting ReplyTest application
End of ReplyTest body
Controller: starting calculator
Controller: message set
Calculator received: 4
Calculator processing completed, returning result
Controller received: 96
```

Notice that the two Strings printed by the main application body are at the start of the output. Thus the main program completes before the controller and the calculator start their message processing. This clearly indicates that the Controller and the Calculator are executing in their own threads of execution.

37.3 Futures

The previous example illustrates how one actor can return a result to another actor. However, what happens if the sending code is not part of an actor? One answer is to use a scala.concurrent.Future. A Future is a object which offers to return the result of some process or calculation, at a point in the future, allowing the current code to continue processing. Futures can be used in many different situations, such as reading data from a database, executing some long running process, requesting data from a remote service etc.

The key to a `scala.concurrent.Future` is that it can take an actor, and the message to send to the actor, and wrap the resulting response message in a form that the requesting code can access. As in the last section a simple `Calculator` Actor will be used. This Actor again has a companion object to generate the properties for the `Calculator` and again the `receive` message handles Integers and returns a result by sending that result back to the `sender`.

```
object Calculator2 {
  def props = Props(classOf[Calculator2])
}

class Calculator2 extends Actor {
  def receive = {
     casex: Int => {
     println("Calculator2 ->  received: " + x)
     var total = x
     for (i <- 1 to x) { total = total * i }
     println(
      "Calculator2 ->  processing completed, returning
               result")
     sender ! total
    }
  }
}
```

The code that invokes the above behaviour however uses a Future:

```
import akka.pattern.ask
import akka.actor.Actor
import akka.actor.Props
import akka.actor.ActorSystem
import akka.util.Timeout
import scala.concurrent.Future
import scala.concurrent.duration._
import scala.concurrent.ExecutionContext
import akka.actor.Status.Failure
import akka.actor.Status.Success

object FutureTest extends App {
  import ExecutionContext.Implicits.global

  println("FutureTest -> Starting ReplyTest application")

  val system = ActorSystem("mysystem")
  val calc = system.actorOf(Calculator2.props)
  val future: Future[Int] =
      ask(calc, 4)(Timeout(5 seconds)).mapTo[Int]

  println("FutureTest -> Obtained : " + future)

  future onSuccess {
     case result: Int =>
            println("FutureTest -> Result from future: "
                   + result)
  }

  println("FutureTest -> Finished")
}
```

There are a number of elements to note about this listing including:

1. An implicit declaration is used to provide an Execution Context for the future processing. This is required as Actors run within an execution context and thus the Future must also have an execution context. This implicit statement provides a suitable execution context that can be *implicitly* made available to the Future invocation. This is implemented as:

   ```
   import ExecutionContext.Implicits.global
   ```

2. The ask function for the `akka.pattern` package is used to create the Future which will send the message containing the integer '4' to the `calc` Actor. It is a multiple parameter list function and thus the first parameter list takes the actor and the message and the second parameter list takes a time out. This could also have been declared implicitly.
3. The `ask` function generates a `Future` which returns `Any` type of elements. Where as we know that the `Calculator` returns an Integer as a result and thus the `Future` returned by the ask function is then mapped to one that will work with an integer result using (`mapTo[Int]`).
4. The resulting Future is then stored in the val `'future'`. The main program then continues on and prints out a message. It then defines the behaviour to be invoked once a result is generated—note it does not wait for that result to be made available before continuing on.
5. The main programme then prints out the final string saying it has finished.
6. Once the calculation performed by the calculator has completed, the future `onSuccess` behaviour is executed. As well as `onSuccess` there are other behaviours such as `onFailure` or `onError`. In this case we are only defining the behaviour for `onSuccess`, which prints out the result returned. Once again it uses case pattern matching to handle different possible results.

The result of executing this program is shown below:

```
FutureTest -> Starting ReplyTest application
Calculator2 -> received: 4
FutureTest -> Obtained
scala.concurrent.impl.Promise$DefaultPromise@6861d517
Calculator2 -> processing completed, returning result
FutureTest -> Finished
FutureTest -> Result from future: 96
```

37.4 Dispatchers

In Akka it is a dispatcher (specifically a Message Dispatcher) that provides the foundation for an Akka Actor. That is a Message Dispatcher handles how any request received by the actor is processed.

Notice that the dispatcher triggers an execution as well as determining how the request (or message) will be processed. This is because an implementation of the `MessageDispatcher` is also an `ExecutionContext`. This means that it can execute arbitrary code such as that used to define the behaviour of the actor or to trigger a future.

In many (most) cases the default dispatcher will be more than adequate, however it is possible to change an actors dispatcher. To do this you need to have an alternative dispatcher available. This can be provided by defining an appropriate dispatcher in one of the Akka configuration files. There are two executors available with the default dispatcher. These are the *fork-join-executor* and the *thread-pool-executor*. The first executor forks a separate thread for each request to the Actor and then waits to re-join that thread before continuing. The thread pool executor uses a pool of threads to process multiple requests in parallel across multiple instances of an Actor.

For example, the following dispatcher configuration defines a new thread-pool based executor called jeh-pool-dispatcher.

```
akka {
  actor {
    jeh-pool-dispatcher {
      # Dispatcher is the name of the
      # event-based dispatcher
      type = Dispatcher
      # What kind of ExecutionService to use
      executor = "thread-pool-executor"
      # Configuration for the thread pool
      thread-pool-executor {
        # minimum number of threads to cap
        # factor-based core number to
        core-pool-size-min = 3
        # maximum number of threads to cap
        # factor-based number to
        core-pool-size-max = 3
      }
      # Throughput defines the maximum number
      # of messages to beprocessed per actor
      # before the thread jumps to the next actor.
      throughput = 5
    }
  }
}
```

The above specification states that the thread pool has an initial size of 3, with a maximum of 3 threads. Note that there are numerous properties available including a property to specify how long to keep alive a thread when it is not being used (default 60 seconds).

A thread pool is a set of underlying threads that can be used by instances of an actor to processes messages. When a message is received, the Actor will attempt to obtain a new thread from the thread pool. If one is available (not being used) then that thread will be returned from the pool and processing of a message can start. If no threads are available then the request will wait until one thread is returned to the pool and is thus available to service a request. Note that it is not uncommon for a thread pool to have a minimum and a maximum size—thus when demand is low threads can be removed and at busy times the number of threads in the pool can grow (to some predefined maximum). This provides some control over the number of concurrent requests that can be processed at any one time. However, care needs to be taken when configuring such pools to ensure that a suitable set of defaults can be used otherwise the performance of the system can suffer due to the lack of threads (or thread starvation).

Also note some general rules of thumb regarding *throughput*:

- If you have a case where the number of threads is equal to the number of actors using the dispatcher, set the *throughput* number extremely high, like 1000.
- If your actors perform tasks that will take some time to complete and you need fairness to avoid starvation of other actors sharing the pool, set the *throughput* to 1.
- For general usage, start with the default value of 5 and tune this value for each dispatcher so that you get reasonable performance characteristics without the risk of making actors wait too long to handle messages in their mailboxes.

A significant point of confusion relating to threads and thread pools is that a specific instance of an Actor is *always* a singled threaded process. That is, every Actor instance, when it receives a request, will process that request from start to finish before moving onto the next request in its in box. However, multiple instances of an actor can be created and can be sent requests in parallel. The underlying dispatcher determines whether these are queued up for processing (the default behaviour) or whether the instances of an actor can run concurrently. The following simple application creates four instances of the `LongProcessor` actor and sends 4 messages to the actors. However, the `ActorSystem` uses the earlier configuration file and thus only allows three threads to be used at any one time by a single *type* of Actor. Thus the first three actors to obtain a thread for execution, while the fourth will have to wait until a thread becomes free:

```
package com.jjh.akka

import akka.actor.Props
import akka.actor.ActorSystem
import akka.actor.Actor

class LongProcessor extends Actor {
  def receive = {
    case s:String => {
      for (i <- 1 to 5) print(s)
      println
      Thread.sleep(2000)
      for (i <- 1 to 5) print(s)
      println
    }
  }
}

object AkkaConfigTest extends App {
  val props =
Props[LongProcessor].withDispatcher("akka.actor.jeh-
pool-dispatcher")
  val system = ActorSystem("mysystem")
  val actor1 = system.actorOf(props, "actor1")
  val actor2 = system.actorOf(props, "actor2")
  val actor3 = system.actorOf(props, "actor3")
  val actor4 = system.actorOf(props, "actor4")
  println("Sending messages")
  actor1 ! "A"
  actor2 ! "B"
  actor3 ! "C"
  actor4 ! "D"
  println("Messages sent")
}
```

Notice that the path to the dispatcher configuration is formed from the elements wrapping that definition. Thus the format in the configuration file wraps *akka* around *actor*, which is around the *jeh-pool-dispatcher* and thus the path is `akka.actor.jeh-pool-dispatcher`. Also note that the `withDispatcher` method on the Props type is used to load the configuration information associated with out custom pool based dispatcher.

The output from this application is a mix of the output from the instances of the `LongProcessor` actor handling the "A", "B" and "C" strings. The instance handling the "D" string has to wait until a thread becomes free and thus does not start to run until after the instance processing the "C" string completed.

```
Sending messages
Messages sent
CCCCC
BBBBB
AAAAA
CCCCBBAABC
BB
DDDDD
AAA
DDDDD
```

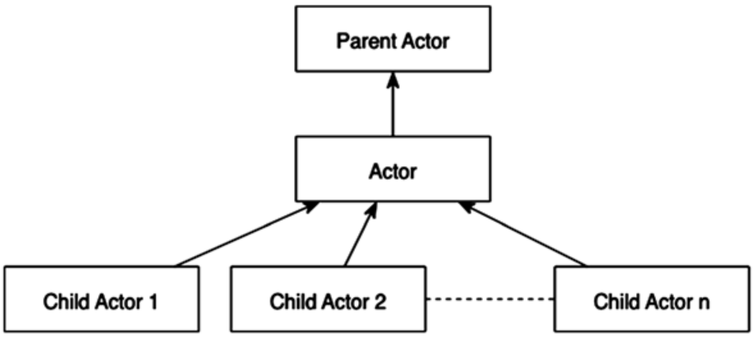

Fig. 37.1 Parent-child relationships for an actor

37.5 Actor Hierarchies

A number of times in this chapter we have seen the term ‘child’ actor. However, we have not really defined what a child actor is. Within the Actor model there can be relationships between one Actor and another. If one Actor is created from within the context of another actor, then this Actor is a child of the originating Actor, while the originating Actor is referred to as a Parent of the Child actor. In addition any actor can create child actors. Thus there can be a hierarchy of actors where any particular actor can have a parent Actor and any number of child actors. This is illustrated in Fig. 37.1.

In addition any Actor can also have grand children and great grand children depending on the level of the hierarchy.

As an example, the following listing illustrates an Actor that creates two child actors and then sends messages to both the children. Note that these child actors are created using the Actors own context rather than the top level ActorSystem:

```
    class Supervisor extends Actor {
      var children = ArrayBuffer[ActorRef]()

      override def preStart(): Unit = {
        children += context.actorOf(Props(classOf[ChildActor],
    "child1"))
       children += context.actorOf(Props(classOf[ChildActor],
    "child2"))
      }
      def receive = {
      case"run" => {
        println("Supervisor run")
        children.foreach(a => a ! "msg")
      }
      case"error" => {
        println("Supervisor error")
        children.foreach(a => a ! "error")
      }
    }
  }
```

In this case the `prestart` lifecycle method is being used to create the children. Child actors are created whenever the Actors `context` is used to create the actor using the `actorOf` method, rather than the `ActorSystem`. As this context is available in the `receive, prestart, preRestart` etc. method, children can be created wherever appropriate within the Actor.

37.6 Actor Supervision

Other than an interesting concept, why is it significant that an Actor be considered a child of another actor? The answer relates to supervision of Actors. Within the Actor model supervision describes a dependency relationship between actors: the supervisor or parent of an actor delegates tasks to its subordinates and therefore must respond to their failures or errors. When a subordinate or child detects a failure (i.e. it throws an exception) it suspends itself and any of its subordinates (or children) and sends a message to its supervisor, indicating the failure (i.e. the exception).

At this point the supervisor can determine what action to take, which includes:

1. **Resume** the subordinate keeping the current state of that subordinate.
2. **Restart** the subordinate that clears out the current state by creating a new Actor instance within the Actor incarnation.
3. **Stop** the subordinate permanently.
4. **Escalate** the failure to its parent.

Note that each of these is an object defined within the `SupervisorStrategy` type. The Supervisor strategy uses the object to determine what action is being requested by the programme.

This hierarchy of supervision extends right up to the top of the Actor framework. Thus an actor can receive failures which were generated by its children, grand children or great grand children etc. At the root of this hierarchy is the Root Guardian. The Root Guardian has two children; the User Guardian and the System Guardian (see Fig. 37.2). All user created actors are the responsibility of the User Guardian. In practice you would normally handle the errors yourself to ensure a clean and stable system rather than allow them to propagate up to the User Guardian.

The Supervisor actor class presented in the previous section can now be modified to specify how it will deal with certain types of failure. This is achieved by specifying a *Supervision Strategy* and is implemented by overriding the default Supervision Strategy. Thus the Supervisor actor can now be defined as:

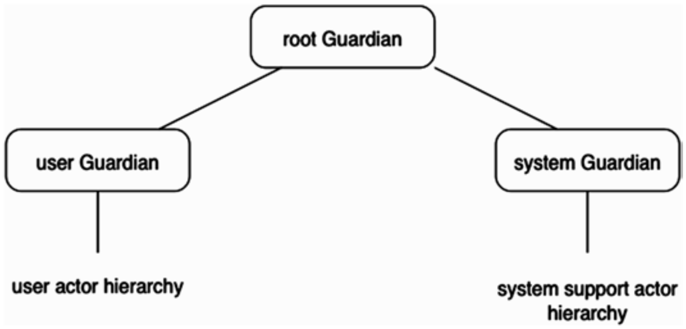

Fig. 37.2 Root of guardianship hierarchy for all actors

```
class Supervisor extends Actor {
  var children = ArrayBuffer[ActorRef]()

  // Restart the child actors child when RuntimeException is
  // thrown.
  // After 3 restarts within 1 minute it will be stopped.
 override val supervisorStrategy =
    OneForOneStrategy(maxNrOfRetries = 3,
                      withinTimeRange = 1 minute) {
         case _: RuntimeException =>
            { println("Supervisor Restarting"); Restart}
    }

override def preStart(): Unit = {
  children +=
     context.actorOf(Props(classOf[ChildActor], "child1"))
  children +=
     context.actorOf(Props(classOf[ChildActor], "child2"))
}
def receive = {
  case"run" => {
    println("Supervisor run")
    children.foreach(a => a ! "msg")
  }
  case"error" => {
    println("Supervisor error")
    children.foreach(a => a ! "error")
  }
 }
}
```

Note that a `OneForOneStrategy` is being used here. There are actually two classes of supervision strategy available in Akka:

- **OneForOneStrategy**—which only applies the following action to the failed child. In our case this means that only the failed child is Restarted.
- **AllForOneSrategy**—which applies the action it defines to all children.

These are defined in the akka.actor package along with other supervision strategy types such as the Restart action. Both the strategies presented above take information on the number of times a child can be restarted in a particular time period. In this example, the child can be restarted 3 times within 1 minute. After this the child will be stopped. Both strategies also use pattern matching to determine what action to take when an exception is thrown. In our case whenever a RuntimeException is thrown by one of the children it will be handled by restarting that child.

There is nothing special about the actors that will become child actors other than the fact that they can throw a RuntimeException if the message "error" is sent to them:

```
class ChildActor(name: String) extends Actor {
  override def preStart(): Unit =
                    { println(name + " preStart") }
  override def postStop(): Unit =
                    { println(name + " postStop") }
  override def preRestart(reason: Throwable,
                            message: Option[Any]): Unit ={
    super.preRestart(reason, message)
    println(name + " preRestart")
  }
  override def postRestart(reason: Throwable): Unit = {
    println(name + " postRestart")
    super.postRestart(reason)
  }
def receive = {
    case "error" => throw new RuntimeException(name)
    case _ => println(name + " received msg")
  }
}
```

The imports for this program are:

```
import scala.collection.mutable.ArrayBuffer
import scala.concurrent.duration.DurationInt

import akka.actor.Actor
import akka.actor.ActorRef
import akka.actor.ActorSystem
import akka.actor.OneForOneStrategy
import akka.actor.Props
import akka.actor.SupervisorStrategy.Restart
import akka.actor.actorRef2Scala
```

The sample programme which uses the Supervisor looks like any other Actor programme with nothing to indicate that the Supervisor is monitoring the child actors (or indeed that there are child actors involved):

```
object ParentChildActorTest extends App {
  val props = Props[Supervisor]
  val system = ActorSystem("mysystem")
  val actor = system.actorOf(props, "supervisor")
  actor ! "run"
  Thread.sleep(100)
  actor ! "error"
  actor ! "run"
}
```

The output from executing these classes is presented below:

```
Supervisor run
child1 preStart
child1 received msg
child2 preStart
child2 received msg
Supervisor error
Supervisor run
Supervisor Restarting
Supervisor Restarting
child2 postStop
child2 preRestart
child1 postStop
child1 preRestart
child2 postRestart
child1 postRestart
child2 preStart
child1 preStart
child1 received msg
child2 received msg
```

Note you can see the `preRestart` and `postRestart` methods producing output as well as the `preStart` and `postStop` methods' output in this example. This is because the supervisor is restarting the ChildActors following an exception being thrown by the children.

37.7 Good Practices

This section provides some guidelines on good practices when developing Akka Actor applications:

1. *Actors should not block while processing a message*. Such blocking will cause performance issue sand may lead to deadlock between communicating Actors.

2. *Communicate with actors only via messages*. Do not try to define additional methods through which you will invoke actor functionality.
3. *Do not share state*. Scala Akka does not prevent actors from sharing state, so it’s (unfortunately) very easy to do. Any shared mutable object represents state including objects in messages.
4. *Prefer immutable messages*. Ensure that all the data within your messages is immutable. Mutable data in a message is shared state.
5. *Make messages self-contained*. When you get a response from an actor, it may not be obvious what is being responded to. If the request is immutable, it’s very inexpensive to include the original request as part of the response. The use of *case* classes often makes messages more readable.
6. *Factory methods*. Provide a factory method for the Actors property configuration:

```
object Calculator {
  def props = Props[Calculator]
}

class Calculator extends Actor {
  def receive = {
    case x: Int => {
      println("Calculator received: " + x)
      var total = x
      for (i <- 1 to x) {total = total * i}
      println(
    "Calculator processing completed, returning result")
     sender ! total
   }
  }
}
```

Online References

Introduction to Actor Model—http://en.wikipedia.org/wiki/Actor_model
Akka Actor homepage—http://akka.io/

Chapter 38
Play Framework

38.1 Introduction

The Play framework is a lightweight, stateless, asynchronous, framework for building web applications and services. It is built on top of Scala and the Akka concurrency API and aims to provide predictable behaviour with minimal resource consumption (i.e. CPU, memory, threads) for highly-scalable applications. Play is open source and can be obtained from http://www.playframework.com.

38.2 Introduction to Play

Play is a framework for building a wide range of different types of web application. These are applications that receive requests for data and functionality over HTTP(s). Play aims to make the construction of such applications simple, flexible and intuitive. It incorporates an integrated HTTP Server (so there is no need for a separate web application server as there is with many Java web frameworks), it also incorporates a templating framework for the creation of web sites and a RESTful web service API for the creation of a service based implementation. It exploits Scala and the facilities within the Scala eco-system, such as Akka, to ensure that the applications developed are scalable and perform well. The basic installation also allows for in code changes to be reloaded and reflected in the web application without the need for separate build and deploy steps (which greatly simplifies, and speeds up, development).

The web application technology stack in the Java Enterprise world is built on technology that has both evolved over many years and requires multiple elements in order to work. The evolution has taken the simple Servlet technology and constructed layer upon layer on top of this to achieve the sophistication needed by todays web applications (see Fig. 38.1). The multiple technologies that actually comprise this stack ensure that even deploying simple applications can be troublesome and error prone as each technology needs to be successfully integrated with the next,

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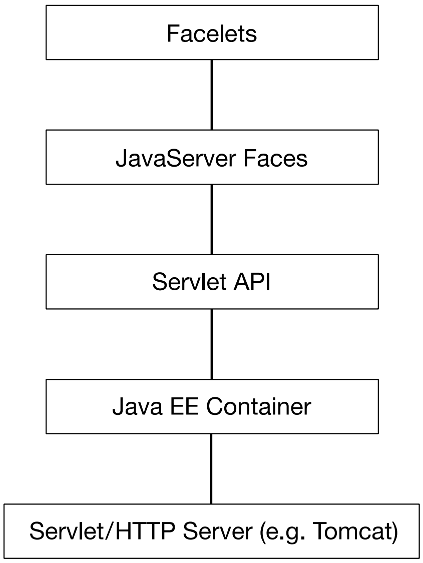


Fig. 38.1 Java EE layered architecture

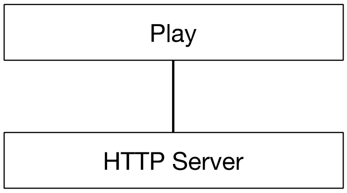


Fig. 38.2 The Play layered architecture

often relying on configuration files or standard conventions. This makes for both a heavyweight infrastructure and an overly complex environment.

By contrast the Play framework is a much simpler stack. The Play framework was designed for the current generation of web application from the start and only requires the services of a HTTP Server (Netty) in order to operate. This means that configuration and deployment are restricted to a single infrastructure (see Fig. 38.2).

Play is comprised of a number of elements, these include:

- **The HTTP Server**—this is the element of the environment which receives the HTTP request from a client (such as a Browser or another software system) and returns a result based on the information provide din the request. This response may be in terms of HTML mark-up, XML data or JSON (Java Script Object Notation) format—or indeed any data format you chose.
- **Routing information**. When a HTTP request is received, Play must determine where to route the request—that is what code to execute in response to the request—it therefore provides a routes configuration file that is used to handle this routing information.

- **Supporting Scala types**. Various types are defined within the Play framework that can be used to implement the programmatic elements of the web application (such as querying a database in response to a request to get the data associated with an id etc.).
- **A Templating system** used to take standard HTML style pages and populate them with data that is dynamically generated by the application. This essentially means that standard HTMKL is augmented with additional elements some of which are placeholders for data that will be provided by the Scala code.
- **An Integrated Play Console and Build System**. To simplify working with Play a suite of tools is provided that can be used to create, update and deploy a Play web application. These tools are accessed from and managed by the play console.
- **A persistent framework** to simplify accessing databases.

38.3 Starting with Play

38.3.1 Download Play

You can download Play from the Play Frameworks home page. You can choose to use the Typesafe Activator installation or the plain play installation. We will use the plain play installation as we can then focus on the just the features provided by Play. To do this download the zip containing the version of play you wish to use. At the time of writing the current version was play-2.0.0.zip.

38.3.2 Unzip Play

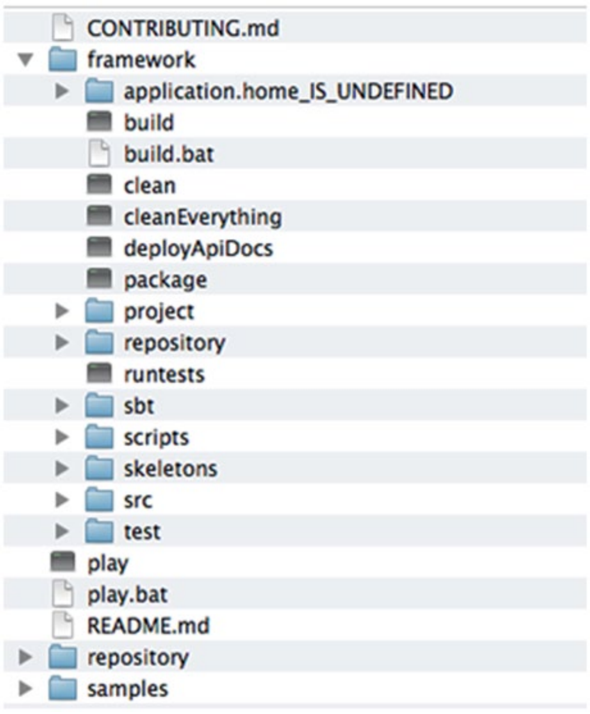
Once you have download the zip file, unzip it into a suitable location. Once you have done that, if you look into the directory created fro you should find a structure similar to that shown in Fig. 38.3.

Note that when you run the *play* command later on it will write some files into this directory structure; so make sure that you have both read and write access to wherever you have installed play.

38.3.3 Setting up the Play Environment

You should now add the play framework installation directory to your system path so that you can issue the play command from any suitable location. On Unix systems you can add the play directory to the path via

