2 The Unified Modelling Language (UML)

Introduction

This chapter will introduce you to the roles of the Unified Modelling Language (UML) and explain the purpose of four of the most common diagrams (class diagrams, object diagrams, sequence diagrams and package diagrams). These diagrams are used extensively when describing software designed according to the object oriented programming approach. Throughout this book particular emphasis will be placed on class diagrams as these are the most used part of the UML notation.

Objectives

By the end of this chapter you will be able to….

- Explain what UML is and explain the role of four of the most common diagrams,
- Draw class diagrams, object diagrams, sequence diagrams and package diagrams.

The material covered in this chapter will be expanded on throughout later chapters of the book and the skills developed here will be used in later exercises (particularly regarding class diagrams.

This chapter consists of six sections :-

1) An introduction to UML
2) UML Class Diagrams
3) UML Syntax
4) UML Package Diagrams
5) UML Object diagrams
6) UML Sequence Diagrams

2.1 An Introduction to UML

The Unified Modelling Language, UML, is sometimes described as though it was a methodology. It is not!

A methodology is a system of processes in order to achieve a particular outcome e.g. an organised sequence of activities in order to gather user requirements. UML does not describe the procedures a programmer should follow – hence it is not a methodology. It is, on the other hand, a precise diagramming notation that will allow program designs to be represented and discussed. As it is graphical in nature it becomes easy to visualise, understand and discuss the information presented in the diagram. However, as the diagrams represent technical information they must be precise and clear – in order for them to work - therefore there is a precise notation that must be followed.

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As UML is not a methodology it is left to the user to follow whatever processes they deem appropriate in order to generate the designs described by the diagrams. UML does not constrain this – it merely allows those designs to be expressed in an easy to use, but precise, graphical notation.

A process will be explained in chapter 6 that will help you to generate good UML designs. Developing good designs is a skill that takes practise to this end the process is repeated in the case study (chapter 11). For now we will just concentrate on the UML notation not these processes.

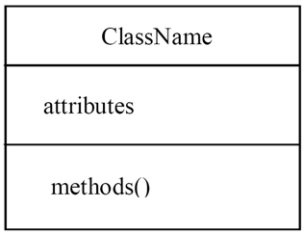
2.2 UML Class diagrams

Classes are the basic components of any object oriented software system and UML class diagrams provide an easy way to represent these. As well as showing individual classes, in detail, class diagrams show multiple classes and how they are related to each other. Thus a class diagram shows the architecture of a system.

A class consists of :-

- a unique name (conventionally starting with an uppercase letter)
- a list of attributes (int, double, boolean, String etc)
- a list of methods

This is shown in a simple box structure…



For attributes and methods visibility modifiers are shown (+ for public access, – for private access). Attributes are normally kept private and methods are normally made public.

Accessor methods are created to provide access to private attributes when required. Thus a public method SetTitle() can be created to change the value of a private attribute 'title'.

Thus a class Book, with String attributes of title and author, and the following methods SetTitle(), GetTitle(), SetAuthor(), GetAuthor() and ToString() would be shown as ….

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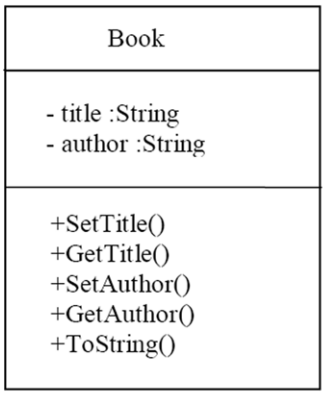

Note: String shown above is not a primitive data type but is itself a class. Hence it starts with a capital letter.

A Note On Naming Conventions

Some programmers use words beginning in capitals to denote class names and words beginning in lowercase to represent attributes or methods (thus ToString() would be shown as toString()). This is a common convention when designing and writing programs in Java (another common OO language). However it is not a convention followed by C# programmers – where method names usually start in Uppercase. Method names can be distinguished from class names by the use of (). This in the example above.

'Book' is a class
'title' is an attribute and
'SetTitle()' is a method.

UML diagrams are not language specific thus a software design, communicated via UML diagrams, can be implemented in a range of OO languages.

Furthermore traditional accessor methods, getters and setters, are not required in C# programs as they are replaced by 'properties'. Properties are in effect hidden accessor methods thus the getter and setter methods shown above, GetTitle(), SetTitle() etc are not required in a C# program. In C# an attribute would be defined called 'title' and a property would be defined as 'Title'. This would allow us to set the 'title' directly by using the associated property 'Title =…..;'.

The UML diagrams shown in this book will use the naming convention common among C# programmers … for the simple reason that we will be writing sample code in C# to demonstrate the OO principles discussed here. Though initially we will show conventional assessor methods these will be replaced with properties when coding.

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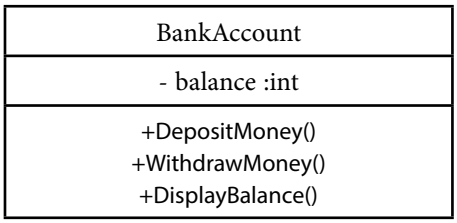
Activity 1

Draw a diagram to represent a class called 'BankAccount' with the attribute balance (of type int) and methods DepositMoney(), WithdrawMoney() and DisplayBalance(). Show appropriate visibility modifiers.

