A Framework for Building Customised CORBA ORBs

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Declaration

I, the undersigned, declare that this work has not previously been submitted as an exercise for a degree at this or any other University, and that, unless otherwise stated, it is entirely my own work.

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Summary

Recently, many distributed applications have been based on Common Object Request Broker Architecture (CORBA) compliant middleware. Such distributed computing middleware provides the components of a distributed application with a uniform view of local and remote application objects. It shields distributed application programmers from having to deal with network and protocol layers and lets them concentrate on the design of the distributed application itself.

To date, most CORBA compliant Object Request Brokers (ORBs) have been based on monolithic implementations. Vendors typically offer the same ORB implementation for use in any number of different application scenarios. Recently, some ORB implementations have appeared that target specific application domains, for example real-time applications and fault-tolerant applications. These ORBs, however, focus on one specific application scenario.

The purpose of this thesis is to explore the alternative approach of designing not a “one size fits all” ORB, but rather an object-oriented framework that allows application developers to instantiate their own customised ORBs from components available in the framework. Thus, one user may, for example, use the framework to create a “standard” ORB supporting mobile computing, or fault-tolerance.

In order to understand the characteristics of ORBs in general, and of those aimed at specific application domains in particular, a number of freely available ORBs were studied. From this, it was possible to infer which components are commonly found in ORBs aimed at specific application scenarios.

Based on this study, an object-oriented framework for CORBA ORBs was designed. Its design is described using the Unified Modeling Language (UML) to illustrate its principal components. To aid in its comprehension, the framework is also documented by describing which principal design patterns it implements. This dissertation also documents the design process that was employed. An actual implementation of the framework was not part of the project. Finally, a set of C++ header files is also provided to document the framework class definitions.

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Table of Contents

List of Figures

Chapter 1

Introduction

1.1 The Problem

The Object Management Group (OMG) Common Object Request Broker Architecture (CORBA) is an emerging standard that combines the fields of distributed computing and object oriented programming. An Object Request Broker (ORB) is a piece of software that enables the implementation of distributed applications that use the object oriented paradigm. ORBs are also known as middleware.

Recently, many distributed applications have been based on the CORBA standard by using CORBA compliant ORBs as middleware. Such middleware provides the components of a distributed application with a uniform view of local and remote application objects. It shields distributed application developers from having to deal with network and protocol layers and lets them concentrate on the design of the distributed application itself.

Most CORBA compliant ORBs have been based on monolithic implementations. Vendors typically offer a single ORB implementation for use in any of a number of different application scenarios. Some ORB implementations have appeared recently that target specific application domains, such as fault-tolerance applications and real-time applications. The problem, however, is that each of these ORB implementations focuses on one specific application scenario. In order to provide an ORB that is tailored to a specific application scenario, generally such an ORB needs to be built from the ground up. This, however, is a non-trivial task, especially when an application developer is more concerned with designing and implementing a distributed application, than having to worry about implementing the required middleware.

1.2 Proposed Solution

This thesis proposes that an object-oriented ORB framework would allow an application developer to focus on the distributed object application at hand, while providing him or her with the ability to easily implement the required ORB middleware, tailored to the particular application scenario. Such a framework provides the architectural design for any ORB created by instantiating it.

In order to arrive at a design for an ORB framework, a number of steps were taken. First, the CORBA specification was studied in detail in order to understand the requirements of a CORBA compliant ORB. In addition to this, the process of designing and developing frameworks in general was studied. Particularly relevant to this study was the area of object-oriented design patterns, which pervade most frameworks.

Next, a number of publicly available CORBA compliant ORBs were analysed. These included one ORB aimed at general distributed object applications, and two ORBs aimed at specific application areas. The findings of this analysis influenced the requirements formulation of the framework design and the design of the framework itself.

Finally, the actual ORB framework was designed. The design was documented using Unified Modeling Language (UML) object and sequence diagrams. Design patterns played an important role in the design of the framework.

1.3 Achievements

A number of things were achieved by this project. Firstly, a design for an ORB framework was developed. The design includes UML object and interaction diagrams. C++ class definitions were also created. These can be used in a possible future implementation of the framework.

Experience was gained in applying design patterns to the development of object-oriented software in general, and frameworks specifically. Experience was also gained in framework development in general, especially with regard to problems encountered in framework design.

Insight was gained into the OMG CORBA specification and how it can be implemented, by the analysis of various publicly available CORBA ORBs.

1.4 Format of Thesis

The following chapter is a survey of CORBA and frameworks in general. Chapter 3 is an analysis of three publicly available ORBs. Chapter 4 describes the design of the ORB framework. Chapter 5 is an evaluation of the framework. Finally, Chapter 6 finishes with some concluding remarks about the project.

1.5 Summary

In this chapter, an ORB framework was proposed as an approach to providing flexible and customised ORB middleware. The steps that were taken in the development of such a framework were outlined, and the achievements of the project were stated. The overall format of the following chapters was also described.

Chapter 2

Survey

2.1 Introduction

The purpose of this chapter is to introduce some of the concepts and areas of research that are relevant to this project. The survey begins with a brief introduction to design patterns. Design patterns are relevant to both framework and ORB design. Next, frameworks are introduced and some characteristics of frameworks are given. Some different types of framework are explained, and frameworks are compared to other types of software reuse. Strategies for framework development are also outlined. After frameworks are discussed, the CORBA architecture is briefly introduced. Some possible CORBA application scenarios are described. Finally, the approach to developing the framework is discussed.

2.2 Design Patterns

Design patterns play an important role in framework design. Since they will be referred to in subsequent sections, they are briefly introduced at this point. The idea of design patterns was adopted from the field of architecture where it was first formulated by Alexander [Ale77]. He and his colleagues formulated a pattern language for the design and construction of buildings and towns. In his own words “Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice”.

This idea also sums up design patterns in object-oriented software design. A design pattern systematically names, motivates, and explains a general design that addresses a recurring design problem in object-oriented systems. It describes the problem, the solution, when to apply the solution, and its consequences. It also gives implementation hints and examples. The solution is a general arrangement of objects and classes that solve the problem. The solution is customised and implemented to solve the problem in a particular context [Gam95].

The seminal work on design patterns is [Gam95]. In it, the authors catalog some 23 design patterns which were found to recur over and over again in well designed object oriented application designs. A pattern consists of four major parts: the *pattern name*, the *problem*, the *solution*, and the *consequences*.

The *pattern name* concisely describes the pattern in a word or at most a few words. It provides designers with a vocabulary that can be used to communicate to others a particular design. It also allows designers to describe designs at a higher level of abstraction.

The *problem* describes a particular situation which may occur over and over again in object oriented designs and which must be solved in some way.

The *solution* describes an arrangement of classes and objects that implement the pattern’s solution to the stated problem. It is not a concrete solution to one particular instance of the problem, but rather an abstract solution which can be used like a template in different situations.

The *consequences* describe the implications of applying the solution to the problem. Implications might be, for example, tradeoffs between subtly varying solutions given to the problem. Consequences may also be used in evaluating different solutions to a problem.

2.2.1 A Design Pattern Example: Facade

As an example of a design pattern, the Facade pattern is briefly introduced here. This pattern is taken from [Gam95].
Often in the design of large applications, it is desirable to divide the overall design into a number of subsystems. Reasons for this might be that different subsystems of the application might be implemented by different programmers and to reduce the overall complexity by allowing the designer to (recursively) think of the overall system as that of a number of subsystems. The complexity is reduced by reducing the amount of dependencies and communication between different subsystems. Ideally, this should be minimal as otherwise small changes in one part of the application will ripple through the entire application thereby preventing easy modification of a system.
To overcome this problem, the Facade pattern proposes that a unified interface be implemented to a set of interfaces in a subsystem. In other words, Facade provides a single higher level interface to a subsystem that might contain a number of interfaces.
The Facade pattern is illustrated in **Figure 1**.

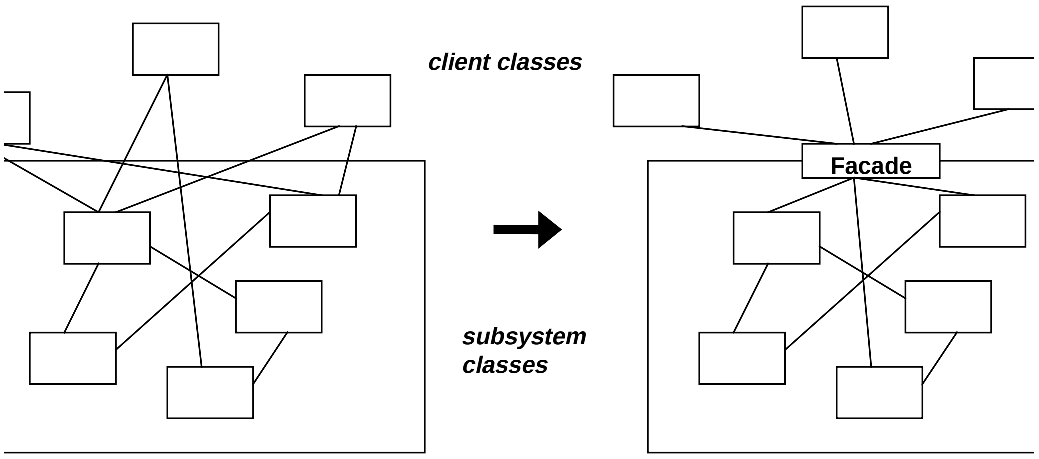


Figure 1 Facade Design Pattern

2.3 Frameworks

2.3.1 Introduction to Frameworks

Frameworks are an attempt to prevent the rediscovery and reinvention of concepts and components in the software industry [Fay97]. Their objective is to facilitate the development of applications in particular domains (eg. Graphical User Interfaces) or business units (eg. manufacturing). In essence, frameworks are one approach to software reuse.

A framework can be defined as a set of cooperating classes that make up a reusable design for a specific class of software. It provides architectural guidance by partitioning the design into abstract classes and defining their responsibilities and collaborations. A developer customises the framework to a particular application by subclassing and composing instances of framework classes [Gam95]. A framework dictates the architecture of an application developed with it. It defines the application's overall structure, its partitioning into classes and objects, the key responsibilities of those classes and objects, how they collaborate, and the thread of control.

Since a framework is more abstract than a finished application, in order to use a framework to develop a particular application, the developer will need to extend framework classes to implement application specific behaviour.

The objective of developing frameworks is to achieve both design and code reuse, as well as shorter development times for applications, thereby reducing the cost of developing an application. Frameworks leverage the domain knowledge of the framework developers, thereby leaving the application developer to focus on specific application design issues and problems.

Advantages of using frameworks are the already mentioned code and design reuse, portability, rapid prototyping, and possibly performance customisation [Cam92]. Portability can be achieved through the separation of machine dependent parts of the framework from machine independent parts. Rapid prototyping is achievable because the framework provides code and design reuse, thus making it possible to quickly test various implementations of a particular application built with the framework. Performance customisation can be achieved through the use of one or another framework component depending on the particular application.

2.3.2 Characteristics of Frameworks

Frameworks possess the following characteristics [Fay97]:

Modularity: Because a framework's potentially unstable implementation details are encapsulated by a stable interface, applications developed with the framework are not exposed to changes in framework implementation and design, as long as the interface remains stable.

Reusability: Since a framework encapsulates application domain specific knowledge and prior effort of the framework developer, the application developer is able to reuse common solutions to recurring application requirements, thereby saving development time and improving the quality and reliability of the application.

Extensibility: Frameworks provide hook methods that allow the application developer to extend the framework where needed.

Inversion of Control: Frameworks generally control the flow of control within an application via event dispatching patterns. This is also known as the "Hollywood Principle", or "Don't call us, we'll call you". When events occur, the framework's dispatcher reacts by invoking hook methods on pre-registered handler objects, which perform application specific processing on the events.

2.3.3 Types of Framework

There are different ways of categorising frameworks. One classification is that of *whitebox* versus *blackbox* frameworks [Joh88]. In a whitebox framework the application developer adds methods to subclasses of one or more of the framework's classes. These methods implement application specific behaviour. Since these methods must be designed and implemented as was intended by the designer of the superclasses, the application developer needs to have an understanding of the framework's implementation.

In a blackbox framework, on the other hand, an application is created by composition rather than inheritance, as in the whitebox framework. Various components may be available as part of the framework and the application developer decides which components are required to create a particular application. The application developer only needs to know the public interface of the components, but not their implementations. Blackbox frameworks have the advantage of being easier to learn, but have the disadvantage of being less flexible, than whitebox frameworks. If there is a good

selection of components, the amount of programming required to create an application with the framework will be much less than to do the same with a whitebox framework.
Thus, whitebox frameworks rely on inheritance whereas blackbox frameworks rely on object composition. Of course, there is a continuous range from whitebox to blackbox frameworks with some frameworks using both inheritance and object composition to achieve application creation.

2.3.4 Frameworks in relation to other approaches to reuse

Other approaches to software reuse are design patterns, class libraries, and components [Fay97]. These are related to frameworks in the following ways:
Design Patterns: Both design patterns and frameworks are approaches to software reuse. However, they differ in a number of ways [Gam95]. Firstly, patterns are more abstract than frameworks. Patterns enable design reuse whereas frameworks allow design and code reuse. Patterns have to be implemented in code every time they are used. Secondly, design patterns are smaller architectural elements than frameworks. This implies that frameworks can contain a number of patterns, but never the other way around. Thirdly, frameworks are specialised to a particular application domain. Design patterns, on the other hand, can be used in any type of application.
Class libraries: Class libraries also are an approach to software reuse. Frameworks extend the benefits of class libraries in the following ways: Firstly, class libraries generally are less domain specific than frameworks. Generally they are lower level than frameworks and thus don’t offer as high a level of reuse as frameworks. Frameworks, on the other hand, can be viewed as semi-complete applications. Secondly, class libraries don’t exhibit the inversion of control that frameworks do. Frameworks often make use of class libraries. An example is the C++ Standard Template Library.
Components: Yet another approach to reuse, components are self-contained instances of abstract data types [Fay97]. They can be plugged together to form complete applications. Components are reused on the knowledge of their interfaces, not their implementations. They can be reused without having to subclass from existing base classes. Thus they represent blackbox reuse. Frameworks can be used to develop components, but components can also be used to develop frameworks.

2.3.5 Examples of Frameworks

Numerous examples of frameworks exist. Here is a brief description of some of them:

Choices is an object-oriented operating system framework implemented in C++. It was developed at the University of Illinois at Urbana-Champaign [Cam92, Joh91]. The motivation behind the development of *Choices* was that different users of operating systems have different needs. For example, some applications for operating systems require large virtual address spaces, whereas others, such as real-time embedded systems don't require virtual memory at all. The *Choices* framework addresses this problem by providing a family of operating systems that the user can tailor to specific requirements. The *Choices* framework consists of a number of subframeworks, such as virtual memory, process management, persistent storage, message passing, and device management. These subframeworks are used to implement subsystems of the operating system. The subframeworks provide abstract classes that are reused through inheritance, making *Choices* a whitebox framework.

Smalltalk *Model/View/Controller* (*MVC*) is a framework for constructing Smalltalk-80 user interfaces [Gam95]. It consists of three types of object: the Model, the View, and the Controller. The Model is the application object and the View is its screen representation. Each Model can have multiple Views. If the Model's data changes, the Views are notified to update themselves. The Controller defines how the user interface reacts to user input. An important aspect of MVC is that it contains a number of design patterns, such as Observer, Composite, and Strategy. Thus it demonstrates how design patterns can be used in the development of frameworks. Observer is a pattern that allows a one-to-many dependency between objects to be created so that when one object changes its state, all the other objects are notified and updated automatically. Composite is a pattern that allows a tree-like structure of objects to be created. It allows clients to treat individual objects and compositions of objects in the same way. Strategy is a pattern that allows algorithms to be encapsulated by objects. It allows clients to freely interchange these objects if the algorithm is to be varied. These patterns are described in more detail in [Gam95].

Microsoft's *Microsoft Foundation Classes* (*MFC*) is a framework for the development of GUIs for the Microsoft Windows operating system [She96]. Its name is slightly misleading, as it is in fact a framework, though parts of it can be used as a class library. To create a Windows GUI application with *MFC*, the user needs to subclass from a number of abstract classes. The relationships and constraints between these classes is known as the document-view architecture, similar to the Model and View architecture in MVC. To be able to create any but the most trivial applications, the user needs to have some understanding of these relationships and constraints. Therefore, the *MFC* could also be classified as a whitebox framework.

2.3.6 Strategies for developing Frameworks

Various methods or strategies for developing frameworks have been proposed. [Bec94] [Dem96] [Kos] [Rob97]. Of these, the method that seems most inclusive of all framework application domains, and pertains to the entire life cycle of framework development is *Evolving Frameworks*, a pattern language for framework development. It is described in more detail below.

2.3.6.1 A Pattern Language for developing Frameworks

One strategy, proposed by Roberts and Johnson, for developing frameworks, applies design patterns to the problem of framework development [Rob97]. More specifically, a pattern language for developing object-oriented frameworks is proposed. It is called *Evolving Frameworks*. A pattern language can be described as a set of patterns that are used together to solve a problem. *Evolving Frameworks* comprises of the following patterns: *Three Examples, Whitebox Framework, Blackbox Framework, Component Library, Hot Spots, Pluggable Objects, Fine-grained Objects, Visual Builder, Language Tools*. The above sequence is the sequence in which the patterns generally will be applied as the framework evolves, although this is not totally rigid.

Three Examples is the first and fundamental pattern in this pattern language. It argues that it is impossible to design, from scratch, a framework without first having built at least three applications of the type that the framework is intended to build. The framework abstractions can then be determined from these examples.

The *Whitebox Framework* pattern proposes that the initial framework design, arrived at by generalising from the classes in the individual applications, should be based on inheritance. This framework subsequently could be changed into a *Blackbox Framework*, but only when it is known which parts of the framework will consistently change across applications and which parts remain constant.

Component Library proposes common classes that should be collected from the application examples to form a component library.

Hot Spots proposes to separate code which changes between applications from code which doesn't. Ideally, the varying code is then encapsulated within objects. This promotes reuse through composition of objects instead of subclassing from other classes.

The objective of the *Pluggable Objects* pattern is to avoid unnecessary subclassing when the subclasses differ only in trivial ways. It achieves this by using parameters in the instance creation protocol. In this way the subclass can be parameterised, in other words, customised for its particular application.

Fine-Grained Objects proposes that objects be broken down into granularities as fine as possible. The reason for this is that code duplication can be avoided in this way. If objects are not broken down like this, some classes may end up encapsulating multiple behaviours that could possibly vary independently. It is better to replace such a class with a composition that recreates the behaviour of that class.

The creation of *Pluggable Objects* and *Fine-Grained Objects* leads to the ability to create applications using composition. Therefore, the next step the design of the framework is to reorganise the framework into a *Blackbox Framework*, which favours composition over inheritance.

The *Visual Builder* pattern proposes a graphical program that lets the application developer specify the objects of the application and how they are interconnected.

The last pattern in the language, *Language Tools*, suggests that specialised inspecting and debugging tools be created for the framework.

Figure 2 shows how the patterns in *Evolving Frameworks* are related in time. It can be seen that many patterns will be applied in parallel.

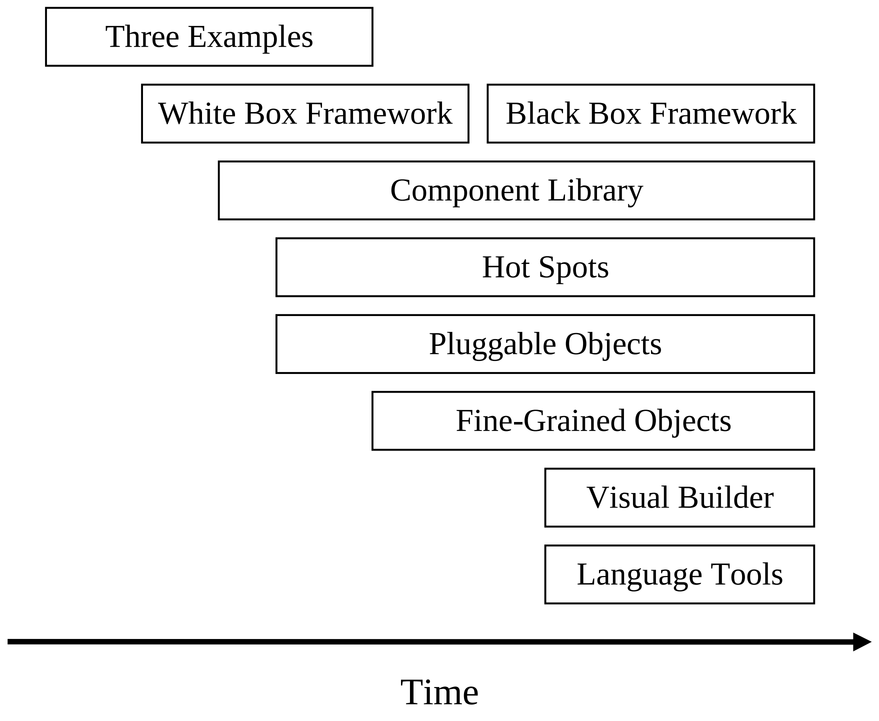


Figure 2 Evolving Frameworks

2.3.7 Documenting Frameworks

An approach to documenting frameworks using patterns has been suggested by Johnson [Joh92]. He proposes that the documentation of a framework has three purposes. Specifically, the framework documentation needs to 1) describe the purpose of the framework, 2) describe how to use the framework, and 3) describe the detailed design of the framework.

The first pattern in the framework documentation describes the purpose of the framework and its application domain. It gives examples of framework applications and introduces the rest of the patterns describing the framework, and which of those patterns should be studied next. This next set of patterns is used to describe how to use the framework. Finally, the detailed design of the framework is described.

2.3.8 Problems regarding Framework Development

The following are some of the problems and challenges that are encountered and that need to be overcome for effective framework development and utilisation [Fay97]:

Development effort: The effort and domain knowledge required for successful framework development is higher than that required for application development in a particular domain.
Learning curve: The learning curve involved in learning to use a particular framework is often quite high. If only a few applications are ever going to be built using a framework, the value of creating such a framework needs to be questioned, since in this case it might not be a cost effective solution. Also, the suitability of a framework to building a particular application may only become apparent after an amount of time has been invested in learning the framework.
Integratability: If applications are built using more than one framework, compatibility and integration problems may result. Specifically, the inversion of control principle of frameworks could cause problems, as event loops in the frameworks may not be designed to allow interoperability.
Maintainability: As application requirements change frequently, the requirements of frameworks may change with them. Modifying and adapting a framework may prove difficult for application developers since a deep understanding of framework internals and relationships between framework components is essential.
Validation and defect removal: Debugging applications created with a framework may be difficult. For example, since the flow of control is controlled by the framework, it may be difficult to step through the application specific code of the application.
Efficiency: The generality and flexibility of a framework may reduce its efficiency.

2.4 CORBA and Frameworks

2.4.1 Introduction to CORBA Object Request Brokers

The Common Object Request Broker Architecture (CORBA) is a standard model for distributed object-oriented systems. The CORBA standard forms part of the Object Management Group’s (OMG) Object Management Architecture (OMA). The current standard is CORBA 2.0. The purpose of the CORBA standard is to abstract distributed object applications, which may run in a heterogeneous environment, away from underlying networking protocols and transports. This facility is provided by Object Request Brokers (ORBs), which lie at the heart of the OMA. An ORB allows a client to deliver a request to a target object acting as a server, and it returns any responses to the clients making the requests. The target object may reside in the same process, on the same machine but in a different process, or on a different machine in a different process somewhere on the network. The client-server relationship is only valid on a request basis. A client object for one request could be a server object for another [Vin97].

CORBA consists of the following main elements:

ORB Core: The ORB core lets client objects transparently make requests to server objects, and receive responses from them, whether they are in-process out-of-process, or remote servers.

Interface Definition Language (IDL): The IDL enables interfaces between client and server objects to be defined in a declarative, language independent manner. An interface specifies the operations and types that the server object supports.

IDL Client Stub: The client stub acts as a local proxy for a remote server object. It provides static interfaces to server object's services. It is created by compiling the interface definition using an IDL compiler.

IDL Server Skeleton: The server skeleton provides the static interface to each service exported by the server. Like the client stubs, it is created by compiling the interface definition using an IDL compiler.

Dynamic Invocation Interface (DII): The DII allows the client to discover at runtime the server interface method to be invoked.

Dynamic Skeleton Invocation (DSI): The DSI is the server equivalent of the DII. It provides a run-time binding mechanism for servers to handle incoming method calls for components that do not have IDL-based compiled skeletons.

Object Adapter: The Object Adapter serves as the glue between object implementations and the ORB core.

Interface Repository: The Interface Repository is a database that contains machine readable versions of the IDL-defined interfaces.

