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In this and other publications you may see references to the 'University of London International Programmes', which was the name of the University's flexible and distance learning arm until 2018. It is now known simply as the 'University of London', which better reflects the academic award our students are working towards. The change in name will be incorporated into our materials as they are revised.

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Introduction

A while ago I decided to build a small tool shed. I took a trip to the local construction yard and bought some wood. Back home, I built a wooden frame for my shed, sawing the bits of wood as I needed them. I then nailed sheets of wood to the frame. I left a space for a window - but I had forgotten to buy any glass at the yard, so I returned there. I discovered that the yard had ready-made windows, and they looked rather good, so I bought one. Returning home, I found that the space was too small for the window unit I had just bought, but this was not a problem because I could easily saw some wood away from the wall panel. And so I continued with my haphazard construction, returning to the yard from time to time to buy roof felt, a door, hinges etc. Finally my shed was finished and it was fine. In fact it was so good and I was so proud of my achievement that I commenced another, larger construction project. I really did need a bigger kitchen.

After many trips to the construction yard to replace ill-fitting pipes and window frames, after knocking down a newly-built wall because I had forgotten to install any plumbing, and after countless other minor re-starts, the kitchen extension was finished, and it was OK, even though it had taken me months to complete. My next project was a complete new house, built from scratch in a neighbouring field.

You know the ending to this domestic tale! My construction techniques just could not scale to this big project. The complexity of the supply of materials (bricks, tiles, concrete, plaster, wood...), the relationship between the various systems (heating, drainage, electric, gas) and the ramifications of late design change (perhaps the stairs should really be to the right of the hall - but then the bathroom needs to be moved to the left of the landing - now this means re-routing the water pipes - ...) meant that, if I were lucky, this project might actually have succeeded, but I would certainly overrun and at a very high cost. And would it be the house I actually wanted?

After some calls I assembled a project team. An architect designed the house, producing several plans of her design according to my initial brief. Several rather artistic drawings showed the house from the outside so I was able to judge the overall physical design. Other more formal plans of the interior layout, so I could imagine walking around inside and visiting the various rooms. At this stage I changed a few things. Still other plans were made for the electrician and the plumber detailing where the pipes and cables should be fitted. There was even a special plan of the kitchen showing in detail the work-surfaces and appliances. A surveyor was employed to organise the supply of materials, builders were employed to perform the construction, and engineers checked the work at various stages. A manager oversaw the whole process.

Learning activity

Extract from this tale some general principles of large-scale construction.

Comments on the activity

Large scale construction requires: analysis of the project so that the right thing is built; early consultation with the client; plans of the project from various perspectives and levels of analysis; inclusion of pre-built components into the design; management to ensure that parts of the project are built in the correct order; builders; people to check the construction, both for accuracy, and for quality.

All of these principles apply to software projects. Here the constructed artefact is not tangible, but is a logical object. A large piece of computer code is very intricate, far too complex for any person to understand. Additional complexity arises from interaction between the software and an uncertain physical world, and in understanding the changing needs of the client. Software, then, needs to be *engineered*.

This course is strategically placed at the midpoint of your studies. You will already have studied a computer language at an introductory level, corresponding to rudimentary do-it-yourself skills. Later in your studies you will be developing a larger software project and this will require a more systematic and scalable approach. You will no longer be able to sit at the computer and type your programme code in a trial and error fashion. As the programme grows in size you will drown in a sea of complexity. Your software project will have to be designed, you must become a software *architect*. It is the purpose of this course to provide you with the skills and insights to bridge the gap between small scale programming and large commercial applications.

The complexity of software is modelled, rather like an architect models a building, with the use of diagrams. We shall use a technique that has become an industry standard: the Unified Modelling Language (UML). Proficiency at UML, along with the computer languages you have studied, will be amongst the main transferable skills you will acquire throughout your entire degree programme.

This subject guide, which covers one half of CIS226, provides an introduction to software engineering. Part I of the guide begins with a look at some principles of good software design and how these principles fit into a particular developmental process. The main topic of this course unit, covered in Part II, examines how to analyse and design software using the Unified Modelling Language (UML). Part III discusses quality assurance, both of the product and in the process. Part IV shows a specimen software project and examination.

There are two software projects in this guide: a Personal Organiser and Space Game. Each chapter of part II ends with an exercise for each project. These exercises cover the analysis and design stages of the software life cycle. Algorithm design is an important part of the implementation phase of a software project, and this is covered in the second half of this course unit. There will not be any implementation of Personal Organiser or Space Game. The final

stages of a software project are testing and maintenance, which, in the absence of actual code, can only be studied theoretically in this course. Later in your studies you will undertake a complete software project and you will find the ideas and skills of CIS226 invaluable for the successful completion of this project.

Here are the main topics of this course, arranged to correspond to the parts of this guide:

I Principles
  (a) the role of design and modelling in software development
  (b) software development process

II UML
  (a) use cases
  (b) class, sequence, state machine and activity diagrams
  (c) objects and links
  (d) compositions, aggregations and dependencies
  (e) other UML diagrams and concepts

III Quality
  (a) Product quality: verification, validation and testing
  (b) Process quality: project management and planning

How to use this subject guide

This subject guide is not a self-contained account, but is a companion to the course texts *UML Distilled* by Martin Fowler and *Using UML* by Perdita Stevens and Rob Pooley. *It is essential that you obtain these books*. This guide is structured in the form of selected readings from these texts. Learning activities will test your understanding of the main points of each reading. You are strongly advised to attempt these activities as a way of monitoring your own progress. There are more exercises at the end of each chapter and a sample examination paper at the end of the guide.

Each chapter begins with a general statement of the essential reading for this part, and throughout the text you will find specific instructions on what to read. It is important that you read the relevant sections of the course texts when instructed to because text subsequent to a reading will only make sense in the context of the reading. The reading will be cited on the following format:

Read UUML/UMLD, Chapter x, heading [omit]

where *UUML/UMLD* are the title initials of the course texts, *x* is the relevant chapter (identical to the chapter(s) of the essential reading) and *heading* is the chapter section for this directed reading. Each chapter of either course text begins with a short introduction which does not have a section heading and is denoted *introduction*. You are expected to read all the subsections contained in the section you have been directed to. Some directions include an omit guard which tells you to ignore certain subsections or boxes. British English is used throughout this guide, except in quotations and section headings for the set readings, where the original punctuation and spelling (which might be American English) is used.

There is an additional list of books which expand on a number of topics and you are advised to deepen your understanding by referring to these additional texts where directed.

Readings

Here are the details of the course texts and additional materials:

- Essential
  1. *UML Distilled (third edition)*, Martin Fowler, Addison-Wesley, 2004
  2. *Using UML (updated edition)*, Perdita Stevens with Rob Pooley, Pearson Education Limited 2000
- Supplementary
  1. *Project-based Software Engineering*, Evelyn Stiller and Cathie Leblanc, Addison Wesley, 2002
  2. *Software Engineering (fifth edition)*, Roger Pressman, McGraw-Hill, 2000
  3. *The Mythical Man-Month (anniversary edition)*, Frederick Brooks, Addison Wesley 1995
  4. *Effective Java*, Joshua Bloch, Addison Wesley 2001

Aims and objectives

At the end of this course you will be able to:

1. Explain the role of software development in the software life-cycle
2. Produce static and behavioural models of software programs
3. Specify and verify software systems
4. Decompose problems and develop software architectures
5. Implement software models in a structured and efficient way.

These are the *major objectives* of this course unit. Each chapter also lists a number of *learning outcomes*. The learning outcomes break the objectives into manageable tasks.

The examination

You will be assessed on your understanding of objectives 1 - 4. (Objective 5 will be assessed at a later stage of your studies when you will be asked to implement a particular project.) The method of assessment for the complete course unit CIS226 will be one unseen written exam paper of 3 hours (85 per cent) and four equally weighted assignments (15 per cent). Software Engineering (the subject of this guide) will comprise one half of the overall mark for CIS226. There is a sample examination paper for Software Engineering and advice on exam preparation in the final chapter of this guide.

Part I

Principles

Chapter 1

Software Engineering

Essential reading

Using UML Chapters 1 and 2

All large-scale construction projects follow five main phases of activity: analysis, design, construction, testing and maintenance. Software projects are no exception. Software engineering is concerned both with the phases themselves and also with how each phase fits into the overall development of the project (in software engineering-speak, *process*).

A large software project runs like this: *software architects* draw up plans (*models*) at various levels (*abstractions*) of analysis. The models facilitate further *analysis* and *design*. Models also serve as construction guides during the *implementation* phase and as documentation of the end result. To facilitate design and implementation, ready-made units (*components*) are used wherever possible. A *project manager* oversees the whole process.

A major aspect of software engineering is therefore concerned with the development process. However, in order to judge how well our software is engineered, we need to have an idea of software quality. In most domains of engineering, we understand fairly well what a successful construction is, and how to achieve it. For example, bridges should not fall down (and they rarely do), and there are accepted design principles, construction techniques and quality assurance assessments. The situation with engineered software is not so clear, however.

This chapter begins by considering what a high quality software system should be like and outlines some important design principles. Software design with objects is an important manifestation of these principles and the important aspects of this paradigm are explained in the remaining sections of this chapter.

1.1 What is a good system?

Read UUML, Chapter 1, What is a good system?.

Stevens and Pooley, the authors of *UUML* point out that a good system is surely one that meets its users' needs. They list five desirable attributes (namely: usability, reliability, flexibility, affordability and availability) of a good system and consider how well current systems satisfy these criteria.

Although successful systems do exist, there are a number of spectacular failures. These are informally known as software horror stories and a web search will reveal many sources of information. Remarkably, many large projects are cancelled, and of those that do survive, most will significantly overrun their initial planning period. Three quarters of large projects that are actually completed will ultimately fail!

Learning activity

Suppose that you are managing a large software project which is slipping behind schedule. Should you employ more people to work on the project? Explain your answer.

Comments on the activity

The surprising answer to this question is that increasing the size of the team will not necessarily have any benefit. The reason for this is that as the team increases in size, more and more of the project's costs and time are consumed in the overhead of inter-person communication. In fact, the time needed to ensure that all the information is available to keep the work consistent can actually extend a project. This idea is expanded at some length in Fred Brooks' The Mythical Man Month.

1.2 The problem

Read UUML, Chapter 1, What are good systems like? [omit Architecture and components, Component-based design: pluggability]

What is behind this gloomy state of affairs alluded to above? Quite simply, software is extremely complex: there is a limit to how much we can understand at one time.

If your only experience of programming has been an introductory course on Java, you will have been the sole author of your programmes and should (in principle) have been able to understand everything about your code. At first you probably just sat in front of a screen and typed code directly into an editor, rather like me and the shed. However, as an application grows in size, this unstructured approach becomes increasingly hard to sustain - the programme becomes a single monolithic unit and is just too complex and difficult to develop and maintain. It seems that some time must be spent planning how you will code your solution to a software problem. Then you will implement your solution. Good quality systems are surely *designed*.

A number of fundamental design concepts are broadly agreed upon. See *Software Engineering* by R. Pressman, sections 13.4 and 13.5 for a full discussion. Above all, the division of software into smaller *modules* is universally accepted as the main way to control complexity. There is nothing special about this idea; it is the way that we seek to understand anything. For example, science works by modularising the world in a process called reductionism. There is a hierarchy of software modules: from methods to classes to packages to subsystems. Note however that an excessive modularisation of a

system could actually increase overall complexity due to the overhead of integrating very many modules.

Abstraction is the thinning away of detail from a problem domain, leaving a more general representation. At the highest level of abstraction, a software solution is provided in broad terms, using the language of the problem domain. And at the lowest level, the language is the programming code itself. In between there are many levels. The software architect will abstract and model the system in various ways in order to focus on the essential programme elements.

A *cohesive* module performs a single task and requires little interaction with other modules in order to accomplish this. For example, it is a common dictum that methods should only do one thing i.e. return or alter a single value with no other side-effects. Similarly, a cohesive class will represent a single concept, or type of real-life object.

Coupling refers to the connectivity between modules, and should be kept to a minimum if the software is to be understood. The elimination of the notorious `go to` statement has done much to reduce 'spaghetti code' and the complexity of a programming unit. There is no such check on modular spaghetti networks however, and software designers must guard against high coupling.

It is generally agreed that all modules should present a simple, public *interface*. The interface defines what tasks the modules can perform, but not how the modules may accomplish this task. These details are private to the module; a client of the module need never know them. Each module in a 'good' system is only linked to a few others and every client is not able to know more about the module than is contained in the interface. This is the important principle of *encapsulation*.

A module with high cohesion and low coupling can be re-used, either in later systems, or in other modules of the present system. The object oriented paradigm supports re-usable modules as we will later explain. High cohesion and low coupling also mean that modules can be replaced without too much disruption to the system as a whole. They are pluggable. Re-usable, replaceable pluggable modules function rather like component parts in a mechanism. That is why they are called *software components*.

Learning activity

Write, *in your own words*, a paragraph on what a good system should be like.

1.3 Building systems with objects

Read UUML, Chapter 2, What is an object?.

This reading relates programming with objects to the reusable, replaceable modules which make good components and ultimately, we hope, a good system.

The fundamental module of object oriented (OO) programming languages is (unsurprisingly) the object. Here we summarise, from a software engineering perspective, some properties of objects, and introduce a small amount of the unified modelling language (UML).

Objects are programming modules that group related data items together. A set of objects with a similar role in a system is grouped into a class. Blocks of code which perform common operations on this data are also grouped together and are maintained by the class. Objects are supposed to be the software analogue, or representation, of an actual object or of a concept. In this way, we hope to map the tangible real world of things onto the logical, abstract world of computer code.