Feedback 1



The diagram above shows this information

UML allows us to suppress any information we do not wish to highlight in our diagrams – this allows us to suppress irrelevant detail and bring to the readers attention just the information we wish to focus on. Therefore the following are all valid class diagrams…

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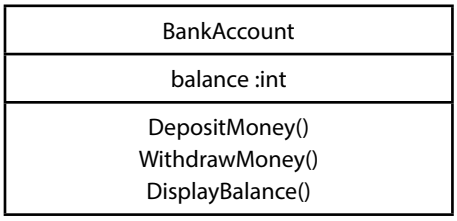
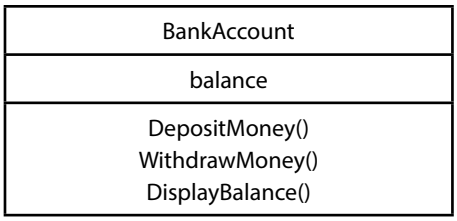
Firstly with the access modifiers not shown….



Secondly with the access modifiers and the data types not shown…..



And finally with the attributes and methods not shown…..

i.e. there is a class called 'BankAccount' but the details of this are not being shown.

Of course virtually all C# programs will be made up of many classes and classes will relate to each other – some classes will make use of other classes. These relationships are shown by arrows. Different type of arrow indicate different relationships (including inheritance and aggregation relationships).

In addition to this class diagrams can make use of keywords, notes and comments.

As we will see in examples that follow, a class diagram can show the following information :-

- Classes
  - attributes
  - operations
  - visibility

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- Relationships
    - navigability
    - multiplicity
    - dependency
    - aggregation
    - composition
- Generalization / specialization
    - inheritance
    - interfaces
- Keywords
- Notes and Comments

2.3 UML Syntax

As UML diagrams convey precise information there is a precise syntax that should be followed.

Attributes should be shown as: *visibility name* : *type multiplicity*

Where visibility is one of :-

- '+' public
- '-' private
- '#' protected
- '~' package

and Multiplicity is one of :-

- 'n' exactly n
- '*' zero or more
- 'm..'n' between m and n

The following are examples of attributes correctly specified using UML :-

- custRef : int [1]

a private attribute custRef is a single int value
this would often be shown as - **custRef : int** However with no multiplicity shown we cannot safely assume a multiplicity of one was intended by the author.

 # itemCodes : String [1..*]

a protected attribute itemCodes is one or more String values

validCard : boolean

an attribute validCard, of unspecified visibility, has unspecified multiplicity

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Operations also have a precise syntax and should be shown as:

visibility name (par1 : type1, par2 : type2): returntype

where each parameter is shown (in parenthesis) and then the return type is specified.

An example would be

+ AddName (newName : String) : boolean

This denotes a public method 'AddName' which takes one parameter 'newName' of type String and returns a boolean value.

Activity 2

Draw a diagram to represent a class called 'BankAccount' with a private attribute balance (this being a single integer) and a public method DepositMoney() which takes an integer parameter, 'deposit' and returns a boolean value. Fully specify all of this information on a UML class diagram.

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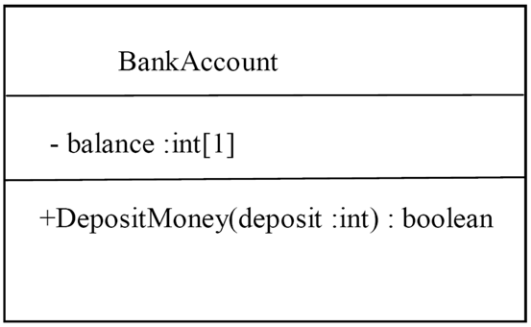
Feedback 2

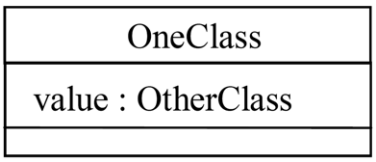
The diagram below shows this information



Denoting Relationships

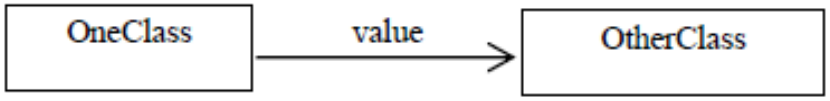
As well as denoting individual classes, Class diagrams denote relationships between classes. One such relationships is called an 'Association'. We will learn a lot more about associations in Chapter 6 where we look at how to model an object oriented system. Here we are just learning the UML notation we will be using later.

In a class attributes will be defined. These could be primitive data types (int, boolean etc.) however attributes can also be complex objects as defined by other classes.



Thus the figure above shows a class 'OneClass' that has an attribute 'value'. This value is not a primitive data type but is an object of type defined by 'OtherClass'.

We could denote exactly the same information by the diagram below.



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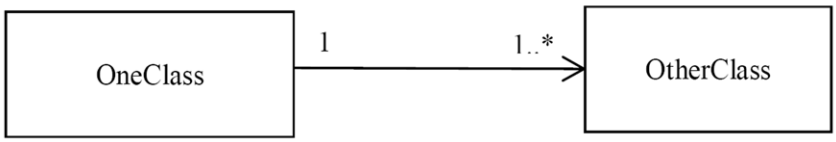
We use an association when we want to give two related classes, and their relationship, prominence on a class diagram

The 'source' class points to the 'target' class.

Strictly we could use an association when a class we define has a String instance variable – but we would not do this because the String class is part of the C# platform and 'taken for granted' like an attribute of a primitive type. This would generally be true of all library classes unless we are drawing the diagram specifically to explain some aspect of the library class for the benefit of someone unfamiliar with its purpose and functionality.

Additionally we can show multiplicity at both ends of an association:



This implies that 'OneClass' maintains a collection of objects of type 'OtherClass'. Collections are an important part of the C# library that we will look at the use of collections in Chapter 7.

