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Interworking Methodologies for DCOM and CORBA.

Edwin Kraus
East Tennessee State University

Interworking Methodologies for DCOM and CORBA

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Edwin Kraus
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ABSTRACT

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The DCOM and CORBA standards provide location-transparent access to network-resident software through language independent object interfaces. Although the two standards address similar problems, they do so in incompatible ways: DCOM clients cannot use CORBA objects, and CORBA clients cannot utilize DCOM objects, due to incompatible object system infrastructures.

This thesis investigates the performance of bridging tools to resolve the incompatibilities between DCOM and CORBA, in ways that allow clients to cross object system boundaries. Two kinds of tools were constructed and studied: tools that bind clients to services at compile time, and tools that support dynamic client-server bindings. Data developed in the thesis shows that static bridges are on the order of five times faster than dynamic bridges. Measurements conducted with remote clients also showed that with increased network delays, performance differences between static and dynamic bridges become negligible.

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Many thanks also to Dr. Barrett and Dr. Bailes for their assistance in the thesis process. I also would like to thank my employer Siemens for their sponsorship, my colleagues at work for their encouragement, and particularly my supervisor Mr. Ed Basconi for his patience during my years of study.

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CHAPTER 1

INTRODUCTION

Inter-computer communication has been a key area of computer research since Defense Advanced Research Projects Agency scientists first connected two computers in 1969 [14]. Early research on data communications focused on the reliable transmission of bits and bytes over distance using guided media. This research, in turn, led to research into protocols for network communication, including simple, standard protocols for networked message transmission. One such protocol, the Open Software Foundation’s Distributed Computing Environment (DCE), was introduced in the early 1990s at a time when structured procedural programming was the dominant software development model. DCE, among its other features, supported the use of Remote Procedure Calls (RPC) to invoke procedures on remote computers as if they were local, and without regard to the details of the communication infrastructure.

Since 1990, the emergence of object oriented application development has created a need for more expressive successors to RPC: protocols that allow applications to invoke not just remote procedures, but procedures associated with specific instances of network-resident classes. This need was addressed, in one way, by the Object Management Group’s Object Management Architecture. The Object Management Group (OMG) is a professional association that develops standards for object-oriented-based distributed computing. The key standard in the OMG’s Object Management Architecture (OMA) is the Common Object Request Broker Architecture (CORBA). CORBA defines an infrastructure for enabling communication between the other components of the OMA. CORBA, like other OMG standards, is a platform independent standard—but, like other OMG standards, has been deployed primarily on UNIX-like[1] systems. This focus on UNIX is due, in part, to UNIX's dominance as a platform for distributed computing in the early 1990's, when CORBA was originally developed.

While the OMG was developing CORBA, Microsoft, the dominant vendor for PC operating systems, was developing its own standard for component-based programming. Microsoft's Component Object Model (COM) started as a programming model that supported inter-process communication infrastructure. Later, when desktop PCs were applied in distributed computing, COM evolved into Distributed COM (DCOM): a standard that, like CORBA, supports the remote creation and invocation of objects.

The CORBA and DCOM standards address similar problems—and address them well enough to support the development of a great many diverse applications. Still, the CORBA and DCOM distributed computing architectures differ in several fundamental ways. Among the differences are incompatible object models with inconsistent object life cycle management and a fundamental difference in what objects are.

In order to facilitate interaction between COM- and CORBA-based applications, the OMG released an interworking specification between COM and CORBA as a part of its CORBA 2.2 specification. The interworking specification provides a methodology for enabling communication between objects in DCOM and CORBA, and describes ways for

[1] UNIX like systems refers to operating systems that are closely related to the UNIX system developed by K. Thompson and D. M. Ritchie at Bell Labs in 1971

objects to access key services in the foreign object system. A key part of this methodology is a *bridge*: a vehicle that enables objects from different object systems to communicate.

This thesis analyzes the characteristics of bridge-based DCOM-CORBA communication. Bridges can be classified into two types, according to when their endpoints are bound to target objects: early (static) bound bridges, which are compiled with specific knowledge of the type of object they service; and late (dynamic) bound bridges, which rely on runtime type information rather than compile time type information to provide their services. The thesis assesses on how the choice of bridge type, in conjunction with the degree of communicating object separation, affects communication performance and flexibility

The work undertaken here was an empirical study. A pair of COM and CORBA servers, together with a corresponding pair of COM and CORBA clients, were created, along with two two-way bridges: one static, and one dynamic. Two series of measurements were then conducted to determine invocation times. One series represents invocations by collocated clients, the other invocations by remote clients. The results showed that dynamic bridges are on the order of five times slower than static bridges. Indications were also present that for remote clients bridge performance differences become less significant as network latencies increase.

1.1 Thesis Plan

The remainder of this manuscript is divided into eight chapters. Chapters two through three survey background material, including the COM and CORBA object management systems. Chapter four presents bridging concepts as they apply to this thesis project, followed by a description of the test tools in chapter five. Chapter six describes the bridges themselves. Chapters seven and eight conclude by presenting the data and discussing the study's results.

CHAPTER 2

CORBA OVERVIEW

As object oriented programming paradigms grew in popularity in the late 1980's, the need for standards for manipulating distributed objects increased in importance. A consortium of software vendors, the Object Management Group (OMG), was founded in 1989 to develop standards for object-based distributed computing [15]. The first OMG draft standard the Object Management Architecture (OMA), was released in 1991.

Since 1991, the OMA has gained considerable popularity. Most people, however, now refer to this architecture using a name originally bestowed upon that architecture's central element: CORBA.

The CORBA portion of the OMA specification describes an infrastructure and interfaces needed for creating, locating, and invoking operations on objects, distributed across a heterogeneous environment of host computers and operating systems. The rest of the OMA is made up of three somewhat blurry categories of interfaces: CORBA Services, CORBA Facilities and Application Interfaces. Interfaces that apply to all CORBA objects normally fall in the CORBA Services category and are often referred to as having horizontal orientation. Domain-specific interfaces (e.g., manufacturing, banking, health care) are said to have vertical orientation and fall in the category of CORBA Facilities. The last category of interfaces, Application Interfaces, is specific to a particular CORBA application. If similar Application Interfaces are used in different applications, over time these interfaces may become part of the CORBA Facilities, as a common need for these interfaces is recognized.

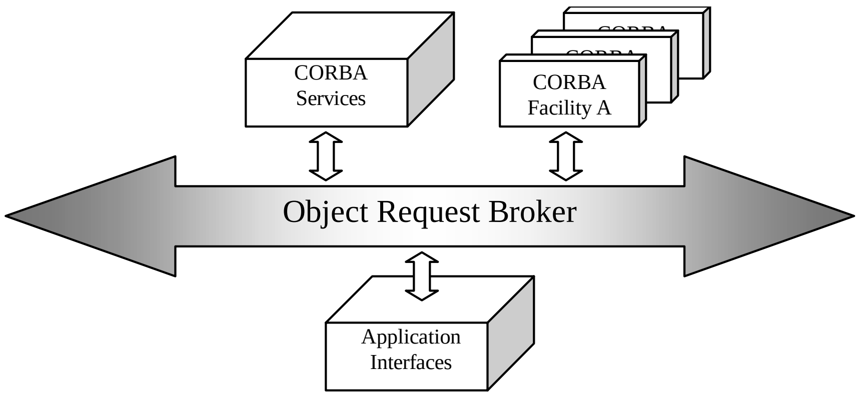


Figure 1 The Object Management Architecture (OMA) [4]

2.1 CORBA Objects

Before the advent of Object Oriented Programming (OOP), procedure-oriented programming was the dominant model for software development. In 1984, Birrell and Nelson [13] devised a strategy for procedure-call-based distributed programming, Remote Procedure Call (RPC), that frames a network send-receive operation as a procedure call and subsequent return from procedure. RPC simplified distributed computing by shielding the programmer from the many details involved in calling a procedure that is in a different address space, or on a different computer.

The more complex OOP model of software development is based on identifiable groupings of procedures and data known as objects. Objects are constructed in accordance with principles like encapsulation, hidden implementation of functionality; polymorphism, variation of behavior depending on object type; and inheritance, propagation of attributes and functionality to child classes.

In the CORBA approach to OOP, programmers use a multipart strategy for defining a network object. First, a language known as an Interface Definition Language (IDL) is used to specify an interface for a class of networked objects. IDLs were first introduced in the context of RPC programming as a necessary tool for location transparency. The CORBA standard expanded the role of IDLs, morphing them into tools that enforce the consequent application of object oriented methods, encapsulation, inheritance and polymorphism. A CORBA-style IDL definition creates a blueprint for an object. This blueprint serves as a vehicle for informing clients about the makeup and behavior of an object, and also as a description of a constructed object's form.

Logically a CORBA object is an instance of a CORBA interface. CORBA provides the programmer with location-transparent, language-independent networked objects. Location transparency means that the programmer does not need to specify a networked code's location: IDL-created code automatically calls the remote object's methods, making it appear as if the remote object resides in the local object's address space. Language independence means that the programmer does not have to ensure that a code that uses an object is written in that object's native language, so long as both objects are coded in CORBA-supported languages: the IDL compiler automatically creates the necessary mappings between method calls and the methods in use.

2.2 Stubs, Skeletons and Servants

The CORBA mechanism for supporting location-transparent method invocation involves substantial behind-the-scenes support and indirection. In part this support is provided through intermediary entities called Stub and Skeleton objects. A Stub object is an object that resides in the client's address space and has an interface identical to the target CORBA object. Likewise, a Skeleton object resides in the server's address space, with the same interface as the target object. The target object, also called a Servant, is the entity that actually performs operations associated with its interface.

Stub and Skeleton objects are proxy objects in the client and server address spaces. When a client program invokes an operation on a CORBA object, the work of invocation begins in the Stub object. The Stub responds to a request for remote invocation by packing (*marshalling*) the operation's parameters into a message, then sending a message, through mechanisms discussed later, to the Skeleton. The Skeleton then unpacks (*unmarshalls*) the message, and invokes the desired operation on the Servant. When the Servant completes this operation the call returns to the Skeleton object, which marshals the results into a response, which is returned to the Stub object. The Stub then completes the call by returning the results to the client program. Before CORBA 3.0 all calls made to CORBA objects via the Stub/Skeleton mechanism were synchronous. CORBA 3.0 also supports asynchronous calls

IDL provides the programmer with all the code needed for the Stub and Skeleton objects. Programmers are left with the task of developing the logic for the Servants, which represent the meat and potatoes of CORBA objects.

Figure 2 shows the relationship between stub objects, skeleton objects and servant objects.

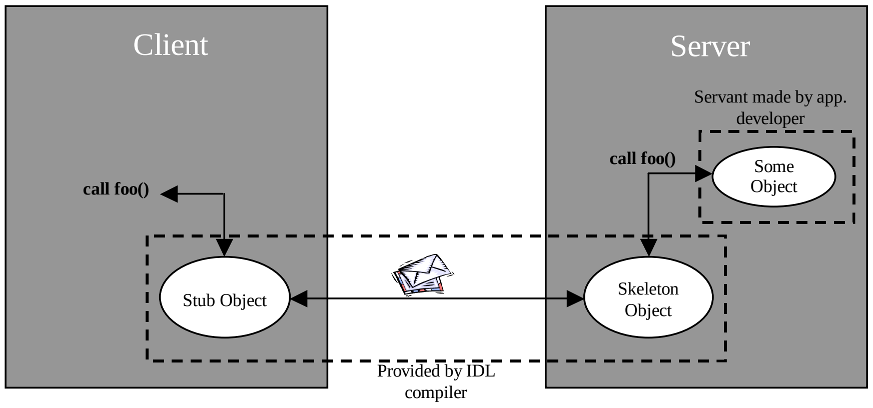


Figure 2 Relationship between Stub, Skeleton, and Servant

2.3 The ORB

The Object Request Broker (ORB), also referred to as CORBA's object bus, is the central CORBA element through which objects on the client side and objects on the server side can communicate. The terms CORBA and ORB are often used synonymously; however, in this paper the term ORB denotes the ORB core, which acts as the glue that holds the different CORBA elements together.

Figure 3 shows a graphical representation of CORBA and demonstrates the central role the ORB plays in the integration of different CORBA elements. What makes the ORB central to a CORBA system is that the ORB interfaces with all elements of the architecture, as well as with other ORBs on remote host computers.