Implementation Repository: The Implementation Repository contains information about the classes supported by a server, which objects are instantiated, and their IDs.
ORB Interface: The ORB Interface contains APIs to some ORB services that may be useful to an application.
Inter ORB Protocols: Inter ORB Protocols, such as GIOP and IIOP, allow ORBs from different vendors to communicate with one another.

2.4.2 Some CORBA Application Scenarios

The objective of developing an ORB framework is to facilitate the implementation of customised ORBs. Customised ORBs are ORBs that are tailored towards one or more particular application scenarios. The following are examples of some such scenarios and the issues that need to be addressed when developing ORBs, and therefore ORB frameworks, for such scenarios.

2.4.2.1 Reliable Distributed Systems

A distributed system can be considered reliable if its behaviour is predictable despite partial failures, asynchrony, and runtime reconfiguration of the system. Building reliable distributed systems using CORBA is a priority in areas such as electronic commerce, flight reservation systems, and real-time data feeds. It is, however, difficult to achieve for a number of reasons. For example, because of partial failures of the system, the mean time to failure of components in the distributed system decreases as the number of nodes and communication links increases. Complex execution states can lead to situations such as race conditions, deadlocks, and communication failures [Maf97].
Some approaches to implementing reliable distributed systems are message queues, transaction processing monitors, and virtual synchrony. [Maf97] describes how these approaches can be combined into an extended CORBA architecture for reliable systems.

2.4.2.2 Performance in CORBA Distributed Systems

Some distributed applications have specific Quality of Service (QoS) demands. Real time systems, such as avionics or motion control systems, and constrained latency systems, such as teleconferencing or telecommunications systems, fall into this category. Until recently, the CORBA specification did not provide definitions for policies or mechanisms for providing QoS guarantees in distributed applications. Recently A/V streams have been added to the CORBA specification.

Existing ORBs exhibit significant runtime throughput and latency overheads. To be able to construct real-time ORBs that can exhibit end to end QoS guarantees, the factors that affect performance of ORBs need to be addressed. Some of these factors are [Sch97]: specification of end to end QoS requirements, operating system and network resource scheduling, communication protocols performance, request demultiplexing and dispatching optimisation, memory management optimisation, and presentation layer conversions.

2.4.2.3 Mobile Distributed Systems

Mobile distributed systems entail some of the following aspects: the frequent movement of users and hosts, the scarcity of network and local computing resources available to the mobile host, the possibility of disconnections. These lead to the following problems with which mobile distributed systems are faced: frequent disconnections from the network, widely varying bandwidths among wired and wireless links, limited CPU power and device capacity on a mobile host, transient servers due to frequent handoff.

These problems lead to the following design guidelines for mobile distributed systems [Che97]:

Minimum host-network coupling: Applications should be designed with minimum coupling between the mobile host and the server as connections generally are unreliable.

Connection transparency: An application should be able to continue operating transparently even if there are changes in the connection between mobile host and server, such as handoff and disconnections.

Indirect interaction: To minimise interaction over the wireless link, user input processing should be performed as close to the mobile host as possible.

Adaptive communication protocols: Because of variable bandwidth and heterogeneous networks, communication protocols need to be adaptable.

Application partitioning: Because of unreliable connections, applications need to be designed so that parts of them can be migrated to and run on the mobile host.

2.4.2.4 Developing a Framework for Customisable ORBs

The previous sections have introduced a number of topics which are fundamental to the project, the development of a framework for customisable ORBs. The content of these sections is to serve only as an introduction to some of the issues and approaches which are relevant to this project.

The suggested approach to developing the framework is to apply the pattern language *Evolving Frameworks* mentioned in the frameworks section. This pattern language begins with the *Three Examples* pattern. Considering the limited amount of time allocated to this project, it would obviously not be feasible to implement three separate ORBs, which may cover various application scenarios, as is suggested by that pattern. On the other hand, a deep, hands-on understanding of the application domain, customisable ORBs, is required in order to attempt the design and implementation of an ORB framework. A possible approach to overcome this problem would be to examine the implementations of a number of different existing ORBs. ORBs exist for which the source code is publicly available, and some of these are also well documented from a design point of view.

Some CORBA ORB implementations which focus on some of the different application scenarios described above and for which source code is available are *TAO*, *Electra*, and *OmniORB*.

OmniORB is a CORBA compliant ORB that has been developed by the Olivetti and Oracle Research Laboratory. It is a plain, “vanilla” ORB, not geared towards any particular application domain.

TAO is a CORBA compliant ORB that has been developed at the Department of Computer Science, Washington University. It is an ORB aimed at applications with real-time QoS requirements. It is designed to be extensible, maintainable, and dynamically configurable. To achieve these objectives its design relies heavily on the use of design patterns. Its design is well documented using these patterns in [Sch98].

Electra is a CORBA compliant ORB that is geared towards fault-tolerance and group communication. It allows object groups, reliable multicast communication, and object replication. It is designed to run on top of platforms such as Horus and Isis which are low-level toolkits for the implementation of fault-tolerant distributed systems.

The first step will be to study the implementations of these three ORBs. This would involve the study of both any documentation and literature that is available about them, and also the source code which is publicly available. For the latter, an object-oriented browsing tool, such as Takefive Software’s Sniff+, might be useful. Some of these tools provide the ability to ‘reverse engineer’ source code to object notation, such as UML.

2.5 Summary

This chapter provided an introduction to some of the issues regarding the development of an ORB framework. Object oriented design patterns were defined and an example of a design pattern was provided. Object oriented frameworks in general were introduced and some of their characteristics explained. Finally, the CORBA standard was briefly introduced along with some possible application areas for distributed object applications.

Chapter 3

Analysis of existing Object Request Brokers

3.1 Introduction

This chapter describes an analysis of three publicly available CORBA compliant ORBs. The three ORBs are OmniORB, TAO, and Electra. OmniORB was developed by the Olivetti and Oracle Research Laboratory. It is a basic ORB which is not geared towards any particular application domain. *TAO* was developed at the Department of Computer Science, Washington University. It is aimed at applications with real-time Quality of Service requirements. *Electra* was developed by Silvano Maffeis while at the University of Zurich. It is an ORB that is geared towards fault-tolerance and group communication. It allows object groups, reliable multicast communication, and object replication.

3.2 OmniORB

3.2.1 Introduction

The first ORB to be analysed was OmniORB2. OmniORB2 is an ORB that implements version 2.0 of the Object Management Group's CORBA specification. It was developed by the Olivetti & Oracle Research Laboratory (`http://www.orl.co.uk`). This section documents the investigation into the implementation of OmniORB2.

3.2.2 Purpose of the analysis

The purpose of the analysis of the implementation of OmniORB2 was to gain insight into how the architecture of a typical ORB is structured. Specifically, the internals of OmniORB2 were to be analysed, in other words, those parts of OmniORB2 that implement the CORBA specification but that are left to be implemented by the different ORB vendors. Especially interesting was to determine whether any design patterns were used. The use of these would facilitate the understanding of the design of OmniORB2 and would be helpful in the subsequent design of an ORB framework. They would also make it easier to document the design of OmniORB2.

3.2.3 Main features of OmniORB2

3.2.3.1 CORBA 2 compliancy

As stated in the introduction, OmniORB2 is an ORB that implements version 2.0 of the OMG’s CORBA specification. It implements the Internet Inter-ORB Protocol (IIOP) and uses this to communicate with other ORBs, and also uses it as its own native protocol, i.e. for the communication between its objects residing in different address spaces.

3.2.3.2 Platform support

OmniORB2 supports the following platforms: Sun Solaris, Digital Unix, HPUX, IBM AIX, Linux, Windows NT, Windows 95, OpenVMS, ATMos, NextStep. Extensive use of preprocessor directives is made in the source code to allow compilation for these numerous supported platforms. This can make the source code quite difficult to understand at times.

3.2.3.3 Missing features

OmniORB2 is not a complete implementation of the CORBA specification. Some features are still missing:

- OmniORB2's Basic Object Adapter (BOA) does not support dynamic server activation and deactivation policies. It only supports the persistent server activation policy.
- The Dynamic Invocation Interface is not supported.
- The Dynamic Skeleton Interface is not supported.
- OmniORB2 does not have its own Interface Repository.

3.2.4 Building and testing OmniORB2

The OmniORB2 distribution was downloaded from the Oracle & Olivetti Research Laboratory's web site. Although ready to run binaries are available to download, OmniORB2 was downloaded in source code form and compiled and linked on site. The download package comes as a zipped tar file which extracts into a directory tree. The main parts of the package are:

3.2.4.1 The documentation

This consists of four documents which address the OmniORB2 itself, the OmniNames naming service, which is an OmniORB2 implementation of the OMG's COS Naming Service Specification, OmniThread, which is a portable thread abstraction library used by OmniORB2, and OmniORB utilities.

Of these documents, the principal one is the OmniORB2 manual. It is addressed at the application developer who wants to know how to get started using OmniORB2. Some of the examples that are provided with OmniORB2 are explained. The OmniORB2 API is explained as is the interface to the Basic Object Adapter (BOA). However, the internal architecture of the ORB is not documented.

3.2.4.2 The source code

Source code is provided for OmniORB2 itself, the OmniThread library, the OmniIDL2 compiler, which is the IDL compiler supplied with OmniORB2, a number of examples, the OmniNames naming service, and the OmniORB2 utilities.

3.2.4.3 Makefiles

Makefiles are supplied to build the various binaries under the supported platforms. To build the binaries under Unix requires GNUmake. To build the binaries under Windows NT requires the gnu-win32 utilities from Cygnus Solutions.

3.2.4.4 Tools and methods used for analysing OmniORB

Initially OmniORB2 was built using the Sun C++ compiler and GNUmake under Solaris 2.6. The three *Echo* examples, which are documented in Chapter 1 of the OmniORB2 manual, were also built and executed as indicated. Because of a lack of suitable debugging, analysis, and browsing tools under Unix, the OmniORB2 binaries were rebuilt under Windows NT using Microsoft Visual C++ 5.0 and the Cygnus Solutions gnu-win32 utilities. The advantage of examining OmniORB2 under Windows NT was that the debugger which is supplied with Visual C++ could be used to step through the application and ORB source code as an application was being executed.

Next, the OmniORB2 source code was analysed using SNIFF+, a cross-platform programming environment by TakeFive Software. SNIFF+ provides a number of features that aid the comprehension of existing source code. Numerous tools, such as an inheritance hierarchy browser, a cross reference browser, and an include browser, are part of this environment and were found to be useful in the understanding of the implementation of OmniORB2. SNIFF+ includes its own source code parser which parses the source code of a project and builds its own internal representation of it. A project therefore does not need to be compiled before the SNIFF+ tools can be used.

3.2.4.5 Problems encountered

Some problems were encountered in trying to analyse the architecture of OmniORB2. Initially Solaris 5.6 was used as a platform for building the ORB and sample applications. It was found that because of a lack of suitable tools it would prove difficult to easily study the implementation of the ORB. The ORB was rebuilt under Windows NT and this was found to be advantageous, especially in the area of debugging.

A principal difficulty was the size of the source code. In the entire source code there are over 360 classes and structures, not including nested classes. The source code is very sparsely commented. There are no documents explaining the OmniORB2 architecture.

The large amount of preprocessor directives relating to macros and conditionally compiled code, made the source code difficult to understand.

A problem noted with SNIFF+ is that it ignores nested classes, ie. those classes that are declared within other class declarations. This meant that nested classes could not be browsed as easily as others, but it was found not to be a big problem.

3.2.5 Overall architecture of the ORB

The following sections describe some of the principal components of the OmniORB2 ORB. C++ `namespace` is not used. Instead, some classes are nested within other classes, for example, the class `ORB` is nested within the CORBA class, thus becoming `CORBA::ORB`. The reason for this is that some of the supported compilers may not have implemented the `namespace` keyword.

3.2.5.1 The ORB

The class that represents the ORB is `CORBA::ORB`. It provides the C++ mapping of the CORBA::ORB interface. It also provides some internal OmniORB2 specific functionality. An instance of this class is created in the function CORBA::ORB_init(…) unless an instance of it already exists. This function is called by both the object implementation and the client in order to obtain a pointer to the ORB.

Another class, `omniORB`, provides the public API of OmniORB2's extension to CORBA. This API is intended to be used in application code. All its members and methods are declared `static` and no actual instance of `omniORB` is ever created. The public API provides features such as run-time tracing and diagnostic messages, limiting the GIOP message size, and trapping internal errors.

3.2.5.2 The BOA

The class that represents the BOA is `CORBA::BOA`. It provides the C++ mapping of the `CORBA::BOA` interface. Again, it also provides some internal OmniORB2 specific functionality. An instance of this class is created in the function `CORBA::ORB::BOA_init` unless an instance of it already exists. As with the function creating the ORB, this function is called by both the object implementation and client in order to obtain a pointer to the BOA. After a call to `BOA_init`, the BOA must be activated using `impl_is_ready`. This starts a thread listening on the port on which IIOP requests are received. Objects can then be registered using the function `_obj_is_ready`. This is a member function of the implementation skeleton class and is called after the object is fully initialised. In the example below, it is a member function of the class `_sk_Echo`.

3.2.5.3 Sample skeleton code generated by the IDL compiler

This section describes which classes are created by the IDL compiler when a sample IDL file is compiled.
If the following example IDL interface

```
interface Echo {
     string echoString (in string mesg);
}
```

is compiled using the OmniORB2 IDL compiler, a number of classes are created by the IDL compiler. They are: `Echo`, `_nil_Echo`, `_sk_Echo`, `_proxy_Echo`, `Echo_proxyObjectFactory`, and `Echo_Helper`. Their relationships are shown in **Figure 3**.
`Echo`: A pointer to this class is the object reference that corresponds to the `Echo` interface.
`_nil_Echo`: This class provides a nil object reference of the `Echo` interface.
`_sk_Echo`: This is the skeleton class used for implementing the `Echo` implementation object. To implement an `Echo` object, a class is derived from `_sk_Echo`.

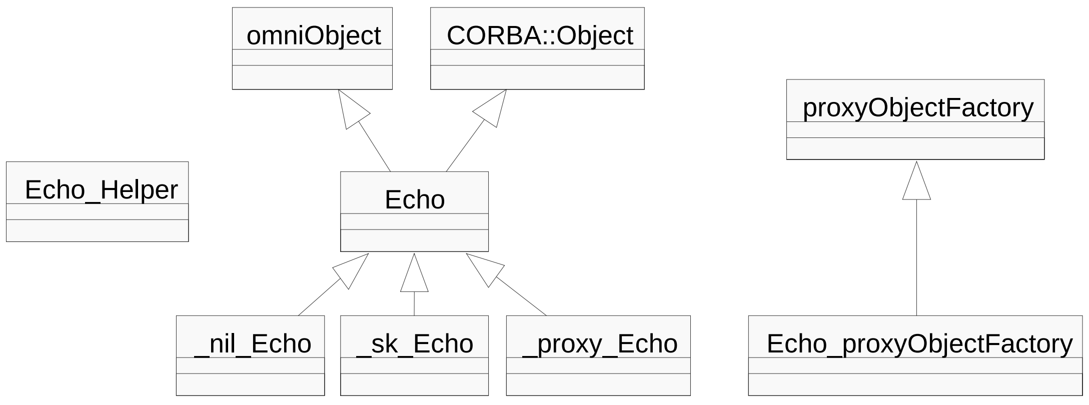


Figure 3 OmniORB Stub and Skeleton Classes
`_proxy_Echo`: An instance of `_proxy_Echo` is created as a local representation of the `Echo` implementation if this resides in a different address space.

`Echo_proxyObjectFactory`: An instance of this class creates the `_proxy_Echo` object on the client side if the `Echo` implementation resides in a different address space.

3.2.5.4 The OmniThread library

The purpose of the Omni Thread library is to provide a common set of thread operations for OmniORB2. Porting between different platforms with different thread interfaces is facilitated through this layer.

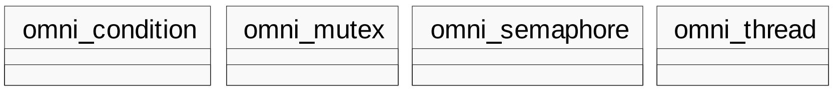


Figure 4 OmniORB Omni Thread Library Classes

The interface to the Omni Thread library is designed to be similar to that of POSIX threads. Essentially, the Omni Thread library consists of wrapper classes around thread calls. There are four principal classes in the Omni Thread library: `omni_condition`, `omni_mutex`, `omni_semaphore`, and `omni_thread`. Depending on the platform, different implementations of these wrapper classes are conditionally compiled. The Omni Thread library is illustrated in **Figure 4**.

3.2.5.5 Implementation of GIOP and IIOP

The `Rope` and `Strand` classes

OmniORB2's underlying GIOP communications mechanism is built on the concept of `Rope` and `Strand` classes.

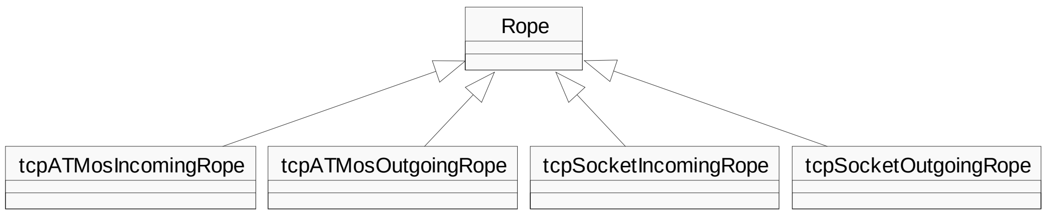


Figure 5 OmniORB Rope Inheritance Hierarchy

The `Rope` class represents a bidirectional buffered stream that connects two address spaces. The connection point of each address space is identified by an object of type `Endpoint`. A `Rope` object is composed of one or more objects of type `Strand`.

Each `Strand` object represents a transport dependent connection. All `Strand` objects of the same `Rope` object can be used interchangeably for the sending and receiving of messages between the two connected address spaces identified by the `Endpoint` objects. The `Rope` inheritance hierarchy is shown in **Figure 5**.

The Rope class is an abstract base class that defines the interface for the derived rope classes. Depending on the transport implementation, `Rope` objects are instantiated as tcpSocket ropes or tcpATMos ropes. They can be of the incoming or outgoing variety. Incoming `Rope` objects are used by the BOA to receive requests and dispatch them to the object. Outgoing `Rope` objects are used by the ORB to send requests. The instantiation of Rope objects is performed by objects derived from the abstract base class `ropeFactory`. Its inheritance hierarchy is shown in **Figure 6**. These classes represent an implementation of the *Abstract Factory* design pattern.

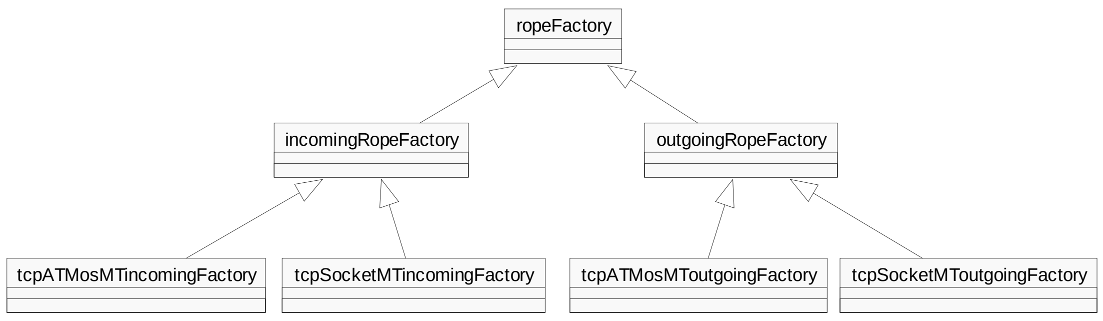

ropeFactory
incomingRopeFactory
outgoingRopeFactory
tcpATMosMTincomingFactory
tcpSocketMTincomingFactory
tcpATMosMToutgoingFactory
tcpSocketMToutgoingFactory

Figure 6 OmniORB Rope Factory Inheritance Hierarchy

An *Abstract Factory* can be used when related objects, in this case objects of type `Rope`, need to be created without specifying their concrete classes, for example `tcpATMosIncomingRope` or `tcpSocketIncomingRope`.

The `Strand` inheritance hierarchy is shown in **Figure 7**. For example, a `tcpSocketIncomingRope` object would contain a number of `tcpSocketStrand` objects.

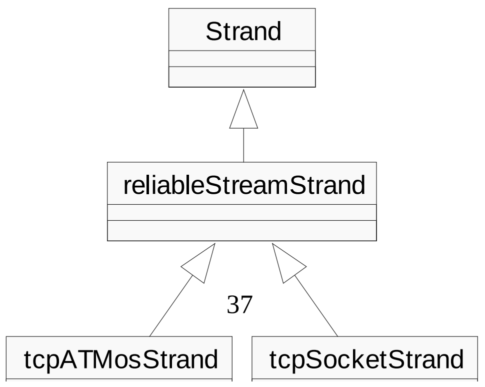


Figure 7 OmniORB Strand Inheritance Hierarchy

The `Endpoint` inheritance hierarchy is shown in **Figure 8**.

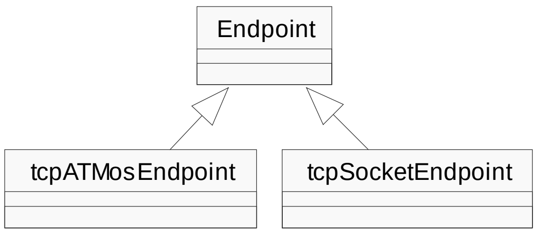


Figure 8 OmniORB Endpoint Inheritance Hierarchy

The GIOP driver classes

The `GIOP_C` and `GIOP_S` classes are built on top of a strand. They implement the General Inter-ORB Protocol (GIOP). The GIOP protocol is asymmetric. `GIOP_C` provides the functions to drive the client side protocol. `GIOP_S` provides the server side functions. The GIOP_C and GIOP_S inheritance hierarchy is shown in **Figure 9**.

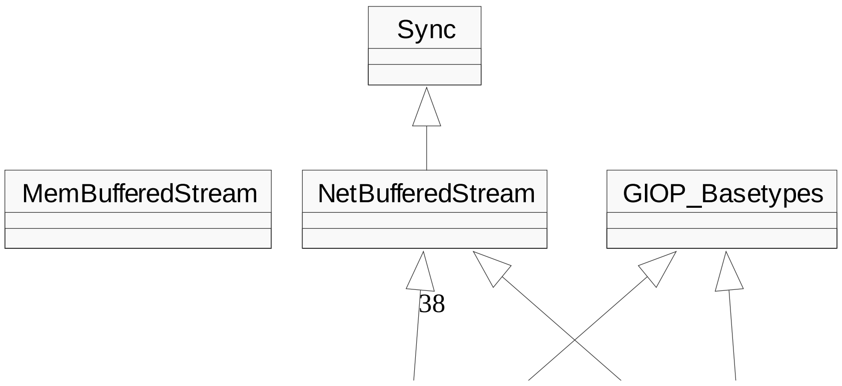


Figure 9 OmniORB GIOP Inheritance Hierarchy

An object of the Sync class is used to provide exclusive access to a Strand object. A number of Sync objects can be associated with any particular Strand object. Derived from Sync is the class NetBufferedStream. This class provides the marshalling functionality for different CORBA data types. In other words, this class provides the functionality to load and unload the buffer that is used for transmitting and receiving using the Strand object associated with the Sync object. The marshalling is totally independent of the transport layer that is used.. The Sync class only refers to Strand and Rope types, but not their concrete subclasses. The MemBufferedStream class has similar functionality to the NetBufferedStream class except that it is used when the client and server reside in the same address space and the transport layer and layers below it can be bypassed. The GIOP_Basetypes class defines some types, such as message header types, that are common to both GIOP_C and GIOP_S. Calling the constructor of GIOP_C or GIOP_S automatically aquires a Strand object.

A GIOP_C object can be in a number of states, such as Idle, RequestInProgress, WaitingForReply, ReplyIsBeingProcessed, and Zombie. Similarly, a GIOP_S object can be in the states Idle, RequestIsBeingProcessed, WaitingForReply, ReplyIsBeingComposed, and Zombie.

Threading models used in OmniORB2

The threading model used to process outgoing requests is determined by the implementation of the GIOP_C class. Only one request per Strand object can be outstanding, in other words, each thread has exclusive access to a Strand object when it has a request outstanding.

The threading model used to dispatch incoming requests is determined by the classes derived from ropeFactory. It is described in the section below.