Activity 3

Draw a diagram to represent a class called 'Catalogue' and a class called 'ItemForSale' as defined below :-

ItemForSale has an attribute 'name' of type String and an attribute 'price' of type int. It also has a method SetPrice() which takes an integer parameter 'newPrice'.

'Catalogue' has an attribute 'listOfItems' i.e. the items currently held in the catalogue. As zero or more items can be stored in the catalogue 'listOfItems' will need to be an array or collection. 'Catalogue' also has one method AddItem() which takes an 'item' as a parameter (of type ItemForSale) and adds this item to the 'listOfItems'.

Draw this on a class diagram showing appropriate visibility modifiers for attributes and methods.

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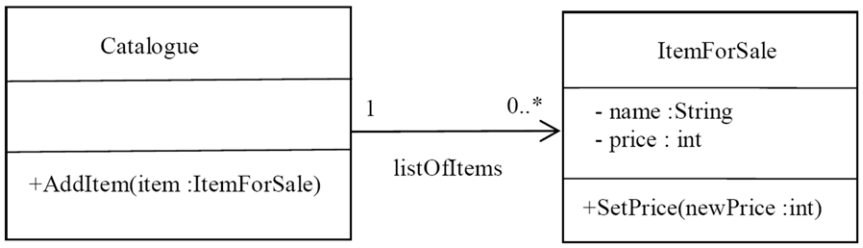
Feedback 3

The diagram below shows this information



Note: According to the naming convention followed here all class names begin in uppercase, attribute names begin in lowercase, method names begin in uppercase and use () to distinguish them from class names. Also note that the class ItemForSale describes a single item (not multiple items). 'listOfItems' however maintains a list of zero or more individual objects.

Types of Association

There are various different types of association denoted by different arrows:-

- Dependency,
- Simple association
- Bidirectional association
- Aggregation and
- Composition

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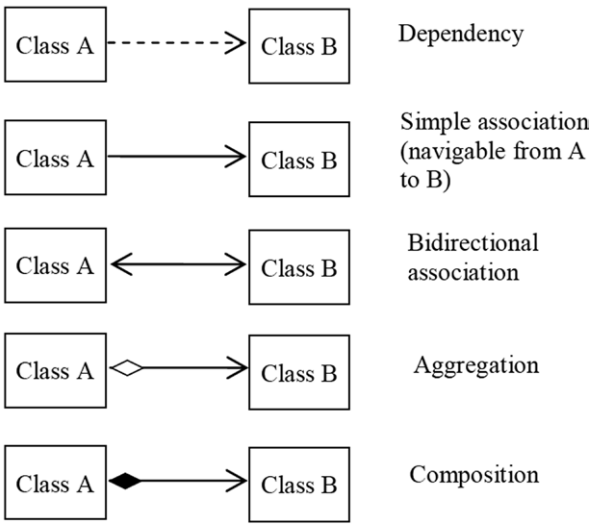
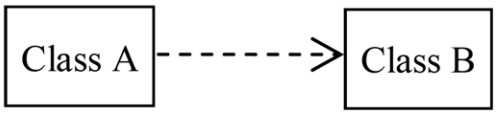


Dependency



- Dependency is the most unspecific relationship between classes (not strictly an „association')
- Class A in some way uses facilities defined by Class B
- Changes to Class B may affect Class A

Typical use of dependency lines would be where Class A has a method which is passed a parameter object of Class B, or uses a local variable of that class, or calls 'static' methods in Class B.

Example: A Print() method may require a printer object as a parameter. Each time the Print() method is invoked a different printer object could be passed as a parameter and thus the printout will appear in a different place. Thus while the class containing the Print() method requires a printer object to work it does not need to be permanently associated with one specific printer.

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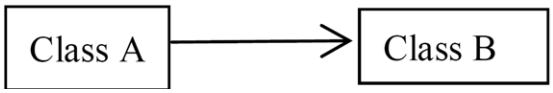
Simple Association

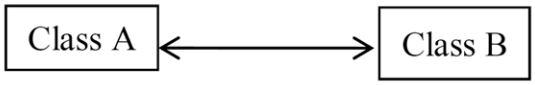


- In an association Class A 'uses' objects of Class B
- Typically Class A has an attribute of Class B
- Navigability is from A to B:
  i.e. A Class A object can access the Class B object(s) with which it is associated. The reverse is not true – the Class B object doesn't 'know about' the Class A object

A simple association typically corresponds to an instance variable in Class A of the target class B type.

Example: the **Catalogue** above needs access to 0 or more ItemForSale so items can be added or removed from a Catalogue. An **ItemForSale** does not need to access a **Catalogue** in order to set its price or perform some other method associated with the item itself.

Bidirectional Association



- Bidirectional Association is when Classes A and B have a two-way association
- Each refers to the other class
- Navigability A to B and B to A:
  -A Class A object can access the Class B object(s) with which it is associated
  -Object(s) of Class B 'belong to' Class A
  -Implies reference from A to B
  -Also, a Class B object can access the Class A object(s) with which it is associated

A bidirectional association is complicated because each object must have a reference to the other object(s) and generally bidirectional associations are much less common than unidirectional ones.

An example of a bidirectional association may between a 'Degree' and 'Student'. ie. given a Degree we may wish to know which Students are studying on that Degree. Alternatively starting with a student we may wish to know the Degree they are studying.

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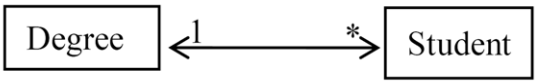
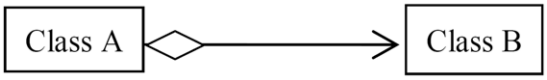


As many students study the same Degree at the same time, but students usually only study one Degree there is still a one to many relationship here (of course we could model a situation where we record degrees being studied and previous degrees passed – in this case, as a student may have passed more than one degree, we would have a many to many relationship).