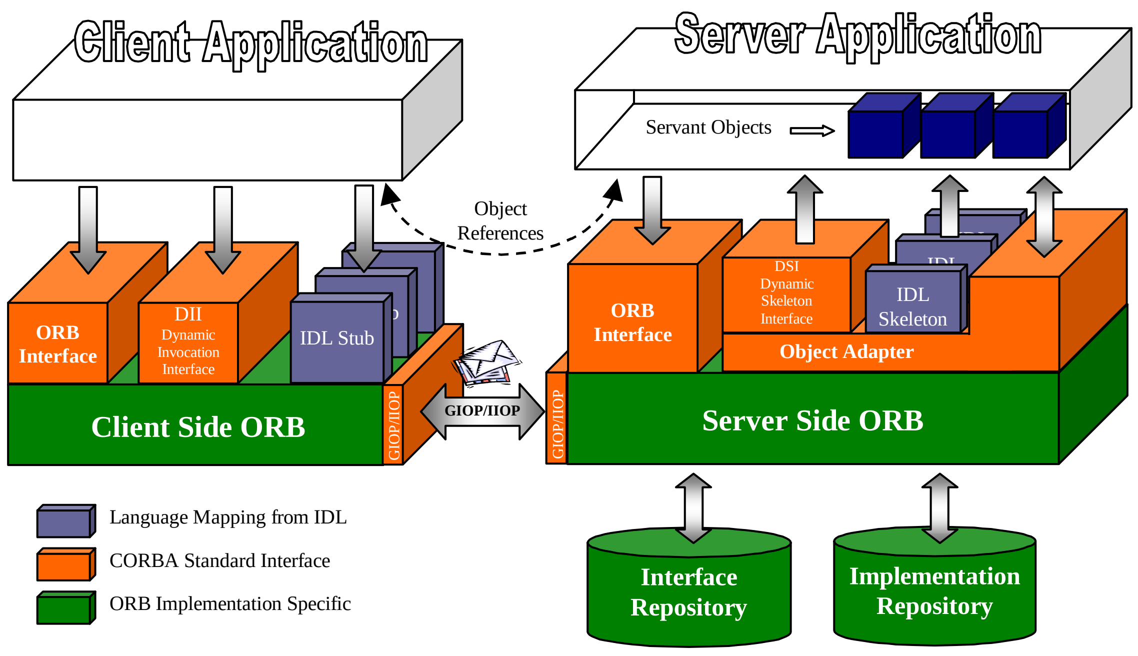


Figure 3 The Common Object Request Broker Architecture (CORBA)

The communication between ORBs, particularly ORBs from different vendors, was standardized in CORBA 2.0, with the introduction of the General Inter-ORB Protocol (GIOP) and the Internet Inter-ORB Protocol (IIOP). GIOP defines the communication between ORBs in general terms. It describes a Common Data Representation (CDR) format and message formats for sending requests and responses between ORBs. GIOP was defined independently of any particular transport protocol in order to accommodate a wide range of networking infrastructures. IIOP, an Internet-specific implementation of GIOP, was released at the same time as GIOP. IIOP provides the full-duplex, connection oriented communication channel that GIOP needs, via the TCP/IP protocol.

Figure 3 shows how client and server applications that reside on different hosts would use their respective ORBs to communicate via IIOP. A client and server that are co-located on a single host should communicate using more efficient, inner-ORB communication primitives.

Communication between ORBs and their respective applications involves the use of one of three CORBA interface mechanisms, according to the communication’s type:

- ORB interfaces support communications between applications and interfaces that are known to those applications at compile time. These interfaces, known as Static Invocation Interfaces (SIIs), are invoked implicitly by invocations of Object References (see next section). They are specific to the server application’s objects. They are represented by the stub and skeleton procedures discussed earlier.
- CORBA’s Dynamic Invocation Interface (DII) and Dynamic Skeleton Interface (DSI) support the invocation and implementation of operations for interfaces where the applications don’t have knowledge of the interfaces at compile time.
- Finally, Object Adapters (OAs) are logical elements that allow an ORB to make the connection between the abstract notion of a CORBA object and its implementation, the Servant.

The ORB interface, OA interface, DII and DSI interfaces are defined by the OMG and published as part of the CORBA standard [8]. The ORB interface is used for ORB initialization and administrative interactions between applications and ORB.

An ORB’s operation is also supported by CORBA’s Interface and Implementation Repositories. The Interface Repository is a database that stores the definition of CORBA interfaces in IDL. The constructs stored in the Interface Repository are equivalent to the

IDL code used to generate the static stubs and skeletons. DII and DSI are the primary users of the Interface Repository.

The Implementation Repository is a storage facility for server entries. ORBs use this facility to activate servers on demand. When a client invokes an operation on a CORBA object, the server hosting the object may not be running at the time of the request. The ORB responsible for the server must determine if the server is already active, and activate it if it is not, before passing it the request from the client. The Implementation Repository maintains a table that associates “Server Name” with “Start Command” and “Activation Mode”. The “Start Command” is executed in order to start a server when needed. The “Activation Mode” is a qualifier that specifies if a new server instance should be started for every client or if clients share the services of a single server instance. More complex features like load balancing are also possible via the Implementation Repository.

2.4 Object References

A CORBA object is an abstract entity that is realized with the aid of a Stub object, a Skeleton object, a Servant and a wealth of mechanisms to enable these elements to interact transparently. An object reference, also referred to as *Interoperable Object Reference* (IOR), is a representation of a CORBA object that gives a code an ability to access that object, while hiding the details of that object’s implementation and status. Ultimately, for the client the only tangible evidence of a CORBA object’s existence is the IOR that client holds on that object. Semantically an IOR is very similar to an object pointer in C++. Vinoski and Henning [4] present the following list of features of an IOR.

- Every object reference identifies exactly one object instance.
- Several different references can denote the same object.
- References can be nil (point nowhere)
- References can dangle (like C++ pointers that point at deleted objects)
- References are opaque (the client is not allowed to look at their contents)
- References are strongly typed.
- References support late binding.
- References can be persistent.
- References can be interoperable.

In a language with explicit pointers like C++, an IOR is represented in the client's address space as a pointer to an instance of a C++ object. Invoking an operation on this pointer invokes an operation on the CORBA object, which means that the invocation has to be propagated through Stub, client ORB, server ORB, object adapter, Skeleton and ultimately to the Servant. An IOR carries all the necessary information in its structure (see Figure 4) in order for a client call, on an object interface, to find its target.

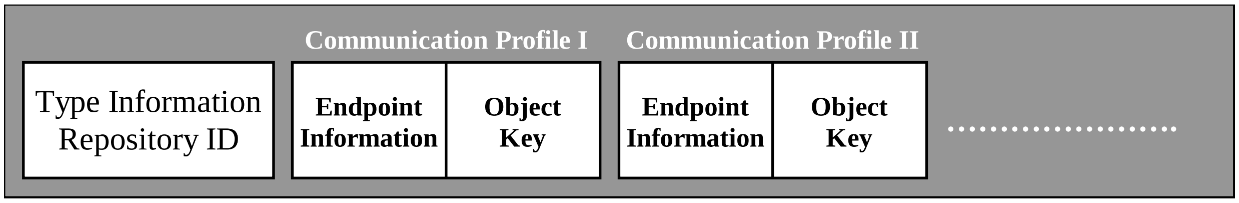


Figure 4 Structure of an IOR

The repository ID is a string that identifies an IOR's type. It can be used for type-safe downcasting or any other operation that requires knowledge of a CORBA object's type. If an ORB implements an Interface Repository, the Repository ID is used as a key to look up entries in the repository. The OMG has defined three possible formats for the repository ID: the IDL format, the DCE UUID format, and the Local format. Of these, the IDL format is by far the most popular. The type of a CORBA object is defined in IDL; therefore it is the IDL compiler that generates the repository IDs. The repository ID always corresponds to the most derived type of an IDL interface. For example, the IDL format of a repository may look like the following:

```
IDL:Building/Skyscraper:1.0
```

The IDL source code resulting in the above repository ID would be the following:

```
module Building {
     interface Skyscraper{
     };
};
```

The number 1.0 in the above example is a version ID that is added by the IDL compiler.

Besides the repository ID, an IOR also contains at least one communication profile. A communication profile stores all information required to locate and establish communication with an object. If an IOR is to be used with different communication protocols the IOR contains multiple profiles, one for each protocol. However, most IORs contain only one profile, a profile for IIOP—the most common protocol in use for CORBA objects.

Because IIOP is based on TCP/IP; it represents endpoint information as an IP address and a port number. A host name that can be resolved via the Domain Name System (DNS) may be used in place of an IP address. The endpoint information in a profile designates either the server that implements the object, or an Implementation Repository that knows the server's address. The former is called direct binding; the latter, indirect binding.

An IOR's endpoint information allows the ORB to locate the server that implements an object. Since a server can implement multiple objects, the ORB also needs additional information that uniquely identifies an object within the server. The additional information is provided in the object key. The object key is a series of octets that can contain any information that the server chooses for the identification of an object. This can range from a string to a Universal Unique Identifier (UUID).

IORs are generated in the servers that implement CORBA objects, and used by clients to access object operations. From this results the need to distribute IORs from servers to prospective clients. Currently an IOR can be distributed either by converting it into a string and sending it via e-mail, or by using a naming or trading service.

A naming service stores associations between an object's name and its IOR. A client that knows a naming service's location and an object's name can query the naming service and acquire an IOR. The trading service, which works similarly, stores associations between object properties and IORs. The client can query for object references from a trading service not by name, but by object properties.

Also noteworthy is the distinction between IORs for transient CORBA objects and IORs for persistent CORBA objects. IORs for transient CORBA objects reference objects that become permanently unavailable when a server is shut down. These IORs contain endpoint information, pointing to the server process that hosts a CORBA object. IORs for persistent CORBA objects reference objects that can be reactivated on demand. These IORs contain endpoint information pointing to an Implementation Repository that activates servers on demand. After server activation, the client is given a new IOR that points to the server process and is valid until the server is shut down. When the server becomes unavailable the client falls back to using the persistent IOR.

2.5 Object Adapter

Next to the ORB core, the Object Adapter is the most significant entity in CORBA—so significant that it is often treated as part of the ORB. Until CORBA version 2.2 the only object adapter in the CORBA specification was the Basic Object Adapter (BOA). However, omissions in the BOA specifications led the OMG to deprecate the BOA, replacing it with a new standard, the Portable Object Adapter (POA).

The POA's main responsibility is to join the interface of a CORBA object, described in IDL, with its implementation, the Servant. In this regard the POA acts as an adapter between servants residing in the server and the ORB. POAs also control the life cycles of CORBA objects and servants. Figure 5 shows the states of a CORBA object throughout its life cycle. A CORBA object transitions through the individual states during its life cycle, controlled by POA operations.

CORBA’s discipline for separating interface and implementation allows a user to create a CORBA object without actually providing an implementation at the time of creation. Two POA operations support object reference creation:

PortableServer::POA::create_reference()
PortableServer::POA::create_reference_with_id().

Either of these operations brings a CORBA object into existence; however, neither instantiates a servant for the new object.

An object, once created, remains available until its server is shut down. When a server is shut down, an object that was created by a transient POA ceases to exist indefinitely. In contrast, an object created by a persistent POA becomes temporarily unavailable. Figure 5 shows the different states a transient CORBA object assumes in the course of its life cycle.

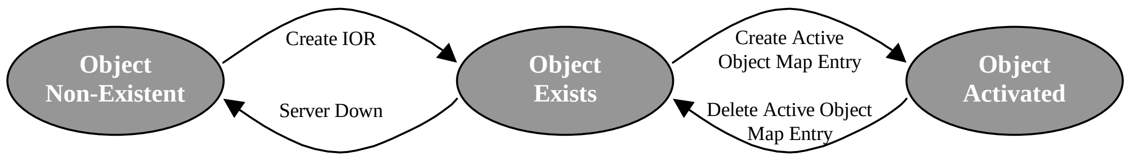


Figure 5 Life Cycle States of a Transient CORBA Object

Whether a POA creates persistent or transient objects depends on the Policies that a POA was given at the time of its creation. Policies are equivalent to attributes. Prior to creating a POA, a list of policies is compiled, which is then passed to the POA create function. Policies, which control a wide range of POA characteristics, include lifespan policies; policies for mapping objects to servants; implicit activation policies; and Object-ID to servant association policies.