Threading model to service incoming requests

A number of thread classes inherit from omni_thread. Two types of class that inherit from omni_thread are the tcpRendezvouser and the tcpWorker variety of class. These come in Socket and ATMos varieties. A worker class, for example tcpSocketWorker, is associated with each incoming Rope object's Strand object. When an incoming object derived from Rope is created, a tcpRendezvouser thread is created and started. This thread is associated with that particular Rope object. For example, a tcpSocketRendezvouser is created and started when a tcpSocketIncomingRope is created. The tcpSocketRendezvouser thread will wait for incoming connection requests using the accept system call. If a request is received, a new Strand, in this case a tcpSocketStrand, will be created and a tcpWorker, in this case a tcpSocketWorker, will be created and started. The worker will be associated with the particular Strand object. For as long as there are incoming requests on a particular Strand, for each request a GIOP_S object is instantiated by the worker. This GIOP_S object will gain exclusive access to the Strand object and will unmarshal and dispatch the request. When the request has been dispatched or otherwise handled, the GIOP_S object will be deleted. The process is repeated for the next request on that Strand object.

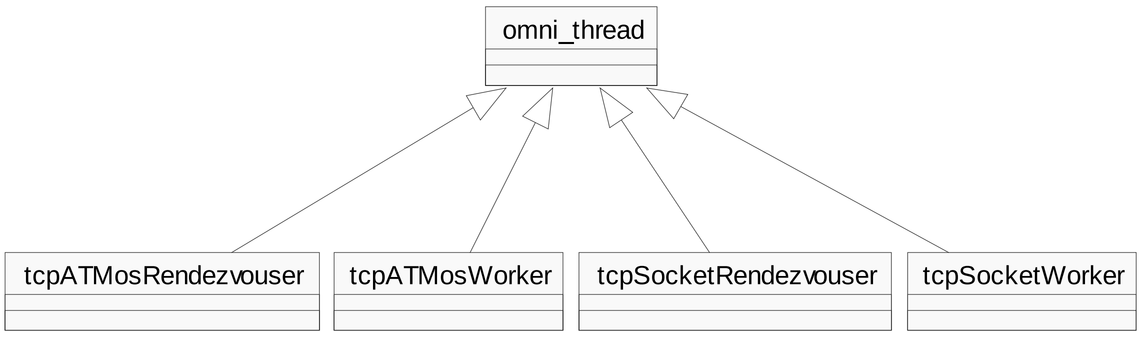


Figure 10 OmniORB Worker And Rendezvouser Inheritance Hierarchy

A scavenger thread periodically scans all the Strand objects. If it detects that a Strand object has been idle for a certain period it may shut it down, i.e. delete the Strand object and stop the associated worker thread. The Worker and Rendezvouser inheritance hierarchy is illustrated in **Figure 10**.

3.2.6 Conclusion

With some initial delays in setting up OmniORB2 and the relatively brief period allocated to its study, it was found that only an overall view of the internals of OmniORB2 could be obtained and that most areas could not be studied in great detail. However, the study has been useful in that it has provided a general insight into the workings of an ORB and that it offers areas of interest, for example, the implementation of certain classes, to be revisited and studied in greater detail at a later stage of the project, if necessary.

3.3 TAO

3.3.1 Introduction

In the study of the implementation of a number of CORBA compliant public domain ORBs, TAO (The ACE ORB) was chosen to be the second ORB to be examined. TAO is a CORBA 2.0 compliant ORB, aimed at high-performance, real-time applications. It extends the OMG CORBA specification by allowing applications to specify Quality of Service (QoS) requirements. It was developed by the Distributed Object Computing Group at Washington University (`www.cs.wustl.edu/~schmidt/TAO.html`). This report documents the investigation into the implementation of TAO.

3.3.2 Purpose of the analysis

The purpose of the analysis of the implementation of TAO was similar to that of OmniORB2. In addition, an objective of the study was to gain insight into how an ORB aimed at the high-performance, realtime application domain might be implemented, and how it would differ from a standard ORB.

3.3.3 Main features of TAO

3.3.3.1 Realtime ORB core

TAO’s realtime ORB core is based on the Adaptive Communication Environment (ACE) framework. It is designed to provide a number of threading models, such as thread-per-connection, or reactor-per-thread-priority. The TAO ORB core uses the Realtime Inter ORB Protocol (RIOP), which is based on IIOP, for interORB communication.

3.3.3.2 Optimised Object Adapter

The TAO Object Adapter is responsible for demultiplexing and dispatching client requests to servant operations. In conventional ORB systems, demultiplexing takes place on a number of layers. TAO’s Object Adapter uses demultiplexing keys assigned by the ORB to clients to achieve delayered demultiplexing.

3.3.3.3 Realtime IDL (RIDL) QoS specification

TAO provides an IDL interface for applicatins to specify their realtime resource requirements. This information is passed to TAO’s Realtime Scheduling Service. The TAO Realtime Scheduling Service performs offline feasability scheduling analysis to determine whether there are enough CPU resources to perform all requested tasks which the application has registered with the Realtime Scheduling Service repository.
The Scheduling Services also perform thread priority assignment during this offline analysis. This information is used by the ORB core at runtime to assign thread priorities. At runtime, requests are queued according to their priorities.

3.3.3.4 IDL compiler optimisations

Because the conversion of typed operation parameters from higher-level to lower-level representations (marshaling) and vice versa (demarshaling) can be a bottleneck, the TAO IDL compiler provides a number of optimising features. For example, either interpreted or compiled IDL stubs and skeletons can be linked into the application. Interpreted code is slower, but smaller in size, whereas compiled code is faster, but bigger in size.

3.3.3.5 Memory Management Optimisations

For efficiency reasons, TAO tries to keep dynamic memory management to a minimum. For example, it uses a “zero-copy” buffer management system when sending and receiving client requests to and from the network.

3.3.3.6 Platform support

Platforms supported by TAO are Windows NT, Solaris, VxWorks, and Linux.

3.3.4 Building and testing TAO

The TAO distribution kit was downloaded from the TAO website. It includes the ACE framework distribution. Uncompressed, the package is about 40MB in size. Both ACE and TAO were built from the source code using GNUmake and the Sun C++ compiler under Solaris 2.6.

3.3.4.1 The documentation

The design of both ACE and TAO is very well documented. A number of papers exist, outlining the design of ACE and TAO, patterns used in their design, and performance measurements and comparisons with a number of other ORBs. Most of the information about the design of TAO was obtained from these papers. They can be downloaded from the TAO website.

3.3.5 Overall Architecture of the TAO ORB

TAO is a CORBA compliant Object Request Broker that is aimed at real time distributed applications. It is designed to deliver end-to-end Quality of Service (QoS) guarantees. QoS guarantees allow applications to meet certain timing constraints, which, if they weren’t met, would render useless the application built on top of the ORB.

3.3.5.1 The ACE Framework

TAO is built using the ACE (Adaptive Communication Environment) framework. ACE is an object oriented toolkit for the development of network and communication applications. It is written in C++ and is targeted for applications on Unix and Win32 platforms. It facilitates the development of object oriented applications that use interprocess communication, event demultiplexing, explicit dynamic linking, and concurrency. The ACE framework also provides instances of a number of design patterns, such as Reactor and Acceptor-Connector, which recur in object oriented network and communication applications. These patterns will be described in a later section.

Layers in the ACE Framework

The ACE framework consists of a number of layers as depicted in **Figure 11**.

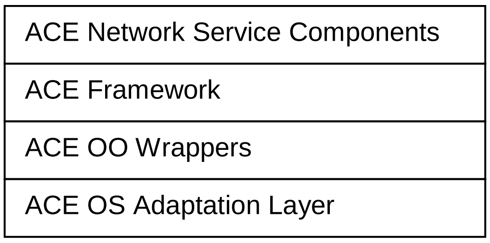


Figure 11 ACE Framework Layers

The ACE OS Adaptation Layer

The ACE OS Adaptation Layer forms an interface to the upper ACE layers for the following platform specific OS mechanisms:

- multithreading and synchronisation
- interprocess communication
- event demultiplexing
- explicit dynamic linking
- memory mapped files and shared memory

The ACE OO Wrappers Layer

The ACE OO Wrappers Layer provides C++ classes that encapsulate the various OS mechanisms in the Adaptation Layer. The wrapper class categories include:

IPC mechanisms

IPC mechanisms such as sockets, TLI, Named Pipes, and STREAM pipes. The wrapper classes in this category all inherit from the abstract base class IPC_SAP (Interprocess Communication Service Access Point) as depicted in **Figure 12**.

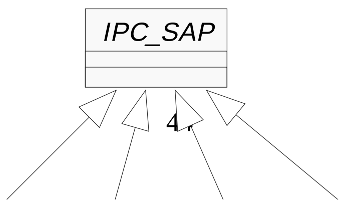


Figure 12 ACE IPC Class Hierarchy

Service Initialisation

Related to the IPC mechanisms are the Accptor-Connector classes which implement the design pattern of the same name. This pattern is used for the implementation of service initialisation in communication software. It decouples the initialisation of a communication service from the tasks the service performs once it is up and running and initialisation has been completed.

Concurrency Mechanisms

Concurrency mechanisms such as mutexes, threads, and semaphores are abstracted through C++ classes. These are illustrated in **Figure 13**. Thread mechanisms include Solaris threads, POSIX Pthreads and Win32 threads.

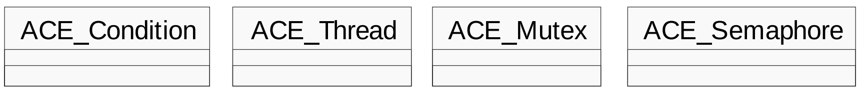


Figure 13 ACE Classes For Concurrency

Memory Management Mechanisms

These provide an abstraction for the dynamic management, ie. allocation and deallocation, of shared and local memory.

Event Multiplexing

This category of wrapper classes provides an encapsulation of OS event demultiplexing calls such as `select`, `poll`, and (Win32's) `WaitForMultipleObjects`.

The ACE Framework Layer

This layer builds on the lower two layers, described above, by instantiating a number of design patterns that can be used in the development of network applications. These patterns include *Reactor* and *Service Configurator*. They are described below.

The ACE Network Service Components Layer

This layer provides a number of network service components that are constructed using the components of the lower layers. Examples of the network services provided by this layer are logging, naming, locking, and time synchronisation services. The components of this layer also illustrate how to construct services and applications using the classes provided by the lower layers.

3.3.5.2 Design Patterns in ACE

The Acceptor-Connector Design Pattern

The `Acceptor` performs passive connection establishment, while the `Connector` performs active connection establishment. The participants of this pattern are shown in **Figure 14**.

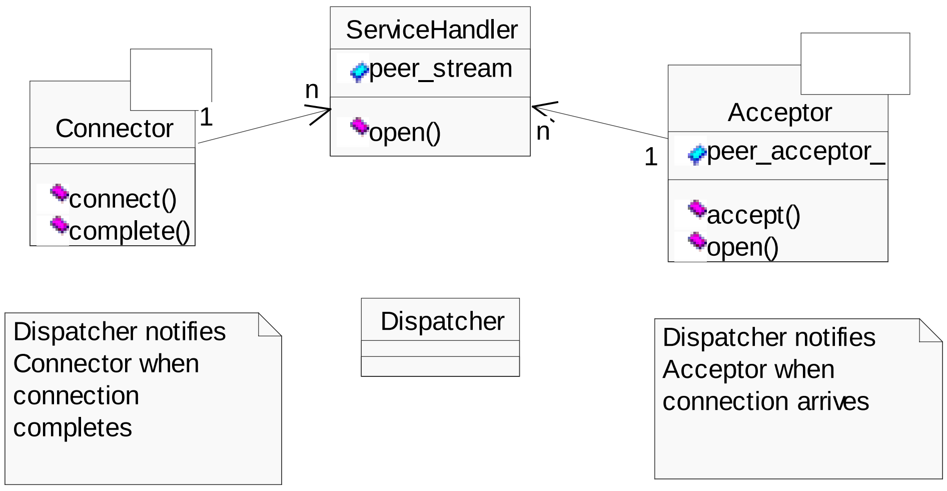


Figure 14 Acceptor Connector Design Pattern

Each `ServiceHandler` contains a transport endpoint. This endpoint might, for example, be a socket descriptor. A `ServiceHandler` on the client side is used to exchange data with its corresponding service handler on the server side, and vice versa. An `Acceptor` is a factory that creates a `ServiceHandler` and initialises it.

It is used for passively establishing a connection. It will listen on its `peer_acceptor` endpoint. When a connection request is received, it will invoke its `accept` method which will create a new `ServiceHandler` to handle that connection. The `Acceptor` will then again wait for new connection requests on its `peer_acceptor` endpoint. The `Connector` is used to actively set up a connection. The `Connector`'s `connect` method will establish a connection with a remote `Acceptor`. It also initialises a `ServiceHandler` which will handle the new connection.

The `Dispatcher` demultiplexes connection requests that may be received for different `Acceptor`s. It will pass the requests to the appropriate `Acceptor`. This allows a number of different `Acceptor`s to wait for connection establishment requests. The `Dispatcher` can be implemented using the *Reactor* design pattern which is described below. The `Dispatcher` is also used on the `Connector` side to complete the establishment of connections that were initiated asynchronously, using `connect`. It is not needed if connections were initiated synchronously by the `Connector` since the thread of control that calls `connect` will also call `complete`, which completes connection establishment.

The Reactor Design Pattern

The *Reactor* (also known as *Dispatcher*) design pattern is used to demultiplex requests that are sent to an application by any number of clients. Each request may be for a particular service. Different services are represented by different `EventHandler`s. Each of these `EventHandler`s is responsible for dispatching its service requests, ie passing the request to the actual service. The structure of this pattern is given in **Figure 15**.

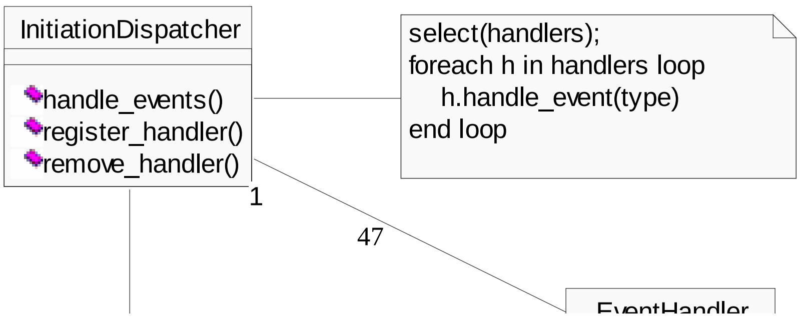


Figure 15 Reactor Design Pattern

A `Handle` represents an OS resource, such as a network connection. The `SynchronousEventDemultiplexer` waits for events to occur on a set of handles. When an event can be handled without blocking, it returns. This class is essentially a wrapper for an event demultiplexing function, such as `select` under Unix. The `InitiationDispatcher` is the central class in this pattern. It allows `EventHandler`s to be registered with it and removed from it. When the `SynchronousEventDemultiplexer` detects a new event occuring, it triggers the `InitiationDispatcher` to call the relevant application specific concrete `EventHandler`.

The Service Configurator Design Pattern

The *Service Configurator* design pattern is used to implement explicit dynamic linking. Dynamic linking allows the addition and deletion of object files into the address space of a process either at program startup or during program run-time. Dynamic linking is supported by various operating systems, such as SunOS 4.x, 5.x, and Windows NT.

The `ServiceObject` represents the interface to a dynamically linkable service. Its inheritance hierarchy is shown in **Figure 16**.

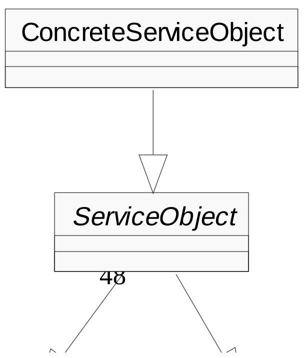


Figure 16 Service Object Inheritance Hierarchy

The `SharedObject` abstract base class provides an interface for dynamically linking service handler objects. The `SharedObject` abstract base class is kept separate from the `EventHandler` abstract base class since certain services may require dynamic linking, event demultiplexing, or both. Concrete subclasses of ServiceObject are used to implement application specific functionality of the service that can be configured by the *Service Configurator*.

`ServiceObjects` are managed by the `ServiceRepository` class. This class is an object manager that handles queries for particular services. It links service names (as ASCII strings) to instances of `ServiceObjects`. The `ServiceRepository` class structure is shown in **Figure 17**.

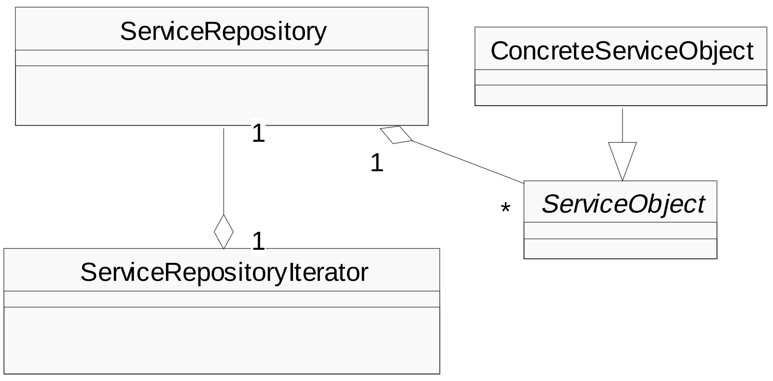


Figure 17 Service Repository Class Composition

The `ServiceConfig` class uses the above classes to enable dynamic linking of `ServiceObject`s, and thereby the dynamic configuration of communication software built using ACE. The class structure is shown in **Figure 18**.

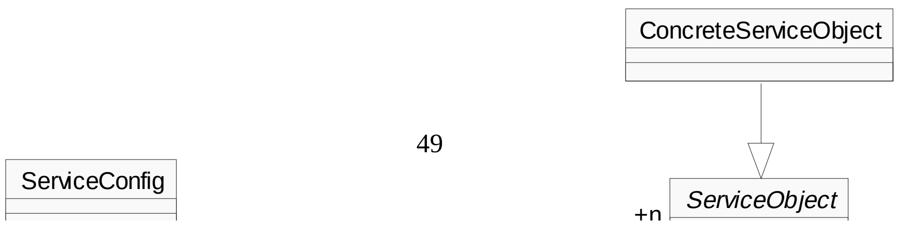


Figure 18 Service Configurator Design Pattern

3.3.5.3 The TAO ORB

The TAO ORB is built using the ACE framework. The principal components of TAO are shown in **Figure 19**.

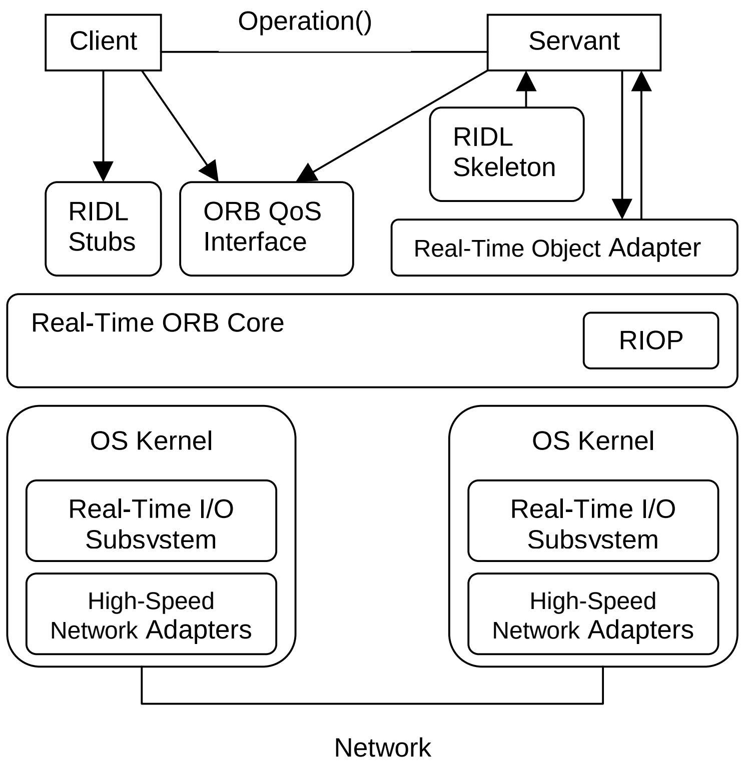


Figure 19 TAO Components

TAO's ORB core

TAO's ORB core makes use of a number of components of the ACE framework, such as *Acceptor-Connector* and *Reactor*. The TAO ORB core is shown in **Figure 20**. The *Acceptor-Connector* pattern is used to establish connections between client and server, with the *Reactor* taking the role of dispatcher on the *Acceptor* (server) side. On the client side, the `Strategy_Connector` caches connections to the server while on the server side the *Reactor* detects new incoming connections and notifies the `Strategy_Acceptor`, which associates the new connection with a `Connection_Handler`. The acceptors and connectors in the ORB core are called `Strategy_Acceptor` and `Strategy_Connector` since they make use of the *Strategy* design pattern. This allows them to use different strategies for connection management and handler concurrency. For example, the Strategy_Connector can use thread-specific cached connections or process-wide cached connections.

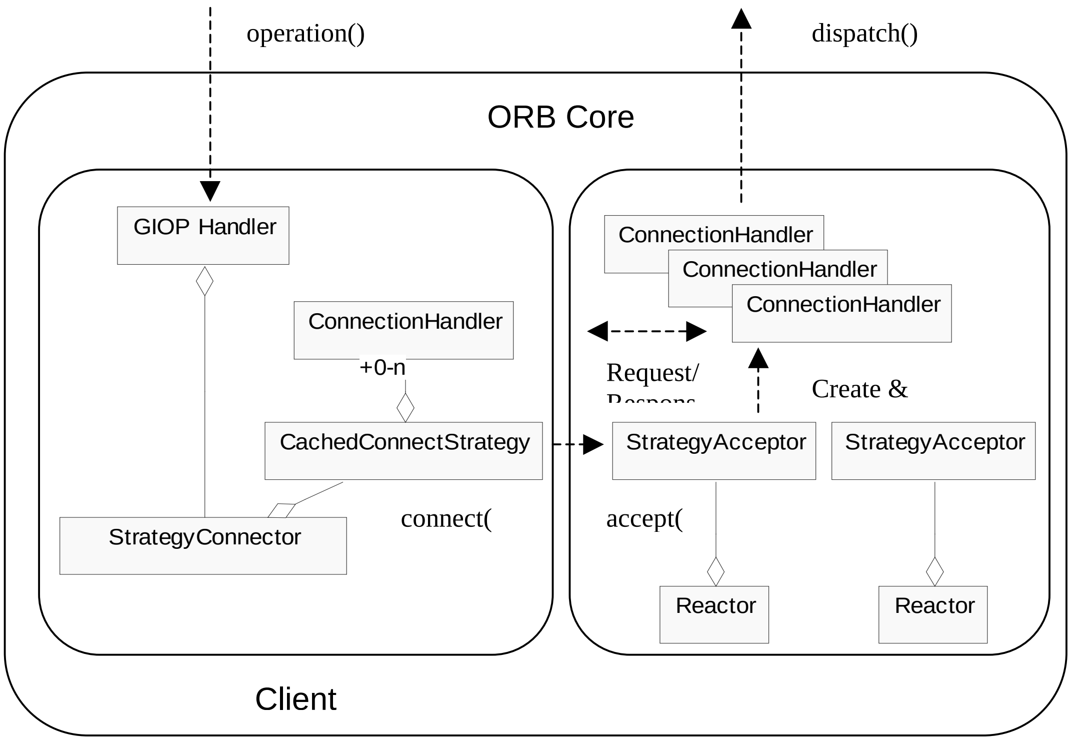


Figure 20 TAO ORB Core

TAO's Real-Time Object Adapter

TAO's real-time Object Adapter associates a servant with the ORB and demultiplexes incoming client requests to the servant. It can be configured, using the *Strategy* pattern, to dispatch client requests according to one of a number of real-time scheduling policies. The currently available strategies are Real-Time Upcall (RTU) dispatching and Real-Time Thread dispatching. In RTU dispatching, one real-time thread is responsible for queuing and dispatching all requests. In real-time thread dispatching, a real-time thread is allocated to each priority queue of client requests.

For demultiplexing client requests to the appropriate servant operation, TAO's Object Adapter offers two mechanisms.

Perfect Hashing: In the perfect hashing strategy, an automatically generated perfect hashing function is used to locate the servant. A second hashing function is used to locate the operation. For this method to work, the keys to be hashed need to be known in advance. This method can be used when servants and operations can be configured statically.

Active Demultiplexing: The second strategy for demultiplexing client requests to the appropriate servant operation is active demultiplexing. Here, the client passes a handle that identifies the servant and operation directly. The client can obtain this handle when the servant's object reference is being registered with a naming service or a trading service.

The above two demultiplexing mechanisms can be configured in TAO using the *Strategy* pattern.

3.4 Electra

3.4.1 Introduction

In the study of the implementation of a number of CORBA compliant public domain ORBs, Electra was chosen to be the third ORB to be examined. Electra is a CORBA 2.0 compliant ORB, aimed at fault-tolerant applications and at applications that make use of object groups and group communication. It allows applications to create object groups and make use of reliable multicast communication. Electra was developed by Silvano Maffeis while at the University of Zurich. The Electra homepage is currently at `www.softwired.ch/people/maffeis/electra.html`.