Aggregation



- Aggregation denotes a situation where Object(s) of Class B 'belong to' Class A
- Implies reference from A to B
- While aggregation implies that objects of Class B belong to objects of Class A it also implies that object of Class B retain an existence independent of Class A. Some designers believe there is no real distinction between aggregation and simple association

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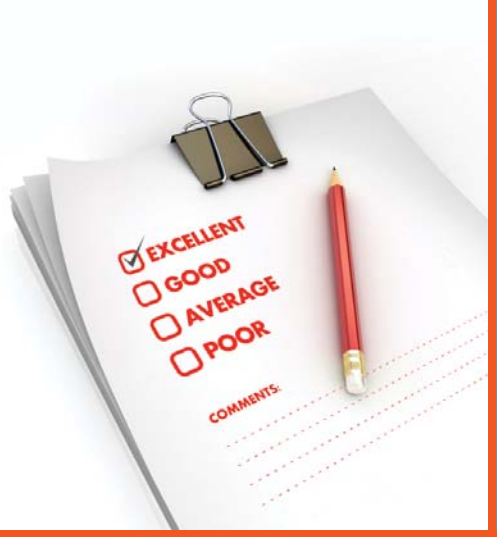

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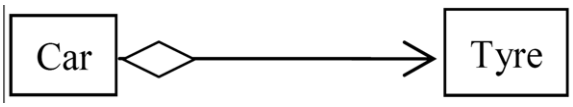
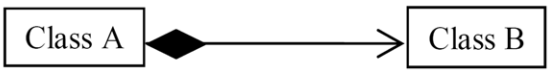
An example of aggregation would be between a class Car and a class Tyre



We think of the tyres as belonging to the car they are on, but at the garage they may be removed and placed on a rack to be repaired. Their existence isn't dependent on the existence of a car with which they are associated. Some designers believe that aggregation can be replaced as a simple association as when implementing this design in a program it makes no difference to the programmer.

Composition



- Composition is similar to aggregation but implies a much stronger belonging relationship i.e. Object(s) of Class B are 'part of' a Class A object
- Again implies reference from A to B
- Much 'stronger' than aggregation in this case Class B objects are an integral part of Class A and in general objects of Class B never exist other than as part of Class A, i.e. they have the same 'lifetime'

An example of composition would be between Points, Lines and Shapes as elements of a Picture. These objects can only exist as part of a picture, and if the picture is deleted they are also deleted.

As well as denoting associations, class diagrams can denote :-

- Inheritance,
- Interfaces,
- Keywords and
- Notes

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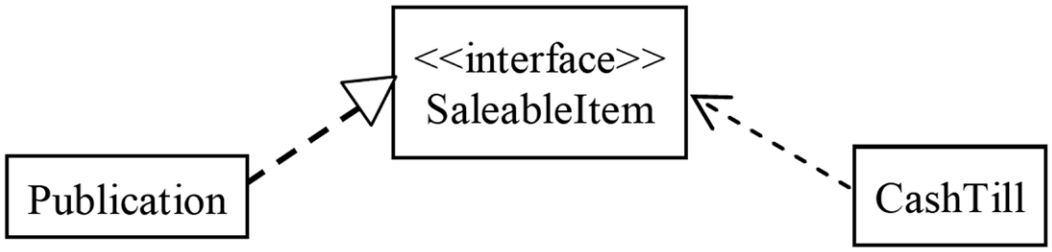
Inheritance

- Aside from associations, the other main modelling relationship is inheritance:
- Class A 'inherits' both the interface and implementation of Class B, though it may override implementation details and supplement both.

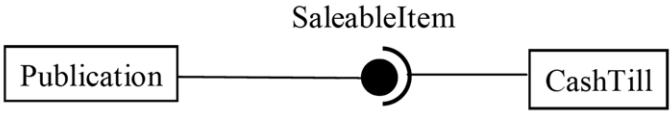
We will look at inheritance in detail in Chapter 3.

Interfaces

- Interfaces are similar to inheritance however with interfaces only the interface is inherited. The methods defined by the interface must be implemented in every class that implements the interface.
- Interfaces can be represented using the <<interface>> keyword:



There is also a shorthand for this



In both cases these examples denote that the SaleableItem interface is **required by** CashTill and **implemented by** Publication.

NB the dotted-line version of the inheritance line/arrow which shows that Publication 'implements' or 'realizes' the SaleableItem interface.

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The "ball and socket" notation is new in UML 2 – it is a good visual way of representing how interfaces connect classes together.

We will look at the application of interfaces in more detail in Chapter 4.

Keywords

UML defines keywords to refine the meaning of the graphical symbols
We have seen <<interface>> and we will also make use of <<abstract>> but there are many more.

An abstract class may alternatively be denoted by showing its name in *italics* though this is perhaps less obvious to a casual reader.

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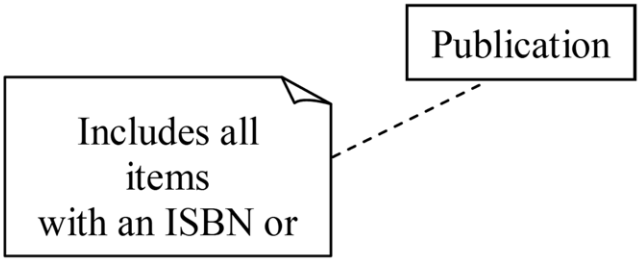
Notes



Finally we can add notes to comment on a diagram element. This gives us a 'catch all' facility for adding information not conveyed by the graphical notation.