The following sample code shows how to apply policies when creating a POA.

```
// create persistent lifespan policy;
// Persistent POA's require the -POAImplName comand line parameter to be set
// to the same value as the name of the entry for this server in the implementation repo
PortableServer::LifespanPolicy_var lifespan =
            poa->create_lifespan_policy(PortableServer::PERSISTENT);

// create ID assignment policy; default is SYSTEM_ID but we want the user
// to set the object ID; object ID must be unique for the POA
PortableServer::IdAssignmentPolicy_var IDAssignment =
            poa->create_id_assignment_policy(PortableServer::USER_ID);

// create empty policy list for new child POA
CORBA::PolicyList policy_list;

// add to policy list
policy_list.length(2);
policy_list[0] = PortableServer::LifespanPolicy::_duplicate(lifespan);
policy_list[1] = PortableServer::IdAssignmentPolicy::_duplicate(IDAssignment);

// create POA
PortableServer::POA_var test_poa = poa->create_POA("TestPOA", poaman, policy_list);
```

Connecting a CORBA object, represented by its IOR, to its Servant is called *activating* the object. A POA maintains a table called an active object map that associates object IDs with servants. An object ID is part of the object key (see Figure 4) and is passed to the POA when a client invokes an operation on an IOR.

By and large the POA is a quite complex construct encompassing a vast number of features. This complexity, however, makes the POA very versatile. It gives CORBA the ability to work with small applications running on embedded systems, as well as with large systems, that use millions of objects.

2.6 MICO Overview

MICO is the CORBA implementation used for this study. The name MICO [2] stands for MICO Is CORBA, following a naming schema introduced by the Free Software Foundation (FSF) for naming the GNU (GNU's not Unix) project. In the spirit of the FSF, MICO is distributed as free software under the GNU public license.

MICO is one of several widely known open source CORBA implementations. MICO was chosen for this study because it easy to learn and highly modular—i.e., capable of supporting emerging features of the CORBA specification.

A partial list of features in MICO 2.3.7, the version used for this study, reads as follows:

- IDL to C++ mapping
- Dynamic Invocation Interface (DII)
- Dynamic Skeleton Interface (DSI)
- Interface Repository (IR)
- IIOP as native protocol (ORB prepared for multi-protocol support)

- Portable Object Adapter (POA)
- Objects by Value (OBV)
- CORBA Components (CCM)
- Dynamic Any
- Interceptors
- Support for secure communication and authentication using SSL
- Support for nested method invocations
- Implementation Repository
- Interoperable Naming service
- Trading service
- Event service

2.6.1 The MICO ORB

The design of the MICO ORB [5] is based on the micro-kernel approach to operating systems design. The ORB core provides only the most basic functionality required of an ORB:

- Relaying of method invocations
- Bootstrapping
- Support for the creation of IORs

Relaying of method invocations is the primary function of an ORB. The MICO designers placed great emphasis on generalizing this function in the ORB. They interjected intermediary objects between applications and the ORB core to achieve maximum generalization of the ORB core. These intermediary objects implement standard CORBA interfaces on the application side, and they use the generalized interfaces on the ORB side. From the ORB's point of view, the intermediary objects fall into two categories: request objects and execution objects. Request objects generate method invocation requests; execution objects process these requests. The ORB implements an interface for each of the two categories of intermediary objects–a method invocation interface, and a method execution interface.

CORBA request objects are typically called "Stub" objects. Applications interact with stub objects either through the SII or DII interface. Requests originate in client applications and are forwarded by the stub objects to the ORB core via the ORB's method invocation interface.

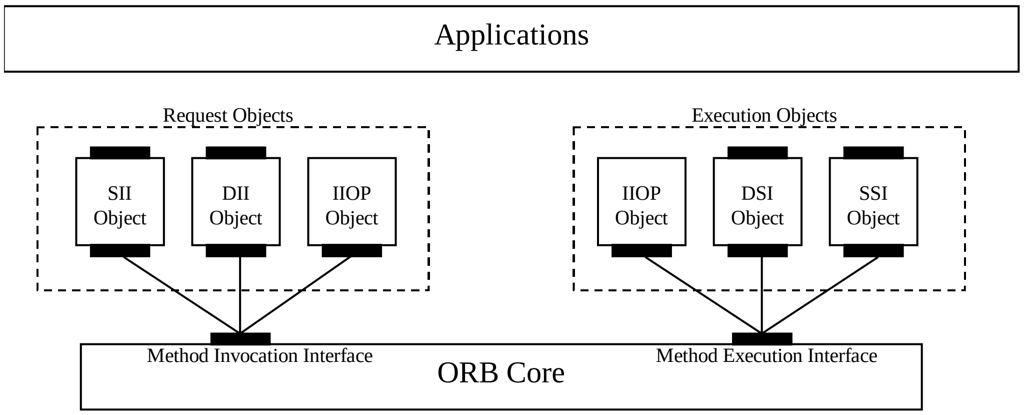


Figure 6 MICO ORB Design Model; adapted from [5]

The ORB core relays requests generated through its method invocation interface to the appropriate execution object, using its method execution interface. Execution objects are called “Skeleton” objects in CORBA. Skeleton objects interact with server applications either via the DSI interface or the SSI interface. Skeleton objects, like Stub objects, forward requests to server applications, which ultimately perform the requested services.

The IIOP object shown in Figure 6 plays a dual role, as either a request object or as an execution object. IIOP objects are communication objects that simply forward and also receive invocations; applications don’t interact with these objects directly. When an ORB cannot find a local execution object to satisfy a request, it uses an IIOP object to forward the request to a remote ORB. In the missing object scenario, each ORB, the local and the remote ORB, uses an IIOP object for communication. The local ORB uses an IIOP object in the role of an execution object, whereas the remote ORB uses an IIOP object in the role of a request object.

Through the use of generically defined, ORB specific interfaces, the MICO ORB allows object adapters or transport objects to be changed without changing the ORB core itself.

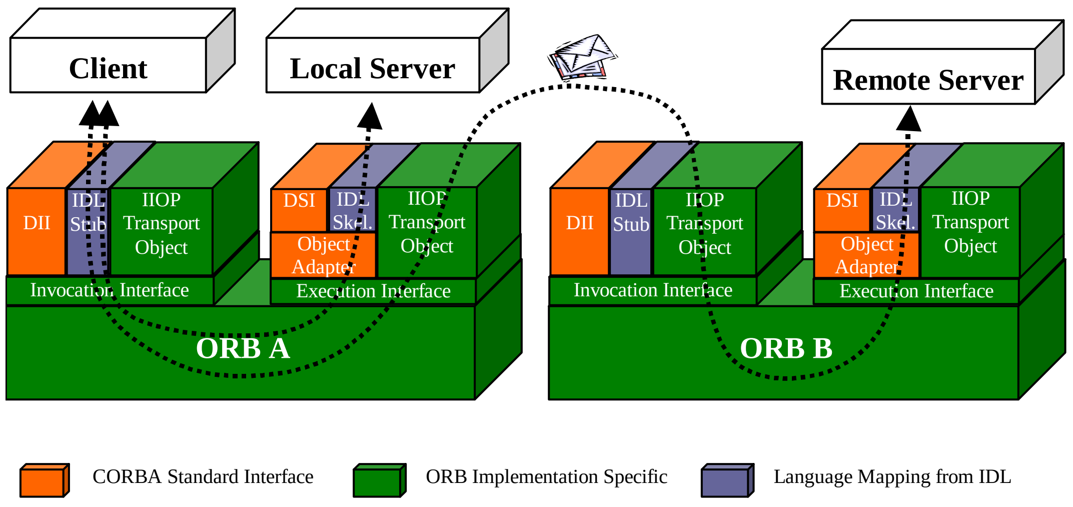


Figure 7 Method Invocation with the MICO ORB

Bootstrapping, the second most important task of an ORB core, is the ability of an ORB to give a CORBA application the ability to acquire an object reference. It is generally thought that bootstrapping is accomplished with the aid of a naming service or a trading service. However, before a naming service can supply IORs, an IOR to the name service itself must be acquired first. For this purpose, the MICO ORB implements the MICO binder, an ORB internal minimal naming service. Using the MICO binder, the ORB can obtain IORs for several key services at startup. To use the binder, the ORB must provide a tuple of locator, object ID, and type ID.

Applications may request IORs for key services from the ORB by calling resolve_initial_references(). This function is provided as part of the OMG-standard ORB interface. In order for calls to resolve_initial_references() to succeed, the ORB must be told at startup what the locators are, to be used in finding objects that implement CORBA services. The CORBA specification defines rules for passing command line arguments to the ORB, which enable the ORB to implement bootstrapping.

Per the CORBA specification, every CORBA server must initialize the ORB by calling CORBA::ORB_init() upon startup. The initialization function receives the application's command line parameters for parsing of ORB parameters. ORB parameters are of the form "–ORB[ParameterName] [ParmeterValue]". The ORB removes its parameters before returning the command line to the application. One of these command-line parameters, "-ORBIIOPAddr", specifies the port that the MICO ORB's IIOP server uses to listen for requests. Other ORB parameters include the IP addresses of CORBA services objects, like Interface Repository, Implementation Repository, and Naming Service

Finally, the MICO ORB supports the creation of IORs through a template. IIOP transport objects contribute the communication endpoint information to the template. Object adapters request the template from the ORB every time an IOR must be created, as they bear the responsibility of creating IORs.

2.6.2 The MICO Runtime Service

A CORBA client application that requires the services of a particular CORBA object must use an IOR to access those services. To obtain an IOR the client may use a CORBA naming or trading service. MICO's implementation of CORBA's naming service is described later in this document.

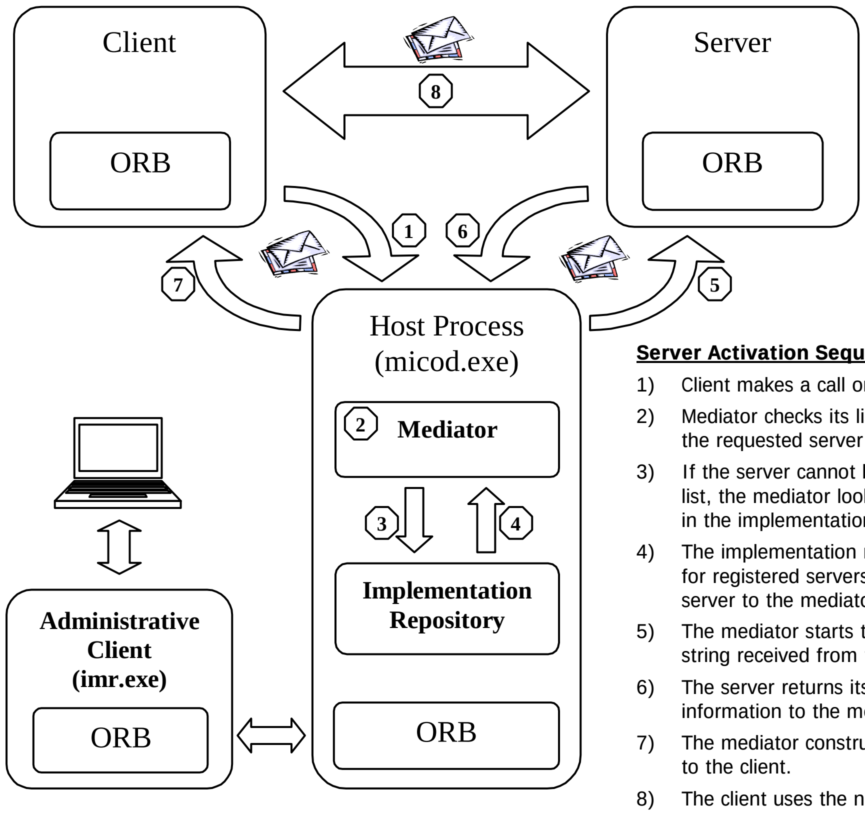
Once in possession of an IOR a CORBA client makes calls to the object, completely unaware if the server is running or not. Ensuring that a server is running when calls are made to its objects is the responsibility of the MICO runtime service. A runtime service is a process that is started when its host is powered up. In a Unix environment these background processes are known as daemons; in Windows they are referred to as services. A single CORBA implementation may actually use multiple daemons for different CORBA services.