3.4.2 Purpose of the analysis

The purpose of the analysis of Electra was similar to that of OmniORB2. In addition, an objective of the study was to gain insight into how an ORB aimed at fault tolerant, and object group based applications might be implemented, and how it would differ from a standard ORB.

3.4.3 Main features of Electra

3.4.3.1 CORBA compliancy

Electra is based on the CORBA 2.0 specification. The current version of Electra is 2.0b. It includes:

- A CORBA IDL compiler
- A binding for the C++ programming language
- A Basic Object Adapter (BOA) that supports object groups and object replication
- An ORB, a Static Invocation Interface (SII), and a Dynamic Invocation Interface(DII)
- A fault tolerant COSS Name Server
- Piranha, the Electra remote activation and network management utility
- A Tcl/Tk interface to the DII (experimental)
- An Internet ORB gateway (experimental)

It does not include

- An Interface or Implementation Repository

3.4.3.2 Platform support

Electra can be built and configured on Solaris, SunOS, and HPUX. It requires that a toolkit for reliable distributed systems is installed and running on the same machine. Toolkits currently supported are Horus, Isis, and Ensemble.

3.4.3.3 Facility for object groups

Electra provides the facility to create object groups , to perform object replication, and to perform reliable multicast communication. To achieve this, Electra is based on toolkits for the implementation of reliable distributed systems. Examples of these are Horus, Isis, and Ensemble. An object group is simply the combination of a number of

network objects. They are treated as a unit. Reliable multicast communication ensures that invocations aimed at an object group will be received by each object implementation which is part of that object group. The provision for object groups allows Electra to be used for a number of application scenarios including fault-tolerance, load sharing, caching, and mobility.
To allow applications to create object groups and to join and remove objects from object groups, a number of operations were added to the BOA interface. These are create_group, join, leave, destroy_group, get_state, set_state, view_change.
A detailed description of the use of object groups in Electra can be found in [Maf95a] and [Maf95b].

3.4.4 Overall architecture of the Electra ORB

The Electra ORB is based on the Electra Object Model (EOM) [Maf95b]. The EOM enhances CORBA by allowing objects to be grouped into object-groups. Object groups can be named as a single unit. Applications can bind object references to both individual objects and object groups, using the same expressions. Communication to object groups is by reliable multicast, which ensures that an operation is received by all members of a group. Communication can take place in transparent or nontransparent mode. In transparent mode only one response is received after an invocation on an object group. In nontransparent mode, each object group member's response can be accessed by clients. Object invocations can be performed asynchronously, synchronously, or deferred-synchronously.
To implement reliable multicast and group communication, Electra can make use of existing distributed programming libraries such as Horus and Isis. Their use avoids having to reimplement much functionality specifically for Electra. Some possible Electra configurations for a number of different distributed programming libraries or operating systems (Horus, Isis, and Chorus) are shown in **Figure 21**.

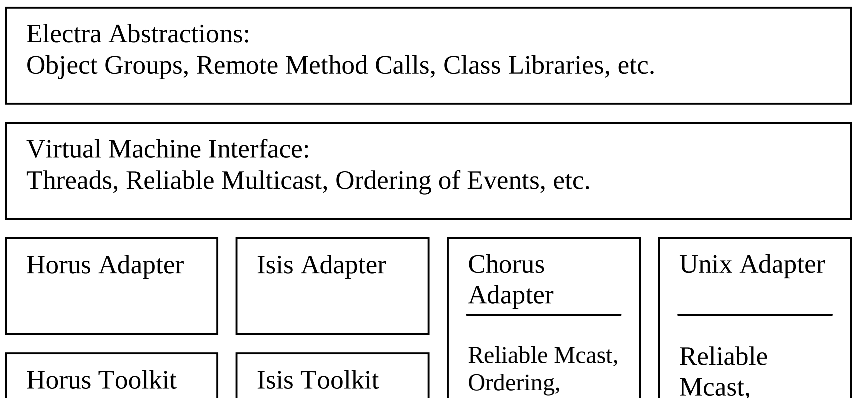

Electra Abstractions:
Object Groups, Remote Method Calls, Class Libraries, etc.
Virtual Machine Interface:
Threads, Reliable Multicast, Ordering of Events, etc.
Horus Adapter
Isis Adapter
Chorus Adapter
Unix Adapter
Horus Toolkit
Isis Toolkit
Reliable Mcast, Ordering,
Reliable Mcast,

Figure 21 Some Possible Electra Configurations

The above is an example of possible configurations of Electra. Currently adapters exist for Horus, Isis, and Ensemble. As can be seen from the diagram, a distributed toolkit library is not necessary, as in the case of the Unix Adapter, which sits directly on top of the OS. However, the implementation of such an adapter would be a nontrivial task.

An important element of this layered model is the Virtual Machine Interface (VMI). This provides an interface of common abstractions, such as reliable multicast, which are implemented by lower layers of Electra. The Adapter layers enable the VMI to always be the same, while providing the connection to the various distributed programming toolkits (or operating systems).

Adaptors are derived from a common abstract base class, `VirtualMachine`. This class defines the interface of the virtual machine, which all adapters must implement. **Figure 22** shows the inheritance hierarchy for the adapter classes derived from the virtual machine interface.

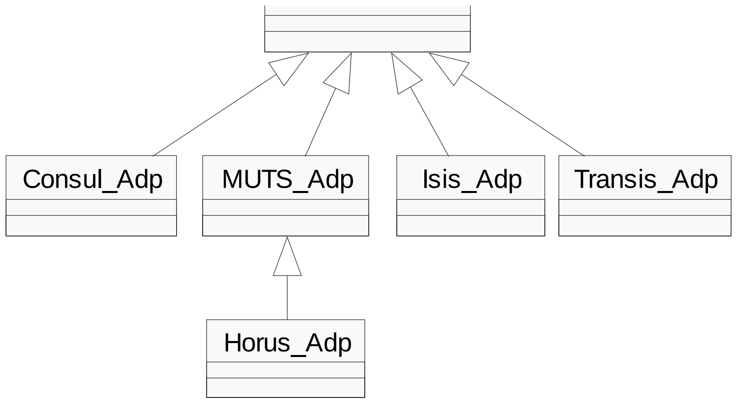


Figure 22 Electra Adapter Classes

`VirtualMachine` contains functions for entity creation and destruction, message passing, group management, thread management, failure suspection, and synchronisation.

The class `AdaptorData` is the base class of those Electra classes which keep information that is specific to the Real Machine. The classes derived from `AdaptorData` are used in the function signatures of the `VirtualMachine` interface. They are illustrated in **Figure 23**.

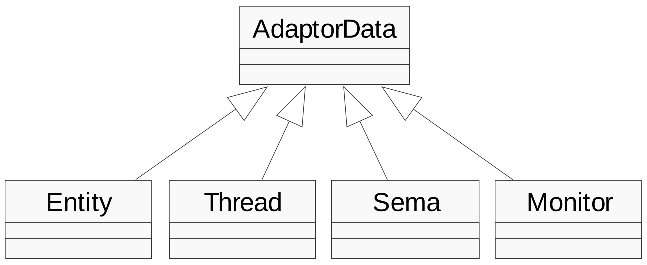


Figure 23 Electra AdaptorData Classes

The class `Entity` is the class that identifies a communication endpoint. `Thread` identifies a thread and is used in their creation and destruction of threads through the `VirtualMachine` interface. `Sema` identifies a semaphore and is used by the `VirtualMachine` functions dealing with the creation, destruction, incrementing, and decrementing of semaphores. `Monitor` is used by the `VirtualMachine` interface to monitor individual objects and object groups for possible failure.

The Electra ORB is layered as shown in **Figure 24**. Above the Virtual Machine layer is the Multicast RPC Module, represented by the class `RpcLayer`. The purpose of this layer is to enable asynchronous RPC to both single and group destinations. RPC is at a lower level of abstraction than remote object invocation. The

RPC layer is solely concerned with the transmission of messages, ie. unstructured data buffers, between communication endpoints. Synchronous and deferred synchronous RPC are implemented by the layer above, the Dynamic Invocation Interface (DII). Changes in group membership are handled by the RPC module. This is done independently of the underlying Real Machine (eg. Horus or Isis). The RPC module is based solely on the `VirtualMachine` interface. The class `Entity` is used to represent an RPC communication endpoint. A connection between `Entitie`s is represented by an `RpcHandle` object.

The DII layer is represented by the class `Request`, which represents a request to be sent to a CORBA object. Its `send` function performs an asynchronous invocation on the destination object, and its `invoke` function performs a synchronous invocation, during which the caller will be suspended until completion of the invocation.

The Virtual Operating System (VOS) module provides a portable interface to operations of the particular underlying operating system that need to be accessed by the upper Electra layers.

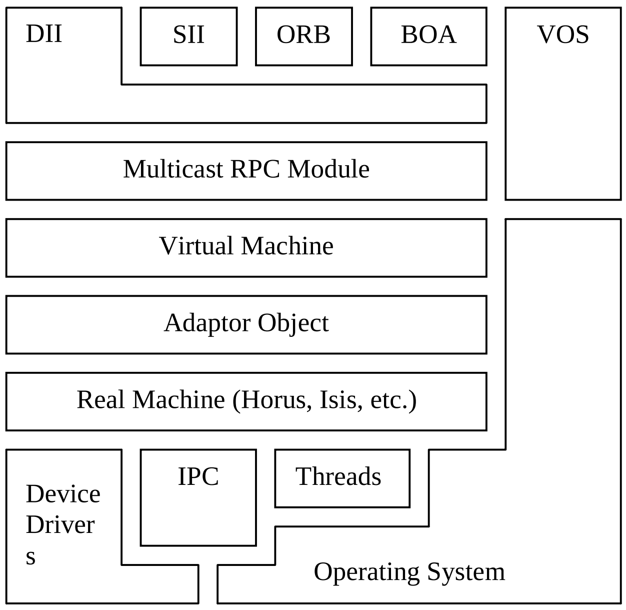


Figure 24 Electra ORB Layering

3.5 Conclusion

This chapter described the analysis of three publicly available ORB implementations, OmniORB, TAO, and Electra. This analysis led to some insights into the internals of ORB implementations. These insights influenced the design of the ORB framework, which is described in the following chapter.

Chapter 4

Design of the Object Request Broker Framework

4.1 Introduction

The objective of this chapter is to document the requirements specification and the actual design of the ORB framework. The first part of the chapter documents the requirements specification for the framework. The specification is influenced by a number of factors.

Firstly, the *Evolving Frameworks* pattern language defines the overall context for developing the framework. Its *Three Examples* pattern inspired the study of the three publicly available ORBs described in Chapter 2. From this study, the functionality and components that are common to all ORBs are factored out. At the same time, functionality that is specific to particular application domains is noted for possible inclusion in the framework. The other important source of information for the framework requirements analysis is the Object Management Group (OMG) CORBA specification. Whereas the three example ORBs provide an insight into how different ORBs might be implemented, the CORBA specification lays down the exact definition of public interfaces that the ORB must provide. It also provides detailed information on communication between CORBA compliant ORBs.

The second part of this chapter documents the design of the ORB framework. The context here is set by the second pattern in the *Evolving Frameworks* pattern language, *White-box* framework. It proposes how to go about an initial design of a framework after having applied the *Three Examples* pattern. The framework that was designed for this thesis is essentially an instance of this pattern, i.e. it is an instance of a white-box framework.

4.2 Framework Requirements

The requirements which the proposed ORB framework must fulfil stem from a number of sources. Firstly, the general type of framework design aimed for is based on the *Whitebox Framework* pattern in the *Evolving Frameworks* pattern language. This pattern defines the general form that the framework should take. Next, the OMG CORBA specification defines the interfaces that a CORBA compliant ORB should support along with a standard protocol for inter-ORB communication. It also defines various language mappings for these interfaces. Any instantiation of the ORB framework needs to be compliant with this specification. Finally, the surveys of the three ORB implementations, documented in Chapter 2, motivate requirements of the ORB framework regarding both common and domain specific functionality. These latter requirements are particularly relevant to the design of the framework as it is important that the framework can be instantiated with such functionality.

4.2.1 Whitebox Framework

The first requirement of the ORB framework is for it to be a whitebox framework. In the context of the *Evolving Frameworks* pattern language for framework development it is the second pattern. It follows *Three Examples*, which was emulated by the survey of the three ORBs in the previous chapter.

The principal problem that is addressed by this pattern is whether to base an initial framework design on inheritance or composition. The *Whitebox Framework* approach is to favour inheritance over composition. The main motivation for favouring inheritance is that initially the framework designer does not know which parts of the framework change and which parts remain constant. Inheritance allows the application developer, ie. the person that instantiates the framework, to override or change functionality that the framework designer never envisaged would change.

For a framework to be based on composition, on the other hand, the framework designer needs to know exactly what is going to change and what is going to remain the same. He has to envisage all application scenarios at framework design time.

Basing a framework on inheritance results in a number of consequences. First of all, inheritance requires programming on the part of the application developer. If a subclass needs to be created, the application developer needs to write this class. This means that the application programmer needs an understanding of the workings of the framework. Hence the name of the pattern *Whitebox Framework*. Inheritance can break encapsulation by overriding members and methods of the base class, so extra care must be taken by the application programmer in the implementation of a subclass.

A second consequence of basing a framework on inheritance is that the design patterns *Factory Method* and *Template Method* probably will feature prominently in the framework design. They are briefly explained below.
The *Factory Method* design pattern can be used when an interface for creating an object needs to be defined, but the actual decision as to which class is instantiated is deferred to a subclass. This design pattern is also known as *Virtual Constructor* and it is found in many framework implementations. The pattern is illustrated in **Figure 25**.

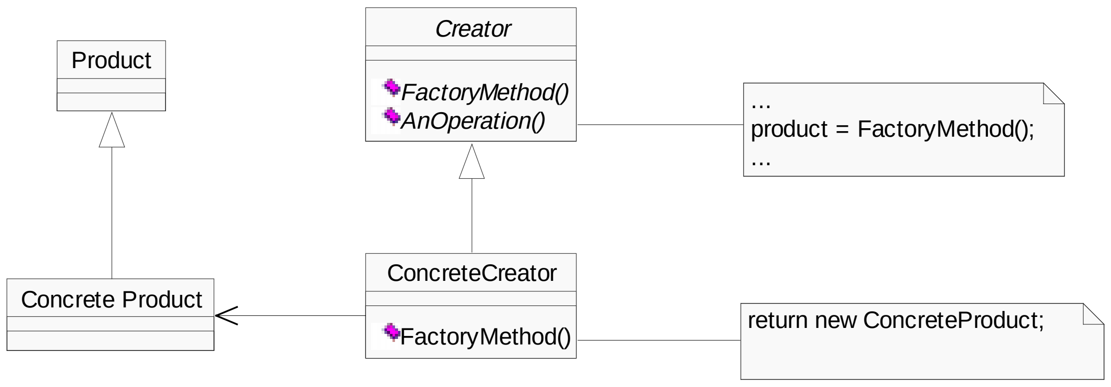


Figure 25 Factory Method Design Pattern

In a framework, abstract classes are often used to define and maintain relationships between objects. Consider the two framework-defined abstract classes `Product` and `Creator`. At some point in the execution of the application `Creator` must instantiate a concrete subclass of `Product`. `Creator` cannot, however, predict which concrete subclass of `Product` to create, as `ConcreteProduct` is only defined by the user of the framework.
In order to be able to let `Creator` specify when a product needs to be instantiated, it provides the virtual function `FactoryMethod`. This method can be called by other

methods of `Creator` or by other classes if the method is declared public. `FactoryMethod` is overridden in a concrete subclass of `Creator`, `ConcreteCreator` in the diagram. This class is also created by the user of the framework. The implications of this pattern are that the flow of control can be defined by the framework, ie. at what stage does the product get created, but the instantiation details of which subclass gets created are left to user defined subclasses. It is also possible for `Creator` to provide a default implementation for `FactoryMethod` in which case a concrete product known at framework design time would be instantiated. In this case it is optional for the framework user to override the method, which in this case is virtual but not pure virtual (ie. it doesn't need to be overridden in subclasses). The *Factory Method* design pattern is so called because it is responsible for "manufacturing" an object.

The *Template Method* design pattern allows the skeleton of an operation to be defined in the operation while some steps are left for subclasses to override in order to provide concrete behaviour.

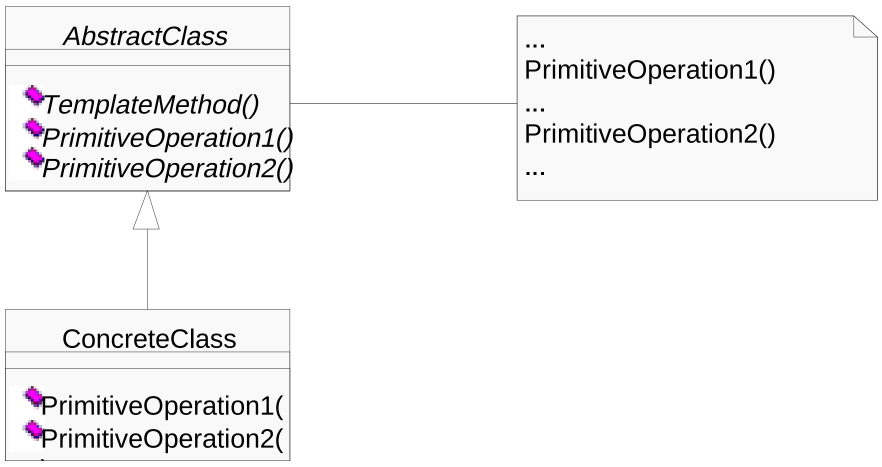


Figure 26 Template Method Design Pattern

Template Method can thus be used to provide the invariant parts of an algorithm once and leave subclasses implement the variable behaviour. It is similar to the *Factory Method* design pattern in that it lets users subclass existing classes to customise an application or framework. The difference between the two is that *Factory Method* lets users override creation of objects whereas *Template Method* lets users override behavior of objects, thus making *Factory Method* a creational design pattern and

Template Method a behavioral design pattern. Of course, behavior of objects often involves the creation of other objects , thus *Template Method* often uses the *Factory Method* design pattern. The structure of *Template Method* is shown in **Figure 26**.
`TemplateMethod` implements a particular algorithm, leaving certain behavior to be defined in `PrimitiveOperation1` and `PrimitiveOperation2`. These functions are overridden in `ConcreteSubclass` which is implemented by the user that customises the application or framework.

4.2.2 CORBA specified components

The ORB framework is to be used for the building of customised CORBA ORBs. This means that while ORBs with emphasis on different application scenarios might be instantiated using the framework, they all must adhere to the OMG CORBA specification, currently at version 2.2.

The CORBA specification has already been introduced in section 2.4. It is important to note that the CORBA specification centres around the specification of interfaces, not implementations. Thus, interfaces for all components of an ORB, such as the ORB core , the Dynamic Invocation Interface (DII), the Dynamic Skeleton Interface (DSI), and the Portable Object Adapter (POA), are provided. The implementation of these principal components, however, is left to the ORB implementor. No attempt is made in the CORBA specification in prescribing how these components should be implemented.

Instances of ORBs created using the proposed framework should provide implementations for these CORBA specific interfaces. In the framework model, which is presented in this thesis, the principal CORBA specified interfaces should be included. It is, however, beyond the scope of the model to include all CORBA specified interfaces. The principal interfaces of the CORBA specification are the ORB, Object, and POA interfaces. These should be included in the ORB framework model.

The CORBA specification specifies a number of components which will not be part of the ORB framework model. These are: an IDL compiler for the generation of stub and skeleton code from OMG IDL code, an interface repository, and an implementation repository. These could be added to the model at a later stage.

4.3 Framework Design

4.3.1 Overall Design

The proposed ORB framework consists of around 40 classes. A class hierarchy for the framework is shown in **Figure 27**.

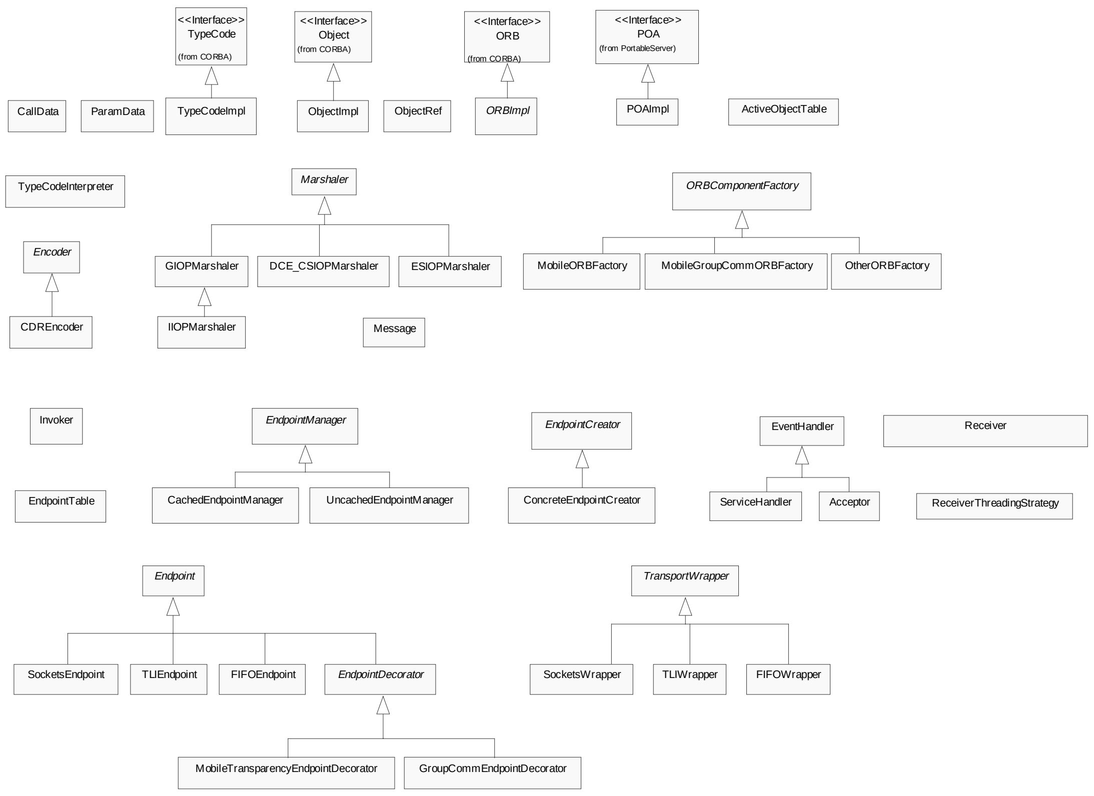


Figure 27 ORB Framework Hierarchy

Some of the classes are abstract with the remainder concrete. A class can be defined as abstract if its primary purpose is to define an interface. It defers some or all of its implementation to subclasses. An abstract class cannot be instantiated. The design focused specifically on the discovery of abstract base classes for the framework. The intention here is that abstract base classes can be used to define an interface for groups of classes. The implementation of concrete classes derived from these abstract base classes is left to application developers using the framework. As can be seen in the diagram, many concrete subclasses have been provided. This is mainly to illustrate which concrete subclasses might be derived from certain abstract base classes.

The framework can be broken down into two general sets of classes. On the one hand are the classes that directly implement CORBA specified interfaces. The interfaces implemented in the model are `TypeCode`, `Object`, `ORB`, and `POA`. The classes that implement these interfaces are `TypeCodeImpl`, `ObjectImpl`, `ORBImpl`, and `POAImpl` respectively.

On the other hand are the classes that provide the core functionality of the ORB framework. These are the `Marshaler`, `Invoker`, and `Receiver` classes and their respective concrete subclasses. These can again be broken down into three groups of classes. The classes relating to `Marshaler`, `Endpoint`, and `TransportWrapper` concern the core functionality of implementing ORBs based on the framework. They are used in the implementation of both client and server functionality. The classes relating to `Invoker` concern client functionality in the ORB. The classes relating to `Receiver` concern server functionality in the ORB. The following sections explain the design in detail.