```
PATH=${PATH}:/Applications/play-2.2.0
```



```
  CONTRIBUTING.md
▼ framework
  ▶ application.home_IS_UNDEFINED
    build
    build.bat
    clean
    cleanEverything
    deployApiDocs
    package
  ▶ project
  ▶ repository
    runtests
  ▶ sbt
  ▶ scripts
  ▶ skeletons
  ▶ src
  ▶ test
  play
  play.bat
  README.md
▶ repository
▶ samples
```

Fig. 38.3 Play Framework installation directory

On a Windows box you will need to add it to your Path system variable.

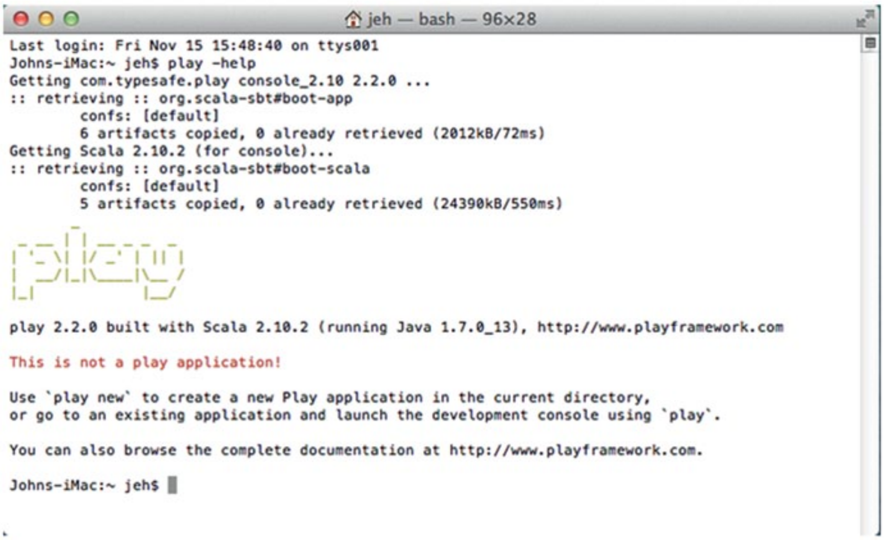
You verify that the play installation directory has been added to your path by opening a command window and issuing the play–help command as shown in Fig. 38.4.

38.3.4 Creating a New Web Application

Let us first look at the basic structure of a Play web application. This is illustrated in Fig. 38.5. This indicates that a HTTP request is routed to an application (Scala) controller. The controller loads data via an element typically referred to as the Model. It then renders a HTML page that is populated with data form the model. This page is known as the View and is defined by a template. Within the template the placeholders are replaced with the values provided by the controller and model.

The easiest way to create a new Play web application is to use the *play* command. This command has numerous options available. One of the options is to request a new Play application to be created with the basic Play application structure. This is done by issuing the *play* command, followed by 'new' and the name of the directory you wish to put the project in, for example:

- play new helloworld



```
Last login: Fri Nov 15 15:48:40 on ttys001
Johns-iMac:~ jeh$ play -help
Getting com.typesafe.play console_2.10 2.2.0 ...
:: retrieving :: org.scala-sbt#boot-app
        confs: [default]
        6 artifacts copied, 0 already retrieved (2012kB/72ms)
Getting Scala 2.10.2 (for console)...
:: retrieving :: org.scala-sbt#boot-scala
        confs: [default]
        5 artifacts copied, 0 already retrieved (24390kB/550ms)

play 2.2.0 built with Scala 2.10.2 (running Java 1.7.0_13), http://www.playframework.com

This is not a play application!

Use `play new` to create a new Play application in the current directory,
or go to an existing application and launch the development console using `play`.

You can also browse the complete documentation at http://www.playframework.com.

Johns-iMac:~ jeh$
```

Fig. 38.4 Testing the Play Framework installation

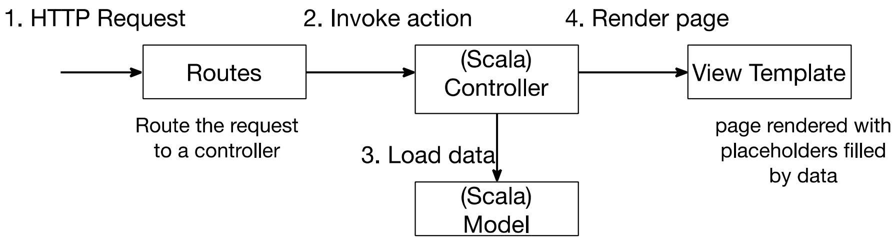


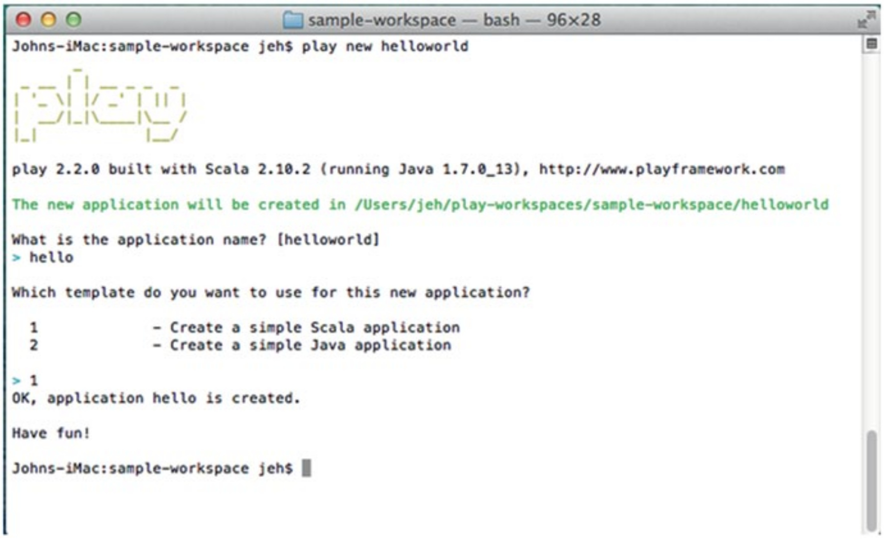
Fig. 38.5 Web Application structure

This starts an interactive session where you can select the name of the application, whether Java or Scala is your preferred implementation language etc. Figure 38.6 illustrates running this command.

As you can see from Fig. 38.6 the name of the application and the generation of a default Scala application has been selected. If you now examine the directory that was created for you (in this case *helloworld*) you should see a structure similar to that displayed in Fig. 38.7. This structure contains your new play web application.

The contents of the *helloworld* directory is explained below:

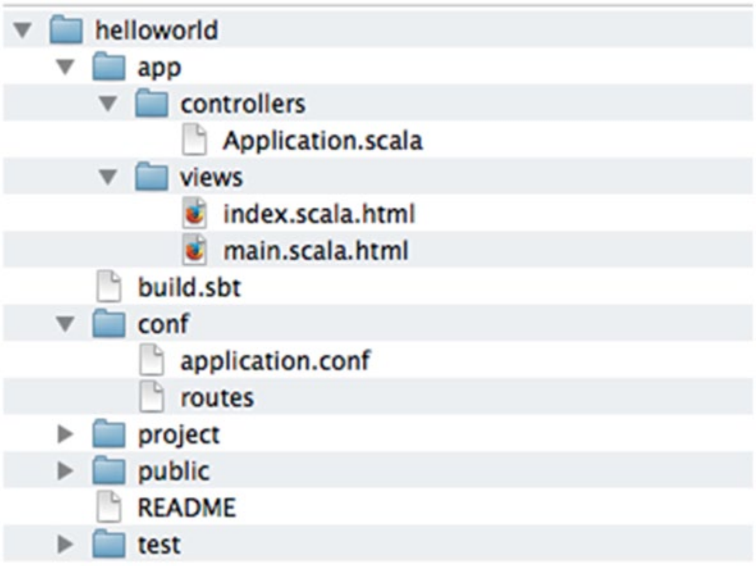
- The app directory. This contains all the application source files.
- The app/controllers directory. This contains all the application controllers. These are the code elements that determine what action should be performed based on user selects.



sample-workspace — bash — 96×28

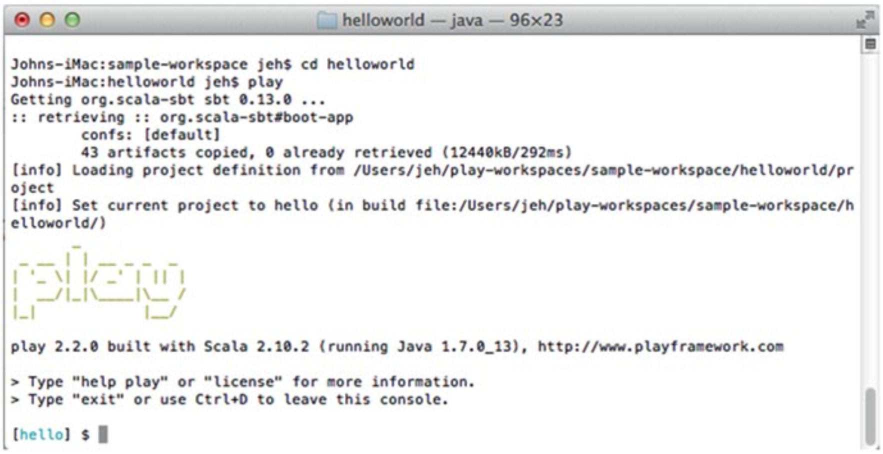
```
Johns-iMac:sample-workspace jeh$ play new helloworld
       _
 _ __ | | __ _ _  _
| '_ \| |/ _' | || |
|  __/|_|\____|\__ /
|_|            |__/

play 2.2.0 built with Scala 2.10.2 (running Java 1.7.0_13), http://www.playframework.com

The new application will be created in /Users/jeh/play-workspaces/sample-workspace/helloworld

What is the application name? [helloworld]
> hello

Which template do you want to use for this new application?

  1             - Create a simple Scala application
  2             - Create a simple Java application

> 1
OK, application hello is created.

Have fun!

Johns-iMac:sample-workspace jeh$
```

Fig. 38.6 Creating a new application



```
▼ helloworld
    ▼ app
        ▼ controllers
            Application.scala
        ▼ views
            index.scala.html
            main.scala.html
      build.sbt
    ▼ conf
        application.conf
        routes
    ▶ project
    ▶ public
      README
    ▶ test
```

Fig. 38.7 The *helloworld* directory structure generated by Play



```
Johns-iMac:sample-workspace jeh$ cd helloworld
Johns-iMac:helloworld jeh$ play
Getting org.scala-sbt sbt 0.13.0 ...
:: retrieving :: org.scala-sbt#boot-app
        confs: [default]
        43 artifacts copied, 0 already retrieved (12440kB/292ms)
[info] Loading project definition from /Users/jeh/play-workspaces/sample-workspace/helloworld/pr
oject
[info] Set current project to hello (in build file:/Users/jeh/play-workspaces/sample-workspace/h
elloworld/)
       _
 _ __ | | __ _ _  _
| '_ \| |/ _' | || |
|  __/|_|\____|\__ /
|_|            |__/

play 2.2.0 built with Scala 2.10.2 (running Java 1.7.0_13), http://www.playframework.com

> Type "help play" or "license" for more information.
> Type "exit" or use Ctrl+D to leave this console.

[hello] $
```

Fig. 38.8 Starting the Play environment

- The app/views directory. This directory contains html template files that are used to generate the output presented to the user via a browser.
- The build.sbt file—the application build script used by the Simple Build Tool a commonly used build tool for Scala.
- The conf directory. This contains configuration files and other non-compiled resources such as the application.conf file used for general application configuration and the routes file used to route URL requests to Scala code.
- The project directory that contains various sbt files.
- The public directory that holds resources used with the browser interface presented to the user such as javascript files, CSS files and images.
- The test directory that is a source directory that can be used for unit or functional test code.

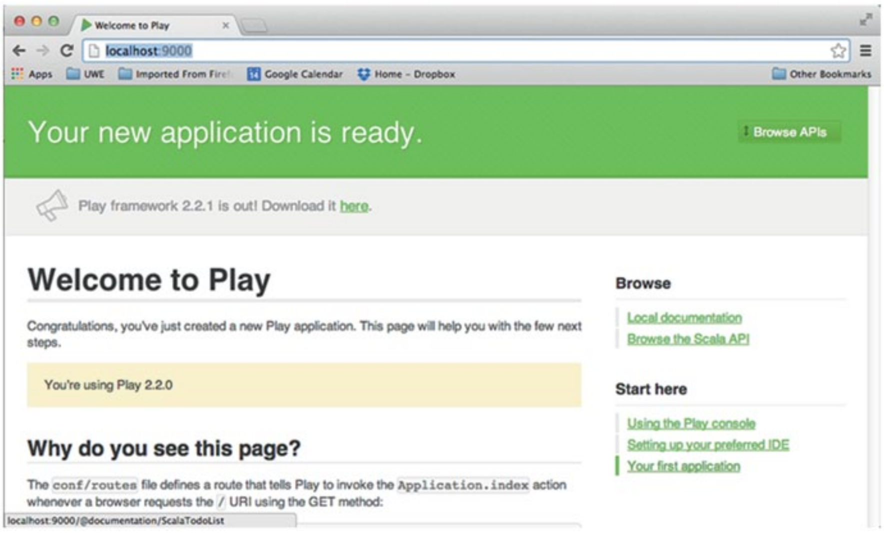
38.4 Starting the Web Application

The application you have created has everything needed to run (including an embedded http server courtesy of Play). To start your web application, change directory into *helloworld* and type *play*. This will cause you to enter the play console. This is illustrated in Fig. 38.8.

Once you have done this you can type *run* to start the server. This will start up the HTTP server for your application. By default the server is listening to port 9000.

To view the results of running this application open a browser and type into the URL bar:

http://localhost:9000/



Your new application is ready.

Play framework 2.2.1 is out! Download it here.

Welcome to Play

Congratulations, you've just created a new Play application. This page will help you with the few next steps.

You're using Play 2.2.0

Why do you see this page?

The `conf/routes` file defines a route that tells Play to invoke the `Application.index` action whenever a browser requests the `/` URI using the GET method:

Fig. 38.9 The default web application

This will cause play to run and the web application you created and display the default web page. This is shown in Fig. 38.9.

Of course this is the default page and the page does not yet reflect you own output. The page is defined by the view element of the application. It was created for you by play and uses a default template into which we will place our own message.

To shutdown the server use CTRL-D, which will stop the server and then 'exit' to terminate the play console.

38.5 Editing the Application

38.5.1 Importing into Eclipse

In order to edit the contents of the files within the play application you can use whatever editor you like. However, it makes it easier if you generate eclipse configuration files, so that you can import the project into eclipse. Issuing the following command from within the helloworld directory does this:

/play eclipse/

This will create some addition files such as*.project* within the directory structure. You then need to *import* the application into your Eclipse workspace using the File->Import menu. On the dialog displayed expand the *General* node in the tree and select the *Existing Project into Workspace* option as shown in Fig. 38.10.

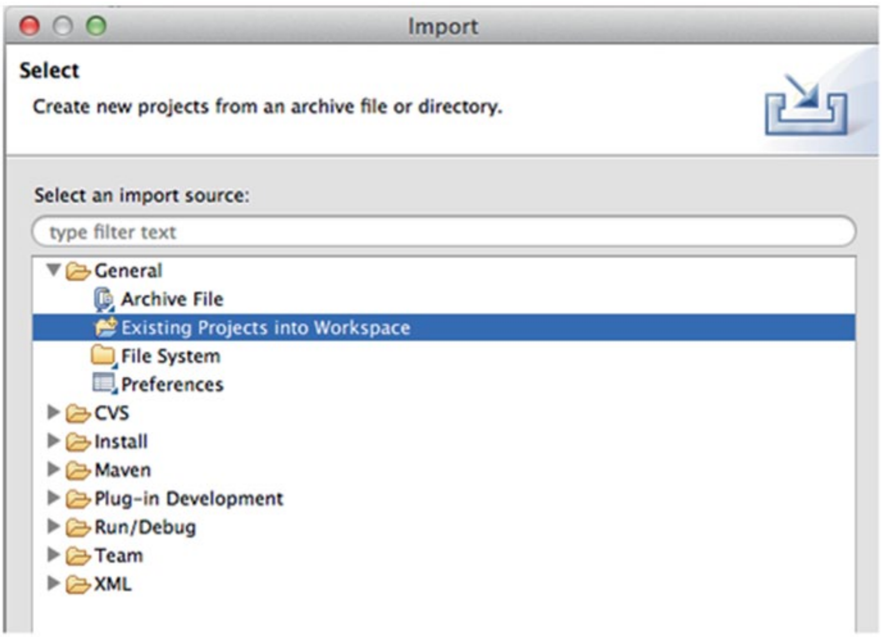


Fig. 38.10 The Import Projects dialog

Now browse to the location you created the *helloworld* directory in and select that directory. When you select that directory you should find that the hello project is listed as shown in Fig. 38.11. Select 'Finish' to load the project.

You should now see the hello project listed in your eclipse list of projects. This is illustrated in Fig. 38.12.

38.5.2 Working with the Application

You can now restart the server by re-entering play and issues the command *run* from within the Play console.

Using any editor open the file Application.scala under controllers within the app folder within your project *helloworld*, for example this file is shown in Fig. 38.13.

This file is the main entry point for the web application and is shown in Fig. 38.14. It indicates that when this web application runs (and the index page is requested, which is the default displayed for the web application) the message displayed to the user is "Your New Application is ready." For larger applications this controller would access one or more *models* that might invoke a persistence layer, business logic or other processing in order to generate the appropriate response.

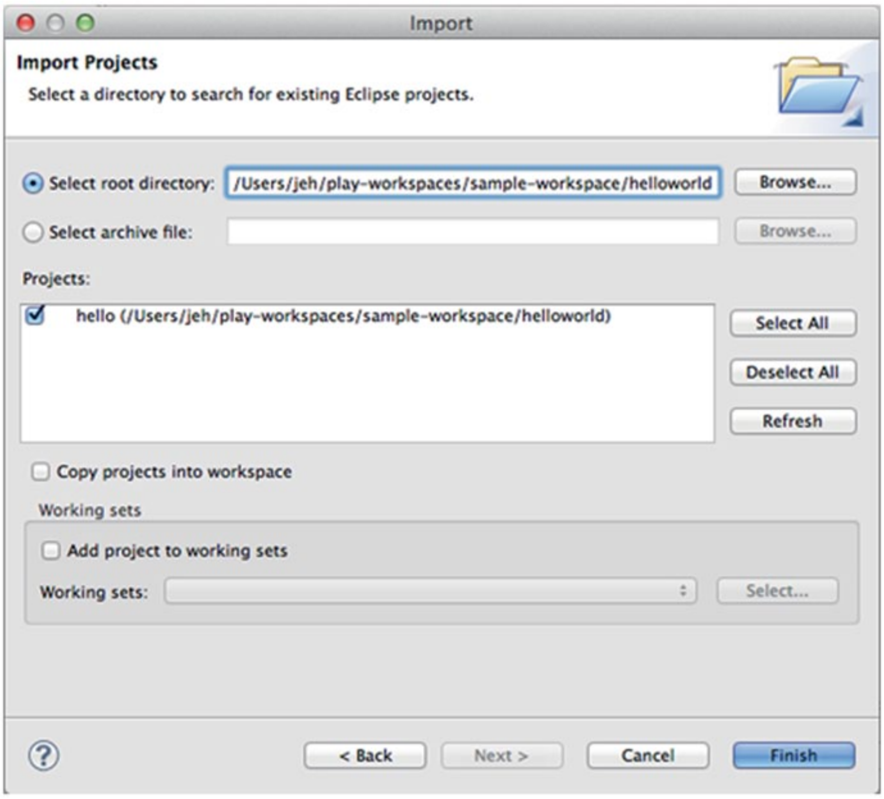

Import
Import Projects
Select a directory to search for existing Eclipse projects.
Select root directory:
/Users/jeh/play-workspaces/sample-workspace/helloworld
Browse...
Select archive file:
Browse...
Projects:
hello (/Users/jeh/play-workspaces/sample-workspace/helloworld)
Select All
Deselect All
Refresh
Copy projects into workspace
Working sets
Add project to working sets
Working sets:
Select...
< Back
Next >
Cancel
Finish

Fig. 38.11 Selecting the project to import

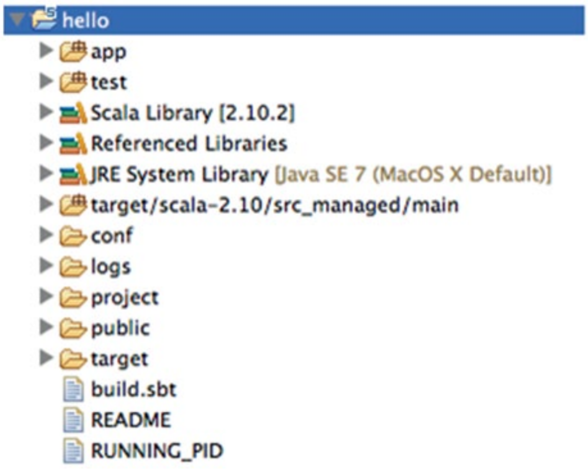


Fig. 38.12 The result of successfully importing the project into Eclipse

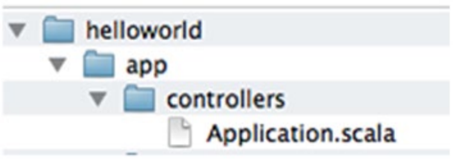
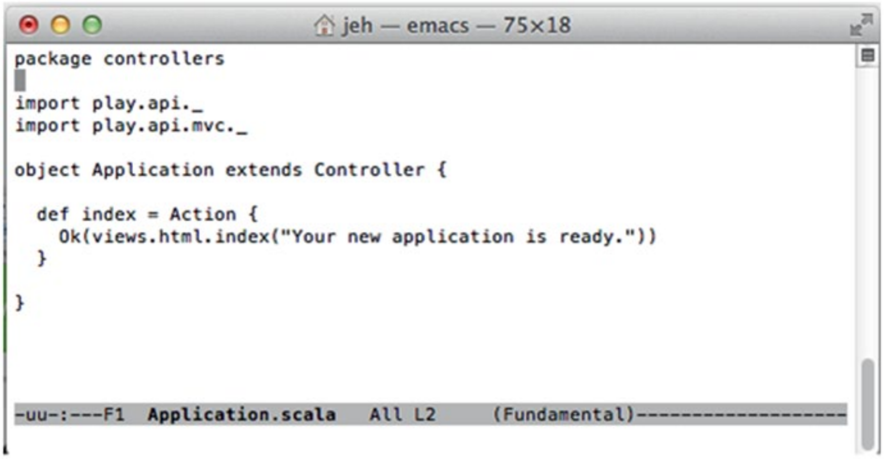


Fig. 38.13 The Application.scala file