MICO's primary daemon process (micod.exe) contains a mediator object that works closely with the MICO Implementation Repository to start servers on demand. The mediator object intercepts a client's first call to an IOR and starts the server process on the client's behalf. However, this is only possible if an entry for the server is found in the Implementation Repository.

In order for the mediator to be able to intercept calls between client and server, the IOR the client uses must contain the endpoint information for the mediator object—and not, more specifically, for the CORBA object it targets. This type of IOR is created by a POA with the persistent lifespan policy. When an IOR is created by a persistent POA, the mediator process's endpoint information is placed into the IOR instead of the endpoint information of the CORBA objects process. Consequently a call made with such an IOR results in a call that is redirected to the mediator object.

The mediator maintains a list of active servers, which is consulted every time a call arrives from a client. If the mediator determines that the requested server is not currently running, it automatically starts the server. Once activated the server informs the mediator of its readiness, and also conveys its endpoint information to the mediator. The mediator then creates a new IOR for the client, this time placing the CORBA server’s address in the IOR. The new IOR is then returned to the client in an IIOP forward message. With the new IOR the client can contact the server directly and invoke the operations it requires. All of this indirection activity is performed transparently to the client.

The approach described above for bringing server and client together is referred to as indirect binding. The alternative method is direct binding. Direct binding requires a server to run permanently. Since this is not possible, a method is required for sending an IOR to the client every time a server restarts. With indirect binding, persistent CORBA objects become possible. IORs to persistent objects remain valid when a server is shut down, and servers can be moved to different hosts without breaking existing IORs. The main drawback of indirect binding is that the first call a client makes takes slightly longer to complete than if the first IOR would have contained the server’s address directly.



Server Activation Sequence

1) Client makes a call on a persistent IOR
2) Mediator checks its list of active servers to see if the requested server is already active.
3) If the server cannot be found in the active server list, the mediator looks up a record for this server in the implementation repository.
4) The implementation repository stores the records for registered servers. It returns the record for a server to the mediator upon request.
5) The mediator starts the server with a command string received from the repository.
6) The server returns its communication endpoint information to the mediator.
7) The mediator constructs a new IOR and returns it to the client.
8) The client uses the new IOR to communicate with the server without intervention from the mediator as long as the server is active.

Figure 8 Structure of The MICO Runtime Service

2.6.3 The MICO Implementation Repository

According to Henning and Vinoski [4] a CORBA Implementation Repository is responsible for all the functions described in the previous section, “The MICO Runtime Service”. However, the MICO documentation characterizes the Implementation Repository as a repository of server records, which provides information to the ORB daemon process.

Each record in the MICO Implementation Repository contains the following information:

- A server name
- The server activation mode (persistent; shared; unshared; per method; library; poa)
- The server activation command
- A list of objects hosted by the server

The following is an example of a record in the MICO repository:

```
       server name:   TestServer
   activation mode:   poa
activation command:   D:\CORBA\TestServer\Debug\TestServer.exe
         object #0:   IDL:IPort:1.0
```

In this record, the server name uniquely identifies a server in the Repository.

The activation mode specifies how and when a new server process should be started. An entry of “persistent” for the activation mode means that the server is started by some other means than the ORB daemon. A server started as “shared” only needs to be started once as all clients share the same server. In the case of an “unshared” server, a new server instance must be started for every client. With “per method” servers a new server instance must be started for every operation invocation on an object in the server. “Library” servers are servers implemented through a dynamic link library and are therefore linked directly into the client process.

Another specialty of the MICO Implementation Repository is the activation mode “poa”. The MICO daemon process uses two types of mediators for activating servers. One type activates BOA based servers, and the other POA based servers. The activation mode "poa" makes the POA mediator responsible for server activation, which starts the server as shared.

The server activation command contains the command line string for starting the server. This command line string may contain any parameters that need to be passed to the server upon startup.

The record's last field lists object types hosted by the server. The object types are expressed by Interface Repository IDs.

For administrative purposes, MICO provides a program called *imr*. This program registers and un-registers servers with the repository. It also provides listing and forced activation capabilities.

2.6.4 The MICO Naming Service

CORBA naming services allow CORBA clients to use an object's name to discover that object's location. A naming service stores name-to-IOR associations called name bindings in a hierarchical structure whose nodes are referred to as naming contexts. Each naming context is an object containing a table of name bindings. The total construct resulting from this abstraction is called a naming graph [9].

MICO implements its CORBA naming service through a daemon process called *nsd*, and an administration tool called *nsadmin*. *Nsd* is configured at startup via command line parameters to listen on the desired TCP port for client requests. Likewise the clients are given the naming service's address as a command line parameter at startup.

A naming service stores object bindings, which are associations between names and object references. Object bindings are stored in a hierarchical tree like structure, very similar to the structure of a file system. The nodes of this structure are called contexts and the leaves are the object references.

The names clients use to denote an object are compound names consisting of an *id* field and a *kind* field. This makes the syntax of a name in string format somewhat cumbersome. However, the *kind* field can be omitted when not in use, which happens fairly often. To fully qualify an object reference, a string containing naming contexts from the root of the tree to the object name—a notation similar to a file system designation—can be used. The following is an example of an object name:

```
root_context/node_context1/node_context2/object_name
```

The OMG naming service specification describes in great detail the exact representation of object names as strings, including the use of escapes for the "/" character and the representation of a string's *kind* field.

2.6.5 The MICO Interface Repository

The Interface Repository stores interface definitions, which are equivalent to the interface definitions stored in IDL files. The Interface Repository enables processes that have an incomplete understanding of an object at compile time to access that object via dynamic invocation. The IR is most often used with the Dynamic Invocation Interface (DII) and Dynamic Skeleton Interface (DSI) to discover the parameters and parameter types of interface operations at run-time. With this information, the data can be marshaled for transport across ORB boundaries, and also across object system boundaries.

The Interface Repository is itself implemented as a CORBA object. In MICO the server that hosts the Interface Repository is called *ird*. *Ird* is configured at startup through a command line parameter to listen on the desired TCP port for client requests. The same mechanism is used to convey to the client on what port *ird* is listening.

Information is entered into the Interface Repository through the MICO IDL compiler. This use of the IDL compiler to feed idl files into the repository is an obvious implementation decision, since IDL compilers are designed to interpret idl files. The compiler can also re-create idl files from the information in the Interface Repository.

The following is an example of a command that feeds an idl file into a repository:

```
idl --feed-ir --no-codegen-c++ filename.idl
```

The parameter "--no-codegen-c++" suppresses the creation of language mapping files for C++. The reverse for the previous operation is as follows:

```
idl --repo-id=IDL:InterfaceName:1.0 --no-codegen-c++ --codegen-idl --name=FileName
```

The command above extracts the information for the interface specified by a repository ID, and creates the idl file specified by the name parameter.

The Interface Repository stores information on interfaces in hierarchical groupings. At the top of the hierarchy are CORBA modules.

CHAPTER 3

COM/DCOM OVERVIEW

The idea at the root of COM is to break up monolithic applications into smaller, more manageable components[2]. A monolithic application is understood as a compiled and linked unit of code that is distributed to end-users. The problem with monolithic applications is that they are difficult to maintain. To counteract aging and obsolescence, applications must continuously be updated with newer code. By building applications from discrete components, the upgrading process can be simplified to replacing only the out of date components as opposed to the entire application.

The concepts behind COM seem very much inspired by the concepts of object-oriented programming, with only the motivation and problem domain being somewhat different. Microsoft saw component based application development as a means of overcoming problems related to the realities of application development, distribution, and maintenance.

One cornerstone of COM, as well as object oriented programming, is the notion of encapsulation. According to Rogerson [10], the concept of encapsulation places the following constraints on components:

- A component must hide the programming language used for its implementation, to enable any client written in any language to use the component.

- A component must be transparently relocatable on a network, to avoid breaking clients when a component is moved to a new location

The balance of this chapter describes how the COM design supports these constraints. Not surprisingly, many of COM's architectural features have direct counterparts in the CORBA framework.

3.1 Interfaces

An interface, as it is understood in COM, describes the behavior of a software component. An interface specification can be likened to a contract between a component and its clients, whereby the component trades the right to change existing interfaces for the certainty that it will always be able to communicate with correctly designed clients. If the need arises to modify an existing component, new interfaces may be added to it, but old interfaces must also be kept intact, because COM interfaces are defined as immutable.

At the functional level, interfaces are groupings of related methods, defined in a meta language called MIDL (Microsoft Interface Definition Language). MIDL is used to describe the interfaces in terms of their operations, operation parameters, operation return types, and interface identifier.

At the lowest level, the binary level, interfaces are list structures of pointers to functions. The COM runtime library uses these function pointers to invoke the operations of an interface on behalf of a client. The COM documentation specifies interfaces at this

[2] Components are self-contained units of code with a well-defined method of access.

lowest level to allow the use of any programming language, capable of producing the structures of function pointers described by COM, for component development that is.

Apart from defining the structure of interfaces, the COM specification also defines a set of standard interfaces. Standard interfaces describe essential operations, which form the backbone of the infrastructure for component lifetime management, interface discovery, and many other essential services. In many respects, standard interfaces have the same purpose as services and facilities in CORBA. IUnknown is the one standard interface all other interfaces must inherit from in order to be considered COM interfaces. Interface inheritance is the commonly employed method in COM programming to extend or modify the behavior of an interface. The COM specification recommends a graphical notation format, which depicts interfaces as circles or jacks (see Figure 9), for clients to plug into the components.

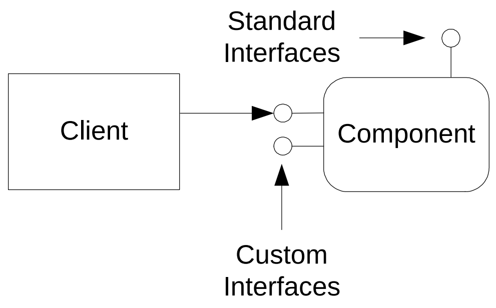


Figure 9 COM Interface Symbology

COM interfaces are sometimes classified as Custom or Automation interfaces. This nomenclature refers to an interface’s ability to support different programming languages. Although COM is a binary interface standard, and therefore independent of syntactic standards, scripting languages like VB Script or Java Script lack the capability to access the binaries that define an interface. To enable these languages to use COM components, developers may choose to support a standard COM interface called IDispatch. This interface is commonly known as the Automation interface. The IDispatch interface provides scripting languages and other languages that don't support direct access to function pointer tables with the ability to use COM components. Essentially, IDispatch binds components to callable procedures at runtime, thereby trading speed of access for ease of use.

Languages that support the use and creation of custom interfaces include C, C++ and recent versions of VB. VB can now read and interpret type library files (*.tlb files), which are a binary representation of the interfaces supported by a particular component.

3.2 COM Objects

Interfaces, rather than objects, are the key conceptual element in COM. A COM object—also known as a COM component, or coclass—is a kind of secondary element that serves as a concentrator for a set of interfaces.

A COM object's identity is established through a globally unique identifier (GUID). GUIDs are system-generated names that, supposedly, are generated in ways that prevent their reuse after generation. GUIDs identify several kinds of COM entities: a GUID that identifies a COM object is also known as class ID (CLSID).

COM also supports a second type identifier for COM objects. These identifiers, known as programmatic identifiers (ProgIDs), are easier to read than CLSIDs—but they are not guaranteed to be unique in time and space. COM supports mapping operations between ProgIDs and CLSIDs.

3.2.1 Object References

COM does not directly support the notion of an object reference, or the use of references to access COM codes. The entity in the COM standard that most closely resembles an object reference is a COM interface pointer. A COM interface pointer is essentially a pointer to a table of function pointers that corresponds to a particular interface. In contrast to CORBA object references COM interface pointers are simply references to memory structures in the client process. The memory structures pointed to are responsible for establishing the link to the interface implementation. CORBA references have more semantic depth in that they themselves represent the link to the object implementation.

To acquire interface pointers, clients use the one standard interface, which is implemented on all COM objects and is known as IUnknown. IUnknown is defined in MIDL by the COM specification as follows:

```
[local, object, uuid(00000000-0000-0000-C000-000000000046),
 pointer_default(unique)]
interface IUnknown
{
   HRESULT QueryInterface(
     [in] REFIID riid, [out, iid_is(riid)] void **ppvObject );
   ULONG AddRef();
   ULONG Release();
}
```

TheAddRef() and Release() functions, which support object lifetime management, are discussed later. The remaining function, QueryInterface(), takes two parameters: an interface identifier and a variable that serves as placeholder for the corresponding interface pointer. Interfaces identifiers are GUIDs and are usually referred to as IIDs. When called, the implementation of QueryInterface() looks for a match on the requested IID. If one is found, the corresponding interface pointer is returned.