4.3.2 Core Components

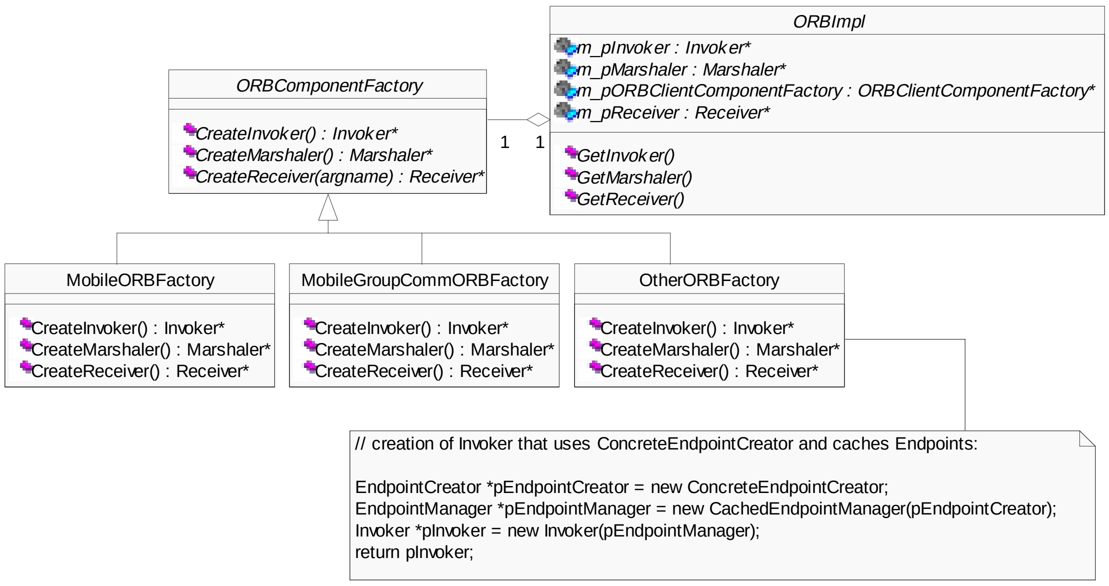
This section lists those framework classes that are part of the core ORB functionality. They include the classes `ORBImpl`, `Marshaler`, `TransportWrapper`, and `Endpoint` and other classes associated with each of these classes, respectively.

4.3.2.1 ORBImpl

`ORBImpl` is the core class of the ORB framework. `ORBImpl` inherits from the CORBA specified ORB interface. Its purpose is to implement the CORBA ORB interface and to create instances of the core ORB framework classes, i.e. `Marshaler`, `Invoker`, `Receiver`, and `POAImpl`. These classes are described in the following sections. `ORBImpl` is an instance of the *Singleton* design pattern, which is described in section 4.3.5.5.

4.3.2.2 ORBComponentFactory

In order to create instances of the core ORB framework classes, `Marshaler`, `Invoker`, and `Receiver`, a concrete subclass of `ORBComponentFactory` is used. The `ORBComponentFactory` inheritance hierarchy is shown in **Figure 28**.


ORBImpl
m_pInvoker : Invoker*
m_pMarshaler : Marshaler*
m_pORBClientComponentFactory : ORBClientComponentFactory*
m_pReceiver : Receiver*
GetInvoker()
GetMarshaler()
GetReceiver()
ORBComponentFactory
CreateInvoker() : Invoker*
CreateMarshaler() : Marshaler*
CreateReceiver(argname) : Receiver*
1
1
MobileORBFactory
CreateInvoker() : Invoker*
CreateMarshaler() : Marshaler*
CreateReceiver() : Receiver*
MobileGroupCommORBFactory
CreateInvoker() : Invoker*
CreateMarshaler() : Marshaler*
CreateReceiver() : Receiver*
OtherORBFactory
CreateInvoker() : Invoker*
CreateMarshaler() : Marshaler*
CreateReceiver() : Receiver*

```
// creation of Invoker that uses ConcreteEndpointCreator and caches Endpoints:

EndpointCreator *pEndpointCreator = new ConcreteEndpointCreator;
EndpointManager *pEndpointManager = new CachedEndpointManager(pEndpointCreator);
Invoker *pInvoker = new Invoker(pEndpointManager);
return pInvoker;
```

Figure 28 ORB Component Factory

As can be seen in the diagram, any number of concrete subclasses of `ORBComponentFactory` can be supplied by the user of the ORB framework. These classes provide a mechanism for the customisation of ORBs created with the framework. This is achieved by customising the creation of the core ORB components, `Invoker`, `Marshaler`, `Receiver` in the functions `CreateInvoker`, `CreateMarshaler`, and `CreateReceiver`. This process is described in more detail in section 5.2.1. `ORBComponentFactory` is an instance of the *AbstractFactory* design pattern, which is described in section 4.3.5.1.

`Marshaler`, `Invoker`, and `Receiver`, like `ORBImpl`, are instances of the *Singleton* design pattern. This pattern is described in section 4.3.5.5.

4.3.2.3 Marshaler

The `Marshaler` class is central to the design of the ORB framework. It is used to create both client and server functionality in an ORB created with the framework. As the name indicates, `Marshaler` is responsible for marshaling and unmarshaling invocation data into and out of messages. Messages are represented by the class `Message`, and are used to communicate between clients and servers. What defines invocation data depends on the protocol used, but usually it includes function parameter values and any required headers.

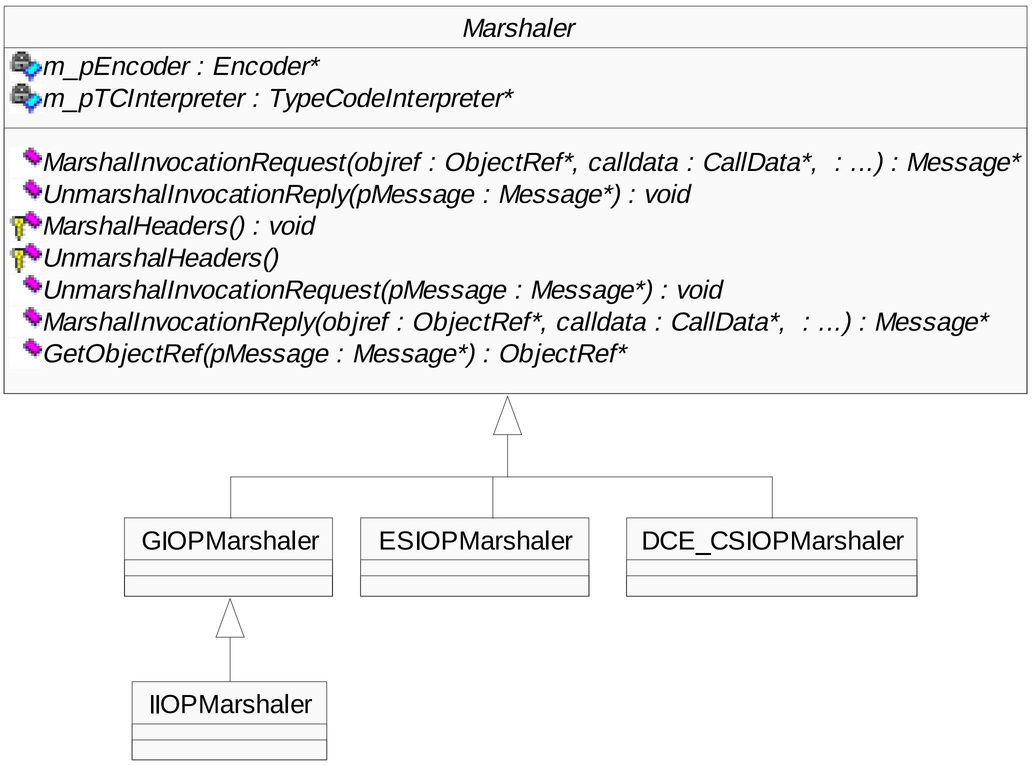

Marshaler
m_pEncoder : Encoder*
m_pTCInterpreter : TypeCodeInterpreter*
MarshalInvocationRequest(objref : ObjectRef*, calldata : CallData*, : ...) : Message*
UnmarshalInvocationReply(pMessage : Message*) : void
MarshalHeaders() : void
UnmarshalHeaders()
UnmarshalInvocationRequest(pMessage : Message*) : void
MarshalInvocationReply(objref : ObjectRef*, calldata : CallData*, : ...) : Message*
GetObjectRef(pMessage : Message*) : ObjectRef*
GIOPMarshaler
ESIOPMarshaler
DCE_CSIOPMarshaler
IIOPMarshaler

Figure 29 Marshaler Inheritance Hierarchy

Any headers that have to be marshaled are specific to the particular inter-ORB communication protocol used. Different concrete subclasses of `Marshaler` can be used to implement various protocols for inter-ORB communication. The `Marshaler` class inheritance hierarchy is shown in **Figure 29**.

The four principal `Marshaler` member functions are for marshaling and unmarshaling of invocation requests and replies. They are `MarshalInvocationRequest`, `MarshalInvocationReply`, `UnmarshalInvocationRequest`, and `UnmarshalInvocationReply` respectively. `Marshaler` is essentially an instance of the *Builder* design pattern. This design pattern is described in section 4.3.5.3.

Marshaler inheritance hierarchy

As can be seen in the hierarchy, there are a number of concrete subclasses of `Marshaler`.

`GIOPMarshaler` represents a marshaler that implements the CORBA specified General Inter-ORB Protocol (GIOP). GIOP is a protocol that can be mapped onto any connection oriented transport protocol.

`IIOPMarshaler` represents a marshaler that implements the CORBA specified Internet Inter-ORB Protocol (IIOP). IIOP is a specific mapping of GIOP which runs over TCP/IP connections. All CORBA 2.2 compliant ORBs need to support IIOP, regardless of what other protocols they might also implement.

`ESIOPMarshaler` is a generic concrete class representing any number of different marshalers that implement various Environment Specific Inter-ORB Protocols (ESIOPs). ESIOPs are protocols that are optimised for particular environments. They might be used where particular networking or distributed computing infrastructures are already in place.

An example of an ESIOP is the DCE Common Inter-ORB Protocol (DCE-CSIOP), which is designed for the OSF DCE environment. The class that represents this protocol in the `Marshaler` inheritance hierarchy is the concrete class `DCE_CSIOPMarshaler`.

Message class

As already stated, the purpose of the `Marshaler` classes is to *build* a `Message` object, or, when `Marshaler` is used to unmarshal messages, to take a `Message` object and to *deconstruct* it. Message is the class that holds marshaled invocation data in the form in which it will be transmitted between client and server ORBs. Message is illustrated in **Figure 30**

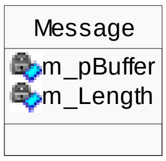


Figure 30 Message Class

Essentially, Message only contains an unformatted buffer, m_pBuffer of length m_Length. It contains the invocation data as it is intended to be received by the receiving ORB.

CallData

In order to understand how invocation data is passed to the Marshaler class and subsequently marshaled into a Message object, it is necessary to look at how method invocation data is passed to Marshaler. All information about a method and its parameters is stored in the CallData class. The composition of this class is illustrated in **Figure 31**.

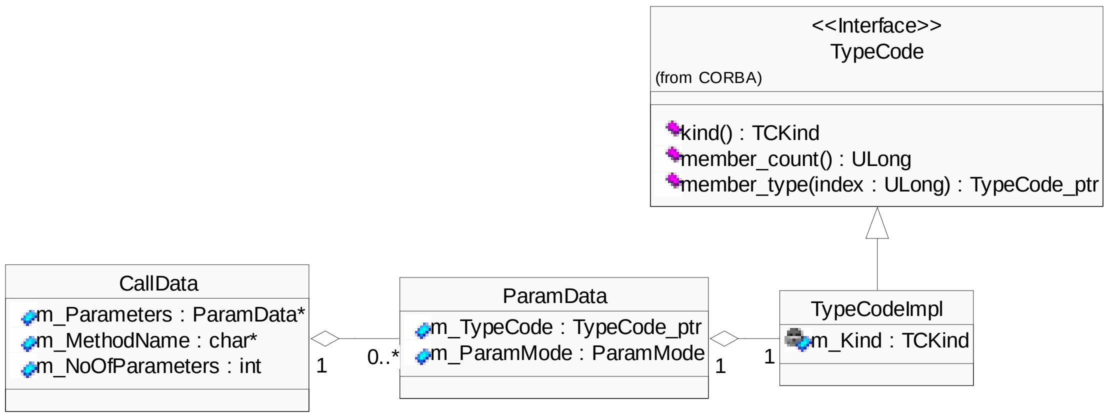


Figure 31 CallData Class Composition

An instance of CallData for each method that has been declared in a CORBA application's IDL code needs to be declared in that interface's client stub and server skeleton code. This could be achieved through the use of an IDL compiler, or by manually inserting the required code. CallData contains the method name (m_MethodName), the number of method parameters (m_NoOfParameters), and an array of ParamData instances (m_Parameters). There is an instance of ParamData for each parameter in the method. ParamData contains two members, a pointer to the TypeCode of the parameter (m_TypeCode) and the parameter mode (m_ParamMode). The mode of the parameter can take the values MODE_IN, MODE_OUT, MODE_INOUT, or MODE_RETURN.

A TypeCode is a value that represents invocation argument types. In the framework, TypeCodes are implemented by the TypeCodeImpl class, which inherits from the CORBA specified TypeCode interface. TypeCodes can be used in the Dynamic

Invocation Interface (DII) to indicate the types of the actual arguments. In the framework they are also used by the Static Invocation Interface (SII), in other words, the stub and skeleton code, to represent the types of the arguments. The advantage of this is that marshalers can be used for both static and dynamic invocation marshaling, as the required interfaces of the marshaler require invocation parameter information to be specified using `TypeCode`s.

The CORBA specification also defines an enumeration, named `TC_Kind`, which identifies the type that is represented by the particular `TypeCode` instance. Included are all primitive types such as `short` (`tk_short`), `long` (`tk_long`), and so on. Also included are complex types such as `struct` (`tk_struct`) and `union` (`tk_union`). Complex types can be made up recursively, for example, a `struct` could have another `struct` as a member. In order for the marshaler to handle complex types, instances of `TypeCodeImpl` representing those complex types need to be defined in the stub and skeleton code of the CORBA application. Instances of `TypeCodeImpl` for all primitive types are declared in the framework.

The CORBA `TypeCode` interface specifies a number of methods, three of which are `kind`, `member_count` and `member_type`. The `kind` operation can be invoked on any `TypeCode` and it returns the `TCKind` for that `TypeCode`. For `TypeCode`s representing complex types, such as structures, unions, and enumerations, `member_count` returns the number of members constituting the type. The `member_type` operation can be invoked on structure and union `TypeCodes`. It returns the `TypeCode` describing the type of the member identified by `index`. Thus, `TypeCode`s can be used to recursively describe even complex object invocation method parameter types.

TypeCodeInterpreter and Encoder

In order to marshal and unmarshal object invocation data into and out of messages, `Marshaler` uses two other classes, `TypeCodeInterpreter` and `Encoder`.

The purpose of the `Encoder` based classes is to convert OMG IDL data types into whichever low-level representation a particular inter-ORB protocol requires for “on-the-wire transfer” between ORBs. For example, GIOP requires IDL data types to be encoded using Common Data Representation (CDR) encoding. CDR addresses such issues as byte-ordering, aligning of primitive data types, and mapping of OMG data types. The `Encoder` class hierarchy is shown in **Figure 32**.

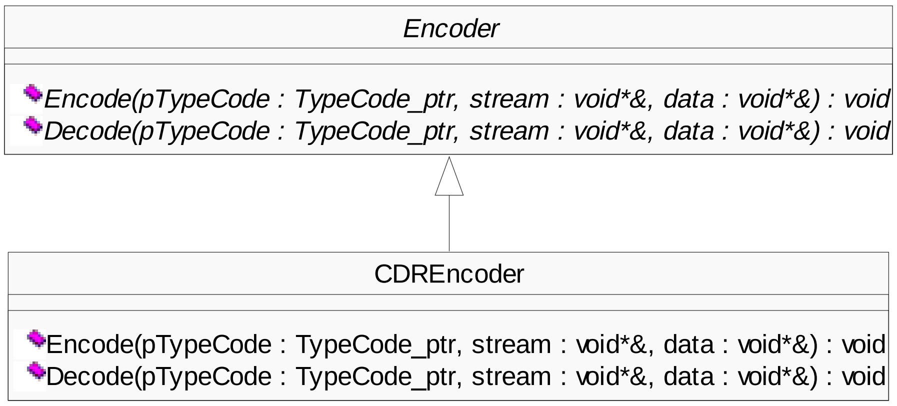

Encoder
Encode(pTypeCode : TypeCode_ptr, stream : void&, data : void*&) : void*
Decode(pTypeCode : TypeCode_ptr, stream : void&, data : void*&) : void*
CDREncoder
Encode(pTypeCode : TypeCode_ptr, stream : void*&, data : void*&) : void
Decode(pTypeCode : TypeCode_ptr, stream : void*&, data : void*&) : void

Figure 32 Encoder Inheritance Hierarchy

An abstract base class, `Encoder`, is defined, from which `CDREncoder` inherits. `CDREncoder` implements the CDR encoding scheme used by GIOP. Other encoding schemes could be represented by new classes derived from `Encoder`.

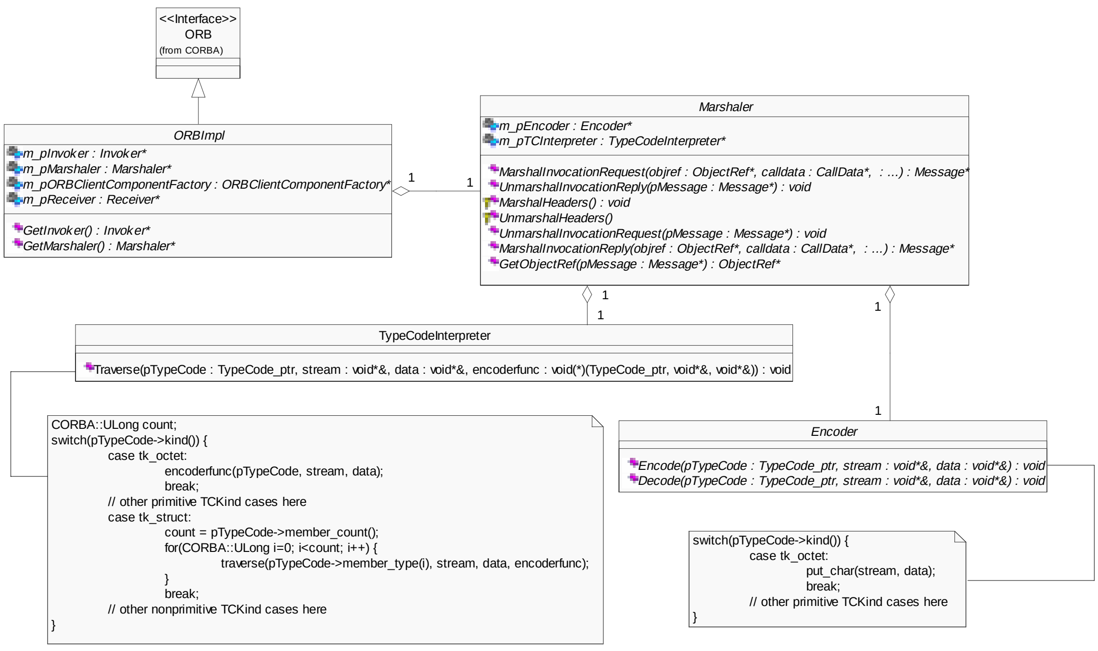
`TypeCodeInterpreter` is used to recursively break down each parameter into its constituent primitive types if its type is complex. Primitive types are then encoded or decoded, depending on whether the marshaler is performing marshaling or unmarshaling. `TypeCodeInterpreter` is a concrete class since it is used only for interpreting `TypeCode`s. In this framework design, the use of `TypeCode`s is common to all marshaling and unmarshaling, no matter which inter-ORB protocol, and hence, which concrete marshaler class is used.

Marshaling and unmarshaling of invocation data

The interaction of `Marshaler`, `TypeCodeInterpreter`, and `Encoder` is illustrated in **Figure 33**. If, for example, a client wants to marshal object invocation data, its stub code calls the `Marshaler` member function `MarshalInvocationRequest`. Its parameters are a pointer to the server object's object reference (`objref`), a pointer to the `CallData` object (`calldata`), and finally, the actual method parameters. For each parameter to be marshaled, the `TypeCodeInterpreter`'s `Traverse` function is called. This function takes as its arguments

- `pTypeCode`, the `TypeCode_ptr`, taken from `ParamData`

- `stream`, the stream into which the data is to be marshaled, ie. `m_pBuffer` in `Message`
- `data`, the parameter value, taken from the variable length argument list of `MarshalInvocationRequest`
- `encoderfunc`, a pointer to the relevant encoder function, `Encode` or `Decode`, depending on whether data is being marshaled or unmarshaled



<<Interface>>
ORB
(from CORBA)
ORBImpl
m_pInvoker : Invoker*
m_pMarshaler : Marshaler*
m_pORBClientComponentFactory : ORBClientComponentFactory*
m_pReceiver : Receiver*
GetInvoker() : Invoker*
GetMarshaler() : Marshaler*
1
1
Marshaler
m_pEncoder : Encoder*
m_pTCInterpreter : TypeCodeInterpreter*
MarshalInvocationRequest(objref : ObjectRef*, calldata : CallData*, : ...) : Message*
UnmarshalInvocationReply(pMessage : Message*) : void
MarshalHeaders() : void
UnmarshalHeaders()
UnmarshalInvocationRequest(pMessage : Message*) : void
MarshalInvocationReply(objref : ObjectRef*, calldata : CallData*, : ...) : Message*
GetObjectRef(pMessage : Message*) : ObjectRef*
1
1
1
1
TypeCodeInterpreter
Traverse(pTypeCode : TypeCode_ptr, stream : void*&, data : void*&, encoderfunc : void(*)(TypeCode_ptr, void*&, void*&)) : void
Encoder
Encode(pTypeCode : TypeCode_ptr, stream : void*&, data : void*&) : void
Decode(pTypeCode : TypeCode_ptr, stream : void*&, data : void*&) : void

```
CORBA::ULong count;
switch(pTypeCode->kind()) {
        case tk_octet:
                encoderfunc(pTypeCode, stream, data);
                break;
        // other primitive TCKind cases here
        case tk_struct:
                count = pTypeCode->member_count();
                for(CORBA::ULong i=0; i<count; i++) {
                        traverse(pTypeCode->member_type(i), stream, data, encoderfunc);
                }
                break;
        // other nonprimitive TCKind cases here
}
```

```
switch(pTypeCode->kind()) {
        case tk_octet:
                put_char(stream, data);
                break;
        // other primitive TCKind cases here
}
```

Figure 33 Marshaler Class Composition

The `Traverse` function can be illustrated by the following code fragment:

```
CORBA::ULong count;
switch(pTypeCode->kind()) {
     case tk_octet:
          encoderfunc(pTypeCode, stream, data);
          break;
     // other primitive TCKind cases here
     case tk_struct:
          count = pTypeCode->member_count();
          for(CORBA::ULong i=0; i<count; i++) {
Traverse(pTypeCode->member_type(i),
stream, data, encoderfunc);
          }
          break;
     // other nonprimitive TCKind cases here
}
```

As can be seen from the code, if the type of the parameter to be encoded is primitive, the appropriate Encoder function is called. If the type is complex, then the Traverse function is recursively called for each of that type's constituent members.

The appropriate `Encoder` function might look like this:

```
switch(pTypeCode->kind()) {
     case tk_octet:
          put_char(stream, data);
          break;
     // other primitive TCKind cases here
}
```

here, the `put_char` function is responsible for the encoding of the data into `stream`, and advancing the stream and data pointer references by the correct amount.

4.3.2.4 TransportWrapper

The `TransportWrapper` inheritance hierachy is shown in **Figure 34**. The main purpose of the `TransportWrapper` classes is to provide an object oriented interface to a number of transport layer APIs. In any CORBA based ORB, the transport layer ultimately is responsible for the sending and receiving of unstructured data between clients and servers. Many of the available transport layer APIs are written in the C programming language, which is non-object oriented. The provision of wrapper classes for transport layer APIs ensures a consistent object oriented interface which can be used by other classes.

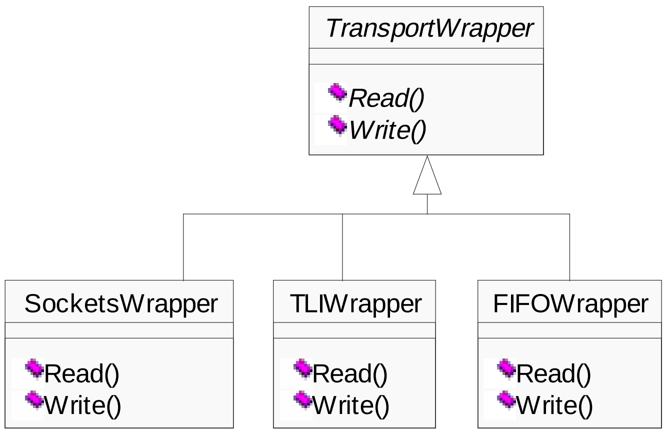


Figure 34 Transport Wrapper Inheritance Hierarchy

The `TransportWrapper` classes represent instances of the *Adapter* design pattern, which is described in section 4.3.5.2.