```
package controllers

import play.api._
import play.api.mvc._

object Application extends Controller {

  def index = Action {
    Ok(views.html.index("Your new application is ready."))
  }

}
```

```
-uu-:---F1  Application.scala    All L2     (Fundamental)------------------
```

Fig. 38.14 The Application object

Using your editor change the message to will be displayed by editing the String such that is says something like "`Hello Play World`", for example:

```
Ok(views.html.index("Hello Play World"))
```

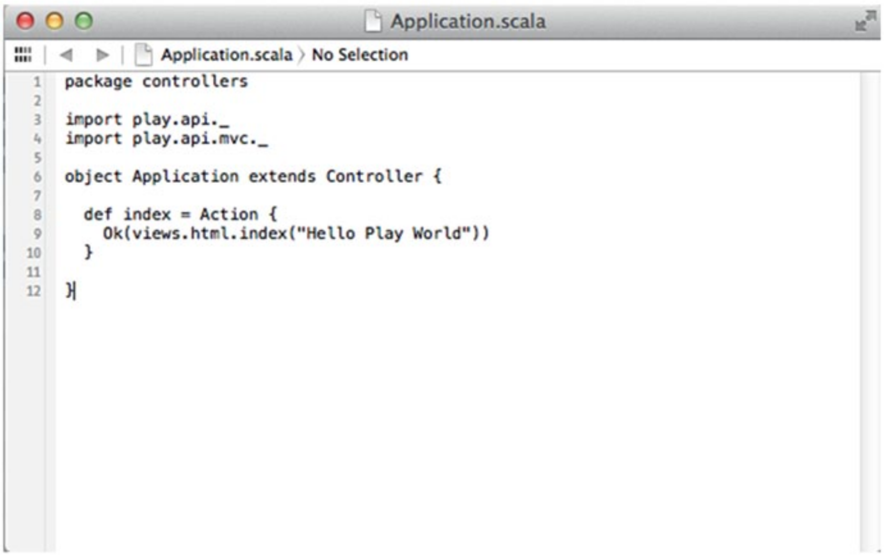
This is illustrated in Fig. 38.15.

Now return to your web browser and refresh the page. You should now see your message displayed at the top of the page as shown in Fig. 38.16.

The page has been updated because *auto reload* is enabled by default in Play. That is, when a file changes Play automatically reloads it. In Scala's case it first recompiles it and then reloads it.

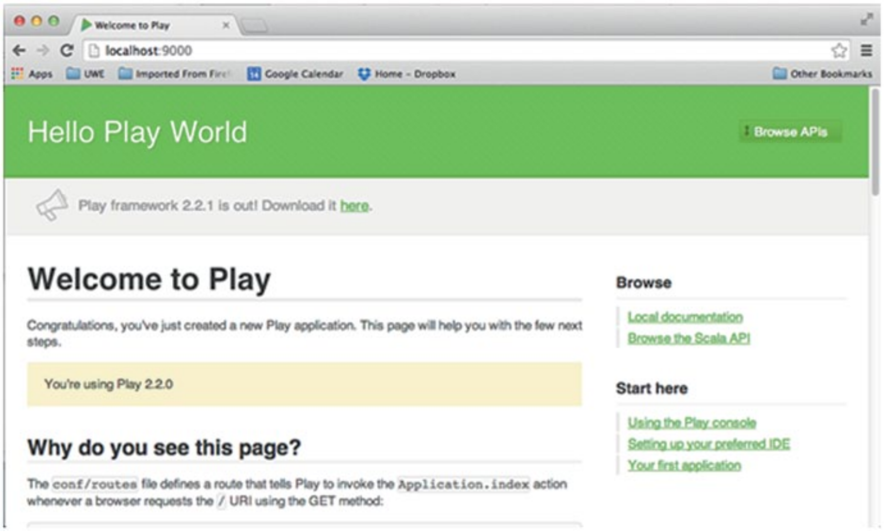
38.6 Model View Controller

From the previous section you may be wondering where the rest of the data on the web page came from. To understand this we must first talk about the Model-view-Controller framework on which Play is built.



```
package controllers

import play.api._
import play.api.mvc._

object Application extends Controller {

  def index = Action {
    Ok(views.html.index("Hello Play World"))
  }

}
```

Fig. 38.15 Updating the Application



Hello Play World

Play framework 2.2.1 is out! Download it here.

Welcome to Play

Congratulations, you've just created a new Play application. This page will help you with the few next steps.

You're using Play 2.2.0

Why do you see this page?

The `conf/routes` file defines a route that tells Play to invoke the `Application.index` action whenever a browser requests the `/` URI using the GET method:

Fig. 38.16 Updated web page

The Model–View–Controller (MVC) architecture separates the interface objects (the views) from the objects that handle user input (the Handlers) from the application (the model). The MVC is not a new idea, it originated in Smalltalk back in the 1980s, but the concept has been used in many places and in many languages. It has become particularly popular within the web development community.

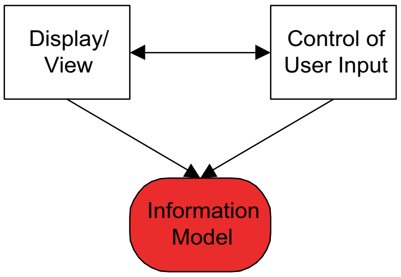


Fig. 38.17 The Model-View-Controller architecture

The intention of the MVC architecture is the separation of the user display, from the control of user input, from the underlying information model as illustrated in Fig. 38.17. This is often referred to as model-driven programming (i.e. the separation of GUIs from the data the present). There are a number of reasons why this is useful:

- reusability of application and/or user interface components,
- ability to develop the application and user interface separately,
- ability to inherit from different parts of the class hierarchy.
- ability to define control style classes which provide common features separately from how these features may be displayed.
- A very clean separation of concerns.

This means that different interfaces can be used with the same application, without the application knowing about it. It also means that any part of the system can be changed without affecting the operation of the other. For example, the way that the graphical interface (the look) displays the information could be changed without modifying the actual application or how input is handled (the feel). Indeed the application need not know what type of interface is currently connected to it at all.

In Play the view is implemented using HTML, CSS, JavaScript and a templating language. The Controllers are implemented as Scala objects (as you have already seen) and the Models are the data and business logic that a controller would invoke or construct. Given this introduction we can now explore how the web page presented to us was constructed.

38.7 Exploring the Play Application

First of all let us look at how the URL request entered into the browser URL resulted in our Scala code being run. The elements that we are going to look at are illustrated in Fig. 38.18.

The data entered into the URL bar causes the browser to generate a HTTP GET request to the server running on *localhost* and listening to port *9000*. That server is the Play server. When it received the request it look at the contents of the *conf/routes*

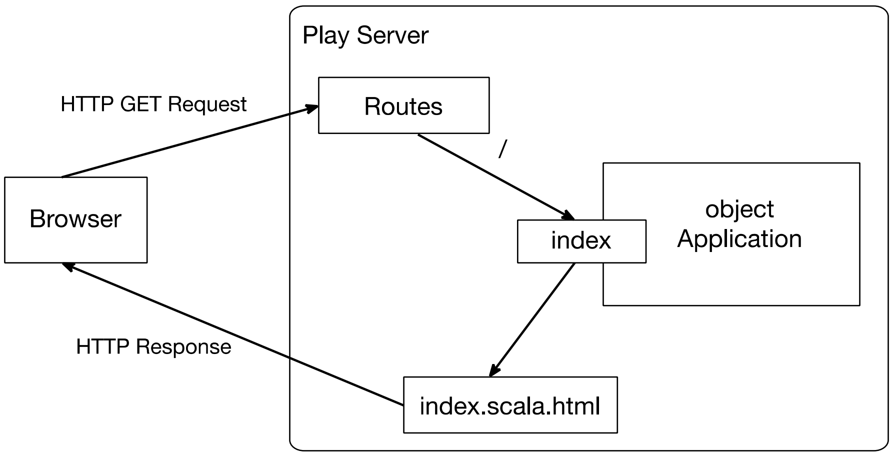
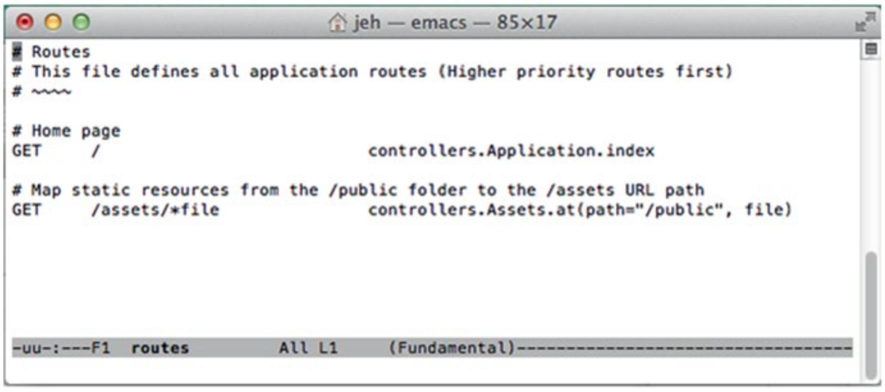


Fig. 38.18 Layout of a Play application



```
# Routes
# This file defines all application routes (Higher priority routes first)
# ~~~~

# Home page
GET     /                           controllers.Application.index

# Map static resources from the /public folder to the /assets URL path
GET     /assets/*file               controllers.Assets.at(path="/public", file)




-uu-:---F1  routes          All L1     (Fundamental)--------------------------------
```

Fig. 38.19 The routes file

file to determine what to do with that request. The contents of this file are shown in Fig. 38.19. The main entry of interest is the line

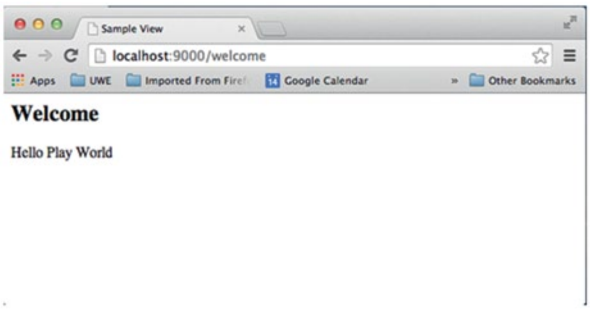
GET/controllers.Application.index

This line essentially states then when a GET request is received, where there is nothing beyond the server name and the port number, then invoke the `controllers.Application.index` Scala method. If you change this line to read:

```
GET/welcome
controllers.Application.index
```

It is now necessary to enter a URL of the from

```
http://localhost:90000/welcome
```

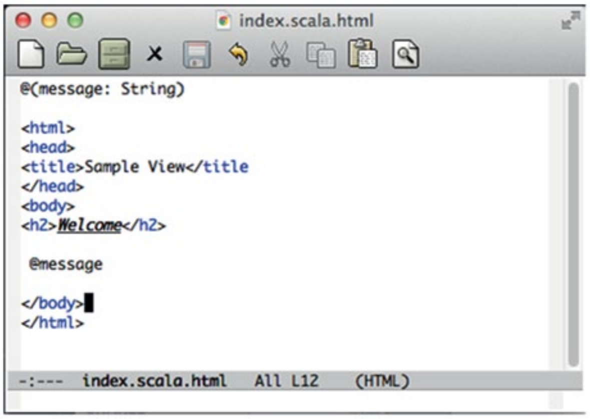


```
localhost:9000/welcome
```

Welcome

Hello Play World

Fig. 38.20 Changing the URL path



```
@(message: String)

<html>
<head>
<title>Sample View</title
</head>
<body>
<h2>Welcome</h2>

 @message

</body>
</html>
```

```
-:---  index.scala.html   All L12    (HTML)
```

Fig. 38.21 The index.scala.html file

into the browser URL bar in order to run the index method of the Application object, as illustrated in Fig. 38.20.

So the URL is routed to the appropriate method on the Application class. The index property shown below sets the index message of the views.html:

```
def index = Action {
Ok(views.html.index("Hello Play World"))
 }
```

An Action is actually a function that handles the request and generates a result to send back to the web client. In this case an OK response is being generated using a template to fill in the content. The template is defined in the

app/views/index.scala.html file

and compiled into a Scala function. The generic template generates information about Play. However, we have re-written the template to use HTML and to use the message passed to the view as a placeholder that will be populated with information provided by the controller. This template is shown in Fig. 38.21.

The template defines the function signature (it takes a String and stores this in the variable message) and the content of the body of the web page. These files can mix HTML, CSS, JavaScript and Scala code and represent the presentation or view aspect of the MVC framework. In our case we are using HTML to manage the layout and leaving the message presented within the page to be generated from the data passed into the view (form the controller) Fig. 38.21.

Notice that the parameter to the page is defined at the top of the page using the Play templating language and is accessed in the body of the page by prefixing the parameter with an '@' symbol.

Chapter 39
RESTful Services

39.1 Introduction

This chapter looks at RESTful web services as implemented using the Play framework.

39.2 RESTful Services

As well as dynamic web applications, many developers also want to be able to create RESTful services that can be invoked by Ajax style clients.

REST stands for Representational State Transfer and was a termed coined by Roy Fielding in his Ph.D. to describe the lightweight, resource-oriented architectural style that underpins the web. Fielding, one of the principle authors of HTTP, was looking for a way of generalising the operation of HTTP and the web. He generalised the supply of web pages as a form of data supplied on demand to a client where the client holds the current state of an exchange. Based on this state information the client requests the next item of relevant data sending all information necessary to identify the information to be supplied with the request. Thus the requests are independent and not part of an on-going stateful conversation (hence state transfer). If you are interested in the background to this see (http://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm).

It should be noted that although Fielding was aiming to create a way of describing the pattern of behaviour within the web, he also had an eye on producing lighter weight web based services (than those using either proprietary Enterprise Integration frameworks or SOAP based services). These lighter weight HTTP based web services have become very popular and are now widely used in many areas. Systems which follow these principles are termed RESTful services.

A key aspect of a RESTful services is that all interactions between a client (whether some JavaScript running in a browser or a standalone application) are done using simple HTTP based operations. HTTP supports four operations these are

HTTP GET, HTTP Post, HTTP Put and HTTP Delete. These can be used as verbs to indicate the type of action being requested. Typically these are used as follows:

- retrieve information (HTTP GET)
- create information (HTTP POST)
- update information (HTTP PUT)
- delete information (HTTP DELETE)

It should be noted that REST is not a standard in the way that HTML is a standard. Rather it is a design pattern that can be used to create web applications that can be invoked over HTTP and that give meaning to the use of Get, Post, Put and Delete HTTP operations with respect to a specific resource (or type of data).

The advantage of using RESTful services as a technology, compared to some other approaches (such as SOAP based services which can also be invoked over HTTP) is that

- the implementations tend to be simpler,
- the maintenance easier.
- hey run over standard HTTP and HTTPS protocols and
- do not require expensive infrastructures and licenses to use.

This means that there is lower server and server side costs. There is little vendor or technology dependency and clients do not need to know anything about the implementation details or technologies being used to create the services.

39.3 A RESTful API

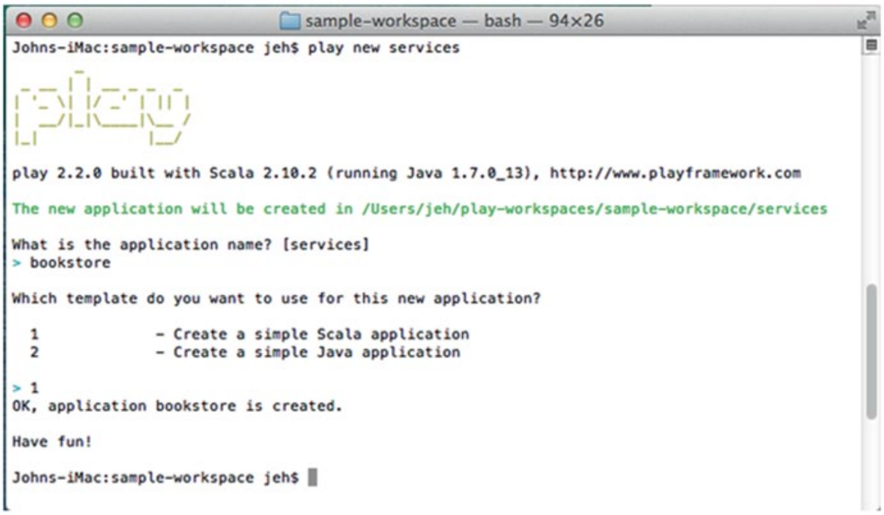
A RESTful API is one in which you must first determine the key concepts or *resources* being represented or managed. These might be books, products in a shop, room bookings in hotels etc. In our case we will assume a bookstore related service in which the data being held represents types of books, CDs, DVDs, etc. This data is split into resources with books as one type of resource. We will ignore the other resources such as DVDs and CDs etc. Based on these books we will identify suitable URLs for these RESTful services. Note that although URLs are frequently used to describe a web page—that is just one type of resource. For example, we might develop a resource such as

/bookservice/book

from this we could develop a URL based API, such as
/bookservice/book/:isbn

Where ISBN indicates a unique number to be used to identify a specific books whose details will be returned using this URL.

We also need to design the representation or formats that the service can supply. These could include plain text, JSON, XML etc. JSON standards for the JavaScript Object Notation and it is a concise way to describe data that is to be transferred from a service running on a server to a client running in a browser. This is the format we will use in the next section. As part of this we might identify a series of operations



```
sample-workspace — bash — 94×26
Johns-iMac:sample-workspace jeh$ play new services
       _
 _ __ | | __ _ _  _
| '_ \| |/ _' | || |
|  __/|_|\____|\__ /
|_|            |__/

play 2.2.0 built with Scala 2.10.2 (running Java 1.7.0_13), http://www.playframework.com

The new application will be created in /Users/jeh/play-workspaces/sample-workspace/services

What is the application name? [services]
> bookstore

Which template do you want to use for this new application?

  1             - Create a simple Scala application
  2             - Create a simple Java application

> 1
OK, application bookstore is created.

Have fun!

Johns-iMac:sample-workspace jeh$ 
```

Fig. 39.1 Creating the bookstore web application

to be performed by our services based on the type of HTTP Method used to invoke our service and the contents of the URL provided. For example, for a simple BookService this might be:

- GET/book/{isbn}—used to retrieve a book for a given ISBN.
- GET/book/list.xml—used to retrieve all current books in XML format.
- GET/book/list.json—used to retrieve all current books in JSON format.
- POST/book (XML or JSON in body of the message)—which supports creating a new book.
- PUT/book (XML or JSON in body of message)—used to update the data held on an existing Book.
- DELETE/book/{isbn}—used to indicate that we would like a specific book deleted from the list of books held.

Note that the *parameter* ISBN in the above URLs actually forms part of the URL path.

39.4 Creating the RESTful Web Application

We will create a new Play application for this. This is done in exactly the same way as before. In fact Play creates web-based applications. These can be treated as web sites or as RESTful services depending upon the type of data supplied and the way in which you expect the service to be invoked. Thus the distinction between a RESTful service and a web page is in the eye of the beholder (or at least the client application).

The new play application we will create will be stored into a directory called services and will be called bookstore as we will be creating a bookstore like service. This is illustrated in Fig. 39.1.

Given the Model-View-Controller structure described earlier. We need the model for our RESTful services. This will be defined in a separate package model and comprise a Book case class and a Books object. This can be accessed by our controller as and when required. The class and object that comprise the model package are shown below:

```
package model

case class Book(val isbn: Int,
               val title: String,
               val author: String,
               val price: Double)
     object Books {
         val list = List(Book(1, "XML", "S. Smith", 10.99),
                         Book(2, "Java", "J. Jones", 12.99),
                         Book(3, "Scala", "A. Adams", 11.99))
         def get(isbn: Int): Book = {
          val result = list.filter(_.isbn == isbn)
               result.head
            }
          }
```

Note that the Books object defines both a property list and a method get. The list property holds the list of books currently available and the get method returns a book given a specified ISBN.

However we now need to determine what the HTTP requests we will support will be. Our bookstore service will be a read only service which will provide a list of books or a single book if an ISBN is supplied. As this is an access oriented service we only need to support the HTTP GET Requests. We therefore want to provide mappings from

- /book/list
- /book/:isbn

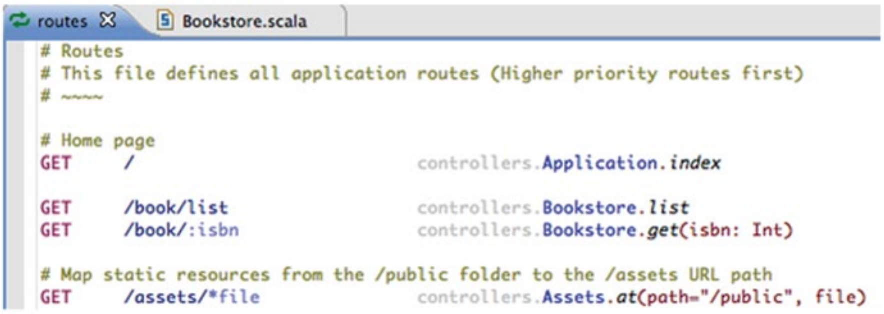
Both of these routes can be supported by the same object, the controllers. Bookstore object via methods list and get, thus we will map:

- /book/list -> controllers.Bookstore.list
- /book/:isbn -> controllers.Bookstore.get(isbn: Int)

Note that the routing information will be used to map the isbn information provided as part of the/book/:isbn URL to the parameter passed into the get method. We will this update our routes file as illustrated in Fig. 39.2.

Next we need to write the Bookstore controller. As with the original Application controller in the last section, our Bookstore will be an object called Bookstore that extends the Controller type. The initial state of the object is shown below:

```
package controllers

import play.api.mvc.Controller

object Bookstore extends Controller {

}
```

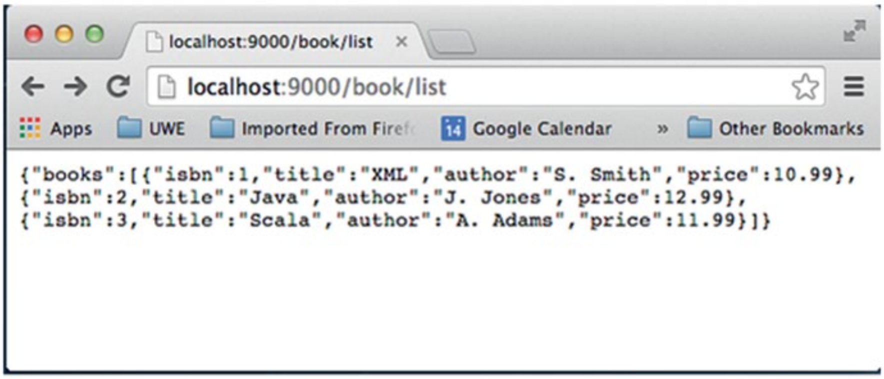


```
# Routes
# This file defines all application routes (Higher priority routes first)
# ~~~~

# Home page
GET     /                           controllers.Application.index

GET     /book/list                  controllers.Bookstore.list
GET     /book/:isbn                 controllers.Bookstore.get(isbn: Int)

# Map static resources from the /public folder to the /assets URL path
GET     /assets/*file               controllers.Assets.at(path="/public", file)
```

Fig. 39.2 Updated Routes for Service

The `list` method will take no parameters and implement an `Action` that will return a list of Books. We will use the JSON data format as it is very widely used within web-based services. However, we need to specify how an instance of the `Book` class should be converted into a JSON object. We will do this using the `toJson` method that is desgined to convert a `Book` instance into a JSON object by extracting the isbn, title, author and price form a book and wrapping them up within an appropriate JSON type. The Play frameworks' JSON library is defined within `play.api.libs.json` and contains case classes for JSON types such as `JsString, JsNumber, JsBoolean, JsObject, JsArray` and `JsNull`.