Since all COM interfaces inherit from IUnknown, QueryInterface() can be called from any interface pointer. Consequently a client can navigate from any interface of an object to any other interface of that object.

3.2.2 Object Lifetime Management

Unlike in CORBA, where object lifetime is distinct from object server lifetime, the lifetime management of COM objects is closely related to the lifetime management of the component server. Details related to COM component servers are discussed in following sections. The end of life determination for COM objects relies on a technique known as reference counting. The reference counting mechanism is implemented through the IUnknown interface.

Two of the three operations described in IUnknown, AddRef() and Release(), support interface reference counting. The reference count for an interface must be incremented when an interface is acquired, and the reference count must be decremented when the use of an interface is no longer required. Several exceptions to these rules make reference counting error prone despite its simplicity. For example, functions that return interface pointers are responsible for incrementing that interface's reference count, and leave the caller responsible for calling the Release() function.

When the reference counts of all interfaces of a COM object reach zero, the object is released from memory. The notion of a persistent object, as supported by CORBA, is non-existent in COM. COM object references or interface pointers always become permanently invalid when the object server is shut down. However, COM does provide a mechanism for persisting object state with the aid of special components called Monikers.

3.2.3 Object Creation

COM objects are created through the use of a COM runtime entity called the Service Control Manager (SCM), and a type of COM component known as a class factory. COM clients as well as COM servers interact with the SCM through an SCM API. The SCM's role is similar to the role of a CORBA ORB, and the API used by COM applications is semantically similar to the ORB interface.

Class factories, otherwise known as class objects, are special COM components that implement an interface called IClassFactory (as a COM object, a class factory must of course implement IUnknown as well). The IClassFactory interface defines two methods, CreateInstance() and LockServer(). CreateInstance() implements the knowledge of how to create an instance of a specific type of COM object, and LockServer() is used for server lifetime management, and is described later.

The process of creating a COM object begins with a call from the COM client to the SCM's CoGetClassObject() method . CoGetClassObject() is given a CLSID that is used to locate and activate the class factory for the requested COM object. CoGetClassObject() returns an IClassFactory interface pointer. The client uses the IClassFactory pointer to call CreateInstance() to create the COM object it desires.

Class factories are implemented by the component developers, and are normally housed in the same server as the components themselves. Therefore, the SCM must locate and activate the component server before it can create a class factory. The directory for COM objects is the Windows registry, which is where the SCM looks for the executables for component servers. Figure 10 shows the sequence of steps required to create a COM object housed in an out of process server.

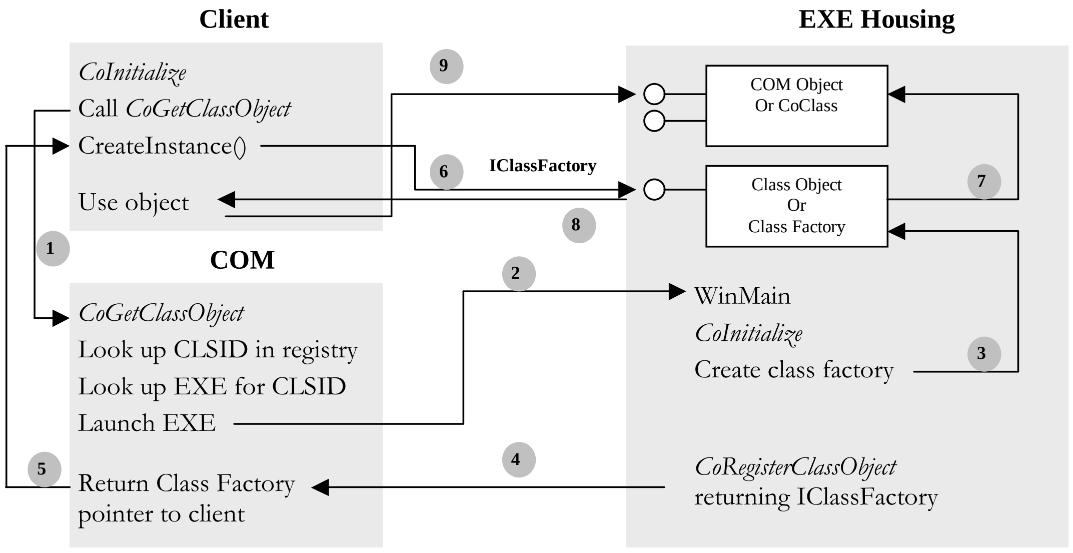


Figure 10 Creation of a COM Object housed in a local server [12]

Objects created with CoGetClassObject() are usually in the same initial state after each startup, because CoGetClassObject() does not support the notion of object persistence. COM facilitates object persistence through components that implement the standard interface IMoniker, and are therefore simply called Monikers. Monikers are a type of factory component that create a COM component, and restore it to a previous state on the client's behalf. The responsibility of implementing the code for state persistence lies with the component itself. By implementing the standard COM interface IPersist, the objects state can be persisted and restored by the client via the components Moniker.

3.3 In-Proc, Out-of-Proc, or Remote Servers

COM interfaces are *implemented* by creating a software component that behaves according to the interface's specifications. It can therefore be said that interfaces exist in the context of the components that implement them. The components themselves also need an environment in which to exist. This environment is usually a Dynamic Link Library (DLL) or an executable file (EXE). In COM terminology it is said that DLLs and EXEs are component housings. The term "Server" typically designates a component housing in COM.

The precise relationship between servers and clients varies according to the degree to which they are separated. A server that executes on a different host from its client is known as a *remote server.* A server that executes on the same host as its client but in different processes is known as an *out-of-process server* or *local server*. A server that executes in the same process as its client, is known as an *in-process server*.

Remote and out-of-process servers are implemented as EXEs. When executed, they reside in their own processes. In-process servers are implemented as DLLs: blocks of code that are loaded into the calling process and that share the process's resources with the caller.

A server's behavior does not necessarily depend on whether it is implemented as remote, in-proc, or out-of-proc. However, the degree of separation between client and server affects server response time. In-proc servers can be accessed through simple function calls, which take micro seconds to perform. To access an out-of-proc server, a client utilizes local procedure calls (LPC), which can take milliseconds to complete. Accessing a remote server is the most time consuming of all. Transmitting messages across a network can take seconds or even minutes, depending on network traffic. The server's intended application must be considered when determining its implementation. For this study, COM servers are implemented as out-of-proc servers, primarily because the code for an out-of-proc server and a remote server is identical and the transition from one to the other is relatively easy.

The degree of separation between client and server also affects process robustness. Out-of-proc and remote servers are more stable than in-proc servers. The crash of an out-of-proc or remote server process should not produce a corresponding crash of the corresopnding client process. From the server's perspective, a misbehaved client cannot take down the entire server and disturb the operation of other clients.

3.4 MIDL Overview

The Microsoft Interface Definition Language (MIDL) is based in large part on the IDL developed by the OSF. An interface definition language's main purpose is to provide developers with a tool for describing interfaces, their operations, and parameters. Since MIDL is just a metalanguage for describing interfaces, it cannot be used to write interface implementations.

MIDL and its associated compiler simplify the work of component development by generating all the support code needed to invoke remote objects. Without the metalanguage all the support code would have to be provided by the developer. This support code enables clients to make calls to objects located outside their address space, in the same way as they would make calls to objects in their own address space.

MIDL is not directly compatible with IDL due to Microsoft's modifications to fit the COM specification. One notable difference between the standards is MIDL's use of braces ([ ]) to flag the MIDL keyword following an attribute. Another is MIDL's support for Microsoft *type libraries*: files that contain binary representations of the components and interfaces defined in MIDL. Programmers reference these files from languages used for component development, or client development in order to discover interface syntax for components.

When a file containing MIDL code is compiled, the compiler produces a number of mapping files from MIDL to C++. The following is a full list of files generated by the MIDL compiler:

- A C++ header file (*.h)
- C++ code files with GUIDs (*.c)
- A binary representation of the interface definitions (*.tlb)

- Stub and proxy code for marshalling (*_p.c)
- Definitions to build the stub and proxy DLL (dlldata.c)

The files generated by the MIDL compiler provide the means for marshalling calls between client and server. Marshalling is the mechanism through which function calls are packaged and relayed from the client process to the server process. Similar to the stub and skeleton objects used by CORBA, COM uses proxy and stub objects for the same purpose.

CHAPTER 4

BRIDGING CONCEPTS

In many respects COM and CORBA are similar. They both, for example, provide infrastructures for object distribution, a language for describing access to objects, and object directories. Yet there are numerous details in their implementations that make COM and CORBA objects incompatible: COM clients cannot make direct use of CORBA objects, and CORBA clients cannot access COM objects.

These incompatibilities between COM and CORBA can be resolved through the use of a *bridge*. A bridge allows a client of one object system to access objects of a different object system, by making the necessary conversions between object access protocols. Bridges resemble COM proxy objects and CORBA proxy objects in their use of marshalling function calls between client and server to disguise these conversions. In addition to parameter marshalling and call forwarding, bridging objects must also map the identities and life cycle models of the different object systems.

Bridges can be one-way or two-way. One-way bridges enable clients in object system A to access objects in object system B (see Figure 11) but the reverse is not possible. Two-way bridges enable clients in both object systems to access objects in the respective other object system (see Figure 12). An implementation of a two-way bridge would have to consist of two generic bridge objects. One bridge object would map COM objects to CORBA clients, and the other would map CORBA objects to COM clients.

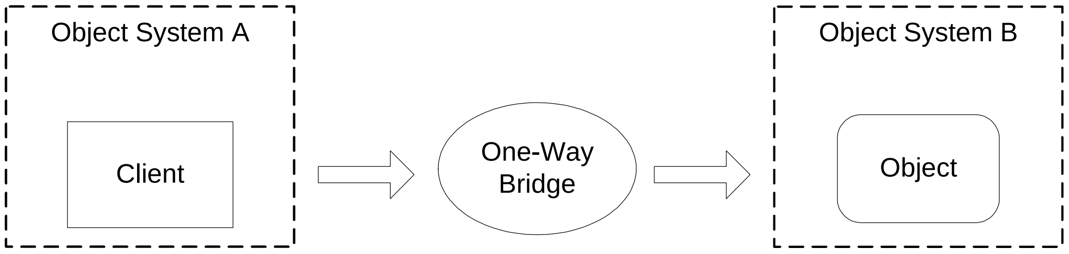


Figure 11 One-way Bridge

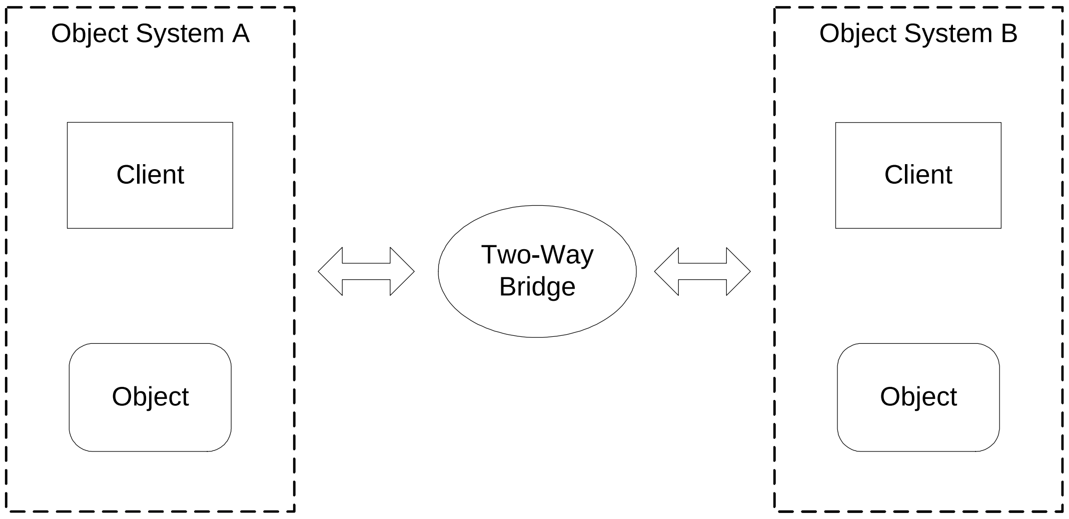


Figure 12 Two-way Bridge

The CORBA interworking specification uses the terms "view of A in B" and "A/B view" to refer to the entities representing an object of object system A to a client in object system B; e.g. a CORBA object visible to a COM client would be called a CORBA/COM view. Figure 13 shows the interworking model as it is defined in the CORBA specification [8]. The bridge object holds a reference to a target object in B and maps this reference to a reference in A. A client in object system A can use the reference exposed by the bridge object and make calls on the object in B.