A number of concrete `TransportWrapper` classes are provided in the framework model. These are provided as possible concrete examples and do not constitute an exhaustive set. They are `SocketsWrapper`, `TLIWrapper`, and `FIFOWrapper`. `SocketsWrapper` represents a concrete wrapper class for the Berkeley sockets API. Sockets are a form of Inter Process Communication (IPC) that provide communication between processes on a single system and between processes on different systems. `TLIWrapper` represents a concrete wrapper class for Transport Layer Interface (TLI), which is a form of IPC provided with UNIX System V Release 3.0. Like sockets, it provides an API for interprocess communication between processes on a single system and between processes on different systems. `FIFOWrapper` represents a concrete wrapper class for UNIX FIFOs, also known as *named pipes*. FIFO stands for First In, First Out. A FIFO is similar to a UNIX pipe. Data written into the FIFO is read out of the FIFO in the same order, i.e. the first byte written is the first byte read. Since it has a name associated with it, a FIFO can be used by unrelated processes on the same system. It can thus be used to implement the transport layer for ORBs residing on the same system.

The only functions specified in the `TransportWrapper` interface are `Read` and `Write`. These are used to read and write unstructured data. Any initialisation to be performed when instantiating a concrete `TransportWrapper` can be done in constructors and initialisation functions which are dependent on the actual transport used. Hence, they are not included in the model.

4.3.2.5 Endpoint

The `Endpoint` class represents a communication endpoint for ORB communication. An instance of a concrete `Endpoint` derived class represents one half of a connection between a client and a server ORB. An ORB can have any number of `Endpoint` instances at any one time, representing connections to one or more ORBs. `Endpoint` instances are used by ORBs in the implementation of both client and server functionality. The `Endpoint` inheritance hierarchy is shown in **Figure 35**.

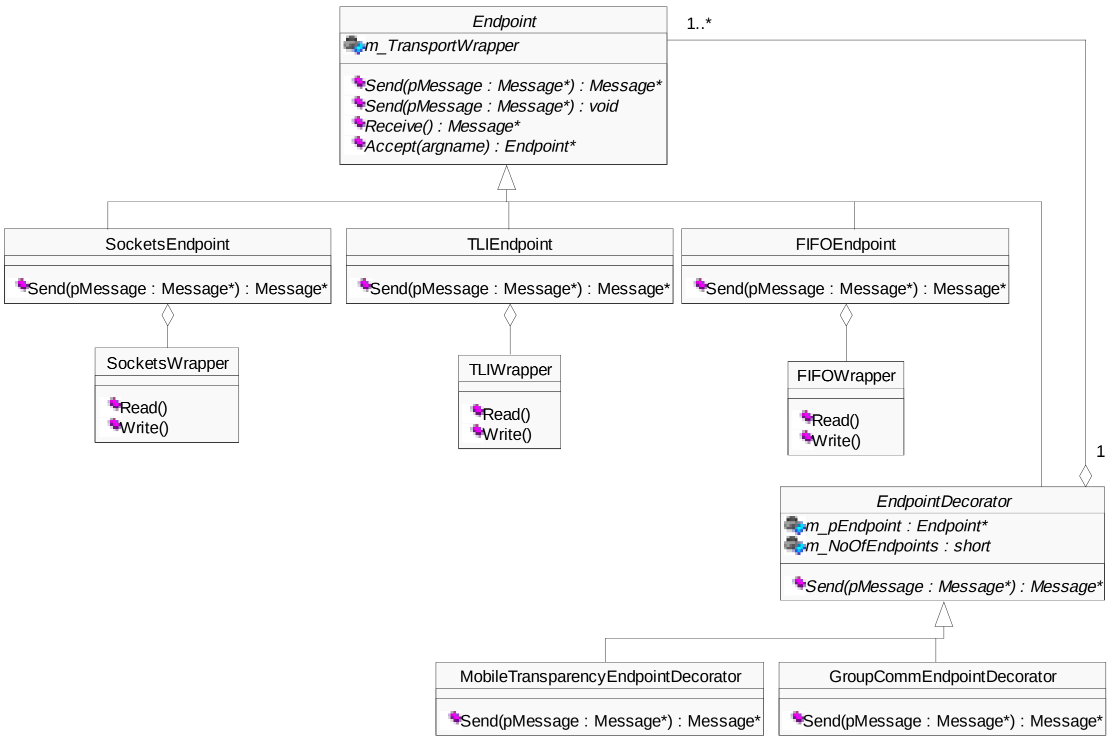

Endpoint
m_TransportWrapper
Send(pMessage : Message*) : Message*
Send(pMessage : Message*) : void
Receive() : Message*
Accept(argname) : Endpoint*
1..*
SocketsEndpoint
Send(pMessage : Message*) : Message*
TLIEndpoint
Send(pMessage : Message*) : Message*
FIFOEndpoint
Send(pMessage : Message*) : Message*
SocketsWrapper
Read()
Write()
TLIWrapper
Read()
Write()
FIFOWrapper
Read()
Write()
1
EndpointDecorator
m_pEndpoint : Endpoint*
m_NoOfEndpoints : short
Send(pMessage : Message*) : Message*
MobileTransparencyEndpointDecorator
Send(pMessage : Message*) : Message*
GroupCommEndpointDecorator
Send(pMessage : Message*) : Message*

Figure 35 Endpoint Inheritance Hierarchy

As can be seen in the diagram, there are a number of concrete subclasses of `Endpoint`. They are `SocketsEndpoint`, `TLIEndpoint`, and `FIFOEndpoint`. Since a concrete endpoint uses an instance of one of the concrete `TransportWrapper` classes to implement communication between the ORBs, a concrete endpoint is provided for each concrete `TransportWrapper` class.

Endpoints have one basic purpose. They are used to send and receive messages between client and server ORBs. For this pupose, `Endpoint` provides two basic functions, `Send` and `Receive`. `Send` comes in two forms, one for synchronous and one for asynchronous transmission. It takes as its argument a `Message` pointer. The synchronous version returns a reply `Message` pointer, while the asynchronous version doesn’t. `Receive` returns a `Message` pointer.

The instantiation of concrete endpoints requires information about the peer ORB process to which the endpoint represents a connection. If, for example, an ORB wants to act as client to an ORB acting as server, and a `SocketsEndpoint` is to be the type of endpoint used, then, to create the endpoint, the Internet Protocol (IP) address of the server ORB’s host and the port number on which the server ORB is listening are required. This information may be contained in the object reference for the server object, and will be provided by the instantiator of the endpoint. Because the different types of concrete endpoint require different information for connection initialisation, this is not provided at this point in the framework model.

As can be seen in **Figure 35**, in addition to the concrete endpoint classes, an abstract class, `EndpointDecorator` is derived from `Endpoint`. It, in turn, has two concrete subclasses, `MobileTransparencyEndpointDecorator` and `GroupCommEndpointDecorator`. `EndpointDecorator` is an instance of the *Decorator* design pattern. This design pattern is described in section 4.3.5.4. The purpose of concrete subclasses of `EndpointDecorator` is to provide additional functionality for an endpoint if required. An endpoint can be *wrapped* with an endpoint decorator class while retaining the `Endpoint` interface, thus appearing the same to other classes. An `EndpointDecorator` itself contains a concrete `Endpoint`, so, in a way, the `EndpointDecorator` class can be seen to be dynamically adding an extra layer of functionality to the framework.

The purpose of `MobileTransparencyEndpointDecorator` is to provide endpoints with additional functionality for mobile applications. Such functionality could, for example, provide automatic reconnection and retransmission of lost messages in case of a mobile connection breaking down.

The purpose of `GroupCommEndpointDecorator` is to provide endpoints with additional functionality for object group communication. It could be implemented to provide reliable multicast to groups of objects represented by one endpoint to other objects. In other words, a `GroupCommEndpointDecorator` appears as a single endpoint to other objects in the ORB, but it itself could contain a number of concrete endpoints representing the objects in that group.

EndpointCreator

The `EndpointCreator` inheritance hierarchy is shown in **Figure 36**. In this hierarchy, one generic concrete class, `ConcreteEndpointCreator`, represents any number of classes inherited from `EndpointCreator` that might be provided by the user of the ORB framework. `EndpointCreator` provides an interface for the creation of concrete `Endpoint` objects. A concrete `EndpointCreator` class is one of the classes that must be provided by the user of the ORB framework, although default implementations could also be be provided. Concrete subclasses of

EndpointCreator instantiate Endpoint objects in the function CreateEndpoint. An example implementation of this function in a concrete EndpointCreator class might look as follows:

```
Endpoint* CreateEndpoint(ObjectRef* pObjectRef)
{
     Endpoint* pEndpoint = new SocketsEndpoint;
     // set Endpoint parameters from pObjectRef here.
     // This depends on format of object reference and
     // concrete transport endpoint used
     Endpoint* pWrapperEndpoint = new
          MobileTransparencyEndpoint(pEndpoint);
     return pWrapperEndpoint;
}
```

This function creates an endpoint that uses the sockets transport wrapper class and has mobile transparency.

To create an Endpoint in CreateEndpoint, an object reference is required. This is represented by the class ObjectRef, and its concrete form depends on the inter-ORB protocol used. For example, if the inter-ORB protocol used is IIOP, then the object reference will contain the object host's IP address and the port number on which the server ORB is listening. In this case, in the function CreateEndpoint this information is used to initialise a sockets endpoint.

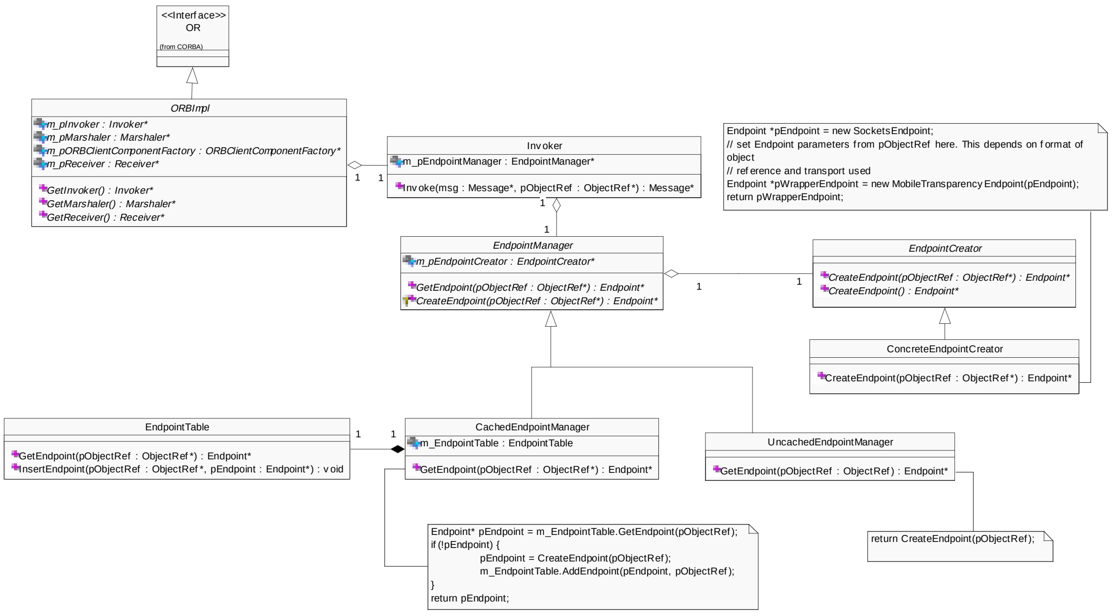
EndpointCreator is an instance of the *Strategy* design pattern, which is described in section 4.3.5.6.

4.3.3 Components for client functionality

This section lists those framework classes that are used to create client functionality in the ORB. They include the classes Invoker and EndpointManager, and other classes associated with each of these classes, respectively.

4.3.3.1 Invoker

The class diagram illustrating the composition of Invoker is illustrated in **Figure 36**. Invoker, as its name suggests, is responsible for performing invocations of remote objects. Basically, this consists of Invoker sending and receiving messages that contain marshaled invocation data. Invoker is not responsible for marshaling or unmarshaling of invocation data. It is purely concerned with managing any number of connections with server ORBs. For this purpose, it has an instance of the `EndpointManager` class.


<<Interface>>
OR
(from CORBA)
ORBImpl
m_pInvoker : Invoker*
m_pMarshaler : Marshaler*
m_pORBClientComponentFactory : ORBClientComponentFactory*
m_pReceiver : Receiver*
GetInvoker() : Invoker*
GetMarshaler() : Marshaler*
GetReceiver() : Receiver*
1
1
Invoker
m_pEndpointManager : EndpointManager*
Invoke(msg : Message*, pObjectRef : ObjectRef*) : Message*
1
1
EndpointManager
m_pEndpointCreator : EndpointCreator*
GetEndpoint(pObjectRef : ObjectRef*) : Endpoint*
CreateEndpoint(pObjectRef : ObjectRef*) : Endpoint*
1
1
EndpointCreator
CreateEndpoint(pObjectRef : ObjectRef*) : Endpoint*
CreateEndpoint() : Endpoint*
ConcreteEndpointCreator
CreateEndpoint(pObjectRef : ObjectRef*) : Endpoint*
EndpointTable
GetEndpoint(pObjectRef : ObjectRef*) : Endpoint*
InsertEndpoint(pObjectRef : ObjectRef*, pEndpoint : Endpoint*) : void
1
1
CachedEndpointManager
m_EndpointTable : EndpointTable
GetEndpoint(pObjectRef : ObjectRef*) : Endpoint*
UncachedEndpointManager
GetEndpoint(pObjectRef : ObjectRef) : Endpoint*

```
Endpoint *pEndpoint = new SocketsEndpoint;
// set Endpoint parameters from pObjectRef here. This depends on format of
object
// reference and transport used
Endpoint *pWrapperEndpoint = new MobileTransparencyEndpoint(pEndpoint);
return pWrapperEndpoint;
```

```
Endpoint* pEndpoint = m_EndpointTable.GetEndpoint(pObjectRef);
if (!pEndpoint) {
        pEndpoint = CreateEndpoint(pObjectRef);
        m_EndpointTable.AddEndpoint(pEndpoint, pObjectRef);
}
return pEndpoint;
```

```
return CreateEndpoint(pObjectRef);
```

Figure 36 Invoker Class Composition

As can be seen in **Figure 36**, `EndpointManager` has two concrete subclasses, `CachedEndpointManager` and `UncachedEndpointManager`. `UncachedEndpointManager` creates a new `Endpoint` for each invocation. `CachedEndpointManager` is used to cache `Endpoint`s between invocations. If an invocation is made using the same object reference, then the cached `Endpoint` is retrieved from the `EndpointTable`. If no `Endpoint` exists for the particular object reference, then a new `Endpoint` is created using a concrete `EndpointCreator`. This is illustrated using the following code fragment for `CachedEndpointManager`'s `GetEndpoint` function:

```
Endpoint* GetEndpoint(ObjectRef* pObjectRef)
{
     Endpoint* pEndpoint =
          m_EndpointTable.GetEndpoint(pObjectRef);
     if(!pEndpoint) {
          pEndpoint = CreateEndpoint(pObjectRef);
          m_EndpointTable.AddEndpoint(pEndpoint,
               pObjectRef);
```

```
        }
        return pEndpoint;
}
```

In this example, `EndpointTable::GetEndpoint` returns a null pointer if no match for `pObjectRef` exists in the table, in other words, no cached `Endpoint` exists that matches the supplied object reference.
`EndpointManager` is an instance of the *Strategy* design pattern, which is described in section 4.3.5.6.

4.3.4 Components for server functionality

This section lists those framework classes that are used to create server functionality in the ORB. They include the classes `Receiver` and `POAImpl`, and other classes associated with each of these classes, respectively.

4.3.4.1 Receiver

The purpose of the `Receiver` class and its associated classes is to provide the ability to establish connections for providing server functionality in the ORB. `Receiver` and its associated classes are shown in **Figure 37**. The principal purpose of the `Receiver` class is to act as demultiplexer of incoming messages for any instances of `EventHandler` registered with it. As can be seen in the `EventHandler` inheritance hierarchy, `EventHandler` has two concrete subclasses, `Acceptor` and `ServiceHandler`. Both `Acceptor` and `ServiceHandler` use an instance of `Endpoint` to implement the server end of a connection between client and server ORBs. `Acceptor` is responsible for the establishment of a connection, while `ServiceHandler` is responsible for handling any subsequent requests incoming on that connection. `EventHandler`s register with `Receiver` by calling its `RegisterHandler` function. `Receiver` then demultiplexes any incoming messages for `EventHandler`s registered with it. It achieves this by utilising a system call for event demultiplexing, for example select if using sockets. One `Acceptor` can create one or more `ServiceHandler`s as it accepts new connections. For example, if using sockets, the `Acceptor`'s `SocketsEndpoint` can use the system call `accept` to create a new endpoint for the `ServiceHandler` that will now handle the new connection. This mechanism allows an `Acceptor` to listen for new client connections on well known ports and creating `ServiceHandler`s to handle subsequent requests on a new connection in order to keep the `Acceptor` free to listen for new connection requests on the same well known port. The `Acceptor` and its associated classes form an instance of `Acceptor` in the *Acceptor-Connector* design pattern. This design pattern is described in section 3.3.5.2.

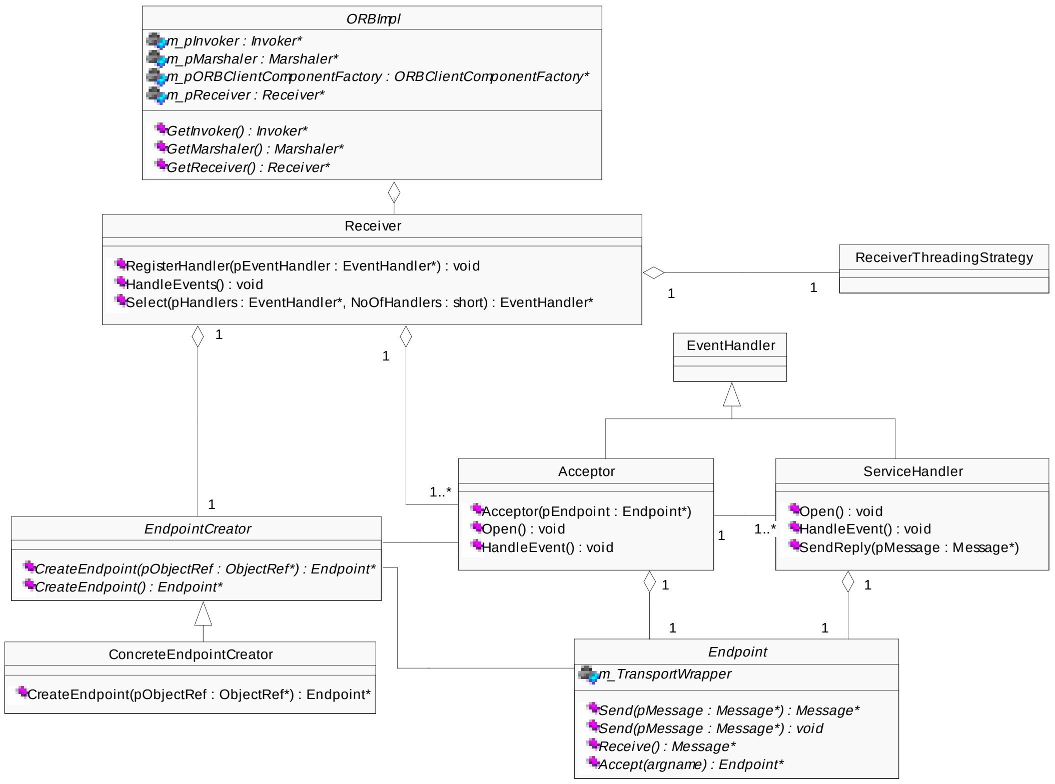

ORBImpl
m_pInvoker : Invoker*
m_pMarshaler : Marshaler*
m_pORBClientComponentFactory : ORBClientComponentFactory*
m_pReceiver : Receiver*
GetInvoker() : Invoker*
GetMarshaler() : Marshaler*
GetReceiver() : Receiver*
Receiver
RegisterHandler(pEventHandler : EventHandler*) : void
HandleEvents() : void
Select(pHandlers : EventHandler*, NoOfHandlers : short) : EventHandler*
ReceiverThreadingStrategy
1
1
EventHandler
1
1
Acceptor
Acceptor(pEndpoint : Endpoint*)
Open() : void
HandleEvent() : void
ServiceHandler
Open() : void
HandleEvent() : void
SendReply(pMessage : Message*)
1..*
1
1..*
1
EndpointCreator
CreateEndpoint(pObjectRef : ObjectRef*) : Endpoint*
CreateEndpoint() : Endpoint*
ConcreteEndpointCreator
CreateEndpoint(pObjectRef : ObjectRef*) : Endpoint*
1
1
1
1
Endpoint
m_TransportWrapper
Send(pMessage : Message*) : Message*
Send(pMessage : Message*) : void
Receive() : Message*
Accept(argname) : Endpoint*

Figure 37 Receiver Class Composition

In order to create concrete endpoints for instances of `Acceptor` and `ServiceHandler`, `Receiver` has an instance of `EndpointCreator`. A `ConcreteEndpointCreator` can be created in the same way as it is for the `EndpointManager` class.

An instance of `Receiver` has associated with it a `ReceiverThreadingStrategy`. As its name suggests, the concrete subclass of

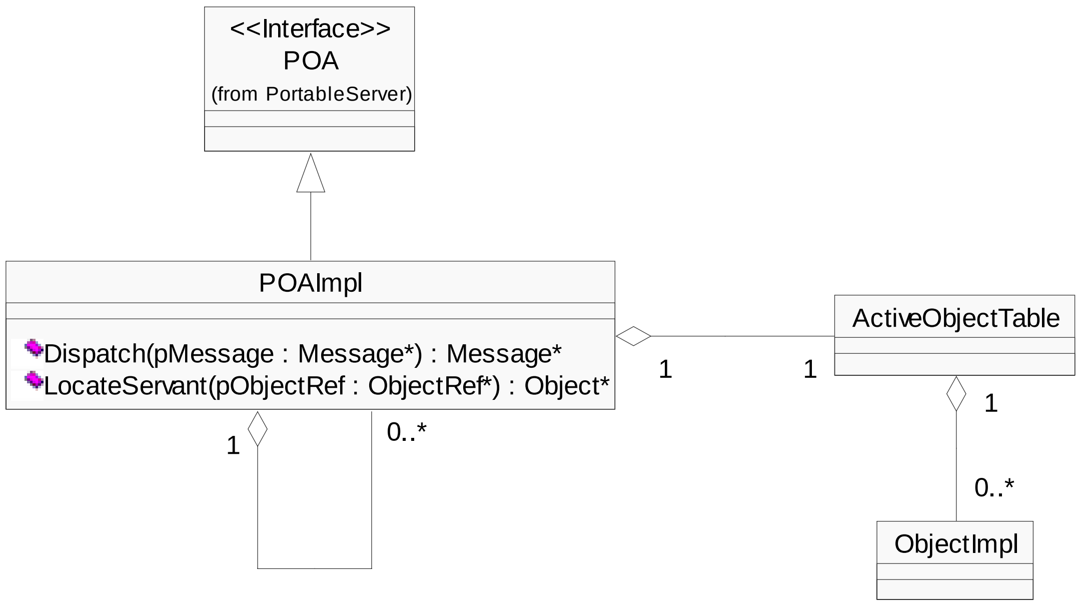
`ReceiverThreadingStrategy` associated with `Receiver` determines the threading model which the `Receiver` uses. Possible concrete subclasses include

- `ThreadPerConnectionReceiverStrategy`
- `ThreadPerRequestReceiverStrategy`
- `SingleThreadedReceiverStrategy`

`ReceiverThreadingStrategy` is an instance of the *Strategy* design pattern, described in section 4.3.5.6.

4.3.4.2 POAImpl

The purpose of `POAImpl` is to implement the CORBA specified `POA` interface. `POA` is the interface of the Portable Object Adapter. `POAImpl` is illustrated in **Figure 38**. The purpose of the POA is to allow object implementations to access services provided by the ORB. Examples of these services are the generation and interpretation of object references, method invocation, and registration of object implementations.



<<Interface>>
POA
(from PortableServer)
POAImpl
Dispatch(pMessage : Message*) : Message*
LocateServant(pObjectRef : ObjectRef*) : Object*
1
0..*
1
1
ActiveObjectTable
1
0..*
ObjectImpl

Figure 38 POAImpl Class Composition

As can be seen in the diagram, `POAImpl` can recursively contain instances of itself. The parent of all `POAImpl` objects represents the root POA as described in the CORBA specification. Each instance of `POAImpl` has an instance of

`ActiveObjectTable`. This is used to store object implementations, represented by the class `ObjectImpl`.

If a `ServiceHandler` needs to invoke an object because it has received an incoming client request, it calls `POAImpl`'s `Dispatch` function with a pointer to `Message` as its argument. `POAImpl` will extract the object reference from the message and use its `ActiveObjectTable` to locate the server object. It then calls the object's `Request` function. The object will proceed to unmarshal the request data, call the appropriate method and marshal the reply message, which is then returned by `POAImpl`. This process is illustrated in more detail in section 5.3.2.