The class is an object factory, responsible for making however many objects the system requires. (An object can be referred to as an instance of a class.) The *state* of an object is the value of all the variables in that object and the *behaviour* of an object is the way that an object responds to messages. In the OO world, a system is a collection of objects which are sending messages to each other in order to accomplish a certain task.

An example of an object message is:

```
resetTime( newTime:  Time )
```

This message is written in UML notation. Here, `newTime` is an object of type `Time` i.e. an instance of the `Time` class. Notice that the message `resetTime( newTime:  Time )` is language independent. Suppose that `myClock` is an instance of a `Clock` class and we would like `myClock` to accept and respond to a `resetTime` message. In Java, we would ensure that a `Clock` object would accept this message by implementing a method in `Clock` with the signature:

```
public void resetTime( Time newTime )
```

The class of an object also defines its interface. In the `Clock` example, `myClock` is an object of class `Clock`. `Clock`'s public interface might specify that each `Clock` object should provide *reset-time* and *report-time* operations. A `Clock` object will also have a private time attribute. Private attributes are only available to the object itself: clients of `Clock` cannot access time directly. Instead, they can only ask the time by sending the message *report-time* to a `Clock` object. This is known as *data-hiding*. In contrast, a public attribute or operation is accessible by any client. Hidden-data is often accessed using specific accessor (getters and setters) methods. Objects from the same class have the same interface. The public and private interface to `Clock` might be:

```
-time :  Time
+ reportTime() :  String
+ resetTime( newTime:  Time )
```

where the symbols + and - refer to public and private *visibility*.

Learning activity

1. What is an object's interface? What is the difference between a public and a private interface?

2. Why bother grouping similar objects together into a class?
3. Write, in pseudo-Java, a class outline for `Clock` based on its declared interface.

Comments on the activity

1. *See section* UUML, What is an object [subsection: Interfaces].
2. *See the digression* UUML, What is an object? [subsection: Digression: why have classes?]. *A basic answer to the problem of maintaining consistent copies of any software artefact is to structure code so that no copies are necessary! For example, all my `Clock` objects need to be reset. It's far easier to maintain (i.e. revise and re-use) a single `reset` method in the class `myClock`. A further and more technical point is that a class can be thought of as a type, and the language compiler can spot possible errors when type-checking.*
3. *The pseudo-Java code, shown below, is a bridge between the design and the implementation phases of a software project.*

```
class Clock
   private Time time

   public String reportTime()
      return time.toString()

   public void resetTime(Time newTime)
      time = newTime
```

Read UUML, Chapter 2, How does this relate to the aims of the previous chapter?.

The previous chapter proposed that reusable, replaceable, component-like modules will lead to reduced development time and cost, ease of maintenance and greater reliability. OO is expected to deliver on these counts, but objects themselves do not make good modules, because there can be many similar objects in a system, and the requirement to ensure consistency between them would be a very high price to pay. A house is made from many `bricks` but a single `Brick` class provides the necessary generalisation.

Another benefit of OO is that it is natural to objectify the world, so that an OO system can provide a better match between abstract computer code and the problem domain of the customer. An object model can help engineers in capturing requirements, following changes in user requirements and allowing for more naturally interacting systems.

OO, of course, is not the only possible approach, but it is one that takes modularity, encapsulation and abstraction as fundamental.

1.4 OO design

Read UUML, Chapter 2, Inheritance.

Inheritance, *polymorphism* and *dynamic binding* are the three features that make OO special.

Inheritance is an important concept in OO design and you should make sure that you understand the explanations given in this reading. Notice in particular how a subclass can inherit attributes and operations from its superclass, a subclass can add extra attributes and operations, and a subclass may override some superclass methods. (Less usefully, a subclass may also shadow superclass variables.)

Apart from the direct advantage of code re-use, inheritance implies another defining feature of the OO paradigm. A subclass object can be freely substituted for its superclass parent. This means that an object can have any one of several types. The ability of an entity to exist in different forms is called polymorphism.

Since methods may be overridden in sub-classes, what code should be executed as the result of some message? For example, a `Lecturer` class can be sub-classed by a `DirectorOfStudies` class with the overridden method `canDo( Duty duty )`. In the following pseudo-code

```
for each o in lecturers
   o.canDo( seminarOrganisation )
```

`lecturers` is a list of `Lecturer` objects, and includes a `DirectorOfStudies` object, `o` is a specific object selected from this list and

```
canDo( seminarOrganisation:  Duty)
```

is an operation on `Lecturer` objects. Note also the dot notation signifies message sending: `o` is the recipient of the message `cando( seminarOrganisation )`. When the program execution reaches the `DirectorOfStudies` object, the overriden `canDo` method is invoked, as we would expect. The runtime selection of the correct method due to a specific message is known as dynamic binding.

Learning activity

Inheritance clearly favours code re-use, and it would therefore appear to be a desirable feature of OO. Do you think that inheritance leads to greater or less encapsulation?

Comments on the activity

Item 14 of Effective Java *by Joshua Bloch warns against inheritance across package boundaries. A subclass depends on the implementation details of its superclass, clearly in conflict with the principle of encapsulation. Composition is a better solution - we shall return to this in a later chapter.*

Read UUML, Chapter 2, Polymorphism and dynamic binding.

Clearly, polymorphism promotes code re-use. But polymorphism also makes code more flexible. For example, the Java classes `Vector` and `ArrayList` both implement the Java interface `List`. Remember that an interface, in general, defines what tasks a module can do, but not how it may do it. In Java, an `interface` type is a programming implementation of this general notion: `Vector` and

`ArrayList` implement certain methods which are specified by the `List` definition. Hence they share the same public interface. Furthermore, an interface defines a type which all implementing classes share. For example, wherever a `Vector` is instantiated

```
Vector subscribers = new Vector();
```

we can use a `List` object:

```
List subscribers = new Vector();
```

and a `Vector` instance method such as `add( Object o )` will still work:

```
subscribers.add( newSubscriber );
```

This is more flexible because we can later switch implementations

```
List subscribers = new ArrayList()
```

and all the surrounding code will still work. Item 34 of *Effective Java* explains this point in some more detail.

1.5 Exercises

1. Would individual objects make good modules?
2. Supporters of OO claim that a major benefit of this paradigm is that it is inherently natural to look at the world in terms of objects. Why should this be beneficial for software design?
3. Suppose that OO enables us to build a good system. How much of this is due to the intrinsic nature of OO techniques?

Answers

1. No. See *UUML, Chapter 2, How does this relate to the aims of the previous chapter? [first three paragraphs]*.
2. The short answer is that the system can better match the users' model of the world. But you should try to understand why software architects consider this to be desirable.
3. If OO succeeds, it is because this paradigm takes modularity, encapsulation and abstraction as fundamental.

1.6 Summary

After studying this chapter you should be able to:

- state what a high quality software system should be like and comment on to what extent we have such systems
- state the basic problem faced by software developers
- list and explain the fundamental design concepts of software engineering (modularity, abstraction, high cohesion, low coupling, simple public interfaces, encapsulation, components)
- explain what software objects are, and how they communicate
- use UML to specify a class interface

- translate object messages into Java methods, and write a class skeleton based on a declared interface
- list and explain the three special features of OO (inheritance, polymorphism, dynamic binding)

Chapter 2

Development Process and Modelling

Essential reading

UML Distilled, Chapters 1-2
Using UML, Chapter 4

Additional reading

R. Pressman, Software Engineering, a Practitioner's Approach, Chapter 2

The first chapter argued by analogy that software, like any other engineering project, proceeds by phases of development. The phases fit together into a process. In this chapter we consider the development process in more detail. We also look again at the fundamental problem of software systems - the intangibility and complexity of computer code. Good design, we have discovered, is modular. But how do we arrive at these modules? We can't play with a lump of plasticine or sketch pictures in order to brainstorm new ideas. However, the system must be modelled in some way. We introduce software modelling languages and the chapter finishes by demonstrating how the most prevalent modelling language, UML, integrates back into the developmental process.

2.1 Iterative and waterfall processes

Read UMLD, Chapter 2, Iterative and Waterfall Process.

The iterative and waterfall methods are the two major categories of software development processes. Both methods agree that the process must be subdivided into phases. The *waterfall* emphasises discrete activities that must be completed sequentially. And just like a real waterfall, back flow is impossible (or at least exceptional). Iterative techniques break the project down into chunks of functionality, called *iterations*. Each iteration is a complete *life-cycle*: analysis, design, implementation and testing. Each iteration outputs a system of production quality, even if it is not actually released at this stage. *Time boxing* forces an iteration to be of fixed duration, even at the expense of slipping functionality. Generally speaking it is better to slip a function rather than a date because the team can then learn just what the most important functional requirements actually are.

Learning activity

Which process is recommended by the OO community? Why is this?

Comments on the activity

See UMLD, Chapter 2, Iterative and Waterfall Processes [last half of this section].

(Martin Fowler, the author of UMLD *recommends "You should use iterative development only on those projects that you wish to succeed!")*

2.2 Design and modelling

Read UUML, Chapter 4, Defining terms [omit: Process and Quality].

As we have mentioned before, a model is an abstract representation of a specification, a design or a system. The model itself is usually represented visually, as a diagram, but can be textual. The model is precise according to the implicit point of view. Room plans, wiring diagrams, elevations and other architectural plans strip away unnecessary detail in order to focus more clearly on what they are representing. The modelling language has syntax and semantics, just as a natural (spoken) language does. The unified modelling language, UML, is quickly becoming the *lingua franca* of software architects. One reason for this is that the language is very flexible and is not tied to a particular process.

Learning activity

What are the attributes of an ideal modelling language?

Comments on the activity

A modelling language should be expressive, easy to use, unambiguous, supported by tools and widely used - see the list of points in UUML, Chapter 4, Defining terms [subsection: Why a unified modelling language?].

Read UUML, Chapter 4, system, design, model, diagram.

The developmental process will produce (we hope) a collection of programmes which work in an appropriate environment to fulfil the users' needs. The architecture of this system abstracts away many details and embodies just how the system should be built.

The plans for a house do not include each brick, each floorboard and every electrical socket, but they do show the relative positions of the walls, floors and ceilings, the electrical wiring, the landscaping of the garden...There are many plans, each one is incomplete in itself, but taken together they describe the project at just the right level of detail for the builders, electricians, joiners and landscape gardeners.

Plans are roughly analogous to *models* in software engineering. Many models are needed even with a simple design; it is impossible that a single diagram can capture every design aspect. There are three groupings of software models, a use case model, a static or structural model and a dynamic or behavioural model. A building plan may be drawn from different perspectives. Similarly, four software "views" have been suggested: logical, process, developmental and physical. A design requires several models, and each model might require several diagrams from various views, and all of these must be consistent.

We are now ready to begin our study of UML.

2.3 A unified modelling language: UML

Read UMLD, Chapter 1, What Is the UML?.

The fundamental imperative behind all graphical techniques is that programme code is not at a high enough abstraction to promote meaningful discussions about design. UML is a family of graphical notations, unified by a single meta-model. These notations help in describing and designing OO software. UML is an open standard, controlled by the Object Management Group, and is a unification of many pre-existing OO graphical techniques.

Read UMLD, Chapter 1, Ways of using UML [omit Model Driven Architecture and Executable UML].

This reading suggests that UML can be used in different ways. This is because people use older graphical modelling languages in different ways, and that legacy has passed to the newer, unified language. The three uses or *modes* outlined are sketching, blueprinting and programming. One criticism of the blueprinting is that it takes too much time to prepare and that textual languages are already very effective for most programming tasks. In programming mode, UML becomes the source code, and this mode demands very sophisticated tools.

Learning activity

Write a few sentences on each of the three modes of use of UML.

As well as the three modes of use, there are two *perspectives*, the software perspective and the conceptual perspective. Some tools will turn a UML diagram into source code. This is very much a software perspective. Alternatively, in the conceptual perspective, the diagrams are language independent representations of structures and relationships.

Read UMLD, Chapter 1, UML diagrams.

Tables 1.1 and 1.2 of *UMLD* show classifications of the thirteen diagram types in UML 2.0. You do not need to learn these tables! They will be useful, though, for you to refer back to as we introduce various diagrams in part II of this guide. The UML authors do not in

fact see the diagrams as the central part of UML and as a result the diagram types are not rigid and there is much flexibility in their use.

Read UMLD, Chapter 1, What is legal UML?

Most people regard that the UML rules are descriptive rather than prescriptive. This means that we infer language rules by looking at how other people have used them, just as we have all done in learning our own first spoken language. The UML does have a standard, although even this is imprecise because UML is so complex. Information may be suppressed in UML, so that nothing can be inferred from the absence of any particular detail in a diagram. But most important, it is better to have good design rather than strictly legal and precise UML.

Read UMLD, Chapter 1, The meaning of UML.

There is no formal definition of how UML maps to any particular programming language. The meaning of UML (within the sketch mode) is to provide a rough idea of what the code will look like. We can trust the bricklayer to actually make the wall, but a plan tells her where to put it.

Read UMLD, Chapter 1, Where to start with UML.

Luckily, Fowler recommends that we don't need to use all thirteen UML diagrams! A team will work well with just a subset of UML. The most common and useful diagrams are class and sequence diagrams. Chapter 9 makes further suggestions.

2.4 Fitting UML into a process

Read UMLD, Chapter 1, Fitting the UML into a process [omit Documentation].