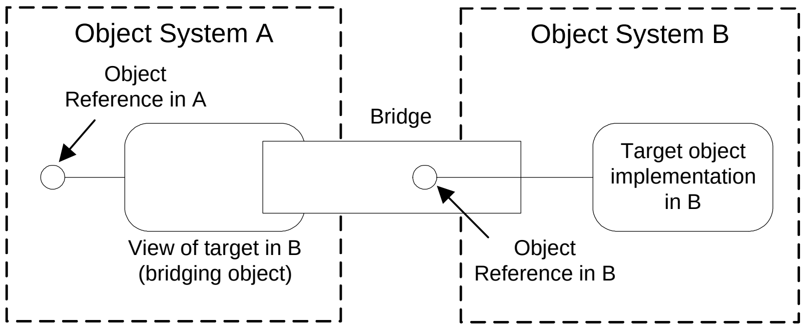


Figure 13 B/A Interworking Model [8]

4.1 Implementation Strategies

COM proxy objects and CORBA stub objects—hereafter referred to as proxy objects, for simplicity—can be implemented as either early bound or late bound objects. Early bound proxies are created by the IDL (or MIDL) compiler, and are sometimes referred to as static or interface-specific proxies. Late bound proxies are generic proxies that can be used for mapping any object and interface, and are sometimes referred to as dynamic proxies.

The main reason for using early bound proxies to implement bridges is performance. Since the operations and operation signatures of an early bound proxy are known at compile time, early bound proxies have less run-time overhead than late-bound proxies. In order to implement an early bound bridge, separate bridge objects must be constructed for every distinct pair of objects to be bridged. These bridge objects can be constructed manually, or using a compiler that generates the bridge objects from IDL code. Building two-way bridges between CORBA and COM would require a compiler that could compile both IDL and MIDL code.

The main reason for using late bound proxies to implement bridges is flexibility. Late-bound bridges can be used to invoke any type of object at any point in a program's operation. However, late bound bridges, like late bound proxies, still need to process target interfaces to satisfy requests. Late bound bridges, like late bound proxies, use a repository to examine the operations and operation signatures of a requested interface at runtime. Using these signatures, a bridge can perform the required parameter conversions at the time of the call. The examination of operation signatures and marshalling of parameters is a time consuming process, thus making late bound bridges uniformly slower than early bound bridges.

4.2 Bridge Architecture

To conduct the research for this study, two two-way bridges were developed: one based on early binding, and the other on late. Both bridges have the architecture depicted in Figure 14.

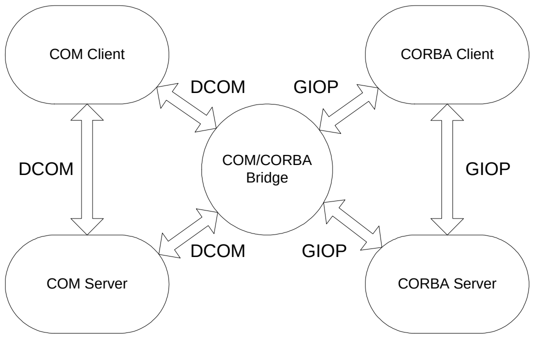


Figure 14 COM/CORBA Bridge - Architectural View

The COM client in Figure 14 communicates with the COM server using DCOM protocols, and the CORBA server using the COM/CORBA Bridge. The bridge translates from DCOM to GIOP communication, as required by the CORBA standard. Similarly the CORBA client may communicate with the CORBA server using the CORBA native GIOP protocol, or with the COM server using the translation service provided by the bridge. Internally the bridge receives calls with the server object, and forwards the calls to its internal client object, which then dispatches the calls to the server in the target object system.

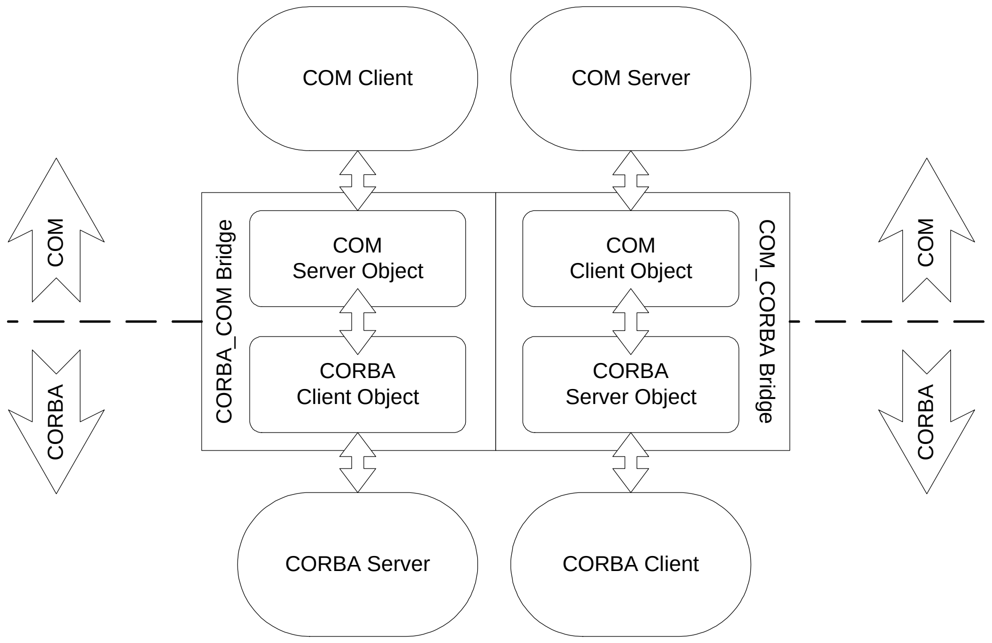


Figure 15 Two-Way CORBA/COM Bridge Model

CHAPTER 5

BRIDGE TEST TOOLS

In addition to the bridges, the work described in this thesis included the creation of codes for testing the bridges. These codes included early-bound and late-bound versions of CORBA and COM server and client tasks (see Figure 15).

5.1 Test Object Servers

The test object servers are the containers that house the test objects. For each object system one object server was built: a simple calculator object that supports one interface, the *BasicMath* interface, with a single function, *Add()*. *Add()* accepts two in parameters and returns an out parameter: the addition's result.

A server's code, regardless for which object system, has two main purposes:

- Bootstrapping and communication with the object system controller
- Implementation of objects

Both of these aspects of an object server are significantly different for COM and CORBA. The balance of this section describes the implementation of the COM and CORBA test object servers.

5.1.1 COM Test Object Server

A COM server's bootstrap code depends on the type of COM server. As mentioned earlier, a COM server is either an *in-process* server, an *out-of-process* server, or a *remote* server. The COM nomenclature is somewhat confusing, since out-of-process and remote servers are identical with respect to the server implementation. The two kinds of servers do, however, vary from the viewpoint of the object system controller. An out-of-process server may run as a *local* server—i.e., on the same host as the client —or a *remote* server—i.e., on a different host. The two kinds of servers use the same executable file format. All COM servers used in this thesis are out-of-process servers, which is why only the bootstrapping for an out-of-process server is discussed.

The task of bootstrapping and communication with the object system controller can be further subdivided into the following sub-tasks:

- COM initialization/termination
- Server self-registration/un-registration
- Lifetime management
- Message loop
- Class factory registration/un-registration

The COM object test server implements the concepts and requirements presented in the following section with the classes shown in the class diagram in Appendix A. All operations for bootstrapping described in the following sections, are implemented in the *HousingManagerClass,* the *ExeHousingManagerClass*, the *COMFactoryClass,* and the *CalculatorFactoryClass*.

5.1.1.1 COM Initialization/Termination

When the executable file of a COM server is first loaded into memory and starts executing, it is just another process running on a host. This process becomes a COM server when it starts communicating with the COM object system controller. The object system controller in COM is called the Service Control Manager (SCM). COM provides developers with an API for communication with the SCM contained in the dynamic link library OLE32.DLL. The first call a process must make to announce itself to the SCM is *CoInitialize()*. *CoInitialize()* initializes the COM library for use by the current process. Any other calls to the COM library before calling *CoInitialize()* result in error conditions. To announce the termination of a COM process to the SCM the function *CoUnitialize()*.

5.1.1.2 Server Self-registration/Un-registration

In order for the SCM to activate a COM object, the SCM must first locate and activate the server that houses the requested object. The information regarding the server for a specific COM object is stored in the Windows Registry. The SCM locates objects in the Windows Registry based on their CLSID.

Entering the information related to a COM object into the registry is the object developer's responsibility. The information can be entered into the registry in several ways. Distributing a *.reg file and merging it into the registry upon installation is one way of registering a server. Another method is the use of a script resource written in registry script language, as provided by the Visual Studio Environment. However, the preferred technique is server self-registration. Server self-registration avoids the distribution of special registration files because the necessary information for registration is kept inside the server executable. Servers supporting self-registration check the command line for the parameters *-RegServer* or *-UnregServer*, and perform the necessary steps to register or un-register the COM objects housed in the server.

5.1.1.3 Server Lifetime management

The *lifetime* of a server is the period of time from the moment the server process is started to the moment the server process is shut down. Shutting the server down is the responsibility of the server itself. The server knows that it has to shut down when there are no more clients using any of its interfaces and no server locks are active. Reference counting is the basic mechanism to determine when an interface is in use.

Lifetime management is defined in the most standard of all COM interfaces, the IUnknown interface. As mentioned earlier, the IUnknown interface supports three functions:

- QueryInterface()
- AddRef()
- Release()

The QueryInterface() function returns a handle on a specified interface, if that interface has been implemented. Before returning, QueryInterface() also calls the interface’s AddRef() function. AddRef() increments the reference counter and Release() decrements the reference counter for an interface. Clients have the responsibility to AddRef() and later Release() an interface when done using an interface.

A client may also choose to activate a server before starting to use any of the server's interfaces. In that case the client must increment a server locks counter to keep the server loaded into memory. The functionality for locking the server is provided via another standard COM function, the LockServer() function of the IClassFactory interface.

The server monitors the interface reference counter and the server locks counter. When both counters reach zero the server shuts itself down.

5.1.1.4 Message Loop

A message loop is a function that keeps the server in memory while it waits for client requests. A message loop is implemented by a simple program loop, which yields the server process' CPU time to the operating system if no client is requesting services from an object in the process.

5.1.1.5 Class Factory Registration/Un-registration

COM objects are created based on the creational pattern Factory Method [11]. COM defines an abstract class, the IClassFactory interface, for which programmers develop implementations, known as class objects or class factories. Clients must acquire an IClassFactory interface in order to create the COM object they wish to use. To obtain an IClassFactory interface clients contact the SCM, which then searches its directory of class objects for the appropriate class factory. The directory of class objects is known in COM as the class object table, and it has some similarities with the active object table implemented by CORBA's POA.

Object servers make entries into the class object table at startup, using the COM library function *CoRegisterClassObject()*. Entries in the class object table are only valid for the duration of a server's lifetime. Hence a server must delete its entries before exiting. The COM library provides the *CoRevokeClassObject()* function for servers to remove entries from the class object table.

5.1.1.6 Object Implementation

COM objects are implemented by creating concrete classes for the interfaces described in MIDL. When implementing COM objects in C++, the concrete class inherits from abstract classes created by the MIDL compiler. The concrete class must provide implementations for all virtual functions it inherited from the abstract interface class. This includes all the functions defined by standard interfaces.

The concrete class for the COM test object is the *ICalculator_BasicMathClass* (see Appendix A). ICalculator_BasicMathClass implements the functions for the standard interfaces IUnknown and IDispatch, along with the ICalculator_BasicMath interface. IUnknown must be implemented, as it provides the basic COM object lifetime and interface discovery functions. The implementation of IDispatch is required for objects that are to be used in a late bound fashion[3]. Details of the IDispatch implementation will be given in a later section, when describing the late bound bridge. Finally, by implementing the ICalculator_BasicMath interface, the ICalculator_BasicMathClass provides an implementation for the function Add(), which were used for bridge testing.