Activity 4

From your own experience, try to develop a model which illustrates the use of the following elements of UML Class Diagram notation:

- simple association
- bidirectional association
- aggregation (tricky!)
- composition
- association multiplicity
- generalization (inheritance)
- interfaces
- notes

For this exercise concentrate on the relationships between classes rather than the details of their members. If possible explain and discuss your model with other students or friends.

To help you get started some small examples are given below:-

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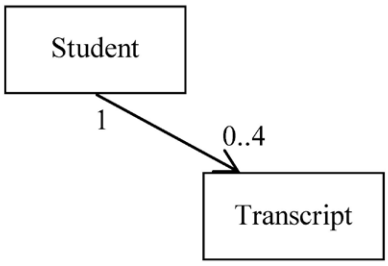
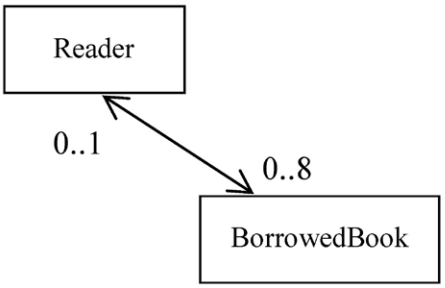


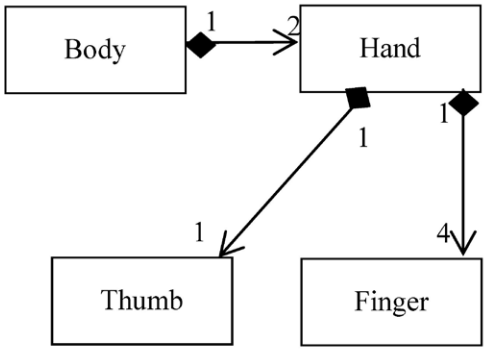
In a University administration system we might produce a transcript of results for each year the student has studied (including a possible placement year).

This association relationship is naturally unidirectional – given a student we might want to find their transcript(s), but it seems unlikely that we would have a transcript and need to find the student to whom it belonged.



In a library a reader can borrow up to eight books. A particular book can be borrowed by at most one reader.

We might want a bidirectional relationship as shown here because, in addition to being able to identify all the books which a particular reader has borrowed, we might want to find the reader who has borrowed a particular book (for example to recall it in the event of a reservation).

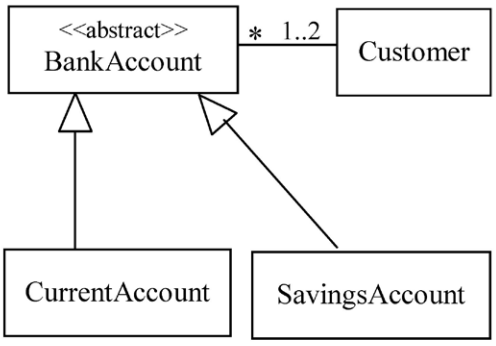


This might be part of the model for some kind of educational virtual anatomy program.

Composition – the "strong" relationship which shows that one object is (and has to be) part of another seems appropriate here.

The multiplicities would not always work for real people though – they might have lost a finger due to accident or disease, or have an extra one because of a genetic anomaly.

But what if we were modelling the "materials" in a medical school anatomy lab? A hand might not always be part of a body! Perhaps the "weaker" aggregation relationship would reflect this better.



A customer can have any number of bank accounts, and a bank account can be held by one person or two people (a "joint account"). We have suppressed the navigability of this relationship, perhaps because we have not yet decided this issue.

A bank account **must** either be a current account or a savings account – hence BankAccount itself is abstract.

(We could have shown this using italics rather than the <<abstract>> keyword)

BankAccount

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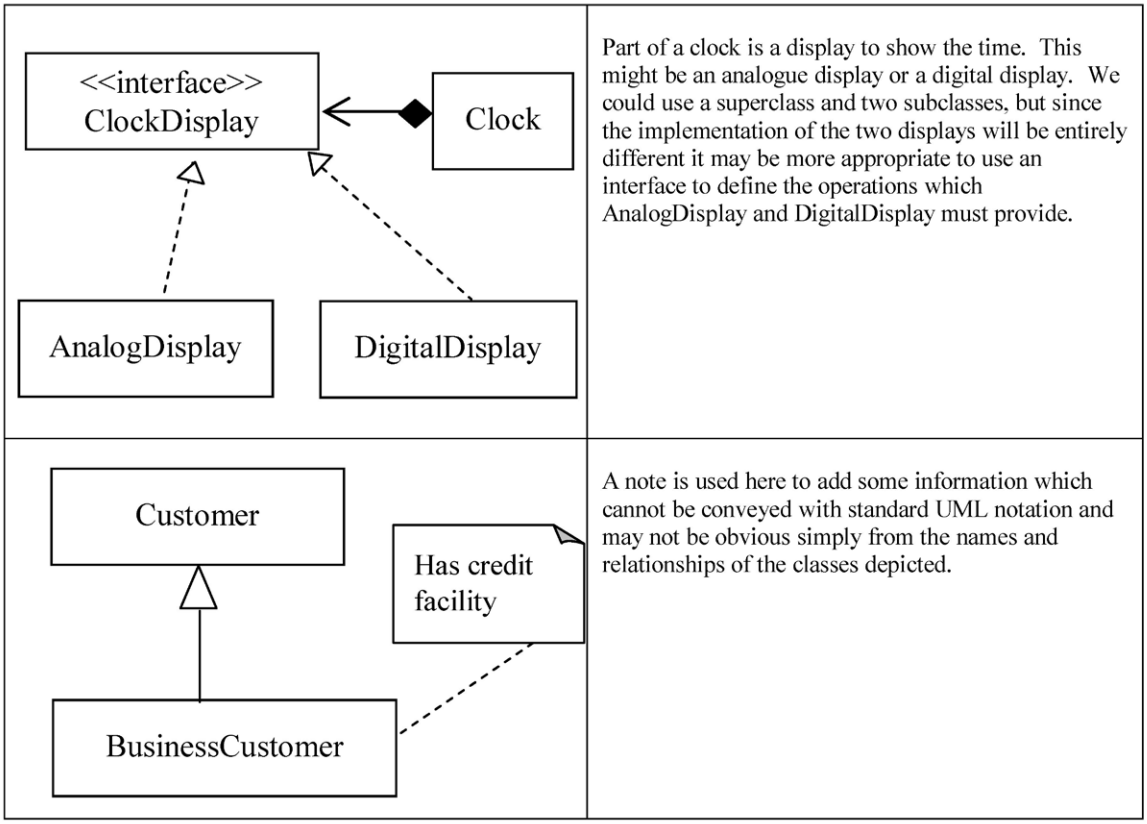