This section of *UMLD* suggests which types of diagrams are useful in the analysis and design phases, and also for documentation. The section also discusses how to use UML in sketch or blueprint mode.

Learning activity

Contrast the different uses of UML in the waterfall and the iterative process.

Comments on the activity

In the waterfall approach to development, the diagrams are prepared as part of each phase and are included in the end of phase documents. UML is used for blueprinting, and the diagrams are definitive.

In the iterative process, the UML diagrams may be sketches or blueprints, but they may be modified at each iteration. The analysis diagrams will be drawn in the iteration preceding the iteration that adds functionality to the software. Blueprint design can be made early in the iterations for targeted, principal functionality, and any iteration can make changes to existing models rather than building a new model. The model itself is not reworked.

2.5 Exercises

1. What are the similarities and differences between the waterfall and iterative development processes?
2. How can you tell if a process is truly iterative?
3. A project manager is overheard saying “This iteration’s buggy, but we’ll clean it up at the end”. What software development process is being used on this project? Explain your answer.
4. (a) What is code rework?
   (b) In many domains, such as manufacturing, rework is seen as being wasteful. Is this true in the software domain?
   (c) Which technical practices can make rework more efficient?
5. (a) Which UML techniques are useful in the requirements analysis phase?
   (b) What is the main objective during this phase?
   (c) How does this impact on the UML techniques?
6. Which diagrams are useful during the design phase, and how are they used?

Answers

1. Two paragraphs summarising the material in *UMLD, Chapter 2, Iterative and Waterfall Processes [first page]* would be a good answer. Diagrams similar to *R. Pressman, Software Engineering: A Practitioner’s Approach, Figures 2.4 and 2.7* will gain bonus marks.
2. Each iteration must produce tested, integrated code that is of (or close to) production quality. The test is that any iteration that has not been scheduled for release, *could* in fact be released.
3. A waterfall process, because the manager admits the current iteration is not of production quality, contrary to the definitive test for a genuine iterative process (see above answer).
4. (a) Rework means that existing code is revised, possibly even deleted.
   (b) Far from being wasteful, code rework saves time (and hence money) in the long run because it is rarely a good idea to patch badly designed code.
   (c) Automated regression tests, re-factoring and continuous integration.
5. (a) See *UMLD, Chapter 2, Fitting the UML into a Process [subsection: Requirements Analysis]*.
   (b) Use cases, class, activity and sequence diagrams are all useful in this phase.
   (c) The overriding aim is communication between architects and users (just as in house building projects), so UML rules may have to be broken because clients - who are the domain experts - will not necessarily be at all familiar with software engineering.

6. See *UMLD, Chapter 2, Fitting the UML into a Process [second page]*. Class diagrams - these show the classes and how they interrelate. Sequence diagrams model scenarios (scenarios will be explained in a later chapter, but basically they are short stories illustrating how a user may interact with the system). Package diagrams - these show the large-scale organisation of the software. State diagrams are useful for any class with a complicated life history. Deployment diagrams show the physical layout of the software.

2.6 Summary

After studying this chapter you should be able to:

- list the four phases of software development (analysis, design, implementation, testing)
- explain why developmental phases must be managed in a process
- describe and distinguish the waterfall, iterative and agile development processes
- explain the importance of modelling and finding a good modelling language
- list the features of a good modelling language (expressive, easy to use, unambiguous, supported by tools, widely used)
- state the three groups of software models (use case, static or structural and behavioural or dynamic)
- state and explain the three modes of use of UML (sketch, blueprinting and programming)
- explain the difference between a software perspective and a conceptual perspective
- recommend types of diagrams for the analysis and design phases

Part II

UML

Chapter 3

Use Cases

Essential reading

UML Distilled Chapter 9

You have been introduced to the idea of a modelling language. Part II of this guide is largely devoted to the unified modelling language (UML). However, we begin with a technique that UML does not standardise, and whose value derives from text rather than diagrams.

3.1 Requirements capture

> The hardest single part of building a software system is deciding precisely what to build. No other single part of the conceptual work is as difficult as establishing the detailed technical requirements, including all the interfaces to people, to machines, and to other software systems. No other part of the work so cripples the resulting system if done wrong. No other part is more difficult to rectify later [1].

[1] Frederick Brooks in *No Silver Bullet: Essence and accidents of software engineering* IEEE Computer, pp. 10-19, 1987

The essential phases of software development are: requirements analysis, design, implementation, testing and maintenance. These phases are common to all software development processes, but each process differs in the duration, completeness and sequence of these steps. But all processes agree on the very first step, namely *deciding what needs to be built*.

Learning activity

Why do you think deciding precisely what needs to be built is so difficult? What are the ramifications for not making these decisions?

Comments on the activity

The important thing is not to decide what to build, but to decide what precisely *to build. This is hard because*

- *the client might only have a vague and unrealistic idea of what they want*
- *the software engineers are not experts in the application domain*
- *of shifting requirements as the project develops*

3.2 The basic technique

The aim of requirements analysis is a description of how the system should behave in certain situations, i.e. a set of *functional requirements*. Use cases are a technique for capturing these requirements. The use cases describe typical interactions between the users and the system. This narrative is built from *scenarios*. A scenario is one thing that might happen, and several scenarios, all tied together by a specific user goal, constitute a use case.

The users of the system are called *actors*, a mistranslation of the Swedish word for role. An actor is a role that a user has when engaging with the system. Actors need not even be people: an external computer system could also be an actor.

Read UMLD, Chapter 9, Content of a Use Case.

Figure 9.1 of *UMLD* shows a possible format of a use case. UML itself does not specify a standard. Notice that the use case is textual rather than diagrammatic. Each statement or step is an element of the interaction between the actor and the system, showing the intention, but not the mechanism. Each step may suggest alternative situations, and these are logged as extensions to the use case. Sometimes a sequence of steps can occur in other use cases as well. These steps can be factored out and replaced with a single more complex step. Pre-conditions, guarantees and triggers can also be added to use cases, but the aim should always be for simplicity.

Learning activity

1. What is a scenario, and why is it used?
2. What is the relationship between scenarios and use cases?

Comments on the activity

1. *A scenario is a sequence of steps describing an interaction between the user and the system. It is written as a paragraph of normal text. They are used for requirements capture. Since they are textual, they are easily understood by the domain expert. A number of scenarios will eventually comprise a single use case. The use case is the principal UML expression of system requirements.*
2. *Several scenarios may share a single goal, but in some of them the user does not succeed in achieving this goal. These scenarios, linked by a common user goal, become a single use case. The main success scenario becomes the main body of the use case, the other scenarios enter the use case as extensions.*

Read UMLD, Chapter 9, Use Case Diagrams.

As you can see in Figure 9.2, UML does specify a diagram for use cases, but really such things serve best as a table of contents to the textual descriptions. The diagram shows the actors, the use cases, and any inclusions.

Read UMLD, Chapter 9, Levels of Use Cases.

The reading distinguishes business use cases from system use cases. The system use case concerns a (relatively short) interaction between an actor and the system. These are 'sea-level' use cases. Interactions that have complex ramifications for the entire business are at a higher (kite) level. And use cases that only exist because they are included in other level 1 cases are at fish level.

3.3 When to use use cases

Read UMLD, Chapter 9, When to Use Use Cases.

Use cases help us to grasp the basic functional requirements of the system and should be generated early in the project. Later, immediately prior to implementation, more detailed versions of these cases can be derived. The use case diagram is of little value compared to the textual specification. As with all good UML, always strive for simplicity and clarity.

3.4 Exercises

1. Your development team has been asked to develop a Personal Organiser. The organiser should allow users to enter appointments in a calendar, receive alarms and maintain an address book of contacts. You might be able to think of other desirable functions. To begin this project, write some scenarios. Form a few simple use cases from these scenarios and draw a use case diagram. Now, in a mini-iteration, study your use cases and include any pre-conditions, guarantees and triggers that might seem appropriate.
2. Your development team has been contacted by a client who wishes to produce a Space Game. This game will be based on classic video games such as Space Invaders, Galaxians and Asteroids *as a single application*. See http://www.spaceinvaders.de/ for information on Space Invaders and links to other retro arcade games.

   To start, develop a set of scenarios and use cases for Space Invaders. If you have time, develop some use cases for at least one more game. Are there common features? Can you now develop some use cases for a generic Space Game?

3.5 Summary

After studying this chapter you should be able to:

- state what a scenario and a use case are
- explain the relationship between a use case and a scenario
- compose scenarios and use cases for software projects
- draw a use case diagram
- understand the different levels of use cases
- add common information such as pre-conditions, guarantees, triggers to a use case

- be able to factor out common steps from use cases and represent this on a use case diagram
- know when (at what stage of the software development process) to compose and amend use cases.

Chapter 4

Class Diagrams: The basic technique

Essential reading

UML Distilled Chapter 3
Using UML Chapter 5

Read UMLD, Chapter 3, Introduction.

The class diagram is a very widely used modelling technique. A class diagram describes the types of objects in the system and the static relationships between them. This chapter shows you the basic techniques of class modelling. We begin by asking: how do we know which classes a system might have in the first place?

4.1 Class identification

Read UUML, Chapter 5, Identifying objects and classes.

The objectives for any software project are to minimise expense and development time whilst maximizing system maintainability and adaptability. These objectives are often in conflict, but they may be met if the class model provides all required system behaviours, and if the classes represent enduring domain objects, irrespective of the particular functionality required during development. A `Book` class in a library system represents just such a domain object.

Any technique that leads to a good class model is satisfactory. It is unlikely that you will find all the correct classes at the first iteration. The most important domain objects (such as books, catalogue, library member) should be easy to spot, because these belong to the problem. More elusive, though, are other classes that will have to be introduced in order to help solve the problem. A common technique is noun identification. Start with the requirements specification and make a candidate list of all nouns and noun phrases. Then eliminate inappropriate classes, and rename, if necessary the remaining classes. *UUML* lists some reasons why a candidate class might be eliminated and you should study this list carefully.

Ultimately, what you will be left with is a list of tangible or real-world things (book, journal, catalogue) and less tangible things such as roles (librarian, library-member). Ideally a software object, as generated by a class, *represents* a real-world object. This correspondence between the world and its representation as code

helps us to conceptualise the system and deal with complexity. The system itself is the sum total of all the objects, and of all their interactions. OO design seeks to avoid the monolithic top-down approach where a single module knows and does everything and you should be careful that your own architecture does not fall into this trap, for example by using a single object to represent the core of the system.

Learning activity

1. What is so bad about top-down design?
2. Suppose you are refining a candidate class list. Under what criteria would you reject any candidates?

Comments on the activity

1. *Top-down systems with a single monolithic class are difficult to maintain and have built-in assumptions about how the system will be used.*
2. *An inappropriate class will have one or more of the following undesirable attributes:*
   - *redundancy*
   - *vagueness*
   - *an event or an operation*
   - *too abstract, not representing an object in the problem domain*
   - *outside the scope of the system*
   - *an attribute with no interesting behaviour.*

4.2 Properties

Read UMLD, Chapter 3, Properties.

Properties are the structural features of a class, and appear on the class diagram as an *attribute* or an *association*. The attribute appears inside the class box, and only the name of the attribute is necessary. At the first attempt, you might wish to restrict attribute descriptions in your class diagram to `name:type`, e.g. `price:Money`. This means that `price` is an object of class `Money`.(In fact there are other possibilities, because an object's type is quite a complicated thing.)

An association is a solid line between classes, directed from the source to the target class. In this case, the name of the attribute appears at the target end of the line. In Figure 3.3, `dateReceived`, `lineItems` and `isPrepaid` are properties of `Order`, represented in the diagram by associations. Following the advice in this reading, you may wish to reserve associations and class boxes for the most significant classes - it all depends on what you want to emphasise by any particular diagram.

Learning activity

Study the associations in Figure 3.3.

1. How many orders may be made on any day?
2. Can we have an order line without an order?

Comments on the activity

1. Any number, including none at all (consider the association between the source `Date` and the target `Order`).

2. No. The `OrderLine` (source) - `Order` (target) association has multiplicity 1. Any number of order lines are associated with one, and only one, order.

4.3 Properties as code

Read UMLD, Chapter 3, Programming Interpretation of Properties.

A simple way of implementing properties in code is with private data fields. Clients of the class can then retrieve or alter this data with public getter and setter methods. However, the property can also be computed rather than stored. In this case a getter method could calculate the data (e.g. multiply the number of items by their unit price). Multi-valued attributes are coded with a collection, and in this case you will certainly choose to update an item with a setter method. An alternative, and dangerous, implementation might return the entire collection to the caller.

The class skeleton for `Order` shows how the `lineItems` property can be implemented by a `HashSet`, which is a particular sort of unordered collection, or *set*. In contrast, this same property is marked as `ordered` in Figure 3.3, and it would be implemented by a `List` or an `Array`. In practice, for consistency, the class diagram and class skeletons should really agree.

Note that the getter/setter methods will retrieve/alter a single item from `lineItems`, rather than pass the whole set to the requesting client object. The client would not need to know that line items are stored in a list, or an array; all the client wishes to do is inspect an item. This is the essence of *encapsulation*.

Learning activity

Why should you be afraid of classes that are nothing but a collection of fields and their accessors?

Comments on the activity

OO design is concerned with objects that have rich behaviour. Objects are not just parcels of data, but also have operations and behaviour. A heavy use of an object's accessors indicates that some behaviour should be moved to this object.

4.4 Adding more information to the class model

Read UMLD, Chapter 3, Multiplicity.

The multiplicity of a property is the number of objects that fill this property. Make sure that you understand the meaning of the notation [1], [0..1], [0..2] etc. and [*].