[3] Com objects implementing both IUnknown and IDispatch are also known as objects implementing a *dual interface*.

5.1.2 CORBA Test Object Server

The bootstrapping requirements in a CORBA server differ in the nuances of the object system specifics, but conceptually they are similar to the bootstrapping requirements of a COM server. The following sub-tasks must be implemented in order to create a CORBA server's frame:

- ORB initialization/termination
- POA creation/initialization
- Object creation
- Object publishing
- Message loop
- Object implementation

5.1.2.1 ORB Initialization/Termination

When a CORBA server starts, it initializes communication with the CORBA object system controller, the ORB, by calling the static method CORBA::ORB_init(). The server uses ORB_init() to pass the server application's command line parameters to the ORB, and to obtain a pointer to an ORB instance. The ORB pointer is then used to call the ORB interface's operations. The ORB uses its command line parameters to establish communication with critical CORBA services, like a naming service, a trading service, and the interface repository. This activity enables ORB users to gain access to these services by calling the ORB interface's resolve_initial_references() function. This function returns a CORBA object pointer, which, after narrowing to the appropriate type, may be used to access the service. Once in possession of a reference to a CORBA naming or trading service, a client may acquire any object it requires to perform its tasks.

5.1.2.2 POA Creation/Initialization

The POA plays a key role in linking client invocations on object references to their respective implementations (see section 2.5). Creating and initializing a POA is therefore another prerequisite for the creation and publication of server-resident objects.

CORBA servers can have many different POAs, organized in a hierarchical tree structure. At the root of this tree structure is the root POA, which is created during the ORB initialization. A reference to the root POA can be obtained from the ORB by using the resolve_initial_references() function. The code sample below demonstrates how a reference to the root POA can be obtained from the ORB.

```
// get the root POA reference
CORBA::Object_ptr obj = m_ORB->resolve_initial_references("RootPOA");

// now cast the object reference into a POA reference
m_RootPOA = PortableServer::POA::_narrow(obj);

// don't need the temporary storage for the object reference anymore
CORBA::release(obj);
```

CORBA specifies the operation *create_POA(),* on the POA interface, which creates new POAs. Newly created POAs are children of the POA whose create_POA() function was called. The create_POA() function takes as parameters the new POA’s name, a reference to the POA manager, and a list of POA policies.

POA policies control the behavior and characteristics of POAs and their objects, as described in section 2.5. The test server object's POA is a persistent POA that allows the user to set the object IDs, and is created as follows:

```
// create empty policy list for new child POA
CORBA::PolicyList policy_list;

// create persisten lifespan policy;
PortableServer::LifespanPolicy_var lifespan =
m_RootPOA->create_lifespan_policy(PortableServer::PERSISTENT);

// create ID assignment policy; default is SYSTEM_ID
PortableServer::IdAssignmentPolicy_var IDAssignment =
m_RootPOA->create_id_assignment_policy(PortableServer::USER_ID);

// add to policy list
policy_list.length(2);
policy_list[0] = PortableServer::LifespanPolicy::_duplicate(lifespan);
policy_list[1] =
PortableServer::IdAssignmentPolicy::_duplicate(IDAssignment);

// create child POA
PortableServer::POA_ptr
new_poa = m_RootPOA->create_POA(POAName.c_str(), m_RootPOAManager,
policy_list);

lifespan->destroy();
IDAssignment->destroy();

return new_poa;
```

The POA manager is a control entity that controls the flow of requests into its associated POAs. The POA manager can be set to one of four different states: holding, discarding, active, or inactive. When set to active, a POA manager passes requests to the connected POAs as soon as they arrive. POA managers manage the flow of requests to POAs, particularly during startup, shutdown, and high load conditions.

5.1.2.3 Object Creation

Object creation is dependant on the POA that creates the object. As described in the previous section, each POA is configured with a set of policies that give the POA its characteristics. The characteristics of a POA are reflected in the types of objects that that POA creates.

The Calculator object used for bridge testing is a persistent object, which means that clients holding a reference to this object may use that reference as long as they whish. Even if the server is shut down, a client can make a call on the reference of a persistent object and re-activate the server.

The creation of a persistent object is typically a four step process, involving the creation of a servant, the creation of an object ID, the activation of the object, and the creation of an object reference. The sample code below demonstrates how the “Calculator” object is created.

```
// instantiate servant
CalculatorClass servant;

// create an object ID
PortableServer::ObjectId_var
      objectID = PortableServer::string_to_ObjectId(“Calculator”);
```

```
// activate the object
POA->activate_object_with_id(objectID, servant);

// get the reference for the new object
CORBA::Object_ptr objectRef = servant->_this();
```

5.1.2.4 Object Publishing

Once created, an object must be published before client objects can use it. An object can be published simplistically by exporting the objects IOR as a string, or in a more sophisticated fashion by registering the object with a naming or trading service. The Calculator object is published through a CORBA naming service.

An object is registered with the name service with the aid of an object pointer to a naming context, returned by the ORB's resolve_initial_references() function. The naming service's interface has two operations, *bind()* and *rebind()*, either one of which can register an object with the name service. Parameters required by bind() and rebind() are a name for the object, and a reference to the object to bind to the name. The combination of a name and the object reference is referred to as name binding. The sample code below demonstrates the registration of an object with a CORBA name service.

```
CosNaming::Name name;
name.length (1);
name[0].id = “Calculator”; // name of the object
name[0].kind = CORBA::string_dup ("");

// register object with the naming service
m_NamingContext->rebind(name, objectRef);
```

Rebind() deletes a binding for the same name, if one exists already, and creates a new binding. When bind() is used and a binding with the same name exists already, a CORBA system exception is thrown.

5.1.2.5 Object Implementation

Object implementation is straightforward in CORBA. CORBA servants, unlike COM objects, don't have to implement specific standard interfaces, thanks to CORBA's strict separation of interface and implementation. All a CORBA object developer has to do is write the IDL code for the object, inherit the servant class from the skeleton class generated by the IDL compiler, and implement the interfaces specific to the objects role. Even access to a CORBA object via the DII is transparent to the object developer. More on this is given in a section 5.2.4, when describing the implementation of a late bound client with the DII.

5.2 Test Clients

Bridge testing requires the use of a number of different clients. Access to COM or CORBA objects is transparent for the clients only if the objects can be early bound. This is the case for clients accessing the test object of its own object system, or clients accessing the foreign object system's objects via the early bound bridge. Use of a generic bridge is not transparent to COM or CORBA clients, as they must prepare the argument structure to be passed to the dynamic invocation interface's invoke() function.

5.2.1 Early Bound COM Test Client

A COM client is considered early bound when it can use the IUnknown interface. A client using the IUnknown interface has complete understanding of the interfaces, operations, and operation parameters at compile time. This knowledge is provided to the client via the MIDL code that was written when the COM object was developed, or via the type library created by the MIDL compiler.

The following list is the series of common steps an early bound client has to perform in order to make calls to an object:

- Initialize COM
- Request a COM factory object
- Call CreateInstance() on the factory object
- Call QueryInterface() on the IUnknown pointer returned by CreateInstance()
- Make calls on the object pointer returned by QueryInterface()

For the same reason COM servers have to make initial communication with the COM library, COM clients also must call CoInitialize() before being able to perform other COM interaction.

As described earlier, COM creates objects based on the Factory Method pattern. Clients must therefore obtain a factory object interface to create the object they wish to interact with. COM provides the library function *CoGetClassObject()* to retrieve a factory object. CoGetClassObject() takes the CLSID of the object to be created as a parameter, and returns a pointer to an IClassFactory interface.

The client can then call the *CreateInstance()* operation on the IClassFactory pointer. CreateInstance() creates the COM object that the client is interested in, and returns an interface pointer to that object. The type of interface pointer to be returned is specified in the call to CreateInstance() by passing the desired interface's IID. The bridge test clients combine object creation and initial interface pointer acquisition in one function called *ResolveObjectGUID()*. ResolveObjectGUID() always specifies an IUnknown pointer to be returned by CreateInstance(). QueryInterface() can then be called using the returned IUnknown pointer, to obtain a pointer to the desired interface on the test object.

5.2.2 Late Bound COM Test Client

The main difference between early- and late bound clients is that late bound clients, given the lack of compile-time type information about the interfaces they wish to use, cannot use the IUnknown interface. COM does provide an alternative interface known as the IDispatch or Automation interface to invoke operations on interfaces not known at compile time. However, the IDispatch interface is far less straightforward for C++ clients to use[4].

A late bound client makes calls on a COM object implementing the IDispatch interface by performing the following steps:

- Initialize COM

[4] For scripting clients the use of IDispatch is straightforward, but only because the environment in which they execute normally provides a lot of behind the scenes support.

- Request a COM factory object
- Call CreateInstance() on the factory object
- Get the DispID of the function to call
- Prepare the argument structure for the call
- Make the call to the object

The late bound client is assumed to know the target object’s CLSID. Consequently the steps required to create the remote object are identical to the early bound client. If the late bound client knows only the remote object’s ProgID, an additional call to the COM library is needed to discover the target object’s CLSID.

The differences between early and late bound clients start when CreateInstance() returns. For a late bound client, CreateInstance() returns an IDispatch pointer instead the IUnknown pointer.

Making a call to a COM object via the IDispatch method requires the Invoke() function. The most important parameters to Invoke() are the dispID and the argument structure. DispIDs are numerical identifiers for the functions that may be called through the *dispinterface*: i.e., the set of functions accessible via the invoke() method of an IDispatch interface. The dispID is needed in order to identify the dispinterface function to invoke.

IDispatch provides a function, *GetIDsOfNames(),* that must be called to prepare the call to Invoke(). GetIDsOfNames() takes a function name as a parameter and returns the corresponding dispID.

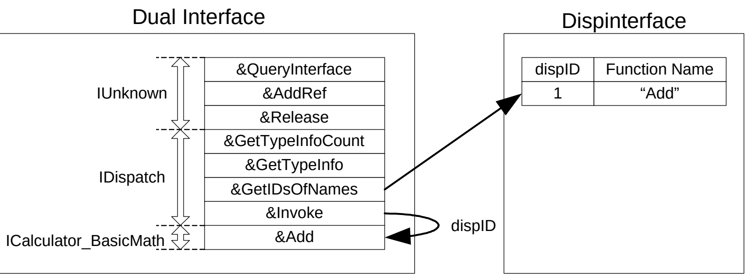


Figure 16 Dual Interface and Dispinterface on a COM object; adapted from [10]

Figure 16 illustrates the structure of the virtual function table (vtbl) for a dual interface COM object, and an access to that table via the Dispinterface. The COM object's functions can be accessed by early bound clients via the vtbl or by late bound clients via the Dispinterface.

The next step in preparation for the call to Invoke() is the creation and initialization of a structure to be passed to Invoke(). This structure, which contains the arguments for the remote object call, is an array of Variants, a type commonly used in Visual Basic to hold an arbitrary value. Variants are very important in the context of IDispatch, as they enable the passing of arbitrary values between clients and servers. A variant stores the scalar value and the type of the value it carries. The ability of variants to store values and type identifiers enables the configuration of the arguments to Invoke() at run time. Type information may be provided at run time by extraction from a type library, or other sources that can store type information. IDispatch provides methods to discover type information of an object via the *GetTypeInfoCount()* and *GetTypeInfo()* methods.

Operations a client can access through IDispatch have a numerical identifier known as the DispID. IDispatch exposes an operation called *GetIDsOfNames(),* which enables clients to get the DispID of a function from the component, by sending in the name of the function as a string. The client needs the DispID when it makes a call to the COM component via the IDispatch method *Invoke()*.