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Feedback 4

There is no specific feedback for this activity.

2.4 UML Package Diagrams

While class diagrams are the most commonly used diagram of those defined in UML notation, and we will make significant use of these throughout this book, there are other diagrams that denote different types of information. Here we will touch upon three of these :-

- Package Diagrams
- Object Diagrams and
- Sequence Diagrams

World maps, country maps and city maps all show spatial information, just on different scales and with differing levels of detail. Large OO systems can be made up of hundreds, or potentially thousands, of classes and thus if the class diagram was the only way to represent the architecture of a large system it would become overly large and complex. Thus, just as we need world maps, we need package diagrams to show the general architecture of a large system. Even modest systems can be broken down into a few basic components i.e. packages. We will see an example of packages in use in Chapter 11. For now we will just look at the package diagramming notation.

Packages diagrams allow us to provide a level of organisation and encapsulation above that of individual classes Packages are implemented in C'# by creating subfolders and defining a 'namespace'. When writing a large system in C# we use this to segment a large system into smaller more manageable sub-systems. We denote these sub-systems using package diagrams during the design stage.

A large C# development should be split into suitable packages at the design stage
UML provides a 'Package Diagram' to represent the relationships between classes and packages.

We can depict

- classes within packages
- nesting of packages
- dependencies between packages

In the diagram below we see two packages :- 'monitor systems' and 'management systems' These depict part of a large system for a multinational corporation to manage and maintain their operations including their computer systems and personnel.

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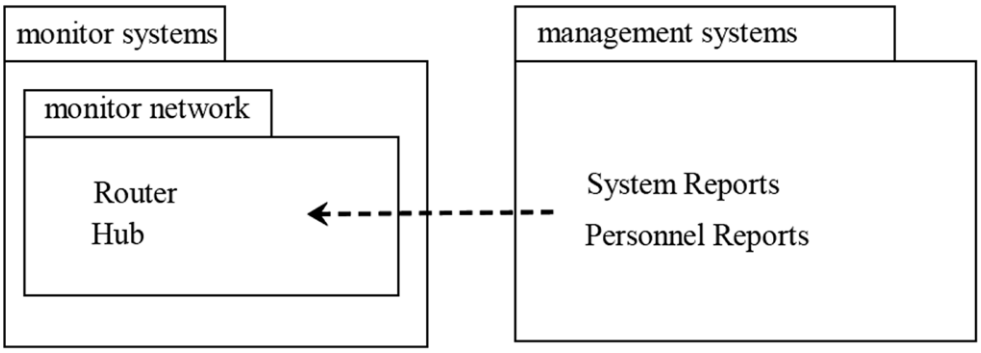


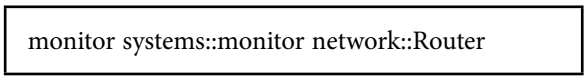
Looking at this more closely we can see that inside the 'monitor systems' package is another called 'monitor network'. This package contains at least two classes 'Router' and 'Hub' though presumably it contains many other related classes.

The package 'management systems' contains two classes (or more) 'System Reports' and 'Personnel Reports'.

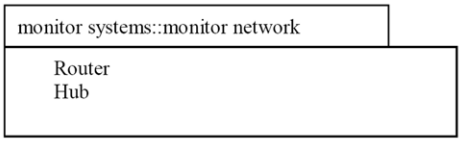
Furthermore we can see that the classes inside the package 'management systems' in some way use the classes inside 'monitor network'. Presumably it is the 'System Reports' class that makes use of these as it needs to know about the status of the network.

Note that the normal UML principle of suppression applies here – these packages may contain other packages and each package may contain dozens of classes but we simply choose not to show them.

In the class diagram below we have an alternative way of indicating that 'Router' is a class inside the 'monitor network' package, which is in turn inside 'monitor systems' package.



And again below a form which shows both classes more concisely than at the top.



These different representations will be useful in different circumstances depending on what a package diagram is aiming to convey.

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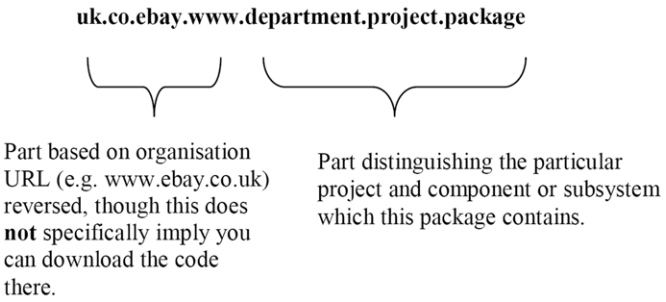
Package Naming

By convention, package names are normally in lowercase. We will follow this convention we will as it helps to distinguish between packages and classes.