Read UMLD, Chapter 3, Bidirectional Associations.

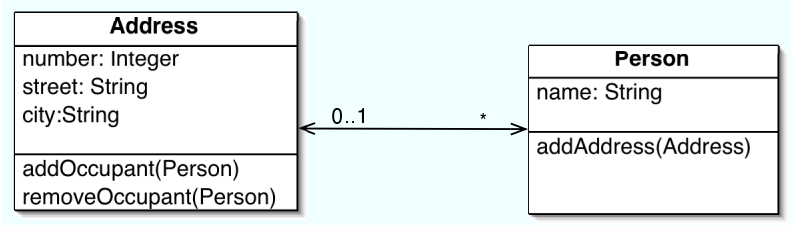
The bidirectional association, signified by navigability arrows at either end, refers to a pair of properties that are linked together, as in the `Person` - `Car` association. Navigating from `Car` to `Person` and back again returns us to the same car. Implementing bidirectionally is difficult due to synchronisation of the data.

Learning activity

1. Could you mark a `Person` - `Address` association as bidirectional?
2. Write down the property pair that represents the actual property 'lives at' for `Person` - `Address`. Draw two class boxes, one for each for `Person` and `Address` and link these boxes with an association. Mark multiplicities on the ends of the association. Add further properties to the diagram.

Comments on the activity

1. *Yes. An object can ask an `Address` instance who lives there. `Address` returns a number of `Person` objects. Take one of these `Persons` and ask where they live. The returned object will be the original `Address`.*
2. *The* Address *class has properties `dweller:Person[*]` and the `Person` class has a property `home:Address[0..1]`. (We assume that no-one has more than one address.)*



Read UMLD, Chapter 3, Operations.

Operations are the actions of a class, and correspond to *methods* in Java. There is a subtle distinction between the two: an operation is a procedure which might be carried out by any one of several methods in an inheritance tree. Notice that operations appear in the lower third of the class boxes in Figure 3.1.

UML distinguishes between *query* and *command* operations. Technically, a query does not change the *observable* state of an object. A useful programming tip is to separate commands from queries by ensuring that commands do not return any value to the caller.

Read UMLD, Chapter 3, Generalization.

Generalisation means that two objects of different types may be freely substituted for each other. The obvious OO mechanism is *inheritance*. Subclasses of a parent inherit all the features of that parent, and may override any method of the parent. In general, a *subtype* can replace a *super-type* in any code block and the programme will still function (although the output may be different, of course). This is a manifestation of the OO principle known as polymorphism. A subclass is therefore a subtype. Different languages might have additional mechanisms for sub-typing, for example `interfaces` in Java. Interfaces are studied in Chapter 5 of *UMLD*.

4.5 When to use class diagrams

Read UMLD, Chapter 3, When to Use Class Diagrams.

Class diagrams are the single most important modelling idea in UML and you will use them all the time. However they can be *very* detailed. Too much detail can detract from the underlying purpose of the diagram. It is best therefore to start simply and add extra information only when necessary. Don't draw models for everything. A few class diagrams should cover the breadth of the system. Each class diagram should be used in conjunction with a behavioural diagram so that the dynamic relationship between objects can be grasped.

4.6 Exercises

1. Examine the scenarios and use-cases that you wrote for the Personal Organiser (Section 3.4). Construct a candidate class list. Refine this list by elimination and renaming until you are confident that you have discovered the base classes. Now construct a class diagram for one or more of the use cases that you have previously identified (see Section 3.4).
2. Draw up a class list for Space Game. Refine this list and construct a class diagram for one or more of the use cases that you have already identified in Section 3.4.

4.7 Summary

After studying this chapter you should be able to:

- draw up a candidate class list from a requirements document
- state what characteristics a candidate class should have

- recognise class boxes, attributes and associations on a class diagram
- be able to use the full textual description of an attribute
- understand how an association on a class diagram relates to message-passing between objects
- draw simple class diagrams
- write class skeletons for simple class diagrams
- add multiplicities to associations
- use, where appropriate, a bi-directional association
- distinguish command operations from query operations
- state the meaning of *subtype*, *super-type* and *inheritance*.

Chapter 5

Sequence Diagrams

Essential reading

UML Distilled Chapter 4

Class diagrams show the static structure of a system and are classified as *Structure Diagrams* in UML (see Fig 1.2 of *UMLD*). But dynamic object message passing is the fundamental way that an OO system executes any particular behaviour. *Interaction Diagrams* describe how objects collaborate, and the most widely-used is the *Sequence Diagram*. The sequence diagram illustrates a single scenario and depicts relevant objects and messages. This chapter will show you how to construct sequence diagrams and add features such as creating and deleting participants and asynchronous and synchronous calls. There will also be an important example of decentralised control, a defining characteristic of the OO paradigm.

5.1 The basic technique

Read UMLD, Chapter 4, introduction.

Figure 4.1 of this reading shows a sequence diagram for the scenario `Calculate Price` for a business system. Note the presence of *participant* boxes at the head of each lifeline. Although a participant is essentially an object, the name of the participant should not be underlined. (Object names are usually underlined in UML). Also note that messages are shown as lines with filled arrow heads and are also named. The participant activation bar shows when a participant is active, corresponding directly to when the object's methods are currently being executed by the CPU (on the stack). Return arrows can be used for each method call, and the *found message* begins the interaction. Finally, this diagram shows how an object can call a method on itself. The order object makes such a call with the message *calculateBasePrice*.

Learning activity

What feature of `Calculate Price` is not evident in Figure 4.1? What features of the interaction are well illustrated by sequence diagrams?

Comments on the activity

This basic sequence diagram does not show when messages have to be repeated. Sequence diagrams are not good at describing algorithmic details such as loops and conditionals (although these can be incorporated) but they do excel in their depiction of calls between participants, and the particular processing that each participant has to undertake.

Look now at Figure 4.2, and carefully study Fowler's account of this diagram which accomplishes `Calculate Price` through distributed rather than central control. You should certainly aim to construct sequence diagrams that look more like Figure 4.2 than Figure 4.1, because your system architecture will then reflect the OO paradigm, which is to use lots of little objects and lots of method calls, rather than a single module that does the bulk of the work.

Learning activity

What are the advantages and disadvantages of distributed control?

Comments on the activity

The main advantage is that the effects of change are localised. Data and behaviour that accesses this data are contained in one place, and this reduces the complexity of system change and enhances system development and maintenance. Another advantage is that opportunities for polymorphism are increased. In the example of Figure 4.2, products with unusual product pricing algorithms can be sub-classed from `Product`*, hence avoiding the use of conditional logic in a larger module.*

However, the OO style is harder to understand because you have to refer to a number of objects to see how the behaviour takes place. You just can't simply read through a single module and expect to understand programme flow. Another disadvantage might be for real-time/embedded systems where programming efficiency is important, and such operations as the creation and destruction of objects will consume valuable memory and CPU cycles.

5.2 Advanced techniques

Read UMLD, Chapter 4, Creating and Deleting Participants, Synchronous and Asynchronous Calls

Figure 4.3 shows the creation of two objects during a scenario `Query Database`. These objects exist only for the course of the interaction, and should be deleted when they are no longer needed. Although Java has a mechanism to do this automatically (garbage collection), in general, the deletion of the object should be notated.

Although we are not studying loops and conditionals in this chapter, you should have a look at Figures 4.4 and 4.5, noting in particular that the arrow heads are not filled. This signifies asynchronous calls: an object makes such a call when it can continue with its own processing and doesn't have to wait for a response. A *thread* is a programming task that can run in parallel (i.e. asynchronously) to

other tasks, and can be an efficient way of programming, although debugging can be hard.

5.3 When to use sequence diagrams

Read UMLD, Chapter 4, When to Use Sequence Diagrams [omit CRC Cards].

In summary, sequence diagrams are an excellent technique for modelling the message-passing behaviour of objects in a single scenario. The procedural details of the behaviour are better represented in an *Activity Diagram*. *State Diagrams* are used for the behaviour of a single object in many scenarios. Other interaction diagrams are *Communication Diagrams* (used to show connections) and *Timing Diagrams* for timing constraints.

5.4 Exercises

1. Choose a scenario for the Personal Organiser project of Section 3.4 and draw a corresponding sequence diagram. You will need to refer to your class diagrams in order to define the participants (see Section 4.6).
2. Draw sequence diagrams for the scenarios of the Space Game project (Sections 3.4, 4.6).

5.5 Summary

After studying this chapter you should be able to:

- construct a sequence diagram from a scenario and a class diagram
- add object creation/deletion and asynchronous calls where appropriate
- state when a sequence diagram is a valuable modelling technique, and state which other *Behaviour Diagrams* are useful in different circumstances
- distinguish, on inspection of a sequence diagram, centralised control from distributed control and state why the distributed technique fits the OO paradigm.

Chapter 6

Class Diagrams: Advanced techniques

Essential reading

UML Distilled Chapter 5

Chapter 4 introduced the key elements of the class model. Sometimes, and especially for design class diagrams, further annotations are needed, and a few of the many advanced concepts are discussed in this chapter.

6.1 Responsibilities and collaborators

Read UMLD, Chapter 4, CRC Cards, Chapter 5, Responsibilities.

Although Class-Responsibility-Collaboration cards are not a UML technique, they are a widely used OO design tool, and you should understand what they are and how they are used.

Read UMLD, Chapter 5, Responsibilities.

In particular, note the definition of class responsibilities and collaborators. Figure 5.1 of *UMLD* shows how responsibilities can be incorporated in the UML class diagram.

Learning activity

What is a class responsibility? Who/what are the class collaborators? At what stage of the software life-cycle do you think that CRC cards could be used?

Comments on the activity

A responsibility is a short sentence that summarises something about an action that the object performs, some knowledge that the object holds, or some important decision that the object can make. Collaborators are other classes that this class must work with in order to maintain this responsibility. In essence, CRC cards are a high level class modelling technique, and can be used during analysis or early in the design phase.

6.2 Static operations and attributes

Read UMLD, Chapter 5, Static Operations and Attributes.

A *static* operation or attribute applies to a class rather than an instance of that class. In other words, all objects have access to a single variable (static attribute) or can use a common operation (in Java this is a static method). For example, in a Library System, each library user might be represented by a unique instance of the `LibraryUser` class, but the `LibraryUser` class would hold a static variable `numberOfUsers` and static methods `getNumberOfUsers` and `incrementNumberOfUsers` and `decrementNumberOfUsers`. Static items are underlined in the class box.

6.3 Aggregation and composition

Read UMLD, Chapter 5, Aggregation and Composition.

Aggregation, which refers to a part-of relationship is a fairly meaningless concept in class diagrams. People are parts of a club, but people are also parts of other structures. Since the class diagram is entirely about such structures, aggregations are unnecessary annotations. In Figure 5.3 of *UMLD*, if a `club` object is deleted, the members of that club would not necessarily be deleted as well, since they are parts of other structures.

However, in the example of Figure 5.4 of *UMLD*, a polygon is said to be *composed* of points if `Point` instances are deleted if the polygon is also deleted. Composition identifies strong associations, and is notated in UML by a filled diamond. The `Point` class is associated with `Polygons` and `Circles`, but `point` objects can only be parts of polygons or circles, and never both.

6.4 Interfaces and abstract classes

Read UMLD, Chapter 5, Interfaces and Abstract Classes.

Interfaces and abstract classes, which are elements of Java and other OO languages, are a common instrument for polymorphism. An abstract class has one or more *abstract* operations, and may contain a number of *implemented* operations. An abstract operation has no implementation and an abstract class cannot itself be instantiated. A concrete sub-class of the abstract super-class may, however, be instantiated, as long as it provides implementations of all the abstract operations.

Abstract classes are useful if we can imagine that different subclasses provide different implementations of a common operation. For example, `ArrayList` is just one sort of `Abstract List`. It shares `equals()` with other `Abstract Lists`, but implements the `get()` operation (see Figure 5.6). (In addition, it overrides the implementation dependent `add()` method.)

An interface is a class that has no implementation at all, but serves to define a type. In the example of Figure 5.6 of *UMLD*, an `order` holds a list of items, stored by the variable `lineItems`. Exactly how this list is implemented is unimportant to `order`, as long as `lineItems` has a `get` operation for retrieval of items. All implementations must therefore conform to the `List` interface, which specifies a `get` operation (and possibly other useful operations too).

The UML annotations for abstract classes and interfaces are illustrated in *UMLD* Figures 5.6 and 5.7. Note the use of an open arrowhead for inheritance, and the dashed line and ball and socket notation for interfaces.

Learning activity

The variable `lineItems` of `Order` could be declared as:

```
private ArrayList lineItems = new ArrayList()
```

However, a better design choice is available. What is it, and why is it better?

Comments on the activity

The problem with the suggested declaration is that it will be harder to change the implementation of `lineItems` at a later date. For example, another implementation of `lineItems` could provide data base accessibility. All the lines of code involving `lineItems` would then have to be changed. However, by using the declaration

```
private List lineItems = new ArrayList()
```

then as long as future implementations conform to `List`, only a single line of code would need to be changed.

6.5 Classification

Read UMLD. Chapter 5 Classification and Generalization, Multiple and Dynamic Classification.

This reading highlights the difference between a classification and a generalisation. Generalisation is distinguished from classification by the property of *transitivity*: if an *a* is a *b* and a *b* is a *c*, then an *a* is a *c*. Study carefully the example of *UMLD* Figure 5.11, paying attention to the generalisation sets which occur as labelled arrowheads. Surgeons can be classified into two sets, `role` and `sex`. In this two-fold classification, a surgeon object would have two types that are not connected by inheritance. On the other hand, a chain of inheritance links a surgeon to a person(a surgeon is a doctor, and a doctor is a person).