```
package controllers

import play.api.data.Forms._
import play.api.libs.json._
import play.api.mvc._
import model.Books
import model.Book
object Bookstore extends Controller {

   // Utility methods
 private def  booksAsJsonList: JsObject =
   JsObject("books" -> JsArray(Books.list.map { book =>
toJson(book)}) :: Nil)

private def toJson(book: Book) = {
JsObject(
  "isbn" -> JsNumber(book.isbn) ::
    "title" -> JsString(book.title) ::
    "author" -> JsString(book.author) ::
    "price" -> JsNumber(book.price) :: Nil)
}

// Request Handling mehtods
def list = Action {
  Ok(booksAsJsonList)
}

def get(isbn: Int) = Action {
   Ok(toJson(Books.get(isbn)))
  }

}
```



```
{"books":[{"isbn":1,"title":"XML","author":"S. Smith","price":10.99},
{"isbn":2,"title":"Java","author":"J. Jones","price":12.99},
{"isbn":3,"title":"Scala","author":"A. Adams","price":11.99}]}
```

Fig. 39.3 The data returned form the book service

The `get` method will take an ISBN. The type of the ISBN needs to be determined. We will assume that all our ISBNs are integers and thus the type of the parameter for the `get` method will be `Int`. The get method uses this ISBN number to return a book with that ISBN number or a message indicating that no book with that number was found.

Note that the `JsObject` constructs a JSON object comprised of key-value pairs that are used to represent the actual `Book`. This type is obtained from the `play.api.libs.json` package. The `JsString` and `JsNumber` are also defined by that package.

If we now invoke this RESTful service from a client browser we can see the data returned. For example, if you enter into the browser:

http://localhost:9000/book/list

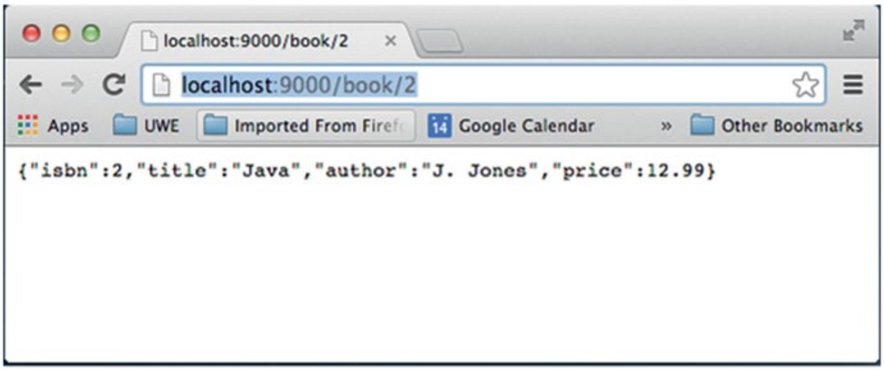
You should see the result presented in Fig. 39.3. The data returned is in JSON format and indicates that the property *books* relates to an array of book information. Each item of book information is comprised of an isbn, a title, an author and a price.

We can also obtain information on a single book using the url/books/:isbn routing information, here the isbn number forms part of the URL—thus indicating a (dynamically generated) resource. For example, using the URL:

http://localhost:9000/book/2

The information about the book with the ISBN 2 is returned as shown in Fig. 39.4.

Alternatively we could construct a client using JavaScript that would be run within a Browser. This client could invoke the RESTful service we have just created asynchronous when requested to do so by the user.



```
{"isbn":2,"title":"Java","author":"J. Jones","price":12.99}
```

Fig. 39.4 Retrieving a single books details from the book service

39.5 JavaScript and jQuery

The web service we have created supplies data that can be consumed by a suitable client. In many cases these clients will be implemented in JavaScript and executed within the client side browser (such as Chrome and Firefox). Note that the server based Scala code will execute within the confines of the server where as the client will run within a browser potentially anywhere in the world.

A very common approach is to create a web page containing some JavaScript that will, in response to user actions, such as clicking a button, asynchronously invoke the remote service and populate the current web page with the data provided. For example, if you are requesting your recent bank transactions, the request for those transactions occurs in page without the need for the whole page to be refreshed.

JavaScript itself is a programming language that can be executed within a wide range of environments. The most common environment to run JavaScript in is within a Browser, where a JavaScript engine interprets it. As such JavaScript is commonly treated as a client side programming language to be embedded in a web page and interacts with the contents of that web page (represented as the Document Object Model or DOM of the page).

A common library to use with such applications is jQuery. This is because it simplifies many activities that you would need to develop from scratch if you were using JavaScript on its own (such as the look and feel generation, calendars, and Ajax style programming). The basic concept behind Ajax is that data can be retrieved from a server asynchronously in the background, without interfering with the display and behaviour of the existing page. The name original came from the acronym for *Asynchronous JavaScript and XML* programming. However, Ajax style applications are very widely used with JSON rather than XML as the data interchange format. It should be noted that Ajax as such is not a technology; rather it is a set of technologies that are used together in a particular "Design Pattern" or implementation strategy. This approach typically utilises:

- XHTML and CSS for presentation
- The Document Object Model (DOM) for dynamic display of and interaction with data
- XML, JSON or plain text for the interchange, manipulation and display of data
- Facilities in JavaScript for asynchronous communication
- JavaScript to bring these technologies together

jQuery make it easy to implement an Ajax style client and to use the data provided by remote services to change the current web page.

39.6 The jQuery Client

We will create a simple jQuery based client. This client will be loaded when an initial web page is displayed to the user. The web page will be created using the Play framework. This allows us to dynamically determine some of the information to display in this page and links the client to the backend service.

To do this we will modify our `Application` object so that the string passed to the index view template provides the name of the Bookstore. This is shown below:

```
package controllers

import play.api._
import play.api.mvc._

object Application extends Controller {

  def index = Action {
    Ok(views.html.index("Johns Bookstore"))
  }

}
```

Next we will rewrite the index.scala.html template file such that it uses more of the templating features of the Play framework. The implementation of our view is presented below.

The head of the template still indicates the information being provided to it. This is the string passed to the view from the `Application` controller. However, this string is now used within a HTML web page. The web page uses the string in the welcome heading presented to the user. The rest of the template is presented below:

```
@(message: String)
   <html lang="en">
   <head>
     <meta charset="utf-8">
     <title>jQuery.getJSON demo</title>
     <meta http-equiv="Content-Type" content="text/html;
   charset=UTF-8">
           <link rel="stylesheet"
   href="@routes.Assets.at("stylesheets/style.css")"
           type="text/css" media="screen"></link>
     <script src="@routes.Assets.at("javascripts/jquery-
   1.9.0.min.js")"></script>
     <script type="text/javascript"
   src="@routes.Assets.at("javascripts/myscript.js")"></script>
   </head>

   <script>
   </script>
   <body>

   <h2>Welcome @message</h2>

         <div class="button" id="show"> Show </div>
       <div id="books"></div>

   </body>
   </html>
```

A HTML page can be divided into a header and a body The header tells the browser information about the page and the body provided the data to be displayed to the user.

The above web page contains a simple HTML body that merely displays a welcome message and places a string shown in a divider and an empty divider called books within the page. Note that use of @message indicates that this is a template where the value of the message will be provided by the Application controller at runtime. However, the interesting parts are in the HTML header. This header includes:

```
<link rel="stylesheet"
     href="@routes.Assets.at("stylesheets/style.css")"
     type="text/css" media="screen"></link>
  <script src=
   "@routes.Assets.at("javascripts/jquery1.9.0.min.js")">
</script>
   <script type="text/javascript"
     src="@routes.Assets.at("javascripts/myscript.js")">
</script>
```

The link specifies the CSS style sheet to use. This style sheet defines various colours and formats to be used with elements within the web page. For example, it defines the button style. This style is used within the body of the HTML page in:

```
<div class="button" id="show"> Show </div>
```

Which indicates that the button CSS style class will be used with the text Show. Note that the location of the style sheets is relative to the web application we are writing and thus the @routes.Assets.at() function is used to generate the actual path to the style sheet directory (this is also used below to access the jQuery files).

The notable aspect of the header is that it specifies two scripts to use. The first is the jQuery library itself (version 1.9.0) and the second is the file containing the custom code that implements our jQuery client.

The contents of the myscript.js file is presented below. This jQuery program, does two things. It first links the hover function to the HTML element with the id "show" such that when the user moves the cursor over the *button* the cursor changes—which provides some useful feedback to the user. The second thing it does is specify what should happen when the user *clicks* on the button.

```
$(function() {
$(function() {
     $("div#show").hover(function() {
           $(this).addClass("hover");
        }, function() {
            $(this).removeClass("hover");
     });
     $("div#show").click(
        function() {
           $.get('book/list', function(data) {
              $('div#books').empty();
              $(data.books).each(
                 function() {
                   var $book = $(this);
                  var html = "<div class='book'>";
                  html += "<h3 class='title'>"
                        + $book.attr('title') + "</h3>";
                  html += "Author: " +
                        $book.attr('author');
                  html += "<br>Price: "
                        + $book.find('price').text();
                  html += "<br>ISBN: "
                          + $book.find('ISBN').text();
                    html += '</div>';
                    $('div#books').append($(html));
              });
           });
        });
     });
  });
```

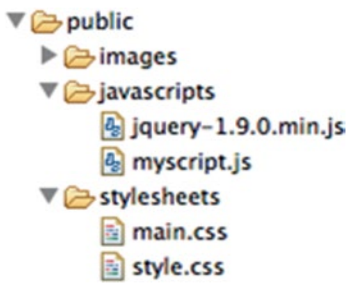


Fig. 39.5 The location of the assets used in the web application

The function defined for the user ‘click’ event on the element called *show* performs an asynchronous get request to the URL books/list. When the data returns the associated second function executes. The data returned from the RESTful service will be supplied to the variable *data*. The second function initially removes anything that is currently being displayed by the element *books*. It then looks through the array of books indexed by the value books in the JSON object structure. For each book in that array it creates some HTML to format the book information and retrieves the appropriate data items from the book structure (such as title, author, price etc.). The resulting information is then appended to the *books* element within the web page.

The above files are stored under the *public* area of web application project structure. This is where static assets of the project are location such as images, stylesheets, JavaScript files and HTML files. In out case the style sheet is under the *stylesheets* directory and the jQuery and myscript.js files are under the *javascript* directory. This is illustrated in Fig. 39.5.

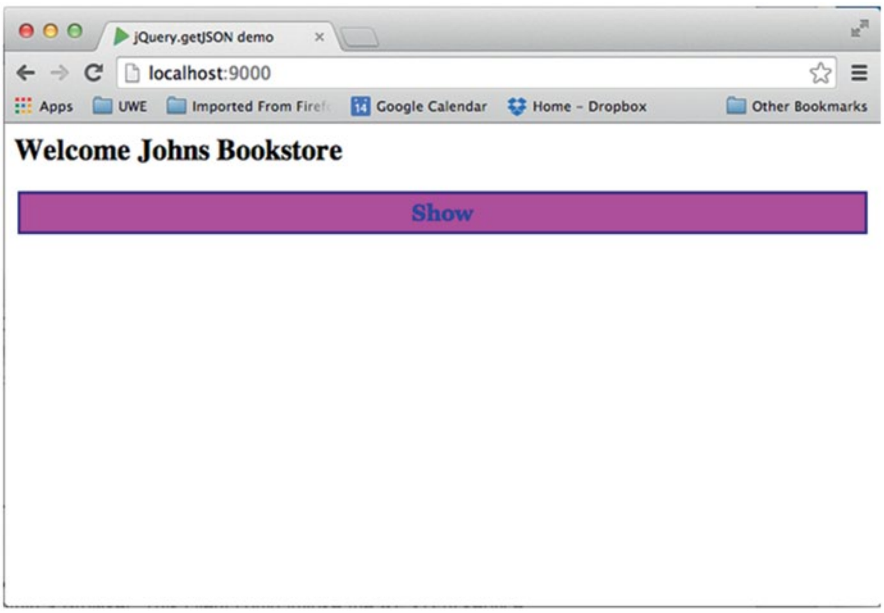
As Play automatically reloads the changes you make, all you need to do to see the behaviour of your jQuery client, is to change the URL in your browser such that the address is:

http://localhost:9000

This will run the index (or default) page of your application that should now display the simplified web page welcoming you to Johns Bookstore (see Fig. 39.6).

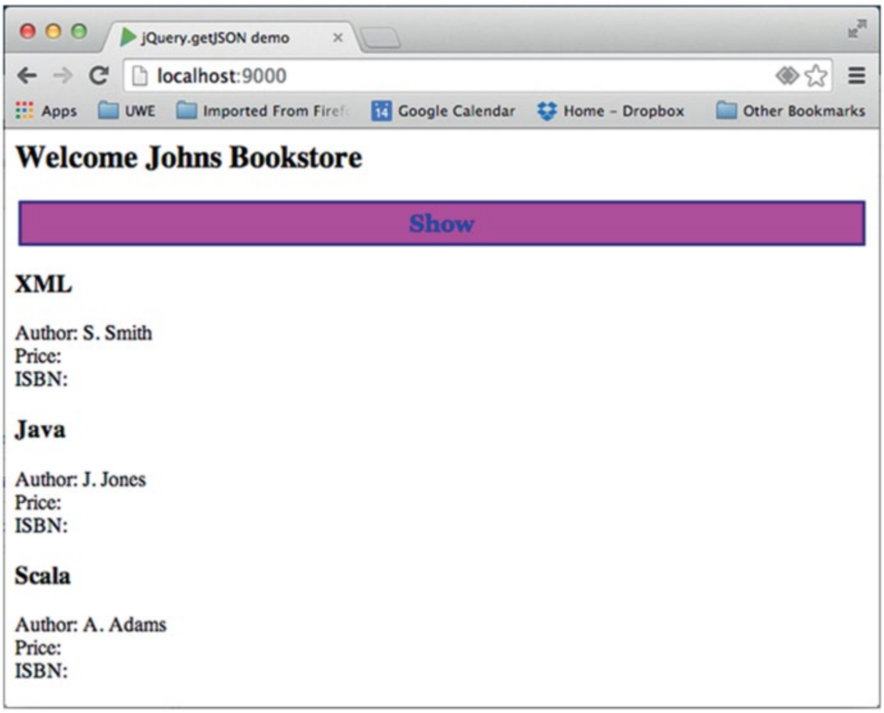
If you move your mouse over the *show* button you should see it change. Now click on the Show button and the page should (in the background) request the data from the bookstore service and display ach of the books within the current page. This is shown in Fig. 39.7.

Interestingly if you view the source code for this page you will see that there are no books listed—this is because they were dynamically obtained form the server and added to that page by the jQuery based functions and are this not part of the static HTML of the page. This is illustrated in Fig. 39.8.



Welcome Johns Bookstore

Fig. 39.6 The modified Index page with the show button



Welcome Johns Bookstore

XML

Author: S. Smith
Price:
ISBN:

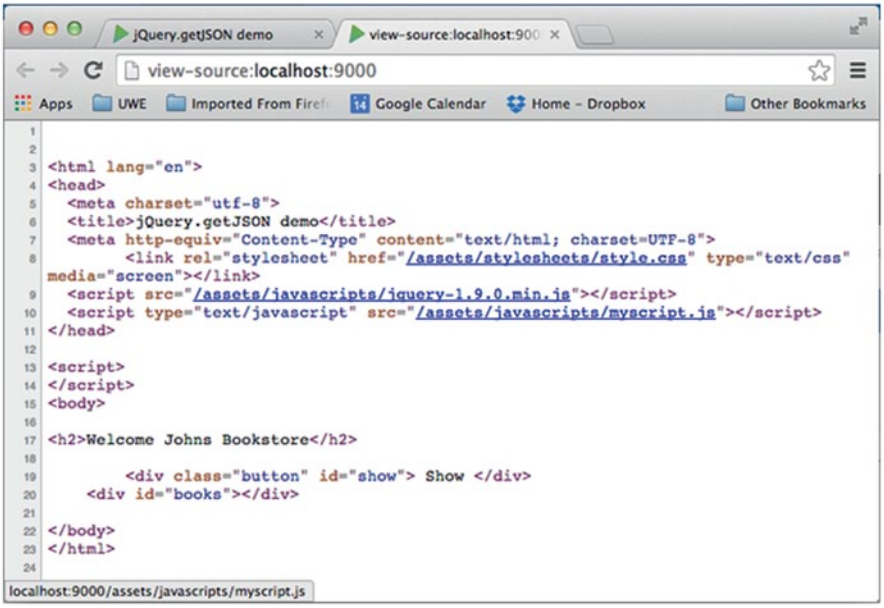
Java

Author: J. Jones
Price:
ISBN:

Scala

Author: A. Adams
Price:
ISBN:

Fig. 39.7 by JavaScript: Book data displayed in browser


jQuery.getJSON demo
view-source:localhost:900
view-source:localhost:9000
Apps
UWE
Imported From Fire
Google Calendar
Home - Dropbox
Other Bookmarks
localhost:9000/assets/javascripts/myscript.js

```


<html lang="en">
<head>
  <meta charset="utf-8">
  <title>jQuery.getJSON demo</title>
  <meta http-equiv="Content-Type" content="text/html; charset=UTF-8">
        <link rel="stylesheet" href="/assets/stylesheets/style.css" type="text/css"
media="screen"></link>
  <script src="/assets/javascripts/jquery-1.9.0.min.js"></script>
  <script type="text/javascript" src="/assets/javascripts/myscript.js"></script>
</head>

<script>
</script>
<body>

<h2>Welcome Johns Bookstore</h2>

        <div class="button" id="show"> Show </div>
    <div id="books"></div>

</body>
</html>

```

Fig. 39.8 The Source code for the index page as received by the browser

Further Reading

Play Framework
http://www.playframework.com.

JQuery
http//www.jquery.com—jQuery homepage
http//docs.jquery.com/Tutorials—Tutorials
http//www.learningjquery.com/—jQuery tutorial blog
http//docs.jquery.com/Sites_Using_jQuery—jQuery Success Stories

REST
http://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm

Chapter 40
GUIs in Scala Swing

40.1 Introduction

This chapter describes how to create rich client graphical displays (desktop application) using the Scala Swing windowing and graphical types. Thus in this chapter we consider how windows, buttons, tables etc. are created, added to windows, positioned and organised in Scala.

40.2 Windows as Objects

In Scala, Windows and their contents are instances of appropriate classes (such as Button or FlowPanel). Thus when you create a window, you create an object that knows how to display itself on the computer screen. You must tell it what to display, although the framework within which the associated method (paint) is called is hidden from you. You should bear the following points in mind during your reading of this chapter; they will help you understand what you are required to do:

- You create a window by instantiating an object.
- You define what the window displays by adding a component to its contents, such as a type of panel or a button.
- You can send messages to the window to change its state, perform an operation, and display a graphic object.
- The window, or components within the window, can send messages to other objects in response to user (or program) actions.
- Everything displayed by a window is an instance and is potentially subject to all of the above.

This approach may very well contrast with your previous experience. In many other windowing systems, you must call the appropriate functions in order to obtain a window, providing default behaviour either by using pointers to functions, or by associating some event with a particular function. You also determine what is displayed in the window by calling various functions on the window.

In the object oriented world, you define how a subclass of the windowing classes respond to events, for example what it does in response to a request to paint itself, etc. All the windowing functionality and window display code is encapsulated within the window itself.

40.3 Windows in Scala

Of course the above description is a little simplistic. It ignores the issue of how a window is created, initialized and displayed, and how its contents are generated. In Scala, these are handled by the concepts of a frame, a component and a container:

Frames provide the basic structure for a window: borders, a label and some basic functionality (e.g. resizing).
Components are graphical objects displayed in a frame. Some other languages refer to them as widgets. Examples of components are lines, circles, boxes and text.
Containers are special types of component that are made up of one or more components (or containers). All the components within a container (such as a panel) can be treated as a single entity.

Windows have a component hierarchy that is used (amongst other things) to determine how and when elements of the window are drawn. The component hierarchy is rooted with the frame, within which components and containers can be added. Figure 40.1 illustrates a component hierarchy for a window with a frame, two containers (subclasses of `Panel`, which is itself a direct subclass of `Container`) and a few basic components.

When the runtime environment needs to redraw the window displayed by the above hierarchy, it starts with the highest component (the frame) and asks it to redraw itself. It then works down the hierarchy to the bottom components, asking each to redraw itself. In this way each component draws itself before any components that it contains; this process is handled by the windowing framework. The user generally only has to redefine the `paint` method to change the way in which a component is drawn.

40.4 Scala Swing

Scala Swing is a Scala wrapping around the underlying Swing library of GUI classes and types. This of course raises the question ‘What is Swing?’ Swing is a generic, platform independent, windowing system originally developed for the Java programming language. It allows you to write graphical programs that have (almost) the same look and feel, whatever the host platform. For example, the graphical applications presented within this section of the book have been written primarily on a Mac, however they have been run on Macs, Windows machines of various flavours

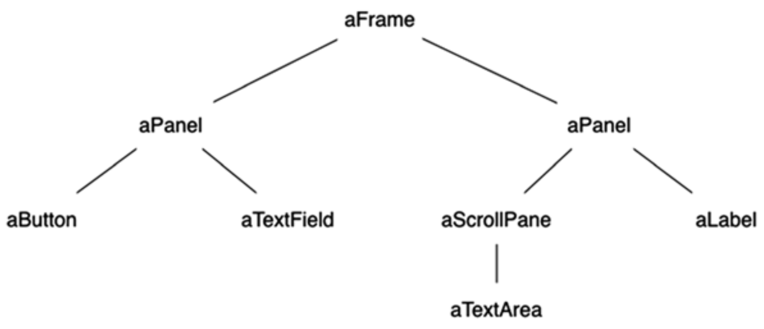


Fig. 40.1 The component hierarchy for a sample window

and Linux boxes. This is because these are the machines available to me, and depending on the time of day, I may be working on one or the other. I do not need to worry about the host environment, only about the Swing.

There are a number of concepts that are important when considering Swing. These are:

- All components in Swing are 100 % implemented purely in byte codes (and are referred to as lightweight). This means that the windows (and their contents) should look the same whatever platform they are on and should be easier to maintain across different operating systems. As all graphical components are "lightweight", their appearance is controlled purely by the runtime code (without the need for platform dependent peers—or platform dependent libraries). In Swing, a separate user interface "view" component performs the actual rendering of the component on the screen. This allows different views to be plugged in. This in turn allows the idea of installing different "looks and feels". This means that it is easier to deploy the same software on different platforms, but with interfaces that match the interface manager on that particular platform. This separation of view from the actual component is based on a modified version of the Model-View-Controller architecture (described earlier in the Play framework chapter).
- Swing also provides a rich set of facilities for graphical user interfaces, including trees, icons on buttons, dockable menus bars, menus with icons, borders and improved support for fonts and colours.

However, the Scala Swing library is more than just a wrapping around the original Swing library. It significantly simplifies the Swing API and the tasks that the programmer must perform to create a user interface. In many ways the Scala Swing library is what the original Swing library should have been; lean, efficient and simple to work with.

Whichever UI framework you choose to use, such toolkits greatly reduce the problems that software vendors often face when attempting to deliver their system on different platforms.

40.5 Scala Swing Packages

There are two key packages within the Scala Swing library.

- **scala.swing** this is the package that contains the core types with which you will be working, such as Button, ComboBox, EditorPane, FileChooser, FlowPanel, MainFrame, RadioButton, ScrollPane etc.
- **scala.swing.event** this package provides types used with the event handling mechanism that underpins how a UI can react to user inputs (such as what to do when a user clicks on a button). This package includes types such as Button-Clicked, KeyPressed, MouseMoved, WindowClosing etc.

However, you will primarily work with the scala.swing package as this is where the majority of the types you will need are defined. The reactor framework (discussed in the next chapter) is used to handle user input and is built on top of the lower level event framework (inherited from Java). This framework is also defined within the scala.swing package.

The key classes within the *scala.swing* package are:

- **Component**. This is the base class for all user interface elements that can be displayed within a Scala window. Components have properties such as whether they are enabled or not, the font used with them, foreground colours and back-ground colours, borders and tool tips (text popped up and displayed to the user if they hover the mouse over the component). Components also publish (or fire) events that allow developers to react to these events (such as the component being selected by a user). There are a large number of subtypes for Component including various types of buttons, panels, fields, menus, tables etc.
- **Container**. This is a base trait for user interface elements that can act as contain-ers of other UI elements. For example, a FlowPanel can *contain* a set of other elements (such as button) organised across the panel. As well as FlowPanel, BoxPanel, BorderPanel, MenuBar, ScrollPane, SplitPane etc. are all examples of containers.
- **MainFrame**. This class defines a *frame* that can be used as the top level, main application window that can contain other *containers* and *components*. When the MainFrame is closed then the UI application is terminated.
- **SwingApplication** and **SimpleSwingApplication**. These classes provide a set of utility methods to handle starting up a UI application. SwingApplication is the root class and SimpleSwingApplication its subclass. Most UI applications will extend the SimpleSwingApplication class (instead of mixing in the App trait for example). The subtype extending this class must implement the top method that must return the top level frame (e.g. MainFrame) to be used with this application. The UI framework initialization and initiation is done by the SimpleSwingApplication. If you wish to customize the behaviour of the start up and shut down process then you can override the *shutdown* method or extend the *startup* method.

- **FlowPanel**. A Panel (i.e. container) that organises its contents horizontally, one after the other. If the contents do not fit in the current display then the pane will introduce a break and try on the next line. It is similar in effect to a JPanel with a FlowLayout in Java Swing.
- **BorderPanel**. A Panel (i.e. container) that organises its contents into discreet locations, such as center, top, bottom, left and right.
- **Button** provides the basic button type display and behaviour present in most user interfaces.
- **Menu**, **MenuBar** and **MenuItem**. The components that can be used to construct a menu across the top of a UI.
- **ScrollPane** a type used to wrap up other UI elements that need to be displayed using a scrollable view. The view is controlled by a set of scroll bars.
- **TextField** and **TextArea**. Both are used to display textual information and may be editable or not. A TextField is a single line display, a TextArea is a multi-line textual display. A TextArea should be displayed within a ScrollPane if it is too large to display within the available space.
- **Table**. Provides a tabular display comprising rows and columns and optionally a set of headings.
- **ComboBox** used to allow a user to make a selection from a list of predefined items.
- **ListView** used to present a (non editable) list of items.

40.6 Swing Scala Worked Examples

This section presents a series of examples, that explore a number of the concepts that underpin the Scala Swing framework and illustrate how some of the key classes presented above can be used.

40.6.1 Simple Hello World UI

The following listing provides a basic user interface containing a Button labelled "Click Me!" and with a window title "Hello World!". The application imports the Button, MainFrame and SimpleSwingApplication types from the scala.swing package. It then defines a class SimpleFrame that is a subclass of MainFrame. It defines the title of the main frame and creates a new instance of the Button class. The button will have the text "Click Me!" displayed. The instance of the button is then used as the contents of the main display area of the frame.

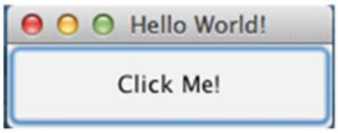


Fig. 40.2 Simple Hello World UI