For local individual projects packages could be named according to personal preference, e.g.

mysystem
mysystem.interface
mysystem.engine
mysystem.engine.util
mysystem.database

However, packages are often distributed and to enable this packages need globally unique names, thus a naming convention has been adopted based on URLs



Note on a package diagram each element is not separated by a '.' but by '::'.

Activity 5

You and a flatmate decide to go shopping together. For speed split the following shopping list into two halves – items to be collected by you and items to be collected by your flatmate.

Apples, Furniture polish, Pears, Carrots, Toilet Rolls, Potatoes, Floor cleaner. Matches, Grapes

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Feedback 5

To make your shopping efficient you probably organised your list into two lists of items that are located in the same parts of the shop:-

List 1	List 2
Apples,	Furniture polish,
Pears,	Floor cleaner
Grapes	Matches
Carrots,	Toilet Rolls,
Potatoes	

Activity 6

You run a team of three programmers and are required to write a program in C# to monitor and control a network

system. The system will be made up of seven classes as described below. Organise these classes into three packages. Each programmer will then be responsible for the code in one package. Give the packages any name you feel appropriate.

Main	this class starts the system
Monitor	this class monitors the network for performance and breaches in security
Interface	this is a visual interface for entire system
Reconfigure	this allows the network to be reconfigured
RecordStats	this stores data regarding the network in a database
RemoteControlthis	allows some remote control over the system via telephone
PrintReports	this uses the data stored in the database to print management reports for the organisations management.

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Feedback 6

When organising a project into packages there is not always 'one correct answer' but if you organise your classes into appropriate packages (with classes that have related functionality) you improve the encapsulation of the system and improve the efficiency of your programmers. A suggested solution to activity 6 is given below.

interface
- Main
- Interface
- RemoteControl

network
- Monitor
- Reconfigure

database
- RecordStats
- PrintReports

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Activity 7

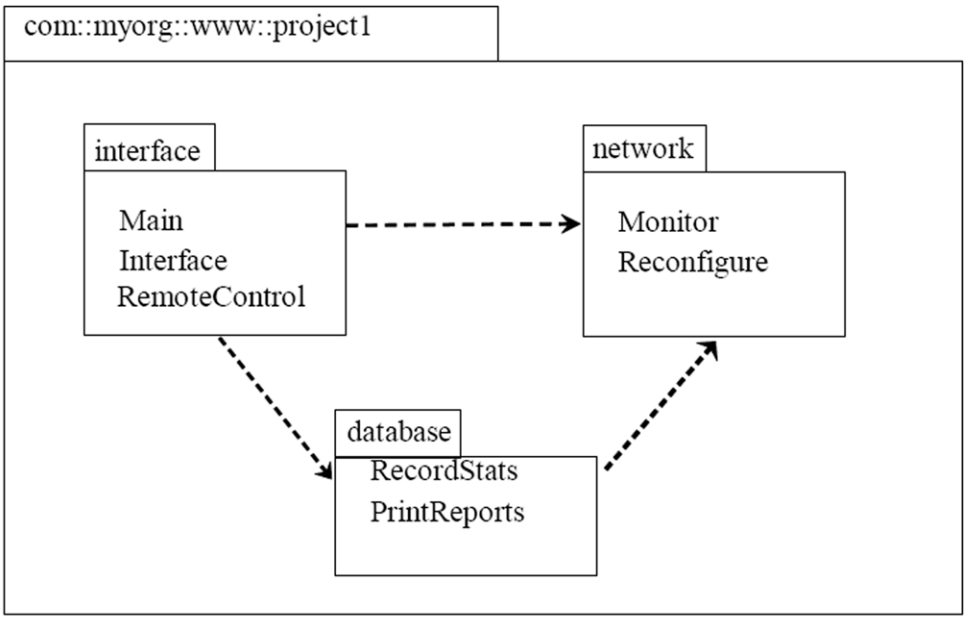
Assume the URL of your organisation is 'www.myorg.com' and the three packages and seven classes shown below are all part of 'project1'. Draw a package diagram to convey this information.

interface
- Main
- Interface
- RemoteControl

network
- Monitor
- Reconfigure

database
- RecordStats
- PrintReports

Feedback 7



Note: Dependency arrows have been drawn to highlight relationships between packages. When more thought has been put into determining these relationships they may turn out to be associations (a much stronger relationship than a mere dependency).

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2.5 UML Object Diagrams

Class diagrams and package diagrams allow us to visualise and discuss the architecture of a system, however at times we wish to discuss the data a system processes. Object diagrams allow us to visual one instance of time and the data that a system may contain in that moment.

Object diagrams look superficially similar to class diagrams however the boxes represent specific instances of objects.

Boxes are titled with :-

objectName : ClassName

As each box describes a particular object at a specific moment in time the box contains attributes and their values (at that moment in time).