Invoke() also takes a parameter of type *DISPPARAMS*. DISPPARAMS is a structure containing the arguments that are passed on to the component implementation that processes the call. Much of a late bound client's work involves the creation of the argument structure. Once this structure is created and initialized, the dispID of the function to call is known: a call to the remote object can be made as such:

```
DISPPARAMS parameters = {myVars, 0, 3, 0};
pIDispatch->Invoke (dispid, IID_NULL, LOCALE_SYSTEM_DEFAULT,
                    DISPATCH_METHOD, &parameters, NULL, NULL,NULL);
```

5.2.3 Early Bound CORBA Test Client

A CORBA client is considered early bound when it uses IDL stub code to make invocations. The IDL compiler generates the stubs, otherwise known as static invocation interfaces. The target object's developer normally provides the IDL files to the client developer. A typical sequence of steps for a CORBA client to make an invocation is as follows:

- Initialize ORB
- Obtain object reference
- Narrow the IOR to the appropriate type
- Make invocation on object reference

The ORB initialization is performed in exactly the same way as it is done for a CORBA server, which means calling CORBA::ORB_init() and passing in the command line parameters.

Object references can be obtained in various ways. One very simple method is to pass the IOR as a string on the command line, which is only useful for debugging or quick testing. Much more practical is the use of a naming or trading service to acquire an IOR. Clients in this study use the MICO naming service as the source for IORs. The naming service reference, returned by the resolve_initial_references() function, provides the function *resolve()* to request an IOR from the directory. Resolve() takes the name of an object and returns a CORBA::Object_ptr.

The CORBA::Object_ptr must then be cast, or narrowed in CORBA terminology, to the appropriate type for the target object. The stub code generated by the IDL compiler provides the means for narrowing the CORBA::Object_ptr with the function _narrow(). Being able to narrow an object pointer to the type of object described in an IDL file is the staple feature of the static invocation interface, and depends on the availability of compile time type information.

The object pointer narrowed to the target object type can then be used as if it where the “real thing”, in the client’s address space.

5.2.4 <u>Late Bound CORBA Test Client</u>

In the absence of an IDL file to provide type information and stub code, late bound CORBA clients have to resort to the DII. The DII, like COMs IDispatch interface, provides the necessary operations to construct and dispatch requests to CORBA objects, based on type information available at runtime. A key DII element is a pseudo object[5] called CORBA::Request. CORBA::Request encapsulates the details for an invocation via the DII. A typical sequence of steps in a late bound client invocation is as follows:

- Initialize ORB
- Obtain an object reference
- Create an argument structure
- Create a request object
- Make the invocation

Initializing the ORB and obtaining an object reference is no different for a late bound client than it is for an early bound client, and has been discussed in previous sections.

The creation of an argument structure is necessary to provide the ORB with the information it needs to marshal the arguments for a call. In early bound clients this task is fulfilled by the stub code, but in late bound clients it is up to the client code.

CORBA provides a number of different ways to construct the argument structure. One possible way is to create a request object first, then use the request object's operations to add one argument at a time to the request. The operations to generate requests are provided by the CORBA::Object type. Adding one argument at a time to the request can be quite time consuming; because the CORBA implementation may consult

[5] A pseudo object is an object that has all the characteristics of a CORBA object, with the limitation that it is local to the client process, and no IOR to it can be generated.

the interface repository each time an argument is added, to verify that argument's validity. The CORBA specification leaves it to the CORBA implementation developer to decide this behavior.

Another, more efficient method to create a request object is to use the ORB, either with or without the aid of the interface repository to construct the argument list first. Once created, the argument list can be used to initialize the request object as it is created. Argument lists are create by the ORB with *create_list()* or *create_operation_list()*, and are of type CORBA::NVList. Create_list() takes a single parameter, the number of elements in the list, and returns an empty named value list (NVList). The client then initializes the elements in the NVList by specifying argument types, directions, and values. Create_operation_list() eases the work of coding by creating an NVList based on a CORBA::OperationDef, returning an NVList with argument types and directions already set from the OperationDef. CORBA::OperationDefs are descriptions of an operation and its arguments, created by an Interface Repository.

With the request created and configured, the client can make invocations on the target object by calling the requests *invoke()* method.

CHAPTER 6

BRIDGE MODELS

6.1 Early Bound Bridge

To construct an early bound bridge, the bridge developer must build a bridge object server for the bridge client's object system. The bridge server must contain a view object, for each object in the target system to be mapped to the client object system. The objects housed in the bridge server are created based on the target object system's translated IDL code[6]. The bridge server also entails the functionality of a client in the target object system in order to forward request to the target objects.

6.1.1 COM_CORBA Bridge

The COM_CORBA bridge described in this section is essentially a CORBA server that also behaves like a COM client (see Figure 17). This characterization necessitates the implementation of elements for CORBA servers and COM clients described in earlier sections.

[6] IDL code refers here to code describing interfaces, regardless of the object system for which the code was generated.

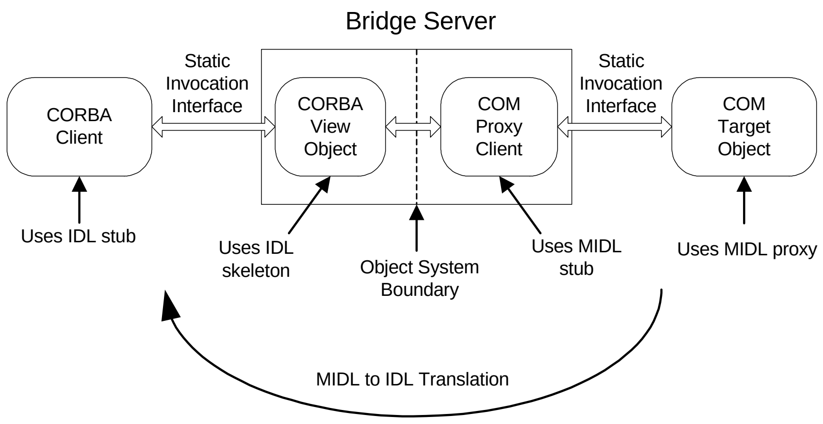


Figure 17 Architectural Model Static COM_CORBA Bridge

A prerequisite for building static CORBA View Objects is the availability of IDL code that describes the objects. Therefore, the MIDL code created by the COM object developer must be translated into the equivalent CORBA IDL code. This translation is nontrivial and requires an extensive rule set. The OMG CORBA specification invests approx. 150 pages on the rule set for mapping COM and CORBA interface definitions.

The MIDL to IDL mapping for the test object used for bridge testing was translated manually based on the CORBA interworking specification. It is conceivable that an automated translation tool could be used to convert MIDL to IDL and vice versa. However, the author is not aware of such a tool in the open source domain.

The IDL code resulting from the translation is used to create a CORBA view of the target COM object. The implementation of the CORBA view object is analogous to the implementation of a CORBA servant. A CORBA view implementation differs from a regular CORBA servant in that it does not process requests from clients; it simply forwards requests to a COM proxy object in its address space. The COM proxy object then forwards the request to the target object for processing. Appendix E shows additional details of the COM_CORBA bridge implementation.

The key aspect of an early bound bridge is that all communication between clients and target object is based on static information, i.e. known at compile time.

6.1.2 CORBA_COM Bridge

The bridge described in this section represents the 2nd leg of the early bound bridge, which provides COM clients with the means of accessing CORBA objects via the static invocation interface. As in the previous scenario, the COM_CORBA bridging, this bridge also requires the translation of the interface description from the target object system into the client object system. Again the translation was done manually.

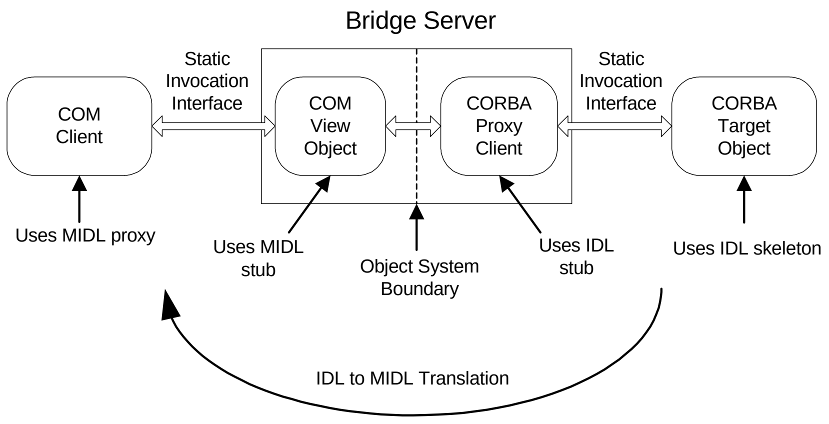


Figure 18 Architectural Model Static CORBA_COM Bridge

As shown in Figure 18 the client makes invocation on the bridge server, which has all the characteristics of a COM server. The bridge server uses a replica of the target COM view object to receive requests from clients, and dispatches the requests via a CORBA proxy object to the target CORBA object. Parameter marshalling is performed by the stub, proxy and skeleton objects, which were generated by the IDL and MIDL compilers. Additional implementation details for this leg of the static bridge can be found in Appendix G.

6.2 Late Bound Bridge

The most characteristic feature of a late bound bridge is that at compile time it does not have any information of the types of objects that it will convey invocations for. This idiosyncrasy allows it to serve as a bridge for any object, making late bound bridges far more universally usable than early bound bridges.

Late bound or dynamically bound bridges achieve their flexibility by using type information stored in an interface repository rather than the type information in an IDL file. Since the information in an interface repository is loaded dynamically at runtime a bridge can also load this information at runtime, thus enabling dynamic binding to objects for which it can find type information in an interface repository.

6.2.1 COM_CORBA Bridge

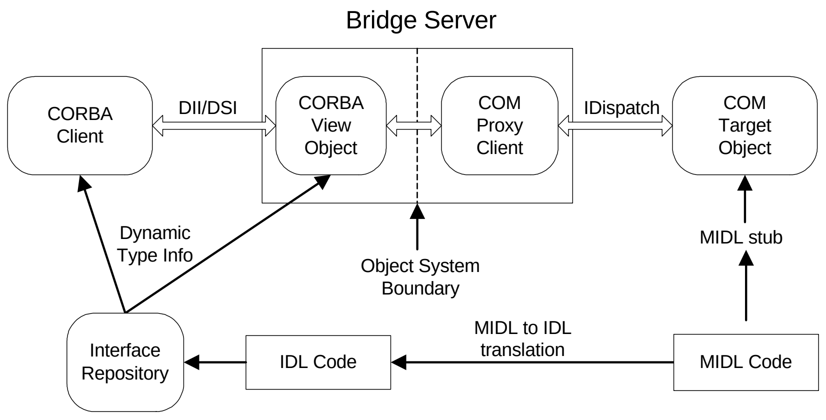


Figure 19 Architectural Model Dynamic COM_CORBA Bridge

A late bound COM_CORBA bridge, like its early bound counterpart, uses view objects, except that the view object in the former is usable as a view for any object in the target object system. To be universally usable, the CORBA view object must implement the Dynamic Skeleton Interface (DSI). The DSI is an interface of the POA, and is provided to servants through inheritance from *PortableServer::DynamicImplementation*. The DSI is transparent to the client, just as the DII is transparent to a CORBA object. The DSI, like the DII, uses a pseudo object, *CORBA::ServerRequest*, to accomplish its primary function of making generic invocations on an object servant.

The POA passes an object of type CORBA::ServerRequest to a servant's invoke() function, which it inherited from PortableServer::DynamicImplementation. The CORBA::ServerRequest object carries the function name and parameters to be invoked on the target object.

Calling invoke() on the CORBA view object's servant in Figure 19 requires the servant to package (marshal) the "in" arguments in a way that allows them to be sent to the target COM object. The servant must invoke the function on the COM object, and un-package (un-marshal) the "out" arguments when the call returns

A COM proxy client object supports the CORBA servant object in making the call to the target COM object. The COM proxy object encapsulates the knowledge of how to communicate to the target COM object via COM's dynamic invocation interface IDispatch. Although primarily designed to provide easy access to COM objects by scripting languages, the IDispatch interface can be used very well for dynamic invocations. IDispatch was discussed earlier when describing late bound clients. The COM proxy client in the late bound COM_CORBA bridge, a good example of a late bound client, uses the IDispatch interface.

In addition to forwarding invocations the bridge server must also provide a bootstrapping mechanism to clients: unlike early bound bridges, late bound bridges are not transparent to clients. The COM_CORBA bridge server provides bootstrapping through a CORBA object called COMFactory. CORBA clients can statically bind the COMFactory object, and by calling the CreateObject() function create a CORBA view object that is dynamically bound to the specified COM object. The client uses the CORBA view object, which was created on its behalf, for invocations on the target COM object.

6.2.2 CORBA_COM Bridge