Learning activity

You are designing a University Library system. The library has public members and employees. Some public members are allowed to read books inside the library, but not

to borrow them, and other public members have full borrowing rights. Library employees are also members of the library, and include staff who can check-in and check-out books, and librarians who can perform these duties as well as order new books. Draw a multiple classification diagram to show these relationships.

Comments on the activity

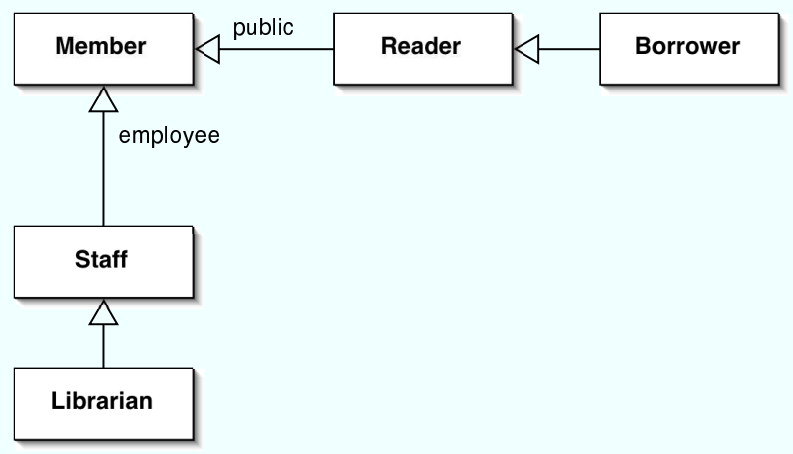


Figure 6.1: Multiple Classifications for a Library System

6.6 Association classes and visibility

Read UMLD, Chapter 5, Association Class and Visibility.

An association class can be added to an existing association on a class diagram. Such a class provides extra attributes and operations to a particular association. If the association class can have numerous objects for the same association, the notation of Figure 5.13, which specifically shows the multiplicities, must be used. Otherwise, the association class can be joined to the association by a broken line.

UML allows attributes and operations to be tagged as public, private, package and protected, with the precise meaning of each visibility determined by the choice of programming language. They should only be used if you wish to draw attention to differences in visibility of some elements in a class diagram.

6.7 When to use advanced concepts

The advanced concepts discussed in this chapter should only be attempted at the late analysis and design phases of the software project. The incorporation of these advanced concepts deepens the class model and leads to a design class diagram. Such a diagram immediately precedes implementation.

6.8 Exercises

1. Take a class diagram from the Personal Organiser example of Exercise Section 4.6 and add multiplicities to the associations and visibilities to the attributes and operations.
2. Continue your development of the Space Game Sections 3.4, 4.6, 5.4 project by adding any of the advanced features introduced in this chapter to your class diagrams. Study your classes for generalisations and classifications and draw a multiple classification diagram for a Space Game.

6.9 Summary

After studying this chapter you should be able to:

- state the CRC technique and know when this technique is useful in the software life-cycle
- define class responsibilities and class collaborations and incorporate responsibilities into a class diagram
- understand the difference between static/instance operations and attributes
- understand the difference between aggregation and compositions and know how to notate composition on a class diagram
- state what an interface and an abstract class are, and why they enable polymorphism in OO design
- know the UML notation for interfaces and abstract classes
- distinguish classification from generalisation and draw multiple classification class diagrams
- understand the purpose of association classes and know the two ways that they may be added to an association between two classes
- know the UML annotation for private, public, package and protected visibility.

Chapter 7

State Machine Diagrams

Essential reading

UML Distilled Chapter 10

State diagrams pre-date UML and even OO analysis and design. They are commonly used to show the behaviour of a system. The UML equivalent is the state machine diagram. Unlike the previous diagrams we have studied, the state machine diagram shows the lifetime behaviours for *a single object*.

7.1 The basic technique

Take a look at *UMLD Figure 10.1*, a state machine for a Gothic Castle controller. There are four features in this diagram: an initial pseudo-state, the states themselves, represented by a box with rounded corners, state transitions and their labels, and a final state. The transitional label has three optional parts:

`trigger-signature[guard]/ activity`.

The `trigger-signature` is usually a single event that triggers a change of state. This change of state is a *transition*, possibly invoking some behaviour or `activity`. The `guard` is a boolean condition that must be true for the transition to occur.

Learning activity

1. The three parts of a transition label are optional. What is signified by any missing part?
2. There can only be one transition out of any state. However the `Lock` state of Figure 10.1 has two exit arrows. Why is this?
3. What is the purpose of the final state?

Comments on the activity

1. *A missing activity means that no behaviour is executed during the transition. A missing guard indicates that the transition always takes place if the event occurs. A missing trigger-signature indicates that the transition occurs automatically, as with activity states.*

2. *Multiple transitions exiting a state are allowed, as long as the transitions are mutually exclusive.*
3. *The final state indicates that the state machine is completed and the object can be deleted.*

Read UMLD Chapter 10, Internal Activities, Activity States, Concurrent States.

We have seen how a controller can be successfully modelled with a state machine diagram. Another frequent use of these diagrams is user interface (UI) modelling, as in Figure 10.2. Internal activities are defined as self-transitions that do not trigger entry or exit transitions. In this example of a text field UI, the trigger signatures `character` and `help` do not cause a transition from the `Typing` state, but they do cause internal activities such as opening a help page and updating a status bar.

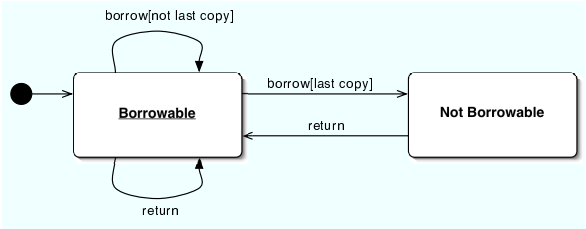
Sometimes states may take a while to complete an activity. These are activity states, and the on-going activity is marked with a `do/` in the state box (see Figure 10.3). As soon as the activity is completed, a transition can occur without an external trigger. For example, in Figure 10.3, as soon as the search is over, the system moves to the `Display New Hardware Window` state.

Figure 10.5 shows how alternative states ('orthogonal' in *UMLD*) can be represented by adjacent boxes within a concurrency region of a superstate. This figure also depicts a useful notation for state history.

Learning activity

A `Book` object represents all the copies of a certain book in a library system. A `Book` object is borrowable provided that there is at least one copy on the shelf. The triggers for state change are `borrow` and `return`. Draw a state machine diagram for `Book`'s life-cycle.

Comments on the activity



7.2 Implementing state diagrams

Read UMLD Chapter 10, Implementing State Diagrams.

This reading outlines three ways of implementing a state machine diagram.

In the *nested switch* technique an `if - else if - else` structure provides a direct, if laborious implementation.

The *state pattern* method uses a hierarchy of state classes to handle state behaviour. In other words, each state has one state subclass and the controller has methods for each event, simply forwarding the handle requests to the respective class. This technique turns the `if - else if - else` structure into a set of objects, a good application of modularisation.

The *state table* approach uses a data table with source/target state information. This table might be generated at runtime, or pre-loaded. In either case, an interpreter can read the table, or an automatic code generator could generate classes based on the table.

7.3 When to use state diagrams

Read UMLD chapter 10, When to Use State Diagrams.

The state machine diagram is good at describing the behaviour of a single object across a number of use cases. This is opposite to the sequence diagram which shows how a number of objects collaborate during a single use case. An intermediate UML model which shows numerous objects for several use cases exists: it is the activity diagram, and this will be the subject of the next chapter.

7.4 Exercises

1. An `Event` class is responsible for making an appointment in a Personal Organiser. Once the appointment has been made, an alarm is set, and the date and time of the appointment are displayed. The alarm flashes if the appointment is current. A past appointment will still exist in the calendar, unless deleted by the user. Draw a state machine diagram for the lifetime behaviour of `Event`.
2. Choose a class with interesting behaviour from the Space Invaders project (Sections 3.4, 4.6, 5.4, 6.8). Draw a state machine diagram for this class.

7.5 Summary

After studying this chapter you should be able to:

- recognise the four features of a state machine diagram
- use the three parts of a transition label, and know what is inferred if any part is missing
- know what internal activities, activity states and concurrent states are, and how they are notated on a state machine diagram
- state and explain the three ways of implementing a state machine diagram
- know when to use state machine diagrams

- draw state machine diagrams using any of the features described in this chapter.

Chapter 8

Activity Diagrams

Essential reading

UML Distilled Chapter 11

Activity diagrams are a generalisation of flowcharts, as used to describe procedural logic, business process and work flow. Activity diagrams differ from flowcharts, however, by the possible inclusion of parallel behaviour. In UML terms, an activity diagram can show the behaviour of several use cases and may involve a number of objects.

8.1 The basic technique

Read UMLD, Chapter 11, Introduction.

Figure 11.1 of *UMLD* shows the diagram for the activity `Receive Order`. Any activity is made from individual *actions*, where each action is represented as a box with round corners. Figure 11.1 shows some other important features: *forks*, *joins*, *decision diamonds* and *merges*. All these elements are connected by *flows* (also called *edges*). The notation for the initial and final nodes is similar to the initial and final states of the state machine diagram.

Learning activity

1. Does the diagram tell us anything about the order of the actions in the two sub-activities headed by `Fill Order` and `Send Invoice`?
2. The final action, `Close Order`, happens immediately following the completion of either sub-activity. True or false? Explain your answer.
3. How is conditional behaviour represented on an activity diagram?

Comments on the activity

1. *No. Sub-activities that originate from a single fork happen in parallel, but no sequence of actions can be inferred from the diagram. For example, the order might be delivered before or after the invoice is sent.*
2. *False. The join establishes a synchronisation between the two branches. The order must be delivered and paid for before it can be closed.*

3. *Conditional behaviour is represented by a decision. A decision has a single incoming flow and several outgoing flows. The outgoing flows are labelled by guards. Guards are mutually exclusive. The conditional behaviour is ended by a merge diamond which has a single out flow.*

Read UMLD, Chapter 11, Decomposing an Action.

Figures 11.2 and 11.3 illustrate how sub-activities from one diagram can be factored out as actions on another. Notice the strange rake symbol, indicating a sub-activity within an action box. Figure 11.3 also shows how a method call can be added to an activity, using the notation

`Class::method`.

Read UMLD, Chapter 11, Partitions.

The activity diagrams we have seen so far depict what happens, but not which objects are involved in the actions. If you need to show which actions are performed by a particular class, the activity diagram can be organised into *partitions*, also known informally as swim lanes (see Figure 11.4).

Read UMLD, Chapter 11, Signals.

The initial mode in an activity diagram corresponds to the invocation of a program or method. Actions can also respond to *time signals* and *accept signals*. A signal arises from an external process.

Learning activity

1. According to Figure 11.5, when can I leave for the airport?
2. Explain how Figure 11.6 resolves the apparent paradox of two contradictory actions, `Book Itinerary` and `Cancel Itinerary` happening in parallel branches.

Comments on the activity

1. *Within two hours of the flight, and only after the taxi has arrived.*
2. *The contradictory sub-activities are in a race. The activities are not `joined`, but end on the final state. The slower flow is terminated upon arrival of the quicker flow at the final state.*

8.2 Advanced techniques

These advanced techniques take us some way into the vast UML specification of an activity diagram. The basic technique will be adequate for most of the activity diagrams you will be drawing. You are not expected to use all of the advanced techniques of this section in your activity diagrams, but you should certainly recognise them in other diagrams and know what the technique is used for.

Read UMLD, Chapter 11, Tokens.

`Tokens` are a means of tracing flow through the diagram. The initial node creates a token which is passed from action to action. Any encountered fork creates additional tokens (one per alternative sub-activity), which are subsequently destroyed at a join.

Read UMLD, Chapter 11, Flows and Edges.

Figure 11.7 shows four ways of depicting an edge. The connectors are purely for convenience, but the lower two diagrams of this figure show how to depict object transfer. The transferred objects play the role of tokens, but they can carry data as well.

Read UMLD, Chapter 11, Pins and Transformations.

`Pins` are an optional annotation, useful if you want to parameterise actions. A transformation must be shown on the diagram if the output parameters of an outboard action do not match the input parameters of a receiving action. This transformation can only change one pin parameter into another. It must have no further side effect.

Read UMLD, Chapter 11, Expansion Regions.

`Expansion` regions are useful for situations involving multiple actions that have been triggered from a single action upstream. In Figure 11.9, `Choose Topics` generates a list of topics which are dealt with at the same time (note the keyword `concurrent`). Figure 11.10 shows another way of indicating that a single action is repeated. In this case, concurrency is assumed. Expansion regions generate multiple tokens: there is a token for each article in Figures 11.9 and 11.10. Simply, there is a single written article for each listed topic.

Read UMLD, Chapter 11, Flow Final.

The `flow final` (see Figure 11.11) indicates the end of a particular flow, but without terminating the entire activity. The decision diamond in this figure rejects articles, and the token is destroyed in the flow final. The overall effect is that the number of written articles can be less than the number of topics.

Read UMLD, Chapter 11, Join Specifications.

A `join specification` attaches a boolean expression to a join. The specification is evaluated at the arrival of each token and an output token is only generated when the expression is `true`.

8.3 When to use activity diagrams

Read UMLD, Chapter 11, When to Use Activity Diagrams.