4.3.5 Principal design patterns used in the framework

As has already been mentioned throughout this chapter, instances of a number of design patterns appear in the framework model. Those patterns which have not already been explained previously are briefly explained here.

4.3.5.1 Abstract Factory

The *Abstract Factory* design pattern provides an interface for creating families of related or dependent objects without specifying their concrete classes.

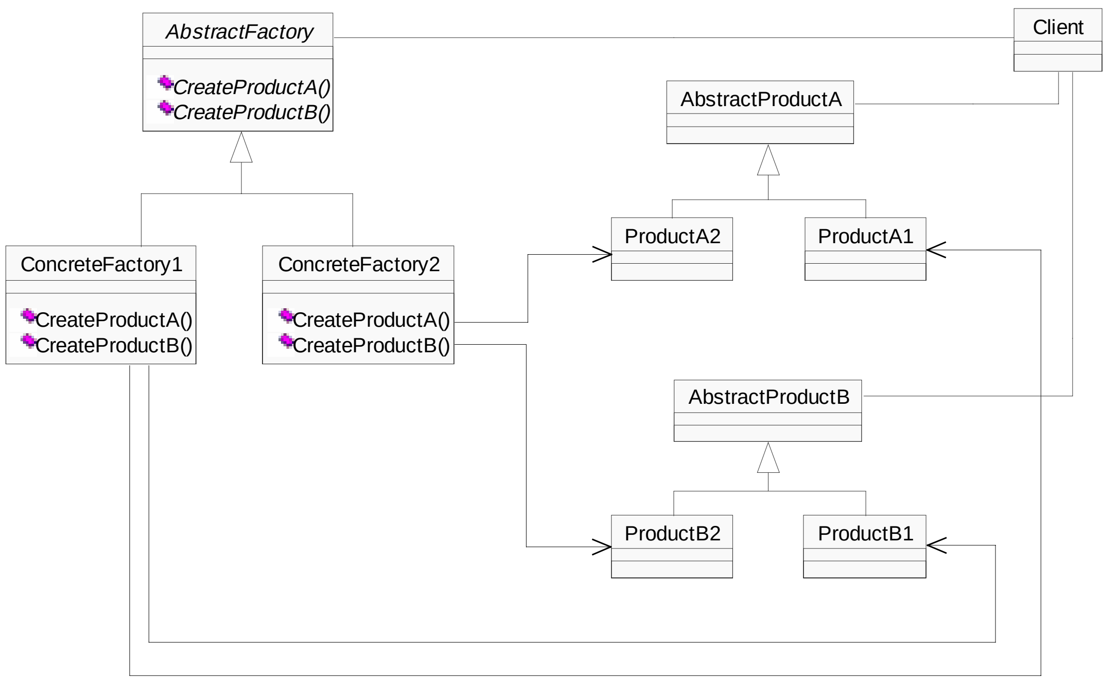


Figure 39 Abstract Factory Design Pattern

The Abstract Factory design pattern is illustrated in **Figure 39**. The abstract class `AbstractFactory` provides an interface for the creation of two products, `ProductA` and `ProductB`. Which concrete product gets instantiated depends on which concrete factory is used.

In the ORB framework, `ORBComponentFactory` is an instance of the *Abstract Factory* pattern. The functions `CreateProductA` and `CreateProductB` are represented by `CreateInvoker`, `CreateMarshaler`, and `CreateReceiver`. `AbstractProductA` could, for example, be `Marshaler`. `ProductA1` might represent `IIOPMarshaler` while `ProductA2` might represent `DCE_CSIOPMarshaler`. The `CreateInvoker` and `CreateReceiver` functions work somewhat differently, as in their case the created classes are not customised by inheritance but by composition. For example, a concrete `ORBComponentFactory` might instantiate an `Invoker` with an `EndpointManager` that caches `SocketsEndpoint`s. A similar mechanism might be used for the creation of `Receiver`. Thus, `CreateInvoker` and `CreateReceiver` are themselves instances of the *Factory Method* design pattern, which has already been described.

4.3.5.2 Adapter

The *Adapter* design pattern converts an interface of a class or a set of functions into an interface that clients expect. The *Adapter* design pattern is also known as *Wrapper*. It is illustrated in **Figure 40**.

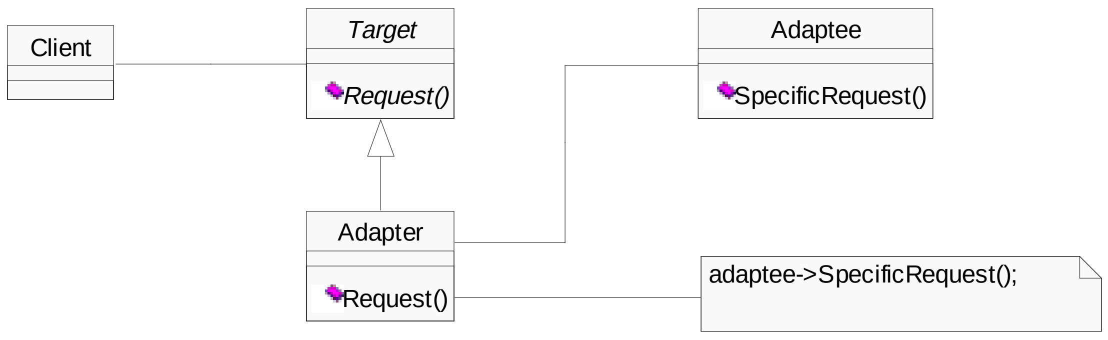


Figure 40 Adapter Design Pattern

`Target` is an abstract class that provides the required interface. `Adapter` is a concrete subclass which adapts the interface of `Adaptee` to the `Target` interface.

In the ORB framework, the `TransportWrapper` classes represent an instance of the *Adapter* pattern. `TransportWrapper` is equivalent to `Target`, while each concrete `TransportWrapper` subclass represents an `Adapter`. The `Adaptee` is represented by the various inter process communication APIs.

4.3.5.3 Builder

The *Builder* design pattern separates the construction of a complex object from its representation, thereby allowing the same construction process to create different representations. *Builder* is illustrated in **Figure 41**.
`Builder` is used to create a product, represented by `Product`. Different concrete `Builder`s allow the product to be assembled in different ways.

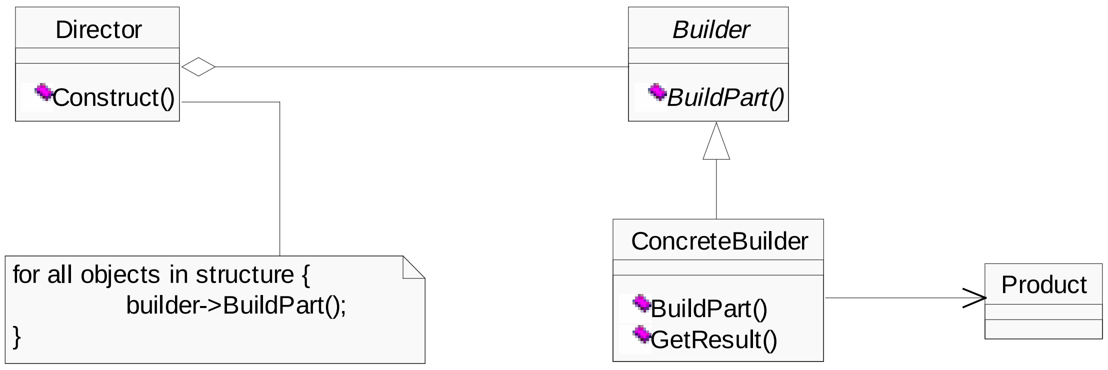


Figure 41 Builder Design Pattern

In the ORB framework, `Marshaler` is an instance of the *Builder* design pattern. Different concrete `Marshaler`s represent different concrete `Builder`s. `Product` is represented by `Message`. The concrete `Message` that is assembled depends on the concrete `Builder` used, while the assembly process remains essentially the same. `Director` is represented by the client stub or server skeleton code. The primary difference between *Builder* and *Abstract Factory* is that *Builder* constructs a product step by step. *Abstract Factory*’s emphasis is on creating families of product objects in one step.

4.3.5.4 Decorator

The *Decorator* design pattern is used to dynamically attach additional responsibilities to an object. *Decorator* is illustrated in **Figure 42**.

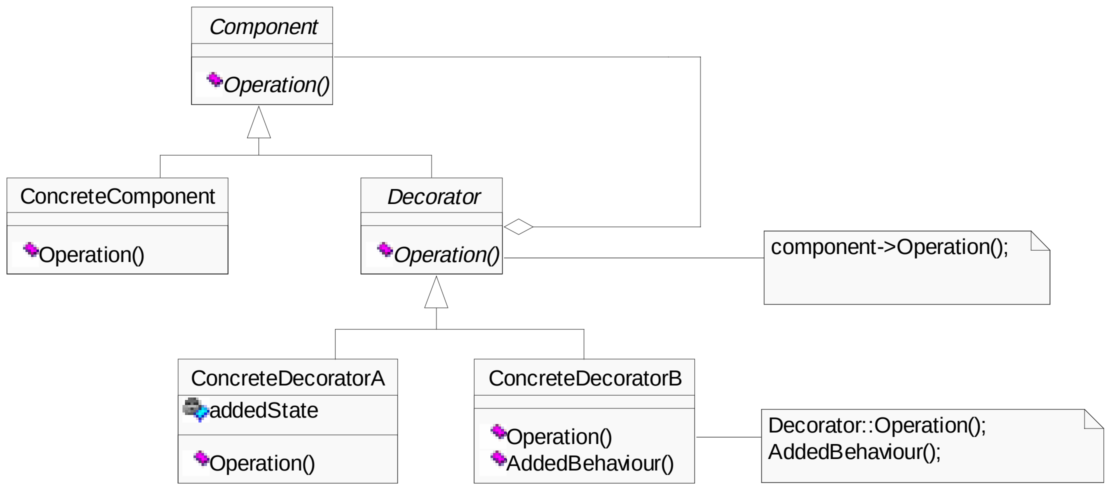


Figure 42 Decorator Design Pattern

`Component` defines a common interface to the objects which can have responsibilities added to them dynamically. `ConcreteComponent` is an example of such an object. `Decorator` conforms to the `Component` interface. At the same time, it maintains a reference to a `Component` object to which it attaches additional responsibilities. A `ConcreteDecorator` is used to attach these additional responsibilities.

In the ORB framework, `Endpoint` and its related classes form an instance of the `Decorator` design pattern. `Endpoint` represents the `Component` interface. `ConcreteComponents` are represented by `SocketsEndpoint`, `TLIEndpoint`, and `FIFOEndpoint`. `EndpointDecorator` represents `Decorator`. Finally, `ConcreteDecorators` are represented by `MobileTransparencyEndpointDecorator` and `GroupCommEndpointDecorator`. These two classes add extra functionality to the other concrete `Endpoint` classes.

4.3.5.5 Singleton

The *Singleton* design pattern is used to ensure that a class has only one instance and to provide a global point of access to it. *Singleton* is illustrated in **Figure 43**.

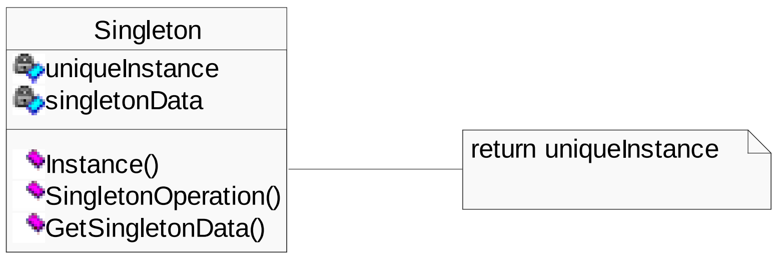


Figure 43 Singleton Design Pattern

`uniqueInstance` represents the one and only instance of `Singleton`. It is created by the `Instance` operation which is a class method and lets clients access `Singleton`'s unique instance.

In the ORB framework, `ORBImpl`, `Marshaler`, `Invoker`, and `Receiver` form instances of the *Singleton* design pattern.

4.3.5.6 Strategy

The *Strategy* design pattern is used to define an interface to an algorithm while letting the algorithm vary. *Strategy* is illustrated in **Figure 44**.

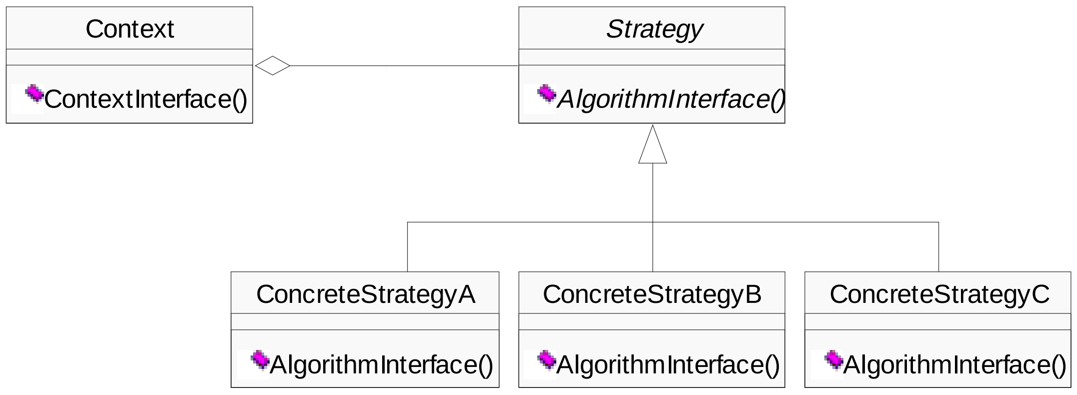


Figure 44 Strategy Design Pattern

`Strategy` declares an interface that is common to all the algorithms. The different concrete algorithms are represented by `ConcreteStrategy` objects. `Context` is the client of a particular strategy and thus maintains a reference to a concrete `Strategy` object.

In the ORB framework, `Strategy` is used in numerous places. Examples of instances of the *Strategy* pattern are `EndpointCreator`, `EndpointManager`, and `ReceiverThreadingStrategy`.

4.4 Summary

This chapter presented the formulation of requirements for the ORB framework and its actual design. The requirements were presented within the contexts of whitebox frameworks, CORBA based ORBs, general requirements of an ORB framework, and domain specific requirements of an ORB framework.

The framework design focused on the proposed principal ORB framework components, ie. `ORBImpl`, `Marshaler`, `Invoker`, `Receiver`, and `POAImpl`. The principal design patterns that were used in the design were also explained.

Chapter 5

Evaluation of the Object Request Broker Framework

5.1 Introduction

The objective of this chapter is to illustrate how the framework can be used to create customised ORBs. It also demonstrates how an ORB created using the framework would execute a simple object invocation. This is visualised using Unified Modeling Language (UML) sequence diagrams.

5.2 Creating customised Object Request Brokers

The ORB framework can be used in a number of ways to provide various degrees of ORB customisation. Customisation of the principal components of the ORB can be achieved by implementing a concrete subclass of `ORBComponentFactory`. A concrete `EndpointCreator` must also be provided in order to allow it create the required concrete `Endpoints` from the object references used by the ORB. To provide even more customised behaviour, any of the abstract classes in the framework can be inherited from to provide behaviour that was unforeseen at framework design time.

5.2.1 Creating a concrete ORBComponentFactory

The most basic way in which to customise an ORB using the framework is to provide a concrete subclass of ORBComponentFactory. As described in the previous chapter, this class is responsible for creating the main components of the ORB, i.e. Marshaler, Invoker, and Receiver. By providing a concrete subclass of ORBComponentFactory, these principal components can be customised.

ORBComponentFactory's function CreateMarshaler is used to instantiate a concrete subclass of Marshaler. If, for example, an IIOPMarshaler is to be created, CreateMarshaler should be written as follows:

```
Marshaller* CreateMarshaler()
{
     return new IIOPMarshaler;
}
```

Similarly, CreateInvoker is used to create an instance of Invoker. Since Invoker is a concrete class itself, and does not form part of an inheritance hierarchy, no subclass of Invoker needs to be created by the application programmer. Rather, Invoker is customised by configuring it with a concrete EndpointManager, which, in turn, is customised with a concrete EndpointCreator. This process can be illustrated by the following sample code for ORBComponentFactory::CreateInvoker():

```
Invoker* CreateInvoker()
{
     // creation of Invoker that uses
     // ConcreteEndpointCreator
     // and caches Endpoints
     EndpointCreator* pEndpointCreator =
          new ConcreteEndpointCreator;
     EndpointManager* pEndpointManager =
          new CachedEndpointManager(pEndpointCreator);
     Invoker* pInvoker = new Invoker(pEndpointManager);
     return pInvoker;
}
```

Thus, it can be seen that the customisation of Invoker relies somewhat on object composition as well as inheritance. In a purely black-box framework customisation would only require object composition since all concrete classes would already be provided as components in the framework.

Finally, CreateReceiver is used to create instances of Receiver. This function needs to be implemented in a similar way to CreateInvoker, since it needs to create an `EndpointCreator` that will be used by `Receiver`. In the same function, `Receiver` needs to be configured with a concrete `ReceiverThreadingStrategy`:

```
Receiver* CreateReceiver()
{
     EndpointCreator* pEndpointCreator =
          new ConcreteEndpointCreator;
     ReceiverThreadingStrategy* pThreadingStrat =
          new ThreadPerRequestReceiverThreadingStrategy;
     Receiver* pReceiver = new Receiver(
          ConcreteEndpointCreator,
          ThreadPerRequestReceiverThreadingStrategy);
     return pReceiver;
}
```

5.2.2 Creating a concrete EndpointCreator

The class `EndpointCreator` is responsible for creating instances of concrete `Endpoints`. A concrete `EndpointCreator` needs to be supplied by the user of the framework in order to map an object reference to the required `TransportWrapper`'s parameters needed to initialise an `Endpoint`. The `EndpointCreator` function in which a concrete `Endpoint` is created is `CreateEndpoint`. Sample code for this function was given in the previous chapter.

5.2.3 Inheriting from other abstract framework classes

In addition to inheriting from the abstract classes mentioned above, the framework permits the creation of customised ORBs by inheriting from other abstract classes in the framework. If, for example, a new inter-ORB protocol is to be created, a new concrete class could be inherited from `Marshaler` in order to implement this protocol. This might also require the creation of a new `Encoder` class, as the required low level data encoding method may vary from those used for existing protocols.

Likewise, other classes could be added to the framework as the need arises. For example, other concrete `TransportWrapper` classes could be added, and with them the associated `Endpoint` classes.

5.3 A sample object invocation

This section illustrates how an ORB created with the framework would perform a simple object invocation. Sequence diagrams for object interaction are provided in the Unified Modeling Language (UML). As an example, consider the following IDL code:

```
Interface Calculator
{
     struct Group
     {
          octet o;
          long l;
          short s;
     };
     Group CubeStruct(in Group values);
};
```

This interface defines a method that takes as its argument an instance of a simple structure. It returns an instance of the same structure. The purpose of the method is to simply cube each element in the structure and return the structure.

In order to use this interface in order to perform CORBA object invocation a stub and a skeleton class are required. These are illustrated in **Figure 45**. As can be seen in the diagram, ObjectImpl is the framework class that implements the CORBA Object interface. ObjectImpl contains a reference to an instance of the ObjectRef class. This class represents an object reference. The contents of ObjectRef depend on the inter-ORB protocol used in the implementation of the ORB. Inherited from ObjectImpl is the class Calculator. This class specifies the Calculator interface based on the IDL definition. Calculator_Stub and Calculator_Skeleton both inherit from Calculator. They provide the stub and skeleton classes respectively. The classes Calculator, Calculator_Stub, and Calculator_Skeleton could be created manually or by a suitable IDL compiler. Finally, Calculator_Impl needs to be provided by the application programmer. It provides the implementation of the Calculator interface.

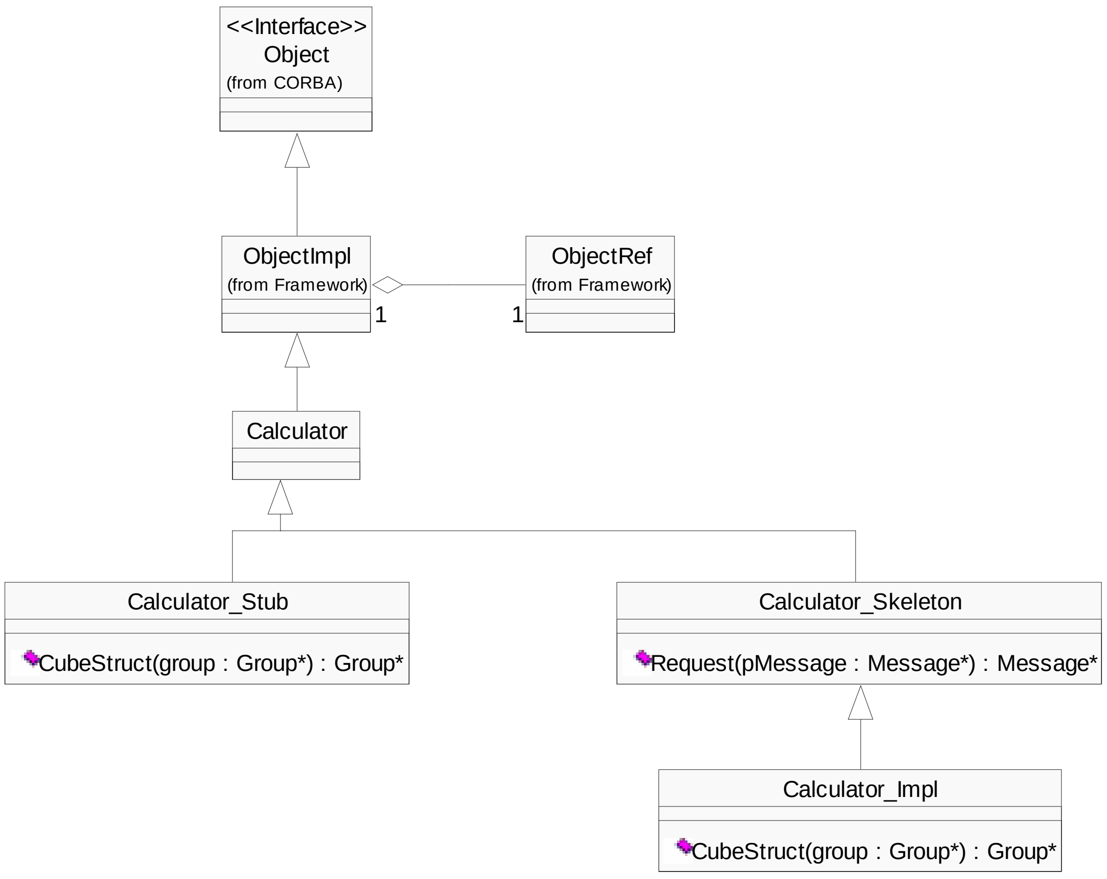
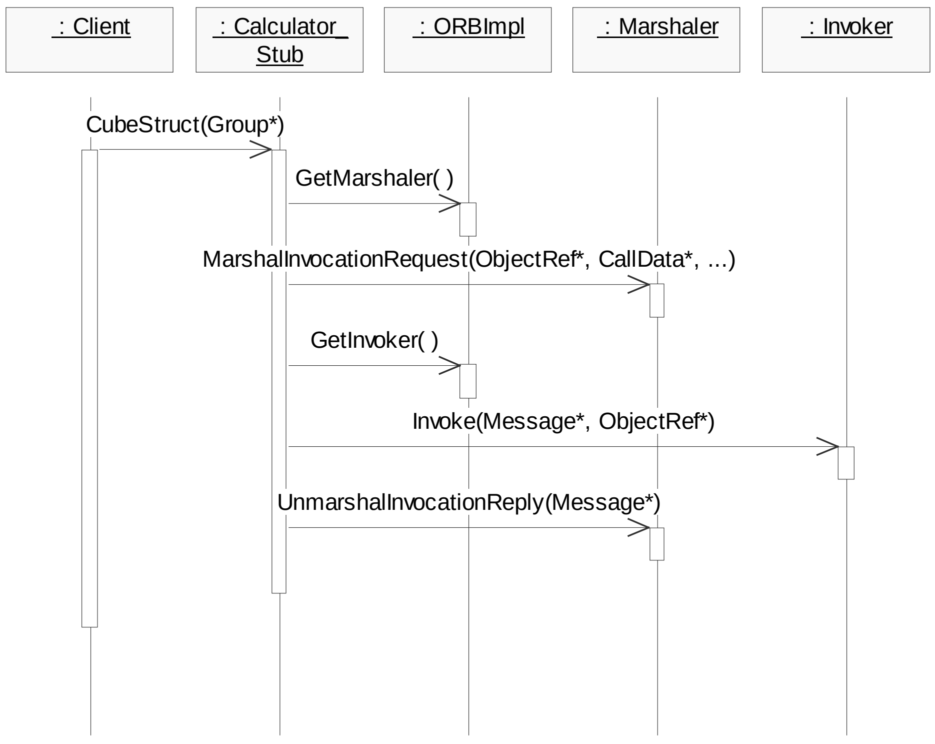


Figure 45 Calculator Stub And Skeleton Classes

5.3.1 Sample Object Invocation: Client Side

The sample object invocation based on the above interface can be split into client and server sequence diagrams. **Figure 46** illustrates the overall client side sequence diagram. As can be seen in the diagram, the Client calls the Calculator_Stub function CubeStruct. What happens next can be broken down into three parts. First, the invocation data is marshaled into a request Message. This is shown in **Figure 47**. To do this, the Marshaller needs to calculate the required size of the request message. This allows the correct amount of space to be allocated for Message's m_pBuffer. Next, the Message object is created. Then, the required headers are marshaled into m_pBuffer. This depends on the inter-ORB protocol and thus on the concrete Marshaler used. After the headers, the invocation parameters are marshaled into the Message using the TypeCodeInterpreter and Encoder. This process was described in detail in Chapter 4. The MarshalInvocationRequest function returns with a Message that is passed to the Invoker using the Invoke function. This is the second part of the client side object invocation sequence. It is illustrated in **Figure 48**. Invoker obtains a suitable Endpoint based on the ObjectRef that has been passed to it. Invoker passes this object reference on to Endpoint Manager which uses it to either retrieve an existing Endpoint or to create a new Endpoint using EndpointCreator. Finally, Invoker calls Endpopint's Send function with Message as its argument. Endpoint uses a TransportWrapper to write the data contained in Message object. It subsequently uses Read to read the data that will form the server's reply Message, which is subsequently returned by Invoker. The third part of the client side object invocation sequence is the unmarshaling of the return Message. This is similar to the marshaling of the outgoing Message, and is illustrated in **Figure 49**.