```
package com.jeh.scala.swing

import scala.swing.Button
import scala.swing.MainFrame
import scala.swing.SimpleSwingApplication

class SimpleFrame extends MainFrame {
  // set title for the window
  title = "Hello World!"
  // Create a button and set it as the
  // contents of the window
  contents = new Button {
    text = "Click Me!"
  }
}

object SwingHelloWorld extends SimpleSwingApplication
{
  // define the method top to return an instance of the
  // SimpleFrame
  def top = new SimpleFrame()
}
```

The object SwingHellWorld extends the SimpleSwingApplication type and defines the top method as returning an instance of the new SimpleFrame class. When this SwingHelloWorld application runs, the main method defined by the SimpleSwing-Application executes and sets up the windowing framework and calls the top method to display the top most element of the UI. The result of executing this application is shown in Fig. 40.2.

40.6.2 Panels and UI Layout

The example shown in the last section works as a simple user interface example, however the whole of the display is taken up with a single button. User interfaces are normally comprised of multiple components displayed within a single frame. This is achieved in Scala Swing using appropriate (potentially nested) containers as discussed earlier.

In this section we will look at using a simple panel, a FlowPanel that allows multiple components and/or contains to be contained within it. The result of executing

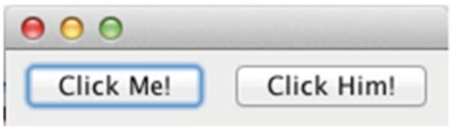


Fig. 40.3 Using a flowpanel

our program is shown in Fig. 40.3. The FlowPanel provides a flow like layout with user interface components being added to the contents buffer of the FlowPanel.

In the following listing we create two buttons (b1 and b2). These buttons are added to the contents of the FlowPanel when we create the panel. Notice that the FlowPanel instance is then set as the content for the main frame's display.

```
package com.jeh.scala.swing

import scala.swing.Button
import scala.swing.FlowPanel
import scala.swing.MainFrame
import scala.swing.SimpleSwingApplication

class ButtonPanel extends MainFrame {
  val b1 = new Button { text = "Click Me!" }
  val b2 = new Button { text = "Click Him!" }

  val panel = new FlowPanel {
    contents += b1
    contents += b2
  }

  contents = panel
}

object SwingHelloWorld2 extends SimpleSwingApplication
{
  def top = new ButtonPanel()
}
```

Note that we could of course have created the FlowPanel and then added the buttons to the FlowPanel's contents buffer at a later date, for example:

```
 val panel = new FlowPanel()
panel.contents += b1
panel.contents += b2
```

You may be wondering at this point how the FlowPanel knew where to position the buttons—we did not give it absolute X and Y coordinates.

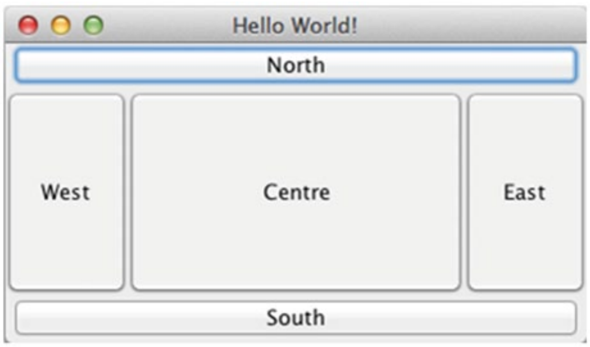


Fig. 40.4 Using the border-panel in a UI

The actual positioning of the components is handled by a object used by the panel. This object is known as a Layout Manager. A layout manager is thus the object that works with a graphical application and the host platform to determine the best way to display the objects in the window. The programmer does not need to worry about what happens if a user resizes a window, works on a different platform or a different windowing system.

Layout managers help to produce portable, presentable user interfaces. There are a number of different layout managers that use different philosophies to handle the way in which they lay out components: `FlowLayout`, `BorderLayout`, `GridLayout`. Note that if you are familiar with Java's Swing library then you will note that in Scala the layout managers, that handle actually determining where components are placed, are combined with the panels rather than being separate entities. Thus we have FlowPanel, GridPanel, BorderPanel etc.

40.6.3 Working with a BorderPanel

FlowPanel is not the only panel type available to theScala programmer. Another type of panel is the BorderPanel. The BorderPanel possesses a layout manager that has a concept of four outer points and a central point (labelled North, East, South, West and Center).

The panel is thus divided up as illustrated in Fig. 40.4. Of course, you do not have to place components at all available locations. If you omit one (or more) locations, the others stretch to fill up the space (except center which depends on the size of the window in which the BorderPanel is being used). The border panel honours the height of the components in the north and south regions (but forces them to fill the region horizontally). In turn it honours the width of the components in the East and West regions (but forces them to fill the available vertical space). The center component is forced to fill the remaining space (thus its preferred width and height are ignored).

```
package com.jeh.scala.swing

import scala.swing.Button
import scala.swing.MainFrame
import scala.swing.SimpleSwingApplication
import scala.swing.event.ButtonClicked
import scala.swing.BorderPanel
class WelcomeFrame extends MainFrame {
  title = "Hello World!"

  val b1 = new Button { text = "Centre" }
  val b2 = new Button { text = "North" }
  val b3 = new Button { text = "South" }
  val b4 = new Button { text = "East" }
  val b5 = new Button { text = "West" }
  val panel = new BorderPanel {
    add(b1, BorderPanel.Position.Center)
    add(b2, BorderPanel.Position.North)
    add(b3, BorderPanel.Position.South)
    add(b4, BorderPanel.Position.East)
    add(b5, BorderPanel.Position.West)
  }

  contents = panel

}

object SwingHelloWorld4 extends
SimpleSwingApplication {
  def top = new WelcomeFrame()
}
```

In the above program, we create five buttons that are positioned within the BorderPanel using the position constraints, Center, North, South, Each and West.

40.6.4 Working with a BoxPanel

Yet another panel is the BoxPanel this is similar to the FlowLayout except that it can have a Horizontal or a Vertical orientation. In which case it either lays out components across the screen or down the screen depending upon the orientation. It therefore offers greater flexibility that the FlowPanel.

The following program uses the Horizontal orientation to create a display similar in style to the FlowLayout. The display contains a button and a label and is shown in Fig. 40.5.

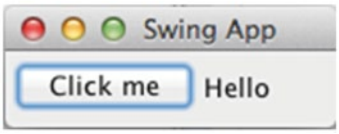


Fig. 40.5 Using a boxpanel

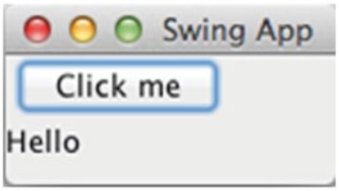
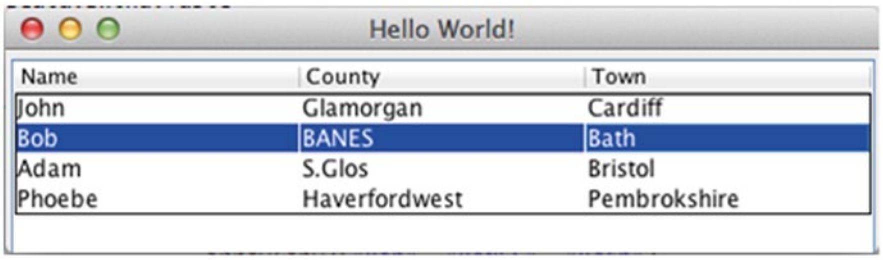


Fig. 40.6 An alternative orientation for the boxpanel

```
package com.jeh.scala.swing

import scala.swing.BoxPanel
import scala.swing.Button
import scala.swing.Label
import scala.swing.MainFrame
import scala.swing.Orientation
import scala.swing.Swing
import scala.swing.SimpleSwingApplication

/**
 * Orientation example
 */
object SwingHelloWorld5  extends
SimpleSwingApplication {
def top = new MainFrame {
    title = "Swing App"
    val button = new Button {
      text = "Click me"
    }
    val label = new Label {
      text = "Hello"
    }
    contents = new BoxPanel(Orientation.Horizontal) {
    //contents = new BoxPanel(Orientation.Vertical) {
      contents += button
      contents += label
    }
  }
}
```

Note that we change the orientation of the BoxPanel such that it has vertical orientation as shown below:



Name	County	Town
John	Glamorgan	Cardiff
Bob	BANES	Bath
Adam	S.Glos	Bristol
Phoebe	Haverfordwest	Pembrokshire

Fig. 40.7 Using a table in a UI

```
        contents = new BoxPanel(Orientation.Vertical) {
              contents += button
              contents += label

            }
```

This results in the display altering as shown in Fig. 40.6. Now the button is positioned above the label rather than beside it.

40.6.5 Displaying a Table

Another common user interface component is the Table. Tabes are user to present tabular information using rows and columns. A simple example table is shown in Fig. 40.7. This table has a row containing the headings (which are 'name', 'county' and 'town'). And four rows with the actual data. Such tables can respond to user selection, editing and ordering. However, in this example, it is a read only table that cannot be altered.

To create a table we use the scala.swing.Table class. This can be constructed with an array of names and an array of arrays for the data. Strictly speaking behind the table is a table model that holds the actual data (see Fig. 40.8). There are also cell renderers that are used to determine how to display different types of data. In the following listing we are merely using two arrays as a very simple way of initialising these models.

The following listing creates a new Table using the headers and rowData arrays. The border property of the Table is set to be a LineBorder coloured in Black. This is from the javax.swing.border package which is part of the underlying Java Swing library that is being reused here. Note that the Colour Black is from the underlhing java.awt package that includes the Color type.

Once the table is created it is added the FlowPanel which is used for the main contents of the window. Note that the table is wrapped within a ScrollPane. This provides any scrollbars for the table if they are required.

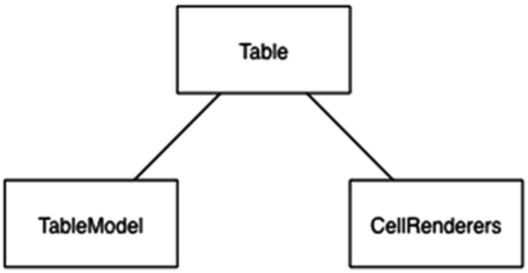


Fig. 40.8 Relationship between table, tablemodel and cellrenderers

```
package com.jeh.scala.swing

import java.awt.Color

import scala.swing.FlowPanel
import scala.swing.MainFrame
import scala.swing.ScrollPane
import scala.swing.SimpleSwingApplication
import scala.swing.Table

import javax.swing.border.LineBorder

class TableFrame extends MainFrame {
  title = "Hello World!"
  val headers = Array("Name", "County", "Town")
  val rowData =
        Array(
          Array[Any]("John", "Glamorgan", "Cardiff"),
          Array[Any]("Bob", "BANES", "Bath"),
          Array[Any]("Adam", "S.Glos", "Bristol"),
          Array[Any]("Phoebe", "Haverfordwest",
"Pembrokshire"))

  val table = new Table(rowData, headers) {
    border = new LineBorder(Color.BLACK)
  }
  contents = new FlowPanel {
    contents += new ScrollPane(table)
  }
}

object TableSample extends SimpleSwingApplication {
  def top = new TableFrame()
}
```

Chapter 41
User Input in Scala Swing

41.1 Introduction

The last chapter looked at various different types of user interface component available within Scala Swing. This chapter now looks at how user input, via those components, can be handled.

41.2 Handling User Input

If you are familiar with the Java Swing event delegation model then you will find the Scala approach to handling user input a great deal simpler. It is based on the idea of using pattern matching within reactors to handle user input. Objects publish events that are listened to by a list of reactors. A `Reactor` a Partial Function that is defined by the Type Reaction on the Reactions object to take an Event and return Unit.

If a reactor matches the event type and the source specified then the associated behaviour is invoked. This framework is based on the classes that emit events mixing in the Publisher trait and classes that listen to publishers mixing in the `Reactor` trait.

The Publisher trait defines the `publish` method, the `listeners` property and invokes the listenTo behaviour. The `listeners` property holds a list of reactors that will react to the events raised by the source component. An event is just an object containing information associated with the action that occurred. For example, a `ButtonEvent` indicates the source object that the user clicked on where as a `MouseEvent` may include the x and y coordinates of the mouse when it was clicked or moved etc. The `publish` method is defined as

```
def publish(e:Event){for(l<- listeners) l(e)}
```

This sends the event 'e' to all the members of the `listeners` list.

DOI 10.1007/978-3-319-06776-6_41, © Springer International Publishing Switzerland 2014

The `Reactor` trait defines two methods `deafTo` and `listenTo` and the property reactions. The methods are defined as:

- `def deafTo(ps:Publisher*):Unit`
- Installed reaction won't receive events from the given publisher any longer.
- `def listenTo(ps:Publisher*):Unit`
- Listen to the given publisher as long as `deafTo` isn't called for them.

For example, for an instance to listen to the event generated by a button we could write:

```
listenTo(`button`)
```

The reactions property is an instance of a subclass of the Reactions abstract class. It defines a set of methods which allow the reactions held in the reactions list to be processed. It also defines the += and −= methods that can be used to add or remove reactors from the list of reactors:

- `def+=(r:Reaction) Add a reaction.`
- `def-=(r:Reaction) Remove the given reaction.`

An example of using the += method to add some reactors is given below:

```
reactions += {
    case ButtonClicked(`b1`) => println("Hello World")
    case ButtonClicked(`b2`) => println("North")
    case ButtonClicked(`b3`) => println("South")
    case ButtonClicked(`b4`) => println("East")
    case ButtonClicked(`b5`) => println("West")
  }
```

In this example, we have added 5 reactors to the reactions list that handle behaviour on different buttons.

Thus to listen to user events on buttons, combo boxes, tables, menus etc. it is necessary to mix in the *Reactor* trait and to register yourself with the UI components you wish to listen to. This is what the following examples do.

The first example relies on the fact that the `MainFrame` mixes in the `Reactor` trait. This means that you can define the reactions to a button within the body of the `MainFrame` itself. Also note that the `MainFrame` uses the `listenTo` method to register itself with the button. The user interface generated by the code is shown in Fig. 41.1.

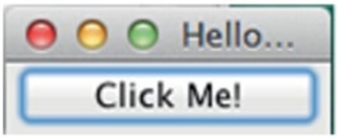
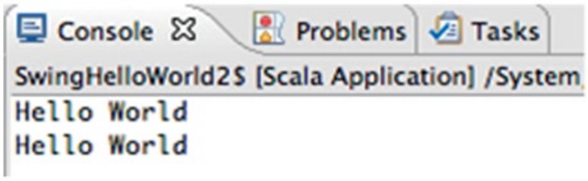


Fig. 41.1 A Button in a UI



```
SwingHelloWorld2$ [Scala Application] /System
Hello World
Hello World
```

Fig. 41.2 Output from the reactor when button clicked twice

```
package com.jeh.scala.swing

import scala.swing.Button
import scala.swing.MainFrame
import scala.swing.SimpleSwingApplication
import scala.swing.event.ButtonClicked

class SimpleFrame extends MainFrame {
  title = "Hello World!"
  valbutton = new Button {
    text = "Click Me!"
  }
  contents = button

  listenTo(button)

  reactions += {
  case ButtonClicked(button) =>
        println("Hello World")
  }
}

object SwingSample1 extends SimpleSwingApplication {
  def top = new SimpleFrame()
}
```

In the above code the mainframe listens to the button for events that it is publishing. When those events are received the reactors in the reactions list are checked in sequence to find one that will handle the event. In this case the event is the `ButtonClicked` event. Thus when the user clicks the button the String Hello World should be printed out to the console. This is illustrated in Fig. 41.2.

One problem with this code is that the reactor is defined by the `MainFrame`. Whist this works for a simple application is it unlikely that this approach would work in a larger application. Therefore the following listing modifies this approach and defines a separate class `ButtonReactor` that mixes in the `Reactor` trait and defines the reactions within itself. It is then instantiated and used by the `SimpleFrame`

(`MainFrame`). Note that the reactor must be registered with the button buy having the `listenTo` method called on it rather than on the `MainFrame`:

```
package com.jeh.scala.swing.event

import scala.swing.Button
import scala.swing.MainFrame
import scala.swing.SimpleSwingApplication
import scala.swing.event.ButtonClicked
import scala.swing.Reactor

class SimpleFrame2 extends MainFrame {
  title = "Hello World!"

  val button = new Button {
    text = "Click Me!"
  }
  val reactor = new ButtonReactor()

  contents = button

  reactor.listenTo(`button`)
}

class ButtonReactor extends Reactor {
  reactions += {
    case ButtonClicked(button) =>
      println("Hello World")
  }
}

object SwingSample2 extends SimpleSwingApplication {
  def top = new SimpleFrame2()
}
```

The actual user interface and the output remain unchanged.

41.2.1 Scala Swing Actions

An action can be used to separate the behaviour associated with a button (or menu item) from the instance of the button (or menu item) concerned. This can be useful as it is common within a user interface to have several ways to access the same operation. For example, from a button bar, from a tool bar or from a menu item etc. Using an action, this behaviour can be defined once (in the Action) and then reused with each of the UI components that will be presented to the user. Thus an Action separates the definition of some behaviour to be applied, from the UI component used to invoke that behaviour.

An action is defined using the `Action` type from the `scala.swing` package. The action can take a *title* and the functionality to be invoked when that action is used. Thus the following lines of code create an action with a title “Click Me” and the function to *apply* when the action is invoked (in this case to print a message to the console):

```
val myAction = Action("Click Me") {
    println("I was clicked")
}
```

This action instance can now be used with a range of UI components such as buttons and menu items. In the following listing we use this action with two buttons, `b1` and `b2`. Note that the action is used to initialise the action property of the buttons. Thus both buttons will invoke the same `println` function when clicked, wherever they are in the UI.