Work flow and process modelling frequently involve parallel behaviour and this is well represented by an activity diagram. The diagram can show several use cases and objects and interpolates between the state machine and sequence diagram modelling techniques. The ability of an activity diagram to represent procedural logic makes them useful to software architects who use

UML in the *programming mode*.

8.4 Exercises

1. Continuing with the Personal Organiser project, draw an activity diagram for an event which is scheduled to occur at a fixed time over a number of weeks. The event might have an associated email reminder which is sent to the event attendees on the day before the meeting, and an alarm is activated on the actual day of the meeting. The alarm is deactivated when the meeting has finished. Any event might be cancelled at any time.
2. Choose a set of use cases from the Space Game project and draw an activity diagram to show how various actions contribute to an overall behaviour.

8.5 Summary

After studying this chapter you should be able to:

- recognise and understand the meaning of: initial node, actions, activity final, forks, joins, decisions, merges, flows and edges as they appear on activity diagrams
- construct activity diagrams for procedural logic
- construct activity diagrams for several use cases or a well defined activity
- describe in words the content of an activity diagram
- know how to decompose an activity into sub-activities
- know how to include method calls in an action
- partition an activity diagram
- recognise the symbols for time and accept signals
- use, where appropriate, the time and accept notation
- understand the use of tokens
- recognise the advanced techniques associated with pins, expansions, and join specifications
- know when to use activity .

Chapter 9

Summary of UML modelling techniques

Essential reading

UML Distilled Chapters 2, 6-8, 12-17

In the preceding chapters we have introduced five UML techniques: scenarios/use cases and class, sequence, state machine and activity diagrams. Figure 1.2 of *UMLD* shows the complete family of UML techniques. As you can see, we have covered a single structural diagram (the class diagram) and four behavioural models. The remaining eight UML techniques (object, package, deployment, composite structure, component, communication, interaction overview and timing diagrams) will not be studied in depth in this course but you might wish to look at them and use them in any project you are subsequently asked to undertake.

UMLD suggests that use cases and class, activity and state machine diagrams are useful tools for requirements analysis. Customer communication is paramount during this phase, so any diagrams you produce here will need to be simple and intuitive. The biggest risk with UML techniques during requirements analysis is that the domain expert will not understand your diagrams. That can lead to bafflement, or to a false sense of confidence.

UMLD recommends that class, sequence, package, state machine and deployment diagrams are useful techniques during the design phase, and the notation can be more precise and the diagrams more refined at this stage. In an iterative process, the diagrams are used as sketches or blueprints. Each iteration modifies the existing body of diagrams, highlighting the inevitable changes as design becomes more detailed. In principle, blueprinting produces very detailed and specific diagrams and will lead directly to implementation. UML in sketch mode is much more fluid - coding is based on, but not prescribed by, UML diagrams, and coding imperatives may well cause the design to alter.

Once the system is built, UML can document the system although it is no substitute for detailed documentation that is generated from the code, as, for example, by the JavaDoc tool. UML illustrates the detailed implementation documents, sketching out the important parts of the system. Package, deployment and class diagrams are all useful for the structural parts of the system, as well as sequence diagrams to show the important interactions between classes, and a state machine diagram for any class with complex life-cycle behaviour.

Part III

Quality

Chapter 10

Product Quality

Essential reading

Using UML Chapter 19

Verification, validation and testing are product-based techniques for ensuring that software is of high quality. Verification is the process of making sure that we have built the product correctly i.e. according to the specification. Validation is an attempt to ensure that the software is fit for its purpose, and this is an open-ended and difficult task, because we even need to look beyond the captured requirements. Software testing contributes to both verification and validation.

Ultimately, the concern of software engineering is to ensure high quality, both of the product and of the process that led to its creation. This is the focus of this part of the subject guide.

Learning activity

Define software quality.

Comments on the activity

This has already been defined in our course - see section 1.1

10.1 Verifying software

Read UUML, Chapter 19, Verification.

Verification is a check that the product and the specification agree. In an iterative process, verification happens at each iteration.

Learning activity

What are the three areas of concern in verification of a UML development?

Comments on the activity

Verification that the use cases satisfy any other requirements specification not contained in the use case descriptions (i.e. that the use cases are complete), verification that the classes and their interactions can provide the use cases and verification that the code corresponds to the class design.

Verification also consists of checking that the programme compiles and runs without error (after all, this should be a requirement of the system!). A check can also be made that the UML diagrams generated by the project are consistent in the sense that there is always at least one programme that is described by the model.

10.2 Validating software

Read UUML, Chapter 19, Validation.

Validation requires the involvement of the customer and is difficult because the aim is to find anything that might make the system less useful to the customer than perhaps it should be, and this is very open-ended indeed.

Learning activity

Why is the developer poorly placed to assess the usability of the system?

Comments on the activity

Unlike a typical user, the developer understands the system, and they will therefore find it very hard to imagine themselves as interacting with the system as users might. Furthermore, the engineer has considerable experience of interacting with software in general, and so is much more confident and competent than the intended users of the system.

10.3 Testing

Read UUML, chapter 19. Testing.

Testing has three aims: to find bugs, to convince the customer that there are no damaging bugs, and to provide information for further product development. The first aim is the most important and has the direct implication that *a successful test is one that finds a bug*. Clearly, if the system passes a set of easy tests, little has been learnt.

Learning activity

What kinds of tests are possible?

Comments on the activity

- *Usability testing - is the system easy to use effectively?*
- *Unit testing - checks the software modules (OO: classes) for bugs*
- *Integration testing - do the parts of the system collaborate correctly?*
- *System testing - this checks that the entire system meets the requirements specification*
- *Acceptance testing - this is the validation of the system by the customer*
- *Stress testing - places the system under extreme conditions to check that the system degrades gracefully rather than failing catastrophically*
- *Regression testing - these tests confirm that the system continues to work correctly after any modification, and can involve reapplication of any of the above tests*

Tests can be white or black box. In a black box test, a module is checked against the specification: none of the implementation details are available to the tester. A white box test, in contrast, is carried out with knowledge of the modules and code. For example, a white box test might examine extreme loop termination conditions. A black box test will only be concerned with the public interface of the module.

Any test needs to be repeatable, documented and precise. A test specification should be written at the same time as the requirements are gathered, and this can help analyse requirements and ensure that they are testable.

Sometimes tests can be automated, and this alleviates some of the boredom of this dull task. Apart from the tedium, testing is time consuming (30-50% of project time), expensive and only perilously left until the end of the development process. In an iterative project, testing is spread throughout the project life-cycle.

10.4 Exercises

1. It might appear that a class can be tested by checking that every method contained in the class is bug free. However this is incorrect. Why is this? How can state machine diagrams help with class testing?
2. What is encapsulation, and why might an encapsulated component be quite hard to test? In practice, how can we test a well encapsulated class?
3. Polymorphism also presents particular problems to the tester. Why is this? What lesson can we learn from this analysis?

Answers

1. Apart from operations, a class may also have attributes, and these variables may determine the effects of method calls. One method may change the state of an object in such a way that a different method call might fail. A better way to test a class is to check all the ways an object may enter and leave all possible states, as described and defined by the state machine diagram.

2. An object is encapsulated if its clients need only refer to the public interface of the object in order to accomplish its task. This is problematic in testing because the internal state of an encapsulated object is private and hidden. In practice, methods can be added to the class that report on the internal state.
3. Polymorphism, for example by inheritance, means the substitution of one component by another. However the substituted component might override superclass methods and produce side effects that were not present before the substitution took place. In general, polymorphism, although a hallmark of OO design, increases inter-module coupling because the whole inheritance tree must be checked to see which method is being overridden, or variable is being shadowed. Therefore the moral is: only use inheritance when the advantages outweigh the disadvantages. It is not a panacea.

10.5 Summary

After studying this chapter you should be able to:

- define verification, validation and testing
- place verification in the context of use case driven development
- explain why validation is difficult from the developer's perspective
- state the aims of testing, and the criterion for a successful test
- state and discuss the kinds of testing and the meaning of black/white box testing
- understand the importance of testing in the software life-cycle, and how testing relates to waterfall and iterative processes
- understand the problems associated with the testing of OO systems.

Chapter 11

Process Quality

Essential reading

Using UML Chapter 20.
UML Distilled Chapter 2.

Higher quality software can be achieved by focusing on two approaches. Product quality, as we saw in the last chapter, involves the verification, validation and testing of the system itself. Process quality involves a scrutiny of the human structure that produced the software system.

There are no learning activities in this short chapter. They have been collected together and placed in the exercises section at the end of the chapter.

11.1 Project management

Read UUML, Chapter 20, Management.

The project manager has the overall responsibility for the success of the project. The manager's responsibilities are wide ranging, as the long list of this reading shows. Clearly an important responsibility is keeping the project on track, especially since large projects overrun, on average, by 50% of the original estimate. Estimation is difficult because the project schedule is usually set at the outset, even before the requirements are well understood. And worse still, requirements themselves may alter during the course of the project. Estimation is especially difficult for an iterative process because there are no milestones that mark the end of each phase (analysis, design, implementation, testing) because all these phases are repeatedly revisited.

If the development is component based - and a large project almost certainly will be - the manager must help the developers to make best use of available components such as code libraries, re-usable modules from other project teams in the organisation and, importantly, re-use from within the project team.

Read UMLD, Chapter 2, Fitting Process into a Project.

Software projects differ greatly, far greater than, say, the difference between a garden shed and a house. This means that the process of developing software depends on many things: the kind of system under development, the technology used by the development team,

the size and distribution of the team, the nature of the risks, the consequence of failure, the working styles of the team and the culture of the organisation.

The manager can also adapt any process to suit a project, although this is a difficult thing to do without experience. Organisations suffer from the repetition of expensive mistakes. In order to reduce this toll, and for managers to gain experience, iteration and project retrospectives are recommended.

11.2 Project planning

Read UMLD, Chapter 2, Predictive and Adaptive Planning.

One reason for the popularity of the waterfall model is that a manager can provide clear costings and time estimates. These estimates are more problematic in an iterative process, but some planning techniques are available.

In *predictive planning*, an initial stage serves to provide the manager with enough information to make long term plans for the second, hopefully predictable, stage of development. Most projects, however, undergo *requirements churn* whereby the requirements change during this second stage. Of course the requirement specification can be frozen at the end of the first stage, but there is a risk that the delivered system no longer meets the needs of the customer.

There are two solutions to requirements churn: place more resources into requirements engineering, or acknowledge the inherent complexity of software development and choose an *adaptive* strategy. In adaptive projects, change is treated as normal. The project becomes controllable, but is still unpredictable. Plans are still made in adaptive projects, but the plans are treated as baselines to assess the consequences of change, and are not a prediction of the future.

Read UMLD, Chapter 2, Agile Processes.

Extreme programming is the most well known Agile process. These processes are all highly adaptive and take as fundamental the assumption that the most important criterion in a project's success is the quality of the people working on the project, and on how they work together. Agile methods use short time-boxed iterations of up to a month in duration and utilise UML in sketch mode. Agile methods are often characterised as being *lightweight* which means that there is a minimum of documentation and control points during the project.

11.3 Exercises

1. What is an iteration retrospective? What is a project retrospective?
2. Compare predictive and adaptive approaches to project planning.

3. What milestones can be set for an iterative project? Are there any ways of estimating project duration for an iterative process?

Answers

1. An iteration retrospective is a meeting by the team at the end of each iteration with the intention of working out what went well and how things can be improved. This meeting can be short, perhaps a couple of hours. It is helpful to maintain a list:
   - Keep: parts of the process that worked well and should be remembered and used in the next iteration.
   - Problems: parts that did not work well.
   - Try: changes to improve the process.

   A project retrospective happens at the end of the project, or at a major release, and is formal, lasting a couple of days. The project retrospective can use the same list as the iteration retrospective, but now the lessons learned apply to the next project, rather than the next iteration.
2. In predictive planning, an initial stage serves to provide the manager with enough information to make long term plans for the second, hopefully predictable, stage of development. This means that the manager can develop a contract stating how much the project will cost, what shall be built, and what will be delivered. This is only possible if precise and accurate requirements are available, and change is not expected.

   In adaptive projects, requirements change is treated as normal. The project becomes controllable, but is still unpredictable. Plans are still made in adaptive projects, but the plans are treated as baselines to assess the consequences of change and are not a prediction of the future. An adaptive approach is recommended in the absence of precise, accurate and static requirements. An adaptive plan can fix a budget and a delivery time but can not predict what functionality will be delivered within these constraints. Only iterative processes can be adapted in this way. Predictive planning can be used with any process, although it is best suited to a waterfall or staged delivery process.
3. Since each iteration must finish with tested code of production quality, we might mark each iteration by delivery of a particular functionality. This can help measure the progress of a project, but it does not help with time estimation. It has been suggested that the use cases - which represent functionalities - are a basic unit of process time. Of course, the time to implement a particular use case must still be guessed.

11.4 Summary

After studying this chapter you should be able to:

- discuss the responsibilities of a project manager
- explain why estimation of cost and project duration is difficult
- discuss the management of component based developments
- explain the terms iteration and project retrospectives

- explain predictive and adaptive planning
- explain requirements churn, and its relationship to predictive and adaptive projects.

Part IV

Resources

Chapter 12

Analysis and design of a personal 0rganiser

12.1 Scenarios

Make Appointment

The user scrolls the calendar to the date of the event. The user clicks on a time box and selects the menu option 'schedule event'. A form appears on the screen and the user enters some event details. It's a meeting with a client at the office, and it is not a regular event. The user sets the alarm and arranges for an email reminder to be sent to the client. The user fills in an additional note 'wear suit'. The user clicks OK, the form disappears and the calendar displays a red circle around the date of the appointment.