: Client
: Calculator_Stub
: ORBImpl
: Marshaler
: Invoker
CubeStruct(Group*)
GetMarshaler( )
MarshalInvocationRequest(ObjectRef*, CallData*, ...)
GetInvoker( )
Invoke(Message*, ObjectRef*)
UnmarshalInvocationReply(Message*)

Figure 46 Cube Invocation: Client Side Overall View

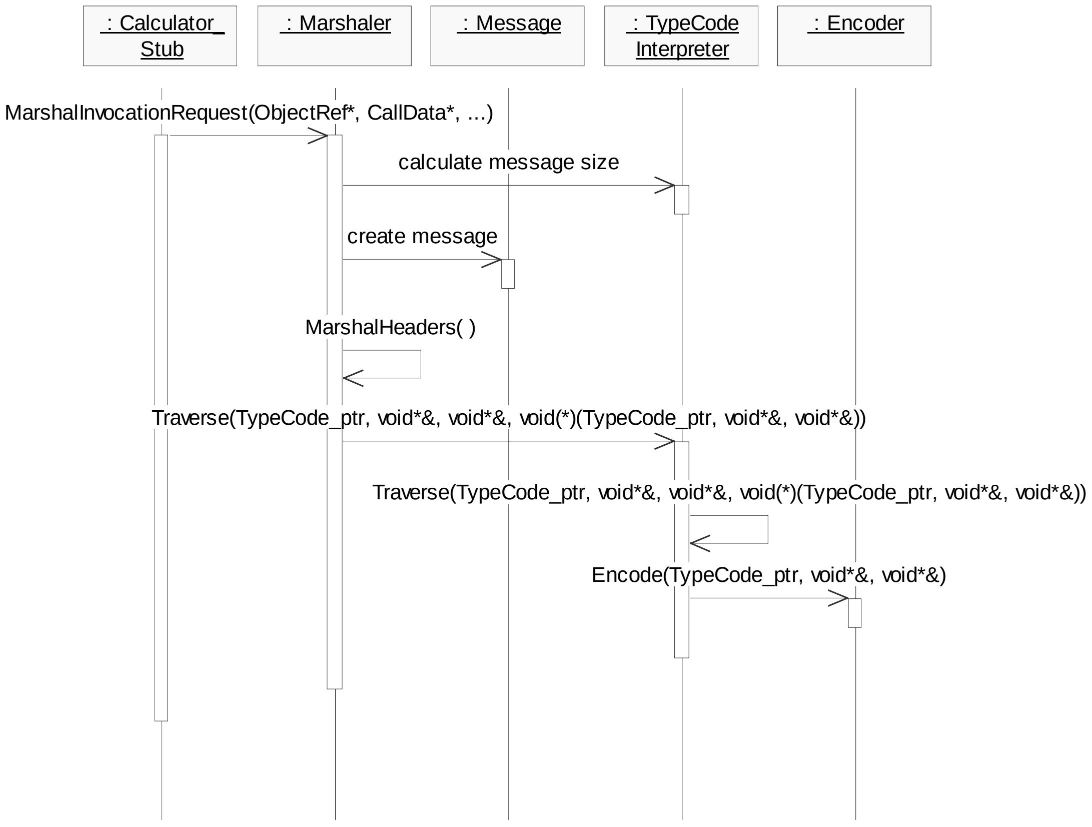

: Calculator_ Stub
: Marshaler
: Message
: TypeCode Interpreter
: Encoder
MarshalInvocationRequest(ObjectRef*, CallData*, ...)
calculate message size
create message
MarshalHeaders( )
Traverse(TypeCode_ptr, void*&, void*&, void(*)(TypeCode_ptr, void*&, void*&))
Traverse(TypeCode_ptr, void*&, void*&, void(*)(TypeCode_ptr, void*&, void*&))
Encode(TypeCode_ptr, void*&, void*&)

Figure 47 Cube Invocation: Client Side Marshaling

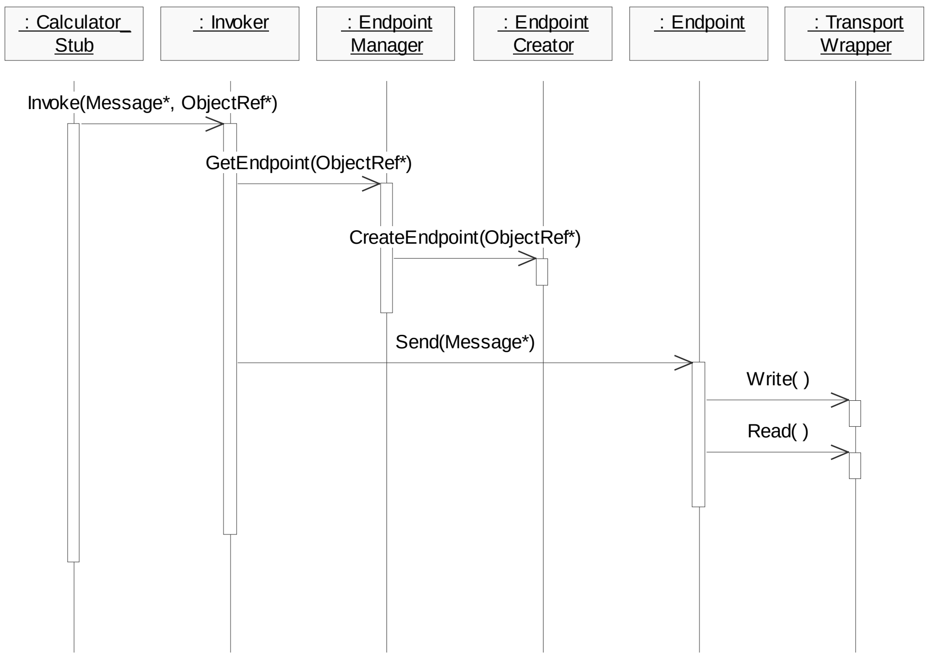
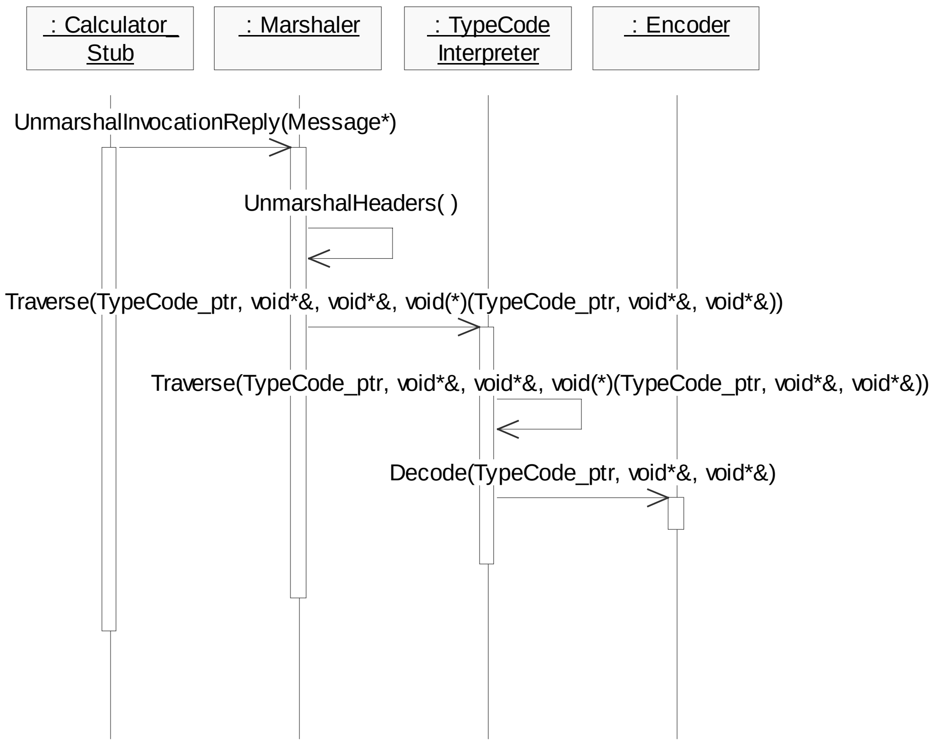


Figure 48 Cube Invocation: Client Side Invocation



: Calculator Stub
: Marshaler
: TypeCode Interpreter
: Encoder
UnmarshalInvocationReply(Message*)
UnmarshalHeaders( )
Traverse(TypeCode_ptr, void*&, void*&, void(*)(TypeCode_ptr, void*&, void*&))
Traverse(TypeCode_ptr, void*&, void*&, void(*)(TypeCode_ptr, void*&, void*&))
Decode(TypeCode_ptr, void*&, void*&)

Figure 49 Cube Invocation: Client Side Unmarshaling

5.3.2 Sample Object Invocation: Server Side

The overall server side sequence for the sample object invocation is shown in **Figure 50**. As can be seen in the diagram, an Acceptor is created and registered with the Receiver. The Receiver's HandleEvents function is called subsequently. This starts the Receivers demultiplexing function, Select. When an event occurs, i.e. an incoming message has arrived, the Acceptor's HandleEvent function is called. The Acceptor proceeds to create a ServiceHandler to handle the message. The ServiceHandler needs to be requistered with Receiver next. If the threading strategy employed is single threaded, this allows the Receiver to demultiplex further incoming events on both the Acceptor and any already existing ServiceHandlers. When an event occurs, the ServiceHandler calls the POAImpl Dispatch function. This is illustrated in more detail in **Figure 51**. POAImpl now uses the Marshaler to obtain the object reference from the Message. Based on the object reference, it obtains the server object from the POAImpl's ActiveObjectTable. It then calls the object's Request function which proceeds to unmarshal the Message in the usual way. The correct function of the server object is then called, based on information that was contained in the Message. A reply Message is marshaled and returned by the POAImpl's Dispatch function. Finally, the ServiceHandler returns this Message using its Endpoint.

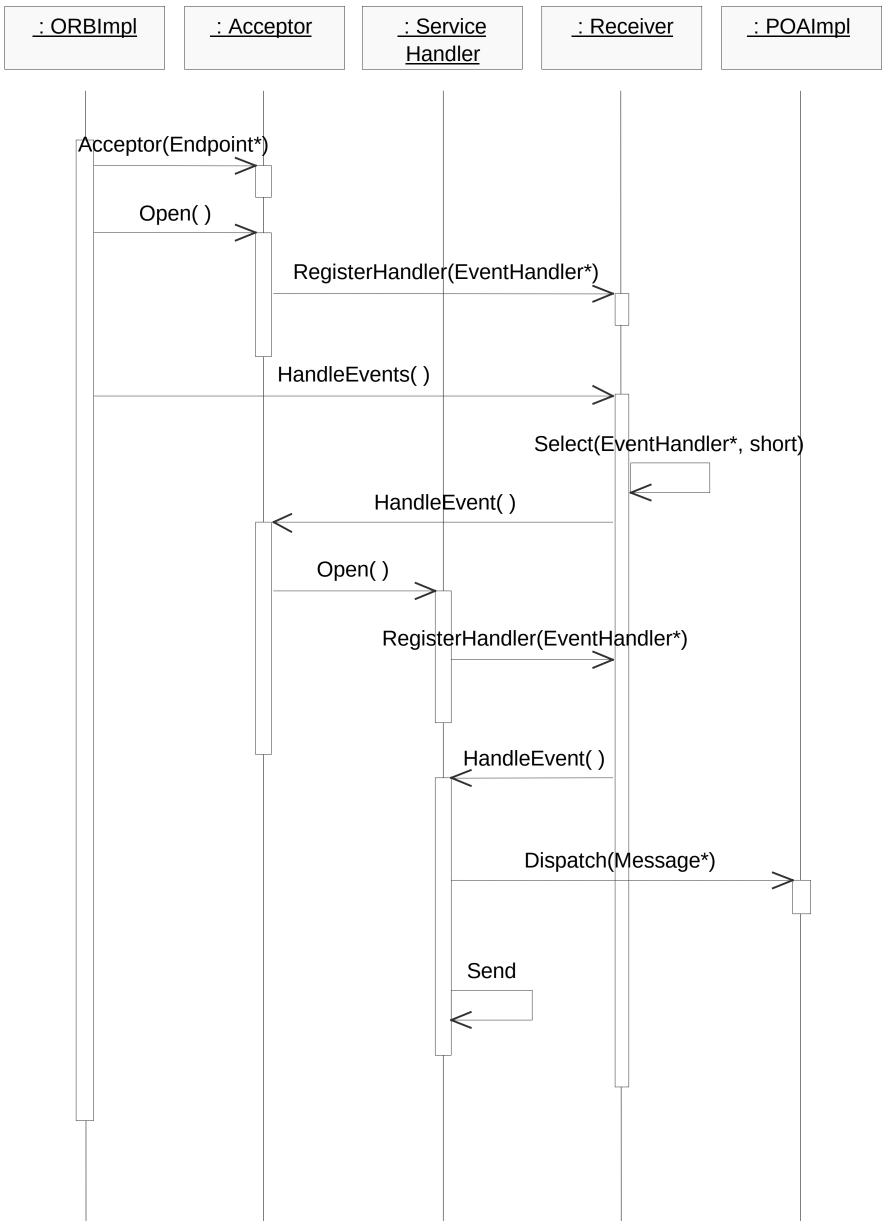
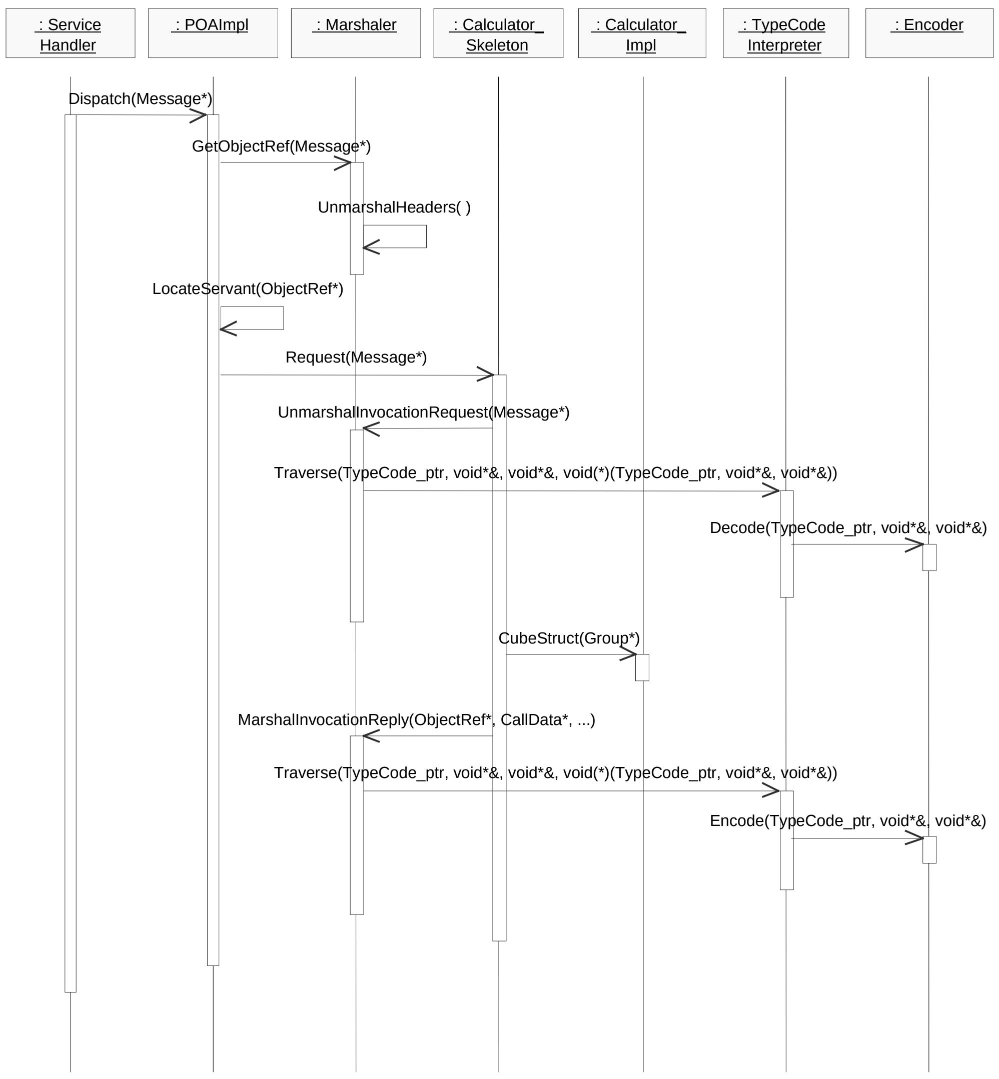


Figure 50 Cube Invocation: Server Side Overall View



: Service Handler
: POAImpl
: Marshaler
: Calculator_ Skeleton
: Calculator_ Impl
: TypeCode Interpreter
: Encoder
Dispatch(Message*)
GetObjectRef(Message*)
UnmarshalHeaders( )
LocateServant(ObjectRef*)
Request(Message*)
UnmarshalInvocationRequest(Message*)
Traverse(TypeCode_ptr, void*&, void*&, void(*)(TypeCode_ptr, void*&, void*&))
Decode(TypeCode_ptr, void*&, void*&)
CubeStruct(Group*)
MarshalInvocationReply(ObjectRef*, CallData*, ...)
Traverse(TypeCode_ptr, void*&, void*&, void(*)(TypeCode_ptr, void*&, void*&))
Encode(TypeCode_ptr, void*&, void*&)

Figure 51 Cube Invocation: Server Side Dispatching View

5.4 Summary

This chapter illustrated how the ORB framework can be used to create customised ORBs. It was shown how ORB customisation focuses on the `ORBComponentFactory` class. It was also shown how a simple object invocation is implemented using a framework based ORB. The following chapter concludes with some comments on the framework approach and the framework itself, as well as comments on implementing the framework.

Chapter 6

Conclusion

6.1 Introduction

The objective of this chapter is to provide some concluding remarks about the design of the ORB framework. First, some problems regarding the framework approach in general are described, and how they relate to the ORB framework specifically. Next, some specific problems encountered with the design of the framework are detailed. Finally, a possible approach to implementing and extending the framework is described.

6.2 Problems with the framework approach

Problems typically encountered when using the framework approach have already been introduced in Chapter 3. This section reiterates some of these, and relates them to the ORB framework design.

Because a framework is developed with a “one fits all” philosophy, the development effort required is much larger than that for an ordinary application in the same domain. The knowledge required from the developers essentially needs to cover the entire application domain. In the case of the ORB framework, this is especially true. Developing a framework for building customisable ORBs that really covers the entire domain of CORBA based middleware is a nontrivial task, since many different application scenarios can be encountered. To create an ORB specifically aimed at a particular scenario, in itself, requires a large effort. An example of this is TAO, the

ACE ORB, described in Chapter 3, the design and implementation of which has required a large effort. Yet TAO is aimed at one specific scenario, that of real time applications. The development of an ORB framework hoping to provide real time functionality corresponding to that of TAO would require at least the amount of effort that went into TAO's development, but much more if it were to cater for other scenarios as well.

Another problem associated with frameworks relates to their use. The learning curve required by application programmers who want to use the framework to build applications based on it is quite large. It is larger for a whitebox framework than for a blackbox framework. The ORB framework described in this project is a whitebox framework and certainly would require the user's insight if he or she were to build ORBs with it. The principal reason for this is that the framework is mainly based on inheritance, which requires familiarity with the classes from which one inherits.

As a consequence of this problem frameworks require a large amount of documentation about their design, inner workings, and use. Again, this contributes to the overall development effort, though it might be argued that any software project should be well documented, be it a simple application or a complex framework.

Since frameworks generally control the flow of execution of applications built using them, problems can occur when attempts are made to combine two or more framework into an application. This problem is also known as architectural mismatch. With an implementation of the ORB framework, this might occur when, for example, an attempt is made to provide a graphical user interface (GUI) using a framework designed for this purpose. For example, the Microsoft Foundation Classes (MFC) provide an application framework for the creation of Microsoft Windows based GUIs. This framework provides its own architectural model, the Document-View architecture, and could thus create problems in combination with the ORB framework.

Related to the fact that a framework generally determines the flow of control within an application built with it, is that debugging is made more difficult in such applications. In an implementation of the ORB framework this would be compounded by the fact that an application built using a framework based ORB would be distributed between client and server ORBs.

Because all applications built using a framework follow one architectural model, an application built using a framework might not be as efficient as a similar application that was purpose built. In other words, the performance of an application from an execution speed point of view may not be as good as that of a purpose built application. This is due to the fact that because of the required generality and flexibility, a framework may use a lot of indirection. An example of such indirection in the ORB framework is the creation of concrete Endpoints. Instead of using the Invoker to create Endpoints directly, it delegates this task to the EndpointManager, which, in turn, delegates this task to the EndpointCreator. Were it known at framework design time that all Endpoints should be SocketsEndpoints with no caching functionality, then all Endpoints could be instantiated in Invoker directly. There is a direct relationship between increased indirection and increased flexibility.

Finally, the maintainability and extensibility of frameworks affects the applications built with them. If a framework needs to be extended or modified, these modifications should remain compatible with previous applications built with the framework. In the case of the ORB framework, if ORBs are created using an implementation of the framework, then future versions of the framework should allow those existing ORBs to be recompiled and work correctly. This is especially important when a number of new concrete classes, concrete Endpoints, for example, have been implemented in order to provide additional behaviour. A new version of the ORB framework should ensure that any such classes that were written for previous versions of the framework will still work.

6.3 Implementing the framework

It was beyond the scope of this project to provide an actual implementation of the ORB framework. A number of issues need to be considered before embarking on an implementation project for the framework.

The implementation language should be an object oriented language such as Java or C++. For performance reasons C++ might be preferred over Java. Since Java uses a Virtual Machine (VM), effectively translating Java byte code at runtime, the performance of a framework implemented in Java may be inferior to one implemented in C++. At the same time, recent increases in hardware performance have made application development in Java more favourable, therefore it could be chosen as a suitable implementation language for the framework.

Included in the Java language is the provision for concurrent programming. In C++, native operating system calls would need to be used to implement multithreaded programming. This is in addition to the fact that Java is operating system independent, whereas C++ effectively is OS dependent and needs to be recompiled for each specific platform.

As regards operating systems and platforms, it is really up to the implementor of the framework to decide which is suitable. This depends on the available development tools, compilers, and programming experience. Obviously, the nature of the framework suggests that the more operating systems and platforms are supported by a particular development effort, the better.

Finally, there is the question of what is needed for a minimum implementation of the framework. The answer to this is that essentially one concrete class is required for each abstract class that has been defined in the framework. An exception to this are any of the EndpointDecorator classes, as they are needed only for the provision of extra functionality to an Endpoint.

A point to note when implementing the framework is that it is not set in stone, and modifications might be required in order to produce an actual implementation. It is possible that the implementor discovers alternative designs for parts of the framework which would facilitate an implementation. These should, by all means, be explored.

6.4 Summary

This chapter provided some concluding remarks about the design of the ORB framework. Problems regarding framework design in general were discussed, as well as problems in relation to the design of the ORB framework. Finally, some points were made about a possible implementation of the ORB framework

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