```
package com.jeh.scala.swing

import scala.swing.Action
import scala.swing.Button
import scala.swing.GridPanel
import scala.swing.Panel
import scala.swing.FlowPanel
import scala.swing.MainFrame
import scala.swing.SimpleSwingApplication

class ButtonPanel extends MainFrame {

  val myAction = Action("Click Me") {
     println("I was clicked")
   }

  val b1 = new Button { action =  myAction }
  val b2 = new Button { action =  myAction }

  val panel = new FlowPanel {
     contents += b1
     contents += b2
   }

  contents = panel
}

object SwingHelloWorld2 extends SimpleSwingApplication
{
  def top = new ButtonPanel()
}
```

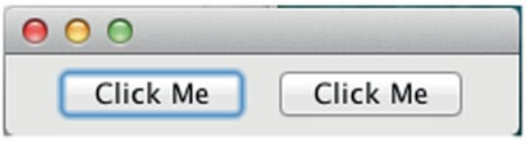


Fig. 41.3 A UI that reuses an Action

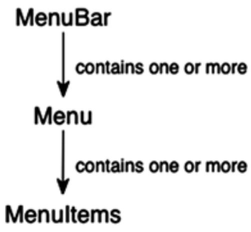


Fig. 41.4 Relationship between Menus, MenuBars and MenuItems

The end result of using the `myAction` with both buttons is that there is a single definition of the action behavior shared between the two button instances. Note that actions can also be enabled or disabled, have icons, tooltips etc.

The display generated from the above listing is shown in Fig. 41.3. The result of clicking on either of the Click Me buttons is that the string "I was clicked" is printed to the standard output.

41.2.2 Working with Menus

Many (most) applications will have some aspect of a menu bar, menus and items on those menus. In Scala such user interface components are represented by instances of the classes `MenuBar`, `Menu` and `MenuItem`. The relationship between these components is illustrated in Fig. 41.4. These classes are all defined in the `scala.swing` package.

As can be seen a `MenuBar` references (holds) one or more Menus. Menus in turn reference one or more `MenuItems`. `MenuItems` can be either simple menu items that may be selected, or menus in their own right. This is because the `Menu` type extends the `MenuItem` type and thus we can create hierarchical menus.

The following listing illustrates how a simple `MenuBar`, with a single Menu (file) can be created. The Menu File has a single `MenuItem` (Exit) that is defined using an Action. Note that the `MenuBar` is used to set the `menuBar` property of the `MainFrame`. The `MenuBar` has a contents property, which we are adding the Menu to. Also note that the Menu has a contents property to which we are adding the `MenuItem` (be careful not to confuse these two).

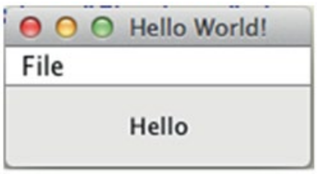


Fig. 41.5 A UI with a Menu Bar

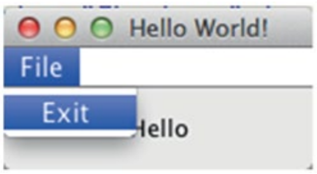


Fig. 41.6 : Selecting the 'Exit' Menu Item

```
package com.jeh.scala.menu

import scala.swing.MainFrame
import scala.swing.SimpleSwingApplication
import scala.swing.Label
import scala.swing.MenuBar
import scala.swing.Menu
import scala.swing.MenuItem
import scala.swing.Action

class SimpleFrame extends MainFrame {
  title = "Hello World!"
  contents = new Label {
    text = "Hello"
  }
  menuBar = new MenuBar {
    contents += new Menu("File") {
      contents += new MenuItem(Action("Exit") {
        sys.exit(0)
      })
    }
  }
}

object SampleMenuUI extends SimpleSwingApplication {
  def top = new SimpleFrame()
}
```

The result of executing this program is illustrated in Fig. 41.5 and Fig. 41.6. The first figure shows the basic `MenuBar` display with the File menu shown. The second figure illustrates what happens when the user moves their mouse over the File menu and selected the Exit Menu Item.

When the user selects the Exit option, as shown in Fig. 41.6, then the behaviour defined by the Action in the earlier listing is invoked. In this case it is to call the `sys.exit(0)` operation. This invokes the exit behaviour on the System with a return code of '0', which typically indicates that the application terminated normally.

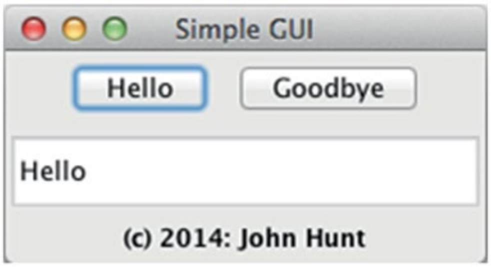


Fig. 41.7 A simple graphical application

Explicitly invoking the `sys.exit` operation is necessary as the *main* method, which is usually used to control when an application terminates is only used to initiate the display. After that, the main method terminates and the execution of the system is handed over to a UI thread (process). We must therefore be able to terminate this process in a controlled manner; this is done using the `sys.exit` operation.

41.3 A Simple GUI Example

In this section we present a very simple GUI example. An instance of this class generated the window displayed in Fig. 41.7. This application performs the following functions:

- Displays the string “Hello” in a text field in response to the user clicking on the Hello button.
- Displays the string “Goodbye” in a text field in response to the user clicking on the Goodbye button
- Exits the application in response to the user clicking on the Exit button.

It combines the layout panels and components presented in the last chapter, with the event handling mechanism described above.

The components that comprise this user interface are illustrated in Fig. 41.8. This shows that the buttons are organised (displayed by) a flow panel (which does not itself have any visible presence). The strings are displayed in a text field and a label displays the copyright statement. These are all organised within a border panel that is the top-level contents of the `SimpleGUI MainFrame`.

The class `SimpleGui`, see the listing below, first sets the title of the frame to be “Simple GUI”. It then creates two buttons, which have a text label and a tooltip. It then creates a new `FlowPanel` onto which it adds two buttons. The program then creates a non-editable field—note that the editable property is set to false after the text field is created—this allows this property to change its value over time. It finally creates a label, for the copyright string. This label uses a new font (the Ariel font) and introduces a buffer to give a bit of spacing around the text using the `scala.swing.Swing` utility type. The button panel, text field and label are added to the border panel using the constraints `Position.North`, `Position.Center` and

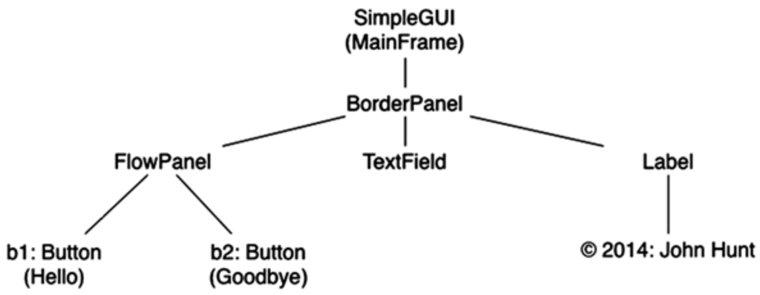


Fig. 41.8 Structure of Simple GUI application

`Position.South` respectively. Note that we have imported `scala.swing.BorderPanel._` so that we only need to specify `Position.North` rather than `BorderPanel.Position.North` which is easier to read. Finally the window sets a default size using a new Dimension instance.

```
package com.jeh.scala.sample

import scala.swing.MainFrame
import scala.swing.SimpleSwingApplication
import scala.swing.FlowPanel
import scala.swing.Button
import java.awt.FlowLayout
import scala.swing.BorderPanel
import scala.swing.BorderPanel._
import scala.swing.TextField
import scala.swing.Label
import java.awt.Dimension
import scala.swing.event.ButtonClicked
import javax.swing.border.EmptyBorder
import java.awt.Font
import scala.swing.Swing

class SampleGui extends MainFrame {
  title = "Simple GUI"
  // Set up the buttons
  valb1 = new Button {
    text = "Hello"
    tooltip = "Click to say hello"
    }
    val b2 = new Button {
        text = "Goodbye"
        tooltip = "Click to say goodbye"
    }

    // Set up panel for buttons (using a flow layout)
    val panel = new FlowPanel {
    contents += b1
    contents += b2
    }
    // Create a non-editable text field and add that
    val field = new TextField()
    field.editable = false

    // Create a label for the frame
    val label = new Label() {
        text = "(c) 2014: John Hunt"
        border = Swing.EmptyBorder(5,5,5,5)
        font = new Font("Ariel", Font.BOLD, 12)
    }

    // Setup litensing to the buttons and reactions
    listenTo(b1, b2)
    reactions += {
      case ButtonClicked(`b1`) => field.text = "Hello"
      case ButtonClicked(`b2`) => field.text = "Goodbye"
    }

    contents = new BorderPanel() {
      // Add the button panel to the frame
          add(panel, Position.North)
      // Add the text field to the centre
          add(field, Position.Center)
      // Add the label to the bottom of the display
          add(label, Position.South)
    }

    // Resize the window
    size = new Dimension(300, 150)

  }

  object SampleGui extends SimpleSwingApplication {
    def top = new SampleGui()
  }
```

Note that the two buttons are listened to and thus we define two reactors to handle what should happen when the user clicks on a button. In this case we set the `field.text` property to the appropriate string. You could have a different controller for each button. In such a situation, you do not need to test to see which button generated an event (thus eliminating the `case` pattern matching statement that selects the actual behaviour to perform).

Chapter 42
Scala Build Tools

42.1 Introduction

There are many ways in which a Scala application can be *built*. These include the REPL loop and automated compilation within an IDE such as the Eclipse based Scala IDE. However, neither of these is suitable for centrally building large applications as might be found within many commercial organisations. The most popular build environments for Scala are Maven and the SBT. In this chapter we will briefly examine both so that you have a flavour of both tools and the potential benefits and drawbacks of each.

42.2 Why we need a Build Tool

The first question to consider is why we need a build tool in the first place. In this book we have successfully compiled our Scala applications using the Scala IDE although we could have compiled them form the command line or used the Scala REPL interpreter. However, many applications are comprised of many parts, all of which need to be processed in the appropriate way and package as required. For example, many web applications are made up of multiple components:

- HTML files and image files
- PHP scripts
- Java or Scala services
- The libraries used by Scala and Java
- Configuration files
- Database scripts
- Property or metadata data files

Multiple people may develop all of these elements at different times and on different machines. In addition, the process of building a project may require several steps or involve different phases, such as compiling the code, testing, the code, packaging

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the system up as required by the target platform, installing it on that platform and deploying it into the target runtime environment etc. This is illustrated in Fig. 42.1.

These steps must be repeatable and must bring together a diverse range of elements.

As mentioned before we could of course use our favourite IDEs or write our own build scripts, however:

- You can build your projects manually but this is tedious and error prone
- You can use IDEs like Scala Eclipse. This approach is easy, but not very portable to server environments, and requires each person to build their part independently of others.
- You can write scripts to automate the process using tools such as Ant. This approach does have benefits to commend it, however a great deal of time can be spent on designing, testing and maintaining the scripts.

Another approach is to use a dedicated build tool such as Maven or SBT. Both these tools come with useful internal or default knowledge about different types of projects, how to build them (for Java and Scala) and what constitutes the normal build cycle for different types of applications.

42.3 Maven

Maven is an Industry standard project build tool that understands project lifecycle as well as the steps that make up such a lifecycle (see http://maven.apache.org).

Maven was originally designed for the Java programming language but is equality applicable to Scala and thus is very widely used within industry.

Maven is a convention over configuration-based system. This means that if you follow the standard conventions then you do not need to explicitly specify additional information. For example, if you are creating a web application then as long as you follow the conventions, Maven will know where to find the elements that make up a web application and can package them appropriately when asked to build the system. This greatly reduces the amount of project set up and management required. However, the defaults are primarily oriented towards Java applications and thus for Scala we need to indicate that we are working with Scala and thus there are additional configurations required (although in practice these can be provided by a Maven archetype—a type of template that provides defaults for different types of projects).

The other major feature of Maven is its ability to handle the dependencies that applications have to libraries (and additionally the transitive dependencies that these libraries themselves have). Maven does this using dependency information associated with the type of the project and the specific libraries used by the developer. To access the definitions for these libraries it uses a dependency framework that can download libraries from a central repository. This idea is illustrated in Fig. 42.2.

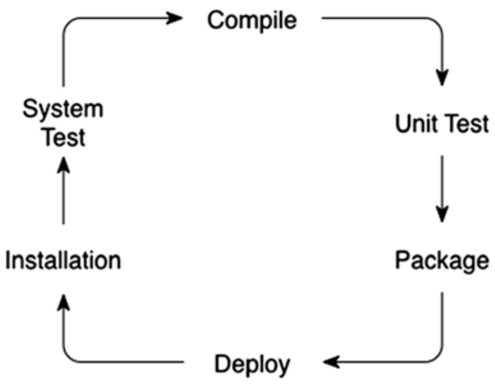


Fig. 42.1 The build cycle for applications

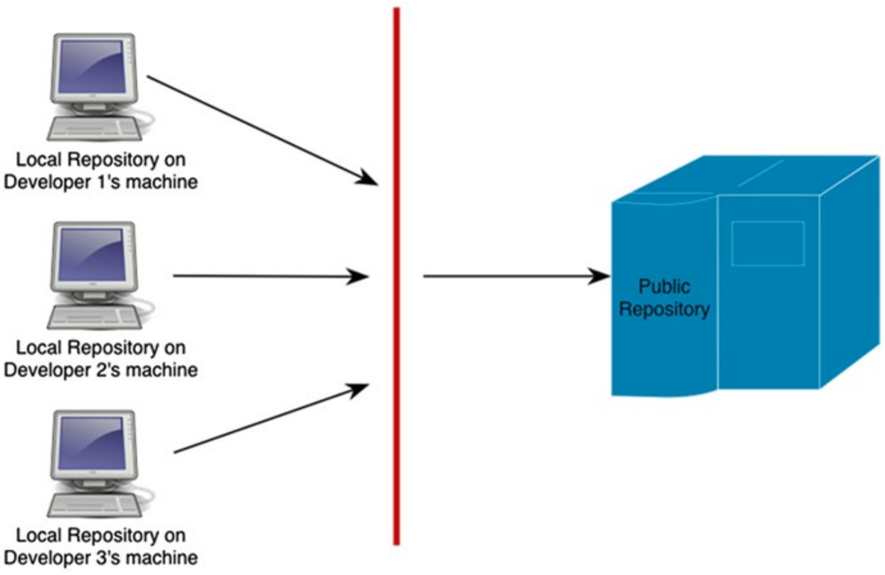

Local Repository on Developer 1's machine
Local Repository on Developer 2's machine
Local Repository on Developer 3's machine
Public Repository

Fig. 42.2 Local versus remote repository structure

When a developer runs a Maven command, maven checks to see if it is necessary to access a particular library. If that is required it will look in a number of predefined repository locations and access the first that it find.

Maven also understands the concept of versioning of libraries and thus it can distinguish between the latest release of a library as well as previous releases of that library (such as release 1, 2 or 3) and access an appropriate version.

42.3.1 Maven Repositories

The concept of a repository is very important within Maven and there are two flavours of repository as shown in Fig. 42.2. These are remote and local repositories:

- **Remote repository**. A remote repository is accessed over a network and may be hosted internally to an organisation and/ or externally on the Internet. The central Maven repository can be viewed via a browser at http://mvnrepository.com. In many cases an organisation will have their own version either to control the library versions used or to improve performance.
- **Local repository**. A local cache of downloaded artefacts, libraries and latest builds is maintained on each developer's machine. Maven first checks locally before trying to download a library—thus reducing the overhead of library access.

The use of repositories and library version information is one of Mavens biggest benefits.

42.4 The Maven POM

The core concept within Maven is the Project Object Model or POM (and example is shown in Fig. 42.3). The POM is actually an XML file that is used to tell Maven what type of project is being created and to provide Maven with any additional configuration information that cannot be deduced using the convention over configuration model.

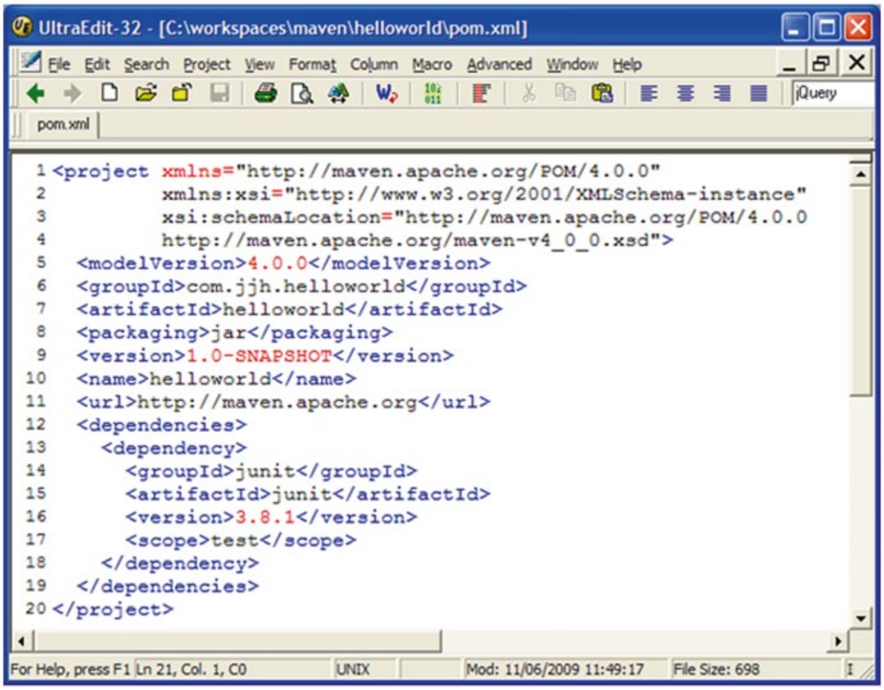
The POM contains detailed metadata information about the project, including

- Organisational information (such as your group Id which is often your organisations domain in reverse) and project specific information such as the name of the project and the version of the project being built.
- Dependencies such as libraries being used within the project. For example, ScalaTest is a common library to specify.
- The type of project being constructed such as a standalone application, a web application, a service etc.
- Application and testing resources such as data or configuration files.

The POM file can also be used to override any of the default assumptions made by Maven but this is often not required.

The Maven conventions not specified in Fig. 42.3 include the location of the source code and the test code, the locations of the repositories containing the libraries, the steps involved in constructing a stand alone application etc. These are all defaulted. For example, Maven assumes that all source code is found in the following locations:

- src/main/java
- src/main/test


UltraEdit-32 - [C:\workspaces\maven\helloworld\pom.xml]
File Edit Search Project View Format Column Macro Advanced Window Help
pom.xml
For Help, press F1 Ln 21, Col. 1, C0 UNIX Mod: 11/06/2009 11:49:17 File Size: 698

```xml
<project xmlns="http://maven.apache.org/POM/4.0.0"
         xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
         xsi:schemaLocation="http://maven.apache.org/POM/4.0.0
         http://maven.apache.org/maven-v4_0_0.xsd">
  <modelVersion>4.0.0</modelVersion>
  <groupId>com.jjh.helloworld</groupId>
  <artifactId>helloworld</artifactId>
  <packaging>jar</packaging>
  <version>1.0-SNAPSHOT</version>
  <name>helloworld</name>
  <url>http://maven.apache.org</url>
  <dependencies>
    <dependency>
      <groupId>junit</groupId>
      <artifactId>junit</artifactId>
      <version>3.8.1</version>
      <scope>test</scope>
    </dependency>
  </dependencies>
</project>
```

Fig. 42.3 Simple Java POM

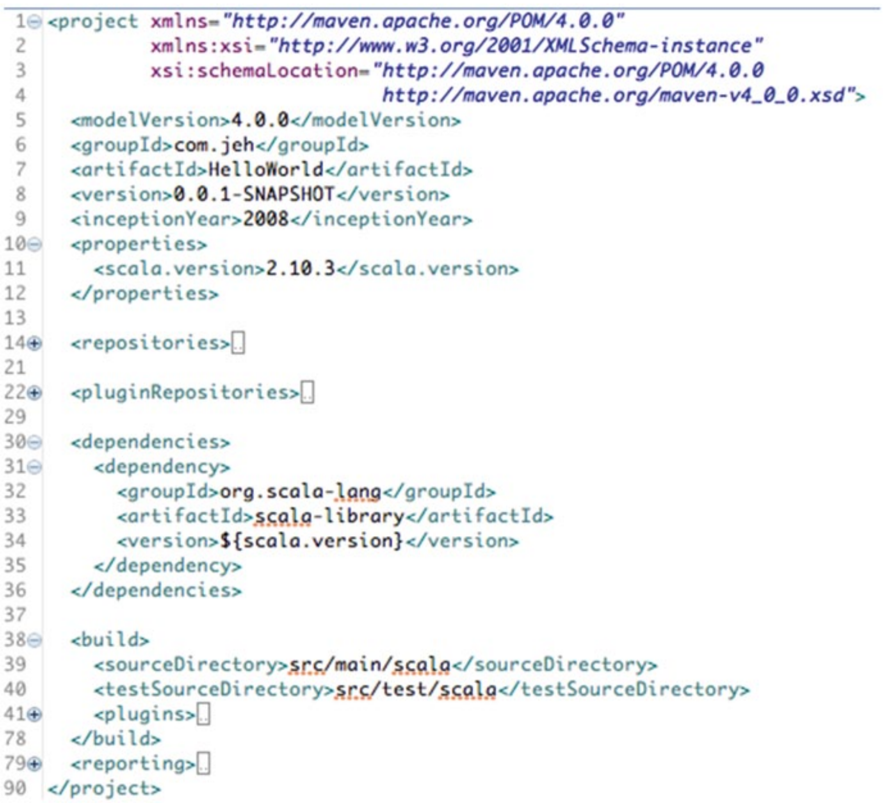
This is why it is common to find such structures in many other (non Maven) projects.

Of course, looking at the above directories you will note that they specify *java* in the path; we are working with Scala and thus this is one of the things that must be changed (or at least added) if we are to use Maven to build a Scala application. This is considered in the next section.

42.5 Scala and Maven

To use Maven with Scala we need to add some additional information to the project POM file. We need to indicate that we are using Scala and that location of our Scala code will not be under java. In Fig. 42.4 we add a dependency specifying that we are using Scala and specify that the Scala source code can be found in:

- src/main/scala
- src/test/scala



```xml
<project xmlns="http://maven.apache.org/POM/4.0.0"
         xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
         xsi:schemaLocation="http://maven.apache.org/POM/4.0.0
                             http://maven.apache.org/maven-v4_0_0.xsd">
  <modelVersion>4.0.0</modelVersion>
  <groupId>com.jeh</groupId>
  <artifactId>HelloWorld</artifactId>
  <version>0.0.1-SNAPSHOT</version>
  <inceptionYear>2008</inceptionYear>
  <properties>
    <scala.version>2.10.3</scala.version>
  </properties>

  <repositories>

  <pluginRepositories>

  <dependencies>
    <dependency>
      <groupId>org.scala-lang</groupId>
      <artifactId>scala-library</artifactId>
      <version>${scala.version}</version>
    </dependency>
  </dependencies>

  <build>
    <sourceDirectory>src/main/scala</sourceDirectory>
    <testSourceDirectory>src/test/scala</testSourceDirectory>
    <plugins>
  </build>
  <reporting>
</project>
```

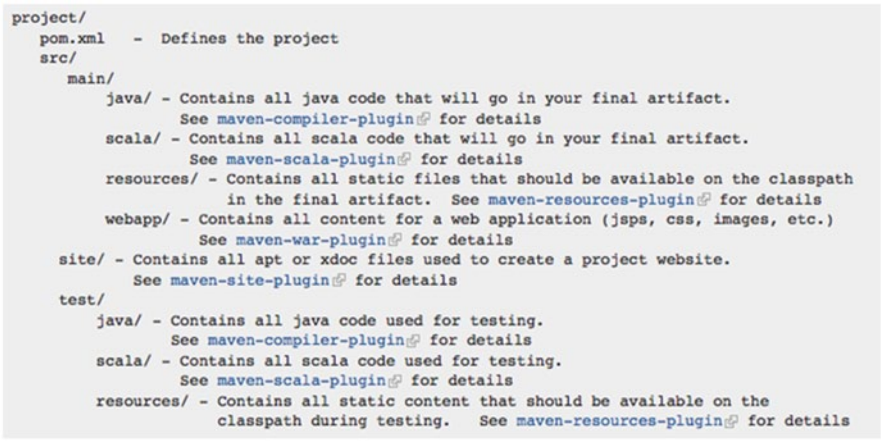
Fig. 42.4 A Scala configuration for a Maven POM file

Note that this does not stop us having multiple source directories under src/main and src/test and it is not uncommon in projects that use multiple language to have a structure such as:

- src/main/java
- src/main/scala
- src/main/javascript
- src/test/java
- src/test/scala
- src/test/javascript

Thus the final default project structure for such an application may be modified to include both a Java and a Scala root directory within the *main* and *test* paths. This is illustrated in Fig. 42.5.

The dependency entry that specifies that we are using Scala indicates the groupId for Scala (essentially the Scala organisations domain) and the artifactId (the name of the library) followed by the version. In the POM file the version is indicated by a Maven property *scala.version*, which is set at the top of the file. This means that it