Make Appointment at a past date

The user scrolls the calendar to the date of the appointment. The user clicks on a time box and selects the menu option 'schedule event'. A warning box appears on the screen with the message 'Cannot schedule event for a past date'. The user clicks OK, the warning vanishes and the screen returns to the calendar.

12.2 Use cases

Make Appointment

Goal Level: Level 1

Main Success Scenario:

1 User scrolls calendar to date of appointment

2 User clicks on time box and selects *schedule event*

3 User specifies the type of event

4 User chooses if the alarm should be set

5 User chooses a regular event or single event

6 User chooses whether or not to send an email reminder, and to whom.

7 User completes any further meeting notes

8 User clicks OK and the calendar is displayed with a red circle around the date of the appointment

Extensions:

2a User has attempted to schedule an event in the past. A warning box is displayed and the user must click OK

12.3 Class Identification

List of nouns from the two scenarios above:

- Calendar
- Date
- Appointment
- Time
- Time box
- Menu
- Form
- Screen
- Event
- Meeting
- Client
- Office
- Regular event
- Alarm
- Reminder
- Note
- Red circle
- Warning box
- Message

The following nouns all refer to the Organiser display: Menu, Form, Screen, Red circle, Warning box, Message, time box. These are possibly already represented by Java classes.

Meeting, Office and Note are the details of a particular event.

Client is a particular role and is a potential class.

Calendar, Date, Appointment, Time, Event, Alarm, Regular event and Reminder are tangible, long-lasting, real-word objects (for example they could exist in a conventional paper-based organiser, post-its etc.) and are good candidate classes.