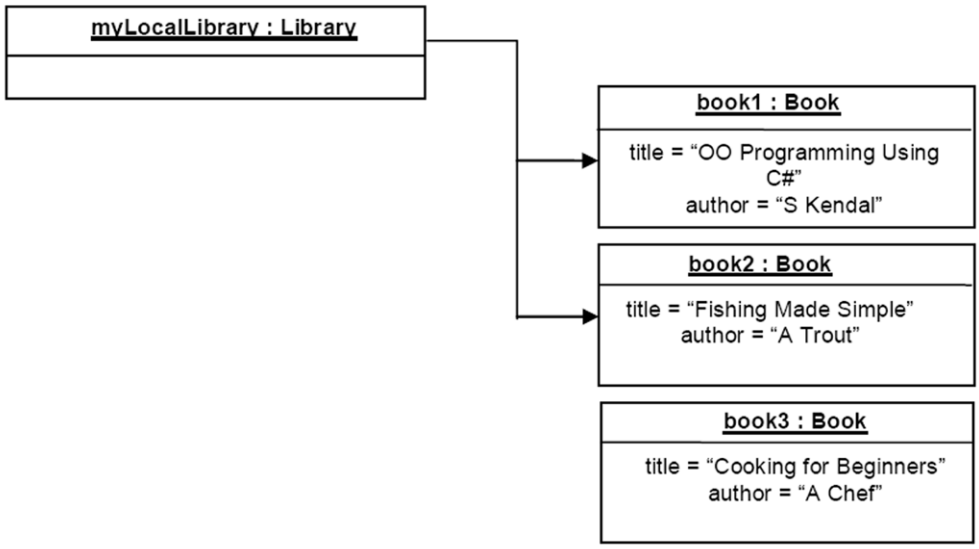
attribute = value

These diagrams are useful for illustrating particular 'snapshot' scenarios during design.

The object diagram below shows several object that may exist at a moment in time for a library catalogue system. The system contains two classes :-

Book, which store the details of a book and

Library, which maintains a collection of books, with books being added, searched for or removed as required.



Looking at this diagram we can see that at a particular moment in time, while three books have been created only two have been added to the library. Thus if we were to search the library for 'Cooking for Beginners' we would not expect the book to be found.

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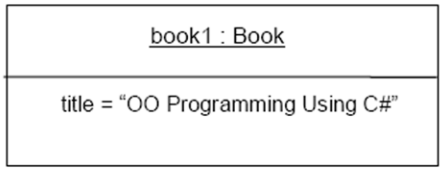
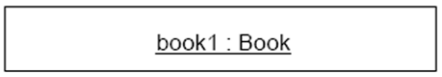
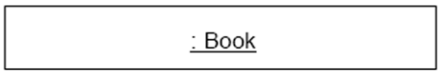
As with class diagrams, elements can be freely suppressed on object diagrams.
For example, all of these are legal:



- suppress some attributes



- suppress all attributes



- suppress object name

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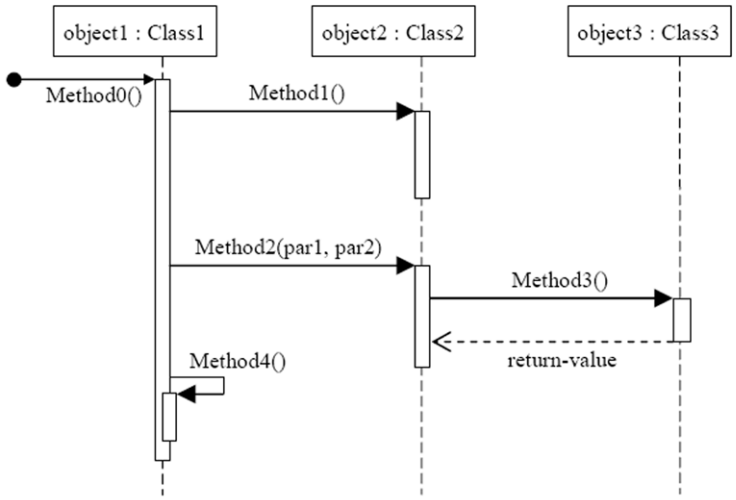
2.6 UML Sequence Diagrams

Sequence diagrams are entirely different from class diagrams or object diagrams. Class diagrams describe the architecture of a system and object diagrams describe the state of a system at one moment in time. However sequence diagrams describe how the system works over a period of time. Sequence diagrams are 'dynamic' rather than 'static' representations of the system. They show the sequence of method invocations within and between objects over a period of time. They are useful for understanding how objects collaborate in a particular scenario.

See the example below :-



We have three objects in this scenario. Time runs from top to bottom, and the vertical dashed lines (lifelines) indicate the objects' continued existence through time.

This diagram shows the following actions taking place :-

- Firstly a method call (often referred to in OO terminology as a message) to Method0() comes to object1 from somewhere – this could be another class outside the diagram.
- object1 begins executing its Method0() (as indicated by the vertical bar (called an activation bar) which starts at this point.
- object1.Method0() invokes object2.Method1() – the activation bar indicates that this executes for a period then returns control to Method0()
- Subsequently object1.Method0() invokes object2.Method2() passing two parameters
- Method2() subsequently invokes object3.Method3(). When Method3() ends it passes a return value back to Method2()
- Method2() completes and returns control to object1.Method0()
- Finally Method0() calls another method of the same object, Method4()

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Selection and Iteration

The logic of a scenario often depends on selection ('if') and iteration (loops).
There is a notation ('interaction frames') which allow ifs and loops to be represented in sequence diagrams however these tend to make the diagrams cluttered.
Sequence diagrams are generally best used for illustrating particular cases, with the full refinement reserved for the implementation code.

Fowler ("UML Distilled", 3rd Edn.) gives a brief treatment of these constructs.

2.7 Summary

UML is not a methodology but a precise diagramming notation.

Class diagrams and package diagrams are good for describing the architecture of a system. Object diagrams describe the data within an application at one moment in time and sequence diagrams describe how a system works over a period of time.

UML gives different meaning to different arrows therefore one must be careful to use the notation precisely as specified.

With any UML diagram suppression is encouraged – thus the author of a diagram can suppress any details they wish in order to convey essential information to the reader.

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