```
project/
   pom.xml   -  Defines the project
   src/
      main/
          java/ - Contains all java code that will go in your final artifact.
                  See maven-compiler-plugin for details
          scala/ - Contains all scala code that will go in your final artifact.
                   See maven-scala-plugin for details
          resources/ - Contains all static files that should be available on the classpath
                       in the final artifact.  See maven-resources-plugin for details
          webapp/ - Contains all content for a web application (jsps, css, images, etc.)
                    See maven-war-plugin for details
     site/ - Contains all apt or xdoc files used to create a project website.
             See maven-site-plugin for details
     test/
         java/ - Contains all java code used for testing.
                 See maven-compiler-plugin for details
         scala/ - Contains all scala code used for testing.
                  See maven-scala-plugin for details
         resources/ - Contains all static content that should be available on the
                      classpath during testing.   See maven-resources-plugin for details
```

Fig. 42.5 Scala Maven project structure

is easy to find and change the version of Scala being used—this is a common idiom in Maven files. The end result is that the actual dependency is as shown below:

```
<dependency>
   <groupId>org.scala-lang</groupId>
   <artifactId>scala-library</artifactId>
   <version>2.10.3</version>
</dependency>
```

We must also indicate where to find the Scala libraries if they are not available within the main Maven repository. For a Scala project, Maven must be told where to find the Scala libraries. This may occur if you wish to use a non-standard or milestone version of Scala. In our case we are also adding the Scala tools repository as this provides some bridging tools between Maven and Scala:

```
<repositories>
      <repository>
          <id>scala-tools.org</id>
          <name>Scala-Tools                  Maven2
  Repository</name>
          <url>http://scala-tools.org/repo-
  releases</url>
      </repository>
  </repositories>
```

42.6 Maven Lifecycle Commands

The same build lifecycle commands can be used whatever the project (as Maven understand what they mean relative to that type of project) and thus we have the following available:

- **validate**—validate the project, check it compiles with the rules for that type of project.
- **compile**—compile the source code into.class files.
- **test**—test the compiled source code; run the tests defined within the src/test directory.
- **package**—package in distributable format e.g. jar
- **install**—install the package into the local repository
- **deploy**—copies the final package to the remote repository for sharing with other developers and projects.

If you are using an IDE, such as the Scala IDE, then you can use a Maven plugin that will help with creating projects, issuing maven commands, finding dependencies etc. For example, using the New Maven Project wizard with the Scala IDE displays a Maven archetype selection dialog. A Maven archetype is essentially a definition or template for a particular type of project. There are archetypes for web-based applications, archetypes for particular frameworks and a Scala archetype (as shown in Fig. 42.6)

The end result of creating a new project in this way is that the default Scala maven project structure is created as shown in Fig. 42.7.

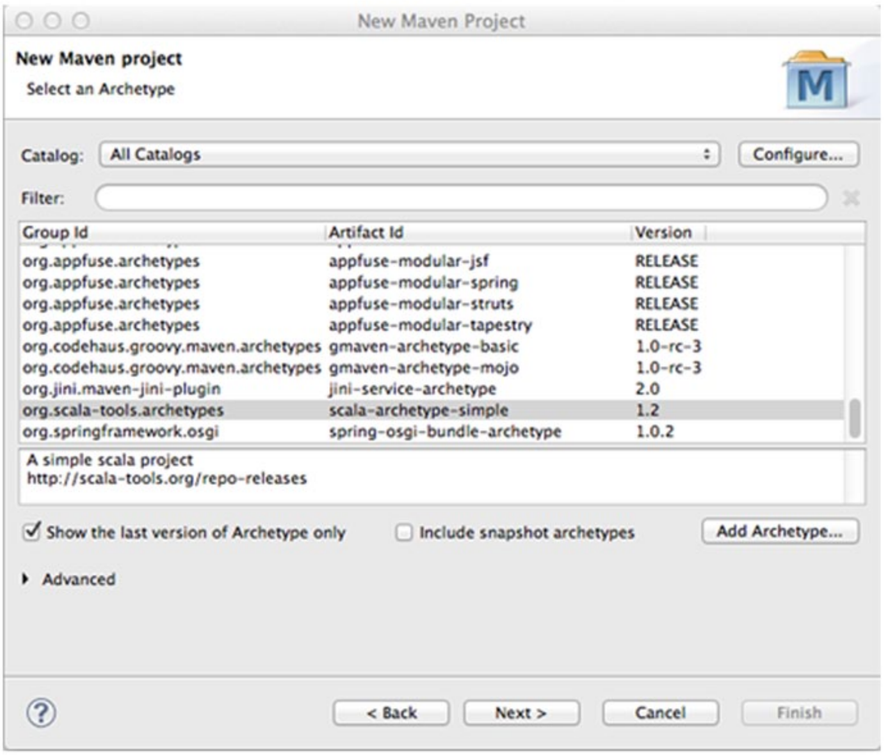
42.7 SBT

Although Maven was intended to simplify the definition and construction of applications, it can seem somewhat complex for very simple applications. As a consequence there have been initiatives to further simplify the project definition and build process. One such initiative is the Simple Build Tool, known as SBT for short.

SBT is an open source build system for Scala (and for Java although it was originally designed for, and is implemented in, Scala). The key features of the SBT are:

- minimal configuration for simple projects,
- support for Scala and (many) Scala Test frameworks,
- build tasks written in Scala DSL,
- dependency support via Ivy. Ivy is a dependencies management system that handles the version of, and dependencies between, libraries,
- Integration with Scala interpreter

It is used in many Scala projects including in the construction of Scala itself. It aims to simplify the build process to allow easy creation, compilation and deployment of Scala based applications.


New Maven project
Select an Archetype

Catalog: All Catalogs

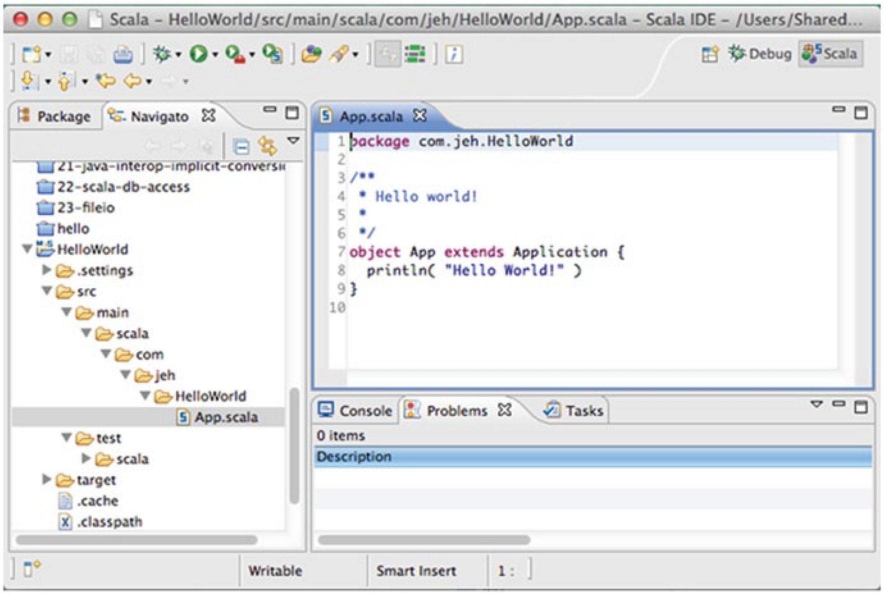
Filter:

Group Id	Artifact Id	Version
org.appfuse.archetypes	appfuse-modular-jsf	RELEASE
org.appfuse.archetypes	appfuse-modular-spring	RELEASE
org.appfuse.archetypes	appfuse-modular-struts	RELEASE
org.appfuse.archetypes	appfuse-modular-tapestry	RELEASE
org.codehaus.groovy.maven.archetypes	gmaven-archetype-basic	1.0-rc-3
org.codehaus.groovy.maven.archetypes	gmaven-archetype-mojo	1.0-rc-3
org.jini.maven-jini-plugin	jini-service-archetype	2.0
org.scala-tools.archetypes	scala-archetype-simple	1.2
org.springframework.osgi	spring-osgi-bundle-archetype	1.0.2

A simple scala project
http://scala-tools.org/repo-releases

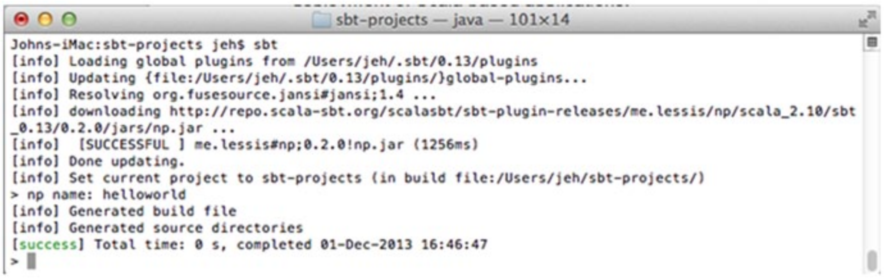
[✓] Show the last version of Archetype only
[ ] Include snapshot archetypes

Fig. 42.6 Selecting the Scala Maven archetype


Scala - HelloWorld/src/main/scala/com/jeh/HelloWorld/App.scala - Scala IDE - /Users/Shared...

```
package com.jeh.HelloWorld

/**
 * Hello world!
 *
 */
object App extends Application {
  println( "Hello World!" )
}
```

Fig. 42.7 A Scala Maven project in the Scala IDE



```
sbt-projects — java — 101×14
Johns-iMac:sbt-projects jeh$ sbt
[info] Loading global plugins from /Users/jeh/.sbt/0.13/plugins
[info] Updating {file:/Users/jeh/.sbt/0.13/plugins/}global-plugins...
[info] Resolving org.fusesource.jansi#jansi;1.4 ...
[info] downloading http://repo.scala-sbt.org/scalasbt/sbt-plugin-releases/me.lessis/np/scala_2.10/sbt
_0.13/0.2.0/jars/np.jar ...
[info]  [SUCCESSFUL ] me.lessis#np;0.2.0!np.jar (1256ms)
[info] Done updating.
[info] Set current project to sbt-projects (in build file:/Users/jeh/sbt-projects/)
> np name: helloworld
[info] Generated build file
[info] Generated source directories
[success] Total time: 0 s, completed 01-Dec-2013 16:46:47
>
```

Fig. 42.8 Creating a project using SBT

42.7.1 Creating an SBT Project

To create a project using SBT you need to take the following steps:

- Install SBT and create a script to launch it.
- Create a project directory with source files in it.
- Create your build definition.

SBT can be downloaded from the main SBT home page (http://www.scala-sbt.org)—there are a number of ways in which it is distributed but the simplest in many cases will be to down load the sbt.zip file. Once you extract the SBT content into an appropriate location you will need to configure it for your environment)—see the guidance on the SBT download page for your platform.

By following the SBT conventions we can get started by ensuring that:

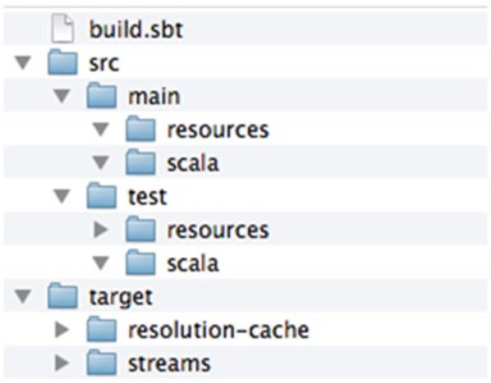
- Sources in the base directory
- Sources in src/main/scala or src/main/java
- Tests in src/test/scala or src/test/java
- Data files in src/main/resources or src/test/resources
- jars in lib directory

By default, SBT will build projects with the same version of Scala used to run SBT itself.

SBT provides an interactive mode (or console) in which you can use the SBT console to issue a series of commands and control the build process. Using the *sbt* command without any options allows the user to enter the interactive SBT console.

We will use SBT to create a new project via the SBT console. To do this we can use the *np* (new project) SBT plugin; prior to version 0.13 of SBT you could create a default project directly using SBT, however it is now necessary to use the *np* plugin (see the np site for directions on how to do this). This is indicated in Fig. 42.8. When issuing the *np* command from within the SBT console, it is necessary to provide the information for the name of the project and your organisation etc. The actual template structure follows that of Maven described earlier.

Fig. 42.9 Project structure



Once we have created a new project, we can now place our application code under the src/main/scala directory structure and place our tests under the src/test/scala structure (as shown in Fig. 42.9). The resources directory is for data files, property files etc. that might be used with our application.

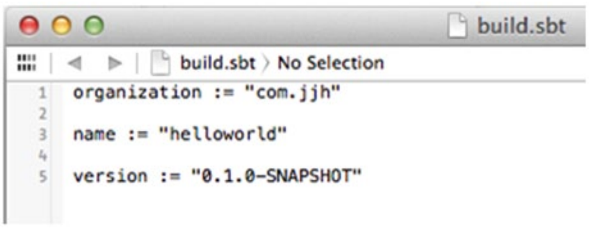
Although the aim of SBT is that there is little or no configuration required for simple projects, there are two ways of configuring SBT. The two approaches are the *light* configuration and the *full* configuration.

The light configuration approach is more akin to Ant (another Java build tool), which is an imperative approach to the definition of a build. That is, the light approach allows you to specify what constitutes the elements that comprise the version of the system to build explicitly but using a lightweight syntax. Figure 42.10 illustrates the SBT configuration file created for our new project earlier.

The *build.sbt* file is also where we would place any library dependency information for our project. For example:

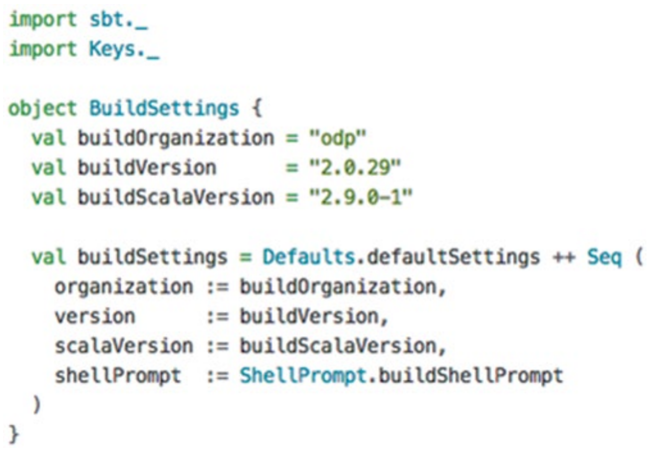
```
// Set the project name and version
name := "my-project"
version := "1.0.0"
// Add a single dependency, for tests.
libraryDependencies += "junit" % "junit" % "4.8" %
"test"
// Add multiple dependencies.
libraryDependencies ++= Seq(
    "net.databinder" %% "dispatch-google" % "0.7.8",
    "net.databinder" %% "dispatch-meetup" % "0.7.8" )
```

This specifies 'my-project' as the name of the project; that it is version 1.0.0; and that it is dependent on the JUnit library as well as two additional libraries.



```
organization := "com.jjh"

name := "helloworld"

version := "0.1.0-SNAPSHOT"
```

Fig. 42.10 The SBT build.sbt configuration file



```
import sbt._
import Keys._

object BuildSettings {
  val buildOrganization = "odp"
  val buildVersion      = "2.0.29"
  val buildScalaVersion = "2.9.0-1"

  val buildSettings = Defaults.defaultSettings ++ Seq (
    organization := buildOrganization,
    version      := buildVersion,
    scalaVersion := buildScalaVersion,
    shellPrompt  := ShellPrompt.buildShellPrompt
  )
}
```

Fig. 42.11 Part of a Scala definition for a full configuration file for SBT

The full configuration approach is essentially a Scala program implemented using the SBT DSL for defining the build process. As such you can write almost anything in the full configuration. However, the DSL makes it easier to specify that common tasks are to be performed. An example of part of a full configuration file is shown in Fig. 42.11. As can be seen from this example, it captures similar information to the simple *build.sbt* file but does it in terms of Scala objects.

42.7.2 SBT Lifecycle Commands

In a similar manner to Maven SBT can be used to issue a series of build commands such as

- **clean** Deletes all generated files (in the target directory).
- **compile** Compiles the main sources (in src/main/scala and src/main/java directories).
- **test** Compiles and runs all tests.

- **console** Starts the Scala interpreter with a classpath including the compiled sources and all dependencies. To return to sbt, type:quit, Ctrl + D (Unix), or Ctrl + Z (Windows).
- **run** <argument>* Runs the main class for the project in the same virtual machine as sbt.
- **package** Creates a jar file containing the files in src/main/resources and the classes compiled from src/main/scala and src/main/java.
- **help** <command>Displays detailed help for the specified command. If no command is provided, displays brief descriptions of all commands.

However, SBT can be used with Eclipse as an underlying tool. This requires the installation of the SBT plugin in a similar manner to the installation of a Maven plugin.

Further Readings

Ant home page http://ant.apache.org/
Maven home page http://maven.apache.org/
Maven and Scala http://www.scala-lang.org/node/347
Maven Repository http://mvnrepository.com/
Simple Build Tool (SBT) http://www.scala-sbt.org

SBT and Eclipse
https://confluence.dev.bbc.co.uk/display/linkeddata/Cheat+sheet+for+using+Eclip
se+to+develop+Scala+applications+on+the+sandbox
SBT np plugin (for new projects)—https://github.com/softprops/np

Chapter 43
Scala & Java Interoperability

43.1 Introduction

In this chapter we will look at the interoperation of Java and Scala. Both Java and Scala are JVM Byte Code Languages. That is, they both compile to the byte code language that is understood by the JVM. The Byte Code language of the JVM was originally designed to be the *compiled* form of Java and was what the Java Virtual Machine executed. However, things have evolved such that today the JVM is a virtual environment for executing Byte Code languages. In fact there are now several languages that can be compiled to JVM Byte Codes including Java, Groovy, Clojure, Jruby, Jython, JavaScript, Ada, Pascal as well as Scala.

As such at the byte code level there is no difference between Java and Scala—they are just different starting points for the same destination. Thus at runtime it is only the byte code that execute—there is no such thing as Java or Scala etc. Scala can thus interoperate with other Byte Code languages.

43.2 A Simple Example

As a simple example, consider the Scala Person shown below:

```
package com.jjh.scala

class Person (name: String="John", var age:Int=47)
```

This class compile to a Person.class file just as any other byte code language. This means that it can be used within Scala or Java. The following code sample illustrates the use of the Scala class Person within a Java application:

```
package com.jjh.scala;

/**
 * This is a standard Java class with a main method.
 * But note that Person is a Scala class.
 *
 * This illustrates the interop between Scala and Java.
 */
public class JavaInteropTest1 {

    public static void main(String [] args) {
        System.out.println("Hello from Java");
        Person p = new Person("Granny", 80);
        System.out.println(p);
    }

}
```

Notice that as far as Java is concerned that this is a class Person with a constructor that takes a String and an Integer. Also notice that both the Scala class Person and the Java class JavaInteropTest1 are in the same package (com.jjh.scala). This works because form a byte code point of view there is no difference between a Scala class Person in the package com.jjh.scala and a Java class Person in the same package—they are both byte classes in the package com.jjh.scala.

43.3 Inheritance

It is possible to inherit between Java and Scala classes. For example, in the following, Employee is a Java class while Person is the Scala class presented in the previous section. The rules for constructors are maintained and the Java class can call the super classes constructor.

```
package com.jjh.scala;

/**
 * This is a Java class that extends a Scala class!
 *
 * Note the call to super for the parent class
 * constructor.
*/
public class Employee extends Person {

    private String company;

    public Employee(String name, int age, String company)
{
        super(name, age);
        this.company = company;
    }

    public String toString() {
        return super.toString() + ", " + company;
    }

}
```

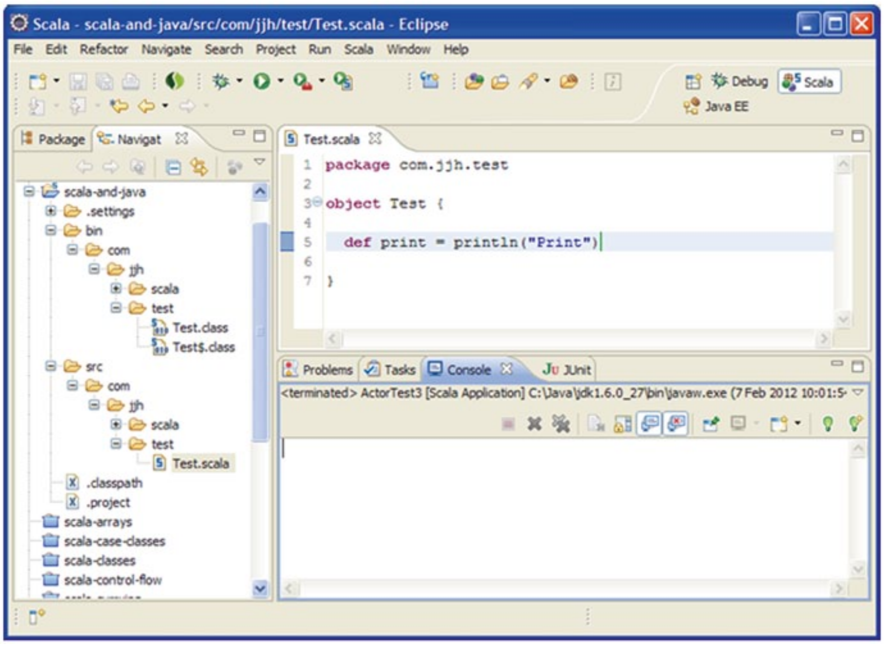
However, there may be some surprises in terms of the methods inherited by the class Employee. The Scala class Person extends the class AnyRef by default (and not the class Object). Thus the class Person inherits all the methods defined by the Scala types AnyRef and Any. However, Any extends Object and this methods such as toString, hashcode and equals define din Object are also present.

43.4 Issues

There are of course some issues related to interoperating between Scala and Java. The first one of which is that Scala requires a Java 6 or newer Runtime to operate within. The other is that Scala has some concepts that Java has no knowledge of such as *obejcts*, *traits* and *functions* as first class language elements. This last may change with the next version of Java but the functional elements of Java 8 may or may not align with Scala. In turn Scala has no concept of an Interface. Therefore if care is not taken problems may arise.

In general Scala to Java interoperability is relatively seamless as Scala builds on top of Java. However, Java to Scala can sometimes be problematic. The most common set of issues are:

- Java has no equivalent of Traits.
- Functions are object values.
- The Scala type system is more complex.
- Scala has no notion of static so can't access statics in the same way as Java code.
- Java doesn't understand Scala's companion module.
- Java sees Scala objects as a final class with statics.