12.4 UML diagrams

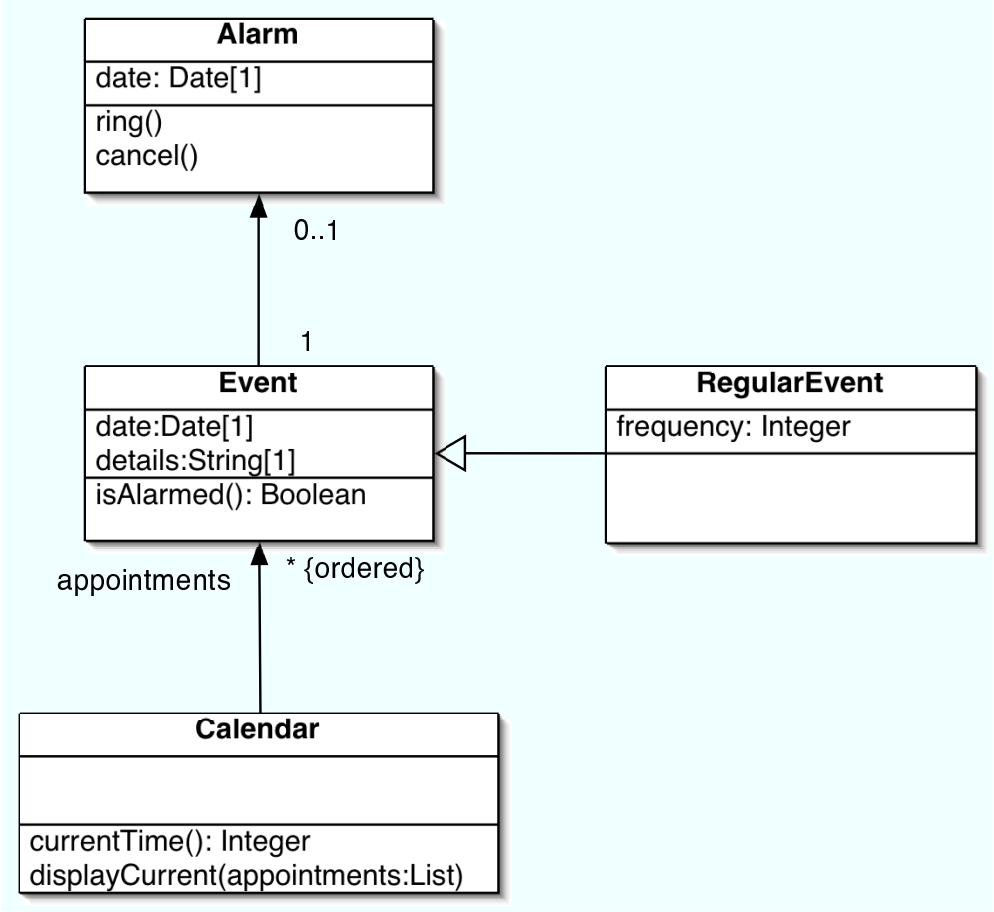


Figure 12.1: A class diagram for the use case **Make Appointment**

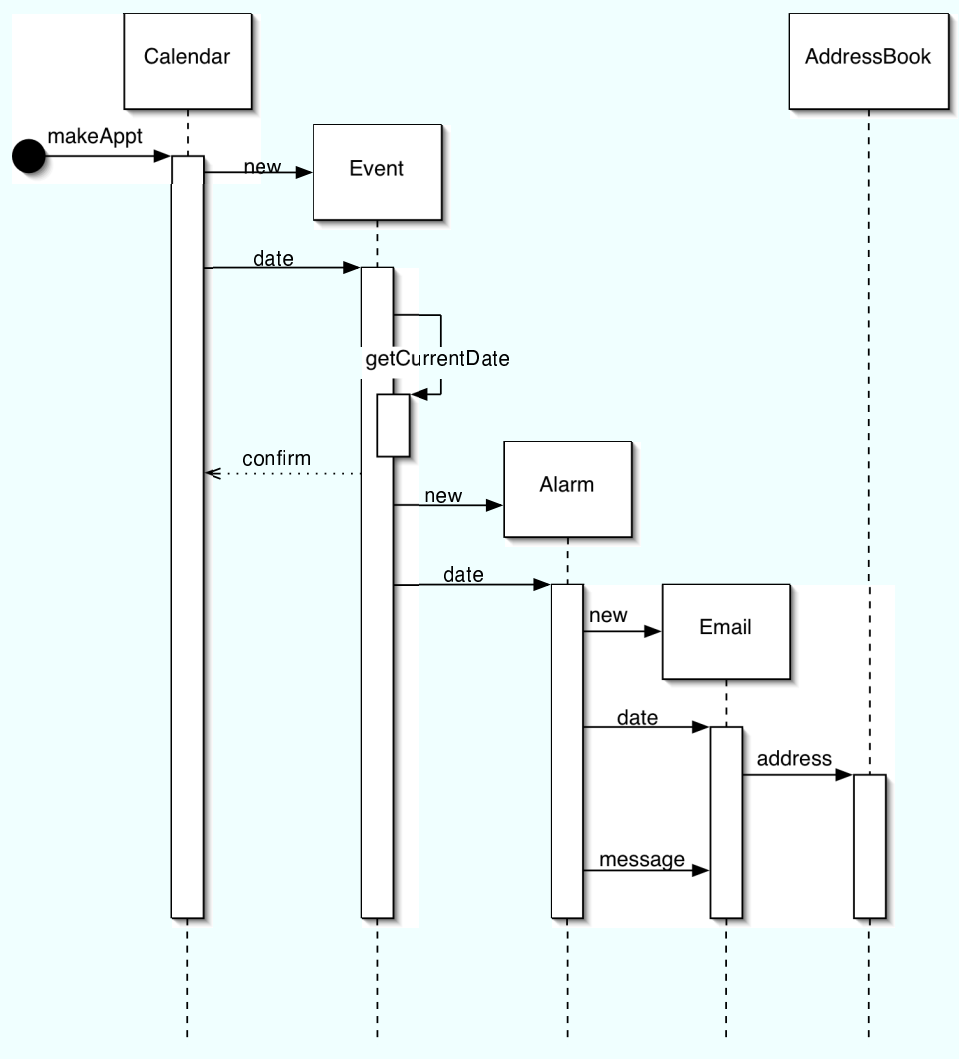


Figure 12.2: A sequence diagram for the scenario **Make Appointment**

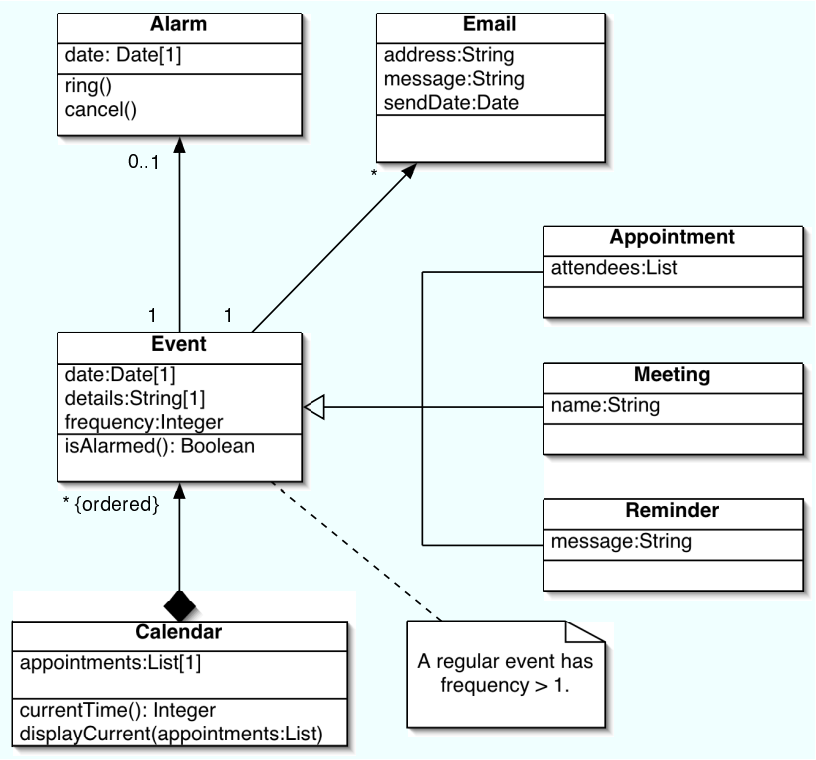


Figure 12.3: A refined class diagram for the use case **Make Appointment**

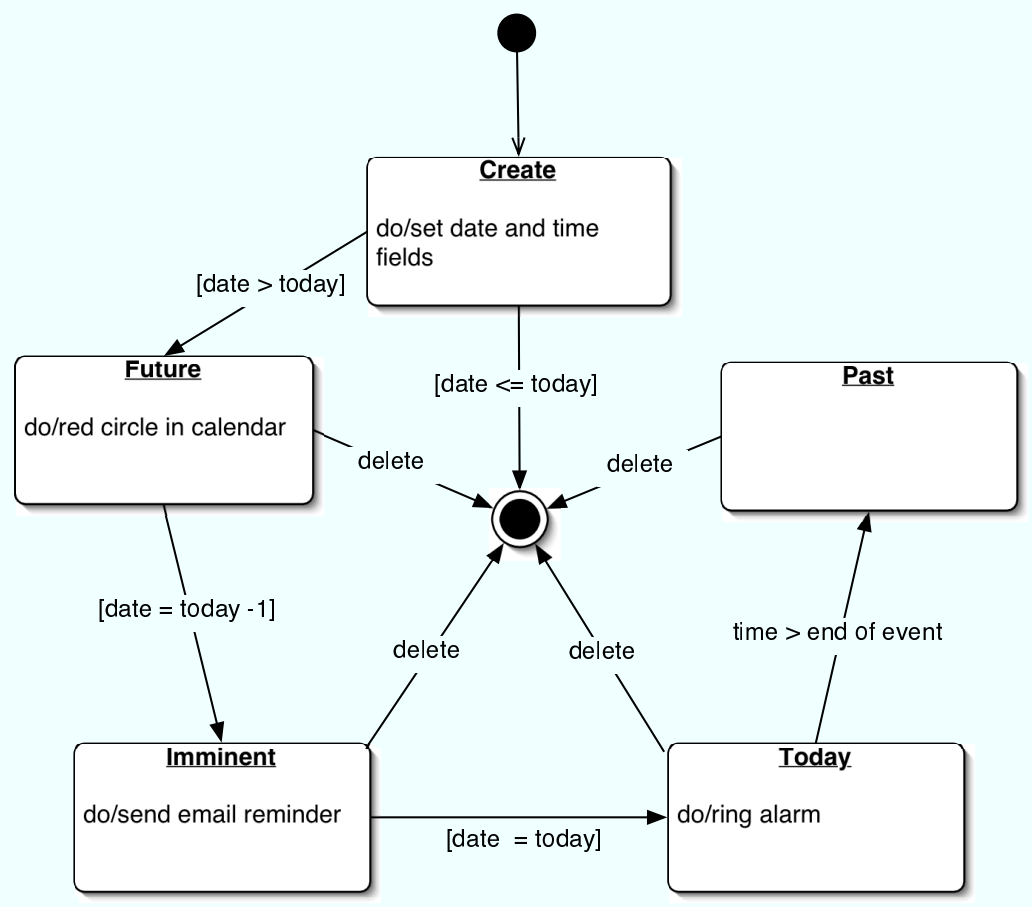


Figure 12.4: State machine for the class `Event`

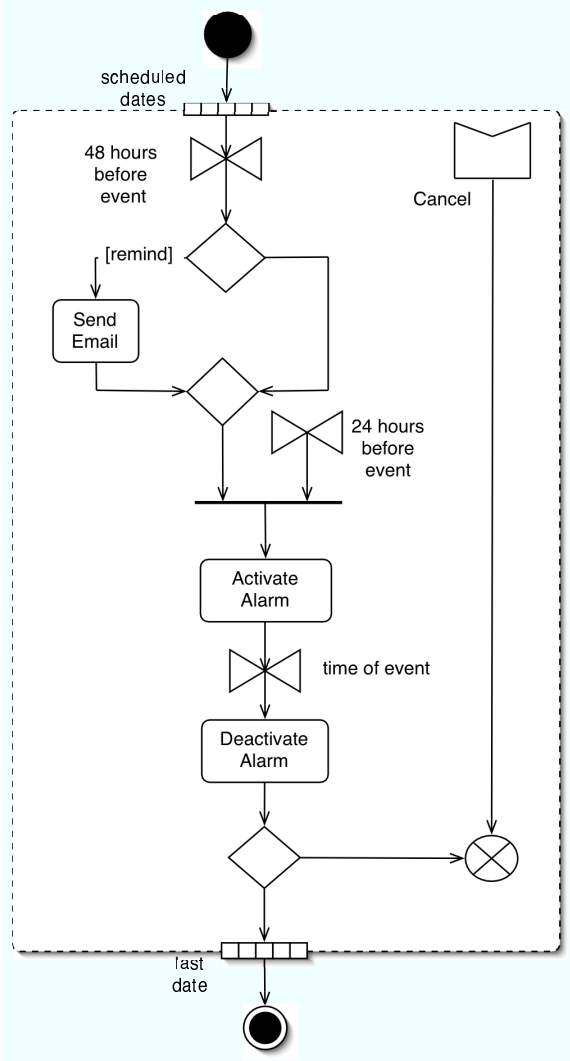


Figure 12.5: Activity diagram for event alarm

Chapter 13

Sample examination paper

13.1 Advice

You will be asked to demonstrate your knowledge of the principles of software engineering (Part I), product and process quality (Part III) and UML notation (Part II). Additionally, you will be tested on your ability to develop software architectures by drawing UML diagrams for a simple design problem (any of the diagrams from Part II). You should know how each UML modelling technique is placed within the whole development process (summary sections of Chapters 3 - 8 and Chapter 9). It is important, too, that you understand, and can use, the non-diagrammatic aspects of part II: requirements capture by use case and scenario development (Chapter 3) and class identification (Chapter 4).

A good revision strategy would be to confirm that you can do all of the things listed in the summary sections that close each chapter. The exercises and learning activities which are part of each chapter provide valuable revision material and examples of questions at examination level. It is strongly recommended that you re-visit either the Personal Organiser or the Space Game project and practise developing these diagrams from scratch.

You should not assume that just because there are three parts of the guide, and that there are three questions in the examination, that each question will test your knowledge and understanding from just one part. The exam will test how well you have integrated all aspects of this course and you should accordingly revise all the material presented in this guide. However you need only answer two questions to obtain full marks, so take some time at the start of the exam to decide which two questions you can answer best.

Good luck!

13.2 Questions

Duration: $1\frac{1}{2}$ hours

Full marks will be awarded for complete answers to a total of two questions. Each question carries 25 marks. The marks for each part of a question are indicated at the end of the part in [] brackets.

There are 50 marks available on this paper.

Electronic calculators are **not** allowed.

1. NailIt is a proposed on-line hardware store. `Calculate price`

`of order` is a scenario that has been written during the requirements capture phase of the project. Read this scenario carefully and answer the following questions.

`Calculate price of order`

A customer has placed an order with an on-line hardware store. The order consists of three order-lines: 9 boxes of nails, 144 wood screws and a packet of washers. The price of the order is calculated by looking up the unit price of each line-item (box of nails, wood screw, packet of washers), and multiplying this price by the number of items in the order, and then summing over all order-lines. The system then calculates a possible discount, determined by some rules that relate to the customer and the order.

(a) Use this scenario to make a list of possible classes. [3 marks]

(b) Prepare a candidate class list by considering each class in turn from the list of part (a). Explain your reasons for choosing/eliminating each possibility. [5 marks]

(c) Explain the meaning of an association class in a UML class diagram. [5 marks]

(d) Draw a class diagram for the classes that are involved in the scenario `Calculate price of order`. [12 marks]

2. (a) What are the aims of testing? [3 marks]

(b) What is the criterion for a successful test? [1 mark]

(c) What is black box testing? [2 marks]

(d) What is white box testing? [2 marks]

(e) Explain the three modes of use of UML. [8 marks]

(f) Figure 13.1 shows a UML diagram. What is the name of this type of diagram? Arrows A, B, C and D refer to elements of this diagram. Name these elements and explain their role in the diagram. [9 marks]

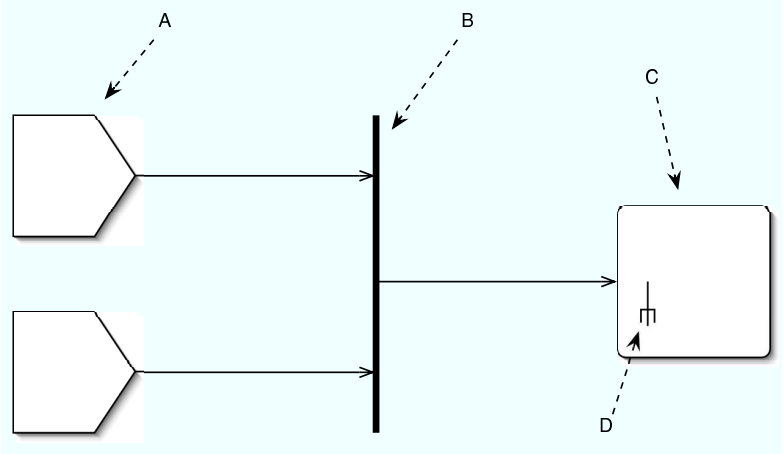


Figure 13.1:

3. (a) It is frequently said that the problem of software complexity can be tackled by *modularisation*. Modules should have high *cohesion* and low *coupling* and present a simple *interface*. Explain the meaning of these italicized words. [6 marks]

(b) Customers at NailIt, a proposed on-line hardware store, are represented by instantiations of a `Customer` class. Write an interface for a customer class. Your interface should include at least four attributes and operations (only two of which may be data accessors). [8 marks]

(c) The NailIt project manager has broken the 1 year project down into four activities: requirements analysis (2 months), design (4 months), coding (3 months), testing (3 months). Which software development process is being suggested by this plan? Explain your answer. [3 marks]

(d) Which software process would you recommend to the NailIt manager? Explain how the four project activities would fit into your process, giving timescales where appropriate. [8 marks]

13.3 Answers

1. (a) Customer, order, store, order-line, box, nail, screw, packet, washers, price, unit price, line item, discount, rules.

   (b) Customer: Yes - a customer class would have data and behaviours such as calculate discount

   Order: Yes - corresponds to an order in real life

   On-line hardware store: No - this is the whole system

   Order-line: Yes - an order is made up from various order-lines

   Box, nail, screw, packet, of washer: No - too specific, relates to a particular order-line

   Price: No - a Price class would not have any interesting behaviour in itself. Can probably be included as a data field in another class

   Line-item: Yes, an actual thing (box of nails, screws, packet of washers)

   Unit price: No, this is an attribute of an item, not sufficiently rich in behaviour for a class

   Discount: No - a method could use the rules to calculate this

   Rules: Yes/no - could be hard-wired into the customer class, but might also be an association class for Customer-Order

   (c) An association class adds attributes and operations to associations. [Diagram similar to Figure 5.12 in *UMLD*]. There can only be one instance of an association class between any two participating objects.

   (d) See Figure 13.2

2. (a) The aims are: to find bugs, to convince the client that there are no important bugs, and to provide information for further development.

   (b) A successful test causes the module/system to fail.

   (c) Black box testing is done without knowledge of the implementation. The system/module is tested against the specification. Only the public interface of the module is available to the tester.

   (d) The full code is available in white box testing. For example, a loop might be scrutinised for abnormal termination conditions.

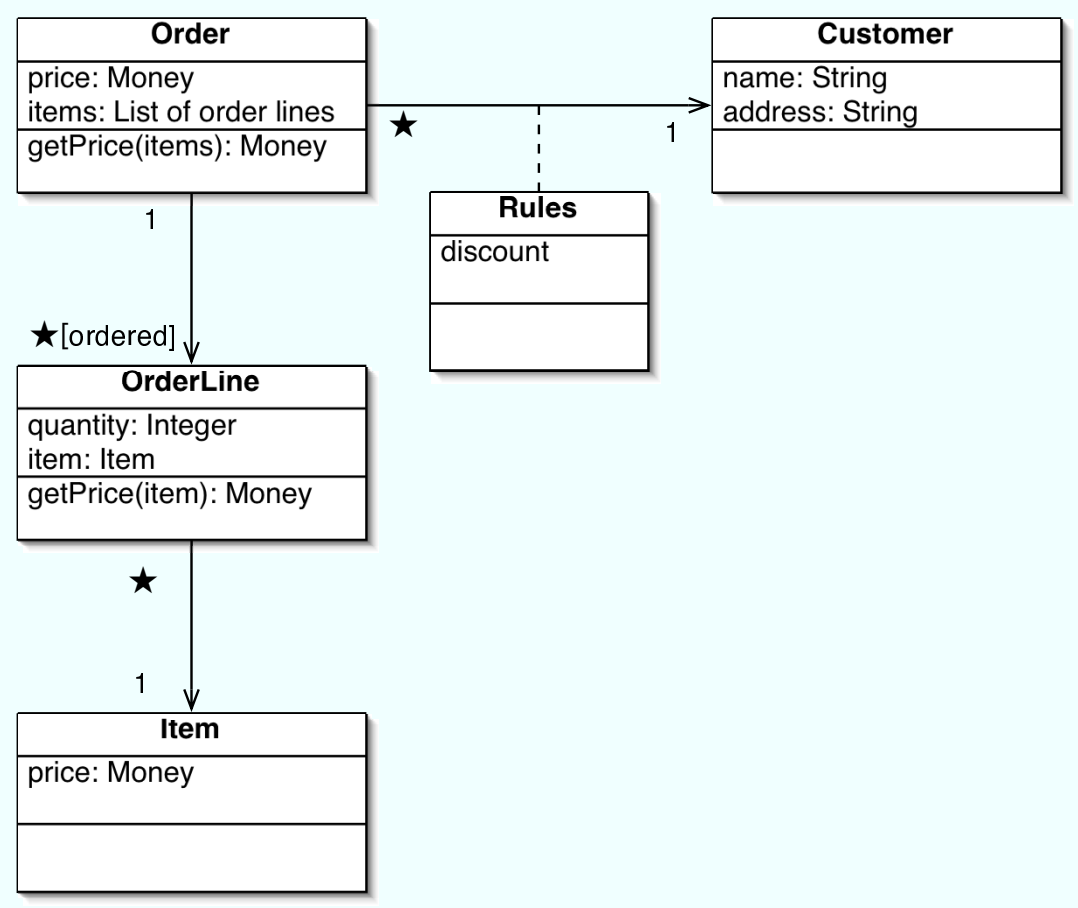


Figure 13.2: Class diagram for Question 1(d)

(e) In sketching mode, UML is an informal method of expressing ideas about the system. Sketches may rough out some ideas about code before it is written. Sketches can also be used to explain the essence of a piece of code (reverse engineering). Sketching is informal, dynamic, often undertaken by a small team around a whiteboard.

UML in blueprinting mode is comprehensive and complete, allowing the programmer to code directly from the diagrams. Blueprinted UML is very detailed, rather like engineering drawings. In reverse engineering, the blueprints show every detail about a class. Whereas UML sketches are explorative, UML blueprints are definitive.

UML in programming mode becomes equivalent to source code itself. A sophisticated tool will convert the diagrams into executable code.

(f) An activity diagram.

A: A send signal. Send signals indicate where an activity receives an event from an outside process. The activity constantly listens for these signals and the diagram shows how the activity reacts.

B: A join. The outgoing flow from a join is taken only when all the incoming flows have reached the join.

C: An action. This is the basic unit of the activity - an activity is a sequence of individual actions. Actions will be

implemented either as sub-activities or as methods on classes.

D: This is a rake symbol. It indicates that the action stands for an entire sub-activity.

3. (a) *Modularisation* is the division of software into smaller programming elements. Java provides a hierarchy of modules: methods, classes, packages.

A *Cohesive* module performs a single task and requires little interaction with other modules to accomplish this. For example, a method should do only one thing or alter a single value, with no other side effects.

Coupling refers to the connectivity between modules. Ideally this should be at a minimum and this is not always in object systems where there is no check to the number of modules that can be inter-related.

(b)

```
-name: String
-address: String
-cardNumber: Integer
-isRegularCustomer: Boolean

+getName(): String
+setName(name: String): void
+calculateDiscount(): Float
+getCreditRating(): Float
```

(c) This is a waterfall style because each activity occurs once and there is no (or, only exceptionally) back flow to previous activities.

(d) An iterative style is far better. The project is broken down into subsets of functionality. A single iteration negotiates the complete software cycle: analysis, design, coding and testing. Four 3 month iterations might be planned, each one delivering one quarter of the functionality. This is called time boxing. The system should be of production quality at the end of each iteration. If it is not possible to build all of the functionality during a particular time box, then some of the planned functionality must be dropped. Unlike the waterfall style, iterative approaches allow for code rework and deletion, so that poorly designed code can be replaced rather than patched.

Notes