```
package com.jjh.test

object Test {

  def print = println("Print")

}
```

```
<terminated> ActorTest3 [Scala Application] C:\Java\jdk1.6.0_27\bin\javaw.exe (7 Feb 2012 10:01:5
```

Fig. 43.1 Scala often generates multiple .class files for a single Scala concept

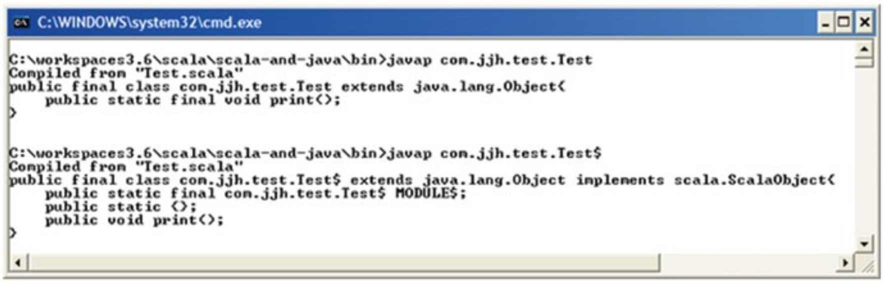
43.4.1 Scala Objects

Of course the underlying Byte Code representation also lacks many of the features of Scala presented above. Scala therefore often generates more than one byte code class or type for a single Scala concept. This is illustrated in Fig. 43.1.

This can make it difficult to decide how to treat a Scala concept form the Java side. It can be useful to examine what these class files contain in order to understanding the Java view of these structures. This can be done using the javap program. Javap is the class file disassembler distributed with the standard Oracle SDK. The result of using the javap program with the Test examples is shown in Fig. 43.2.

What this shows is that the Scala object *Test* is represented at the byte code level by a public final class Test and a second class Test$ which is also public and final. Note that ScalaObject was something added to all compiled code prior to Scala 2.10. Since Scala 2.10 it has been deprecated and is now only included for backwards compatibility.

How would you then call the Scala object Test from java? From the javap decompilation you have a choice of the Test class with a static method print and the Test$ class with a non-static method print. In fact in this case from Java we can just



```
C:\workspaces3.6\scala\scala-and-java\bin>javap com.jjh.test.Test
Compiled from "Test.scala"
public final class com.jjh.test.Test extends java.lang.Object{
    public static final void print();
}

C:\workspaces3.6\scala\scala-and-java\bin>javap com.jjh.test.Test$
Compiled from "Test.scala"
public final class com.jjh.test.Test$ extends java.lang.Object implements scala.ScalaObject{
    public static final com.jjh.test.Test$ MODULE$;
    public static {};
    public void print();
}
```

Fig. 43.2 Decompiling the byte code classes created by the Scala compiler

treat the object test as if it was a statically defined entity. This is because the static method on a final class means that we cannot extend the class test and the we can call the method without needing to instantiate the class. Thus we can just write:

```
package com.jjh.test;

public class JavaTest {

 public static void main(String[] args) {
       Test.print();
 }

}
```

Which is semantically closest to the concept embodied in the Scala object that we can get in Java.

43.4.2 Companion Modules

Companion Modules are another point of conflict in that Scala has the concept of a class and an associated companion object (which must have the same name as the class and be defined within the same file). For example:

```
package com.jjh.companion

/**
 * The Companion class
 */
class Session(var id: Int) {

}

/**
 * Its Companion (singleton) object
 */
object Session {
  private var counter = 0
  def session() = {
    counter = counter + 1
    new Session(counter)
  }
}
```

This listing when compiles generates the classes shown in Fig. 43.3.

If we use the javap de-compiler again on these classes then we can see that the byte code Session class combines elements of both the Scala Session class and the Scala Session object. However, note that the Session is not final and thus can be extended! This is shown in Fig. 43.4.

If you need to access the Session from within Java code then this can be done as the Session just looks like a normal Java class with a static factory method:

```
package com.jjh.companion;

public class JavaTest {

    public static void main(String[] args) {
          Session session = Session.session();
          System.out.println(session.id());
    }

}
```

Indeed you *should* even be able to extend it. However, Java currently gets confused with the inheritance hierarchy if you do try to extend a class such as Session.

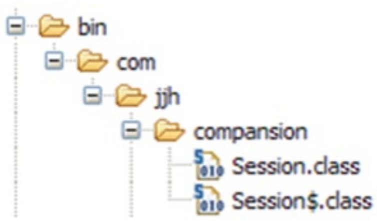
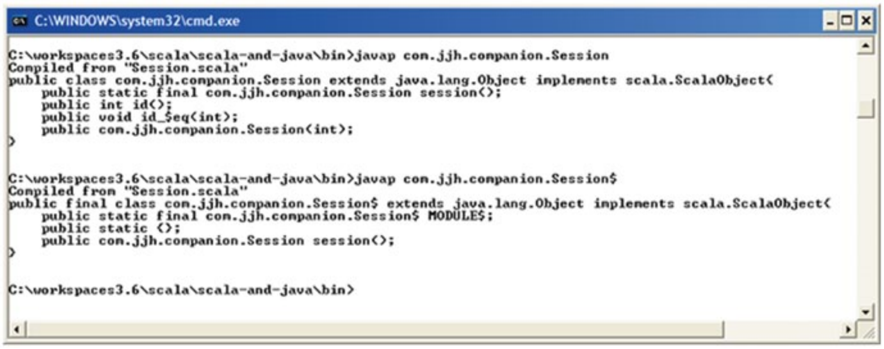


Fig. 43.3 Byte code classes created for a companion module



```
C:\workspaces3.6\scala\scala-and-java\bin>javap com.jjh.companion.Session
Compiled from "Session.scala"
public class com.jjh.companion.Session extends java.lang.Object implements scala.ScalaObject{
    public static final com.jjh.companion.Session session();
    public int id();
    public void id_$eq(int);
    public com.jjh.companion.Session(int);
}

C:\workspaces3.6\scala\scala-and-java\bin>javap com.jjh.companion.Session$
Compiled from "Session.scala"
public final class com.jjh.companion.Session$ extends java.lang.Object implements scala.ScalaObject{
    public static final com.jjh.companion.Session$ MODULE$;
    public static {};
    public com.jjh.companion.Session session();
}

C:\workspaces3.6\scala\scala-and-java\bin>
```

Fig. 43.4 Decompiling the companion module

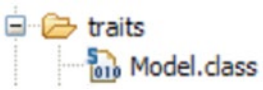
43.4.3 Traits

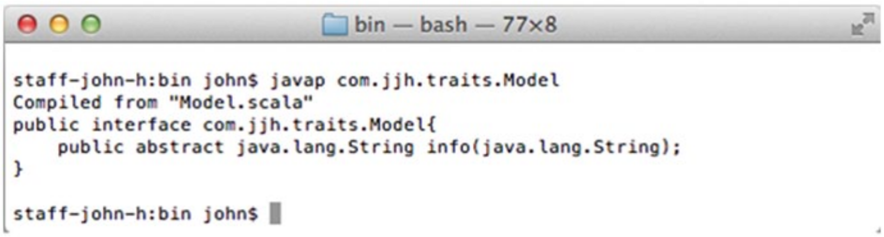
Scala has Traits—these are a type within the Scala type system and they are not abstract classes nor are they Java interfaces. Java does not have Traits although it does have interfaces and abstract classes. There cannot therefore be a direct mapping from a Scala trait to a Java concept. However, this is also true of the underlying byte code representation—it does not have a concept of a Trait. This raises the question what happens when a trait is defined at the byte code level? For example, given the trait Model shown below, how is this represented at the byte code level:

```
package com.jjh.traits

trait Model {

  def info(x: String):String

}
```

If you examine the *.class files* generated for this type you will see that the single trait Model is represented by a single .class file Model.class (Fig. 43.5):

Fig. 43.5 Representing a Trait via two class files





```
staff-john-h:bin john$ javap com.jjh.traits.Model
Compiled from "Model.scala"
public interface com.jjh.traits.Model{
    public abstract java.lang.String info(java.lang.String);
}

staff-john-h:bin john$ 
```

Fig. 43.6 Representing a simple Trait in byte codes

The file Model.class defines an interface containing a single public abstract method that takes a string and returns a string. This can be implemented by Java class who wish to implement the Trait (Fig. 43.6).

However, what happens if the trait defines actual behaviour and data. Java/ Byte Code interfaces are only allowed to define method signatures (abstract methods) and static final constant values.

The following listing defines a modified version of the Model trait that contains behaviour (the print method) and data (the title variable):

```
package com.jjh.traits

trait Model {
var title = "CS123-10"

def info(x: String):String

def print = println("Hello World")

}
```

This results in two class files being generated as shown in * (Fig. 43.7).

The file Model.class seems reasonable but what about the file Model$class. class—this seems a strange name at best. However, the key is what is defined within each file. Using javap we can see that the Model.class file contains an interface definition Model with extends the ScalaObject type and defines a single public abstract method info (Java interfaces can only define public abstract methods and final static constants). The Model$class.class file contains an abstract class called Model$class that extends the java.lang.Object type and defines two static methods

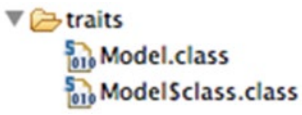
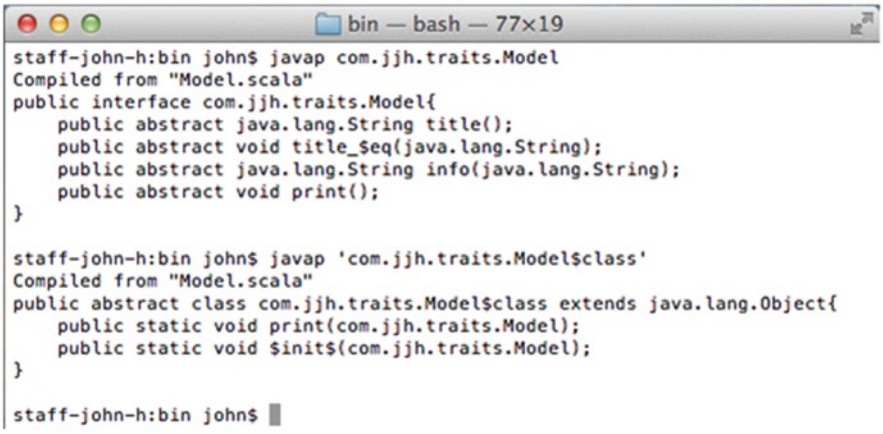


Fig. 43.7 Multiple .class files generated for a Trait

```
traits
  Model.class
  Model$class.class
```



```
staff-john-h:bin john$ javap com.jjh.traits.Model
Compiled from "Model.scala"
public interface com.jjh.traits.Model{
    public abstract java.lang.String title();
    public abstract void title_$eq(java.lang.String);
    public abstract java.lang.String info(java.lang.String);
    public abstract void print();
}

staff-john-h:bin john$ javap 'com.jjh.traits.Model$class'
Compiled from "Model.scala"
public abstract class com.jjh.traits.Model$class extends java.lang.Object{
    public static void print(com.jjh.traits.Model);
    public static void $init$(com.jjh.traits.Model);
}

staff-john-h:bin john$
```

Fig. 43.8 Decompiling multiple .class files for a single trait

one info and the other $init$ both of which take a Model as their parameters. This is shown below (Fig. 43.8):

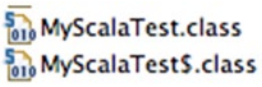
Thus at the byte code level this Trait is implemented as a combination of an interface and an abstract static oriented Java class that provides the functionality for any behaviour in the Trait. By passing instances that implement the interface into the static methods the behaviour in the trait can be accessed.

This means that from the Java world a Trait appears as an interface to implement and a (slightly strangely named) static class that can be used to invoke appropriate behaviour. Thus to use the Model trait from the Java world we could do the following:

```
package com.jjh.traits;
public classFoo implements Model {
  public String info() {
    //works because `this` implements Trait
    return Model$class.info(this);
  }
}
```

However, a general strategy to simplify Java to Scala interoperation is not to expose Traits as part of the interface presented to the Java world. Or if you do need to expose Traits try to ensure that the traits align with the Java rules for interfaces and do not contain behaviour or data as they then appear just as Java interfaces.

Fig. 43.9 The byte code class files for MyScalaTest


MyScalaTest.class
MyScalaTest$.class

43.5 Functions

Scala is a hybrid Object Oriented and Functional language. However Java (at least up until Java 8) is an Object Oriented language and thus has no concept of a Function. Scala of course treats Functions as top level entities, or first class elements in the language with functions making up part of the type system of the language. However, the underlying byte code representation to which Scala compiles also does not have a concept of a function thus there must be some from of mapping from the Scala world into the byte code world. This thus means that from the Java side of things that mapping can be exploited.

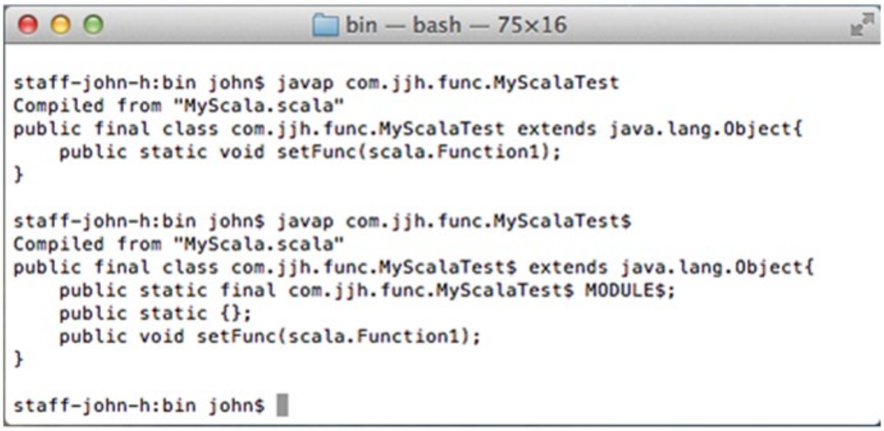
Functions are actually represented at the byte code level by the various Function types that model a function. The following code which defines an object called MyScalaTest containing a method which takes a single parameter of type `Int=>String`. This method is represented at the byte code level as being a method that takes a single parameter of type Function1 which is parameterized to use an Object and a String as the types involved.

```
package com.jjh.func

object MyScalaTest {
  def setFunc(func: Int => String) {
    println(func(10))
  }
}
```

The object MyScalaTest is represented by two *.class* files at the byte code level as illustrated in Fig. 43.9.

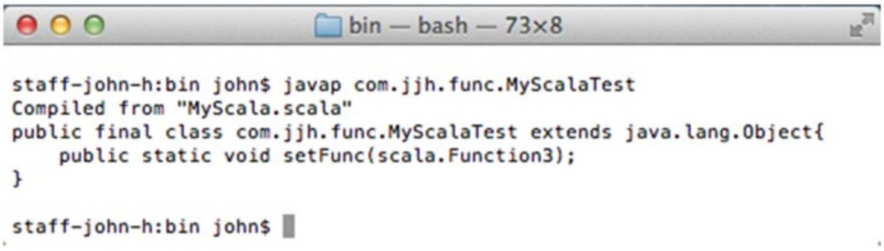
This is shown when we use javap to decompile the compiled version of the MyScalaTest. The MyScalaTest.class contains a final class the defines a single public static method setFunc that takes a parameter of type scala.Function1. The associated MyScalaTest$ class defines a non-static (instance side) method setFunc that also takes a scala.Function1 parameter (Fig. 43.10).

In fact within Scala there are a range of types (actually Traits) that are used to represent functions from Function1, Function2 and Function3 through to Function22. Thus functions can have up to 22 parameters. This appears to be an arbitrary choice and is limited only because the underlying types are only written from Function1 through to Function22. If you find yourself hitting this limit then you probably need to re-think your design!



```
staff-john-h:bin john$ javap com.jjh.func.MyScalaTest
Compiled from "MyScala.scala"
public final class com.jjh.func.MyScalaTest extends java.lang.Object{
    public static void setFunc(scala.Function1);
}

staff-john-h:bin john$ javap com.jjh.func.MyScalaTest$
Compiled from "MyScala.scala"
public final class com.jjh.func.MyScalaTest$ extends java.lang.Object{
    public static final com.jjh.func.MyScalaTest$ MODULE$;
    public static {};
    public void setFunc(scala.Function1);
}

staff-john-h:bin john$
```

Fig. 43.10 Decompiling the MyScalaTest class files



```
staff-john-h:bin john$ javap com.jjh.func.MyScalaTest
Compiled from "MyScala.scala"
public final class com.jjh.func.MyScalaTest extends java.lang.Object{
    public static void setFunc(scala.Function3);
}

staff-john-h:bin john$
```

Fig. 43.11 Decompiling a three parameter function version

As an example, if we changed the function type taken by setFunc to have three input parameters and one result, as follows:

```
object MyScalaTest {
  def setFunc(func: (Int, Int, Int) => String) {
    println(func(10, 1, 2))
  }
}
```

The when we de-compile the resulting .class byte codes we would find that this is now as shown in Fig. 43.11.

To exploit this within the Java world we can create Java code that implements the *Function1* type (which appears as an Interface in the Java world). This can be done by using one of the abstract runtime classes that implement the appropriate interface. For example, if we have a single parameter function then the interface for it in the Java world is Function1 and the abstract class that provides the basic infrastructure for that interface is AbstractFunction1 (where as for a three parameter function we would use the Function3 interface and the AbstractFunction1 class). The following listing illustrates how we can create a Scala function in Java and use it with a Scala *object* that expects to receive a function:

```
package com.jjh.func;

import scala.Function1;
import scala.runtime.AbstractFunction1;

public class FuncTest {
  public static void main(String [] args) {
    Function1<Object, String> f =
      new AbstractFunction1<Object, String>() {
        public String apply(Object someInt) {
           return "Hello world: " + someInt;
        }
      };
      MyScalaTest.setFunc(f);
    }
}
```

In the above example, a new (anonymous) inner class is created on the fly based on the *AbstractFunction1* class. It defines a method apply that takes a parameter of type *Object* (anything in the Java world) and returns a *String*. In this case the string is constructed by prefixing whatever was passed in with the string “Hello World”. Using this new anonymous class a new instance is created and a reference to that instance stored in the variable ‘f’ which is of type Function1. Note that the parameters to Function1 indicate that the function being defined takes one parameter (the first type in the angle brackets ‘<>’ and the return type is String the second type in the angle brackets. The instance referenced by f is then passed on the *setFunc* method of *MyScalaTest*, which is the Java representation of the *MyScalaTest* object. The end result of executing this Java program is the output:

```
Hello world: 10
```

43.6 Collection Classes

Both Java and Scala have libraries of collection classes, and confusingly many of the names are similar. Thus there is a Set collection in both Java and Scala and there is a List in both Java and Scala. However, the Scala collections are *not* just wrappers around the Java collection classes and thus you cannot just assign from one to the other. For example, you cannot assign a Java Set type to a Scala Set type. Thus the following does not work:

```
package com.jeh.scala.interop
object SetTest1 extends App {

  val jSet: java.util.Set[String] = new
java.util.HashSet[String]()

  jSet.add("Adam")
  jSet.add("Phoebe")

  val sSet: scala.collection.mutable.Set[String] =
jSet

}
```

If you do try this you will find that the assignment of the jSet to the Scala Set will result in a compilation error.

You might think that you can create a new instance of the Scala set using the Java Set as a parameter to the constructor:

```
val sSet: Set[String]=Set(jSet.toArray(): _*)
```

For an appropriate Scala set this could work buyt the array type generated by Java is an Array of Objects but we are using a Set with an array of String (which is what both types of sets hold). It is therefore necessary to look at the Java Conversions facilities provided in the scala.collections package. For example the JavaConverters object (introduced in Scala 2.8) provides numerous convertions including:

The following conversions are supported via asJava, asScala

- scala.collection.Iterable <=> java.lang.Iterable
- scala.collection.Iterator <=> java.util.Iterator
- scala.collection.mutable.Buffer <=> java.util.List
- scala.collection.mutable.Set <=> java.util.Set
- scala.collection.mutable.Map <=> java.util.Map
- scala.collection.mutable.ConcurrentMap <=> java.util.concurrent.Concurrent-Map

The following conversions also are supported, but the direction Scala to Java is done my a more specifically named method: asJavaCollection, asJavaEnumeration, asJavaDictionary.

- scala.collection.Iterable <=> java.util.Collection
- scala.collection.Iterator <=> java.util.Enumeration
- scala.collection.mutable.Map <=> java.util.Dictionary

In addition, the following one-way conversions are provided via asJava methods:

- scala.collection.Seq => java.util.List
- scala.collection.mutable.Seq => java.util.List
- scala.collection.Set => java.util.Set
- scala.collection.Map => java.util.Map

Thus the earlier example should be written as follows. However, note that the *asScala* addition introduced by the *JavaConverters* library (based on the pimp-my-library pattern) returns a mutable set not an immutable set. This is because Java collections are all mutable where as Scala has mutable and immutable collections.

```
package com.jeh.scala.interop

import scala.collection.JavaConverters
import scala.collection.mutable.Set
import collection.JavaConverters._

object SetTest1 extends App {

  val jSet: java.util.Set[String] = new
java.util.HashSet[String]()

  jSet.add("Adam")
  jSet.add("Phoebe")

  val sSet: scala.collection.mutable.Set[String] =
jSet.asScala

}
```

It should be noted that the JavaConverters classes use the Adapter pattern to wrap the original Java collection (the underlier) within a Scala interface that resembles the Scala collection types. Thus both converting and accessing converted collections is a constant time (O(1)) operation introducing only a minor overhead. Due to this design pattern, it is also worth noting that converting Java collection to Scala and then back to Java yields the original collection, not double-wrapper.

43.7 Implementing a Java Interface

Java makes extensive use of interfaces, which are used to define abstract definitions of method signatures (and static constant values). Scala has no concept of an interface however it does have traits. One of viewing an interface is as a very restricted type of trait. Thus, a Scala class can *implement* a Java interface by treating it as a *Trait* which it is mixing into that class. However unlike Scala traits, interfaces can only have abstract methods. Thus the class mixining in the interface must implement the method (or methods) specified by the interface.

For example, given the following Java interface:

```
package com.jeh.java;

import java.util.List;

public interface Processor {
     double calc(List<String> l);
}
```

Any Scala class must provide an implementation for the *abstract* method calc. Note also that the method *calc* takes a *List*, which in the Java world is an interface itself. Thus whatever is passed into the *calc* method will be a class or an object that implements that interface.

The following listing provides a simple Scala class that implements the Processor interface. The

```
package com.jjh.interop

import java.util.List

import com.jeh.java.Processor

class MyProcessor extends Processor {
   def calc(l: List[String]): Double = {
     import scala.collection.JavaConverters._
     val list = l.asScala
     return list.foldLeft(0)
        { (total, element) => total + element.toInt }
   }
}
```

The simple class *MyProcessor* convert the Java list into a Scala list to make it easier to work with. It then processes all the elements within the list in order to generate a total (it is assumed that all the string sin the list passed in will contain integer values allowing the *toInt* operation to convert the string into an integer. The result returned is a Double (which is treated as a raw value double in the Java world).

The interesting thing is that the Scala class *MyProcessor* could be used form the Scala world or from the Java world. Thus the following listing implemented in Java creates a new instance of the *MyProcessor* and stores it into a variable of type

Processor. It then creates a list of strings and passes them into the *MyProcessor* object etc.

```
package com.jeh.java;

import java.util.ArrayList;
import java.util.List;

import com.jjh.interop.MyProcessor;

public class TestApp {
     public static void main(String[] args) {
           Processor proc = new MyProcessor();
           List<String> l = new ArrayList<String>();
           l.add("32");
           l.add("5");
           double x = proc.calc(l);
           System.out.println(x);
     }
}
```

The output of this program is 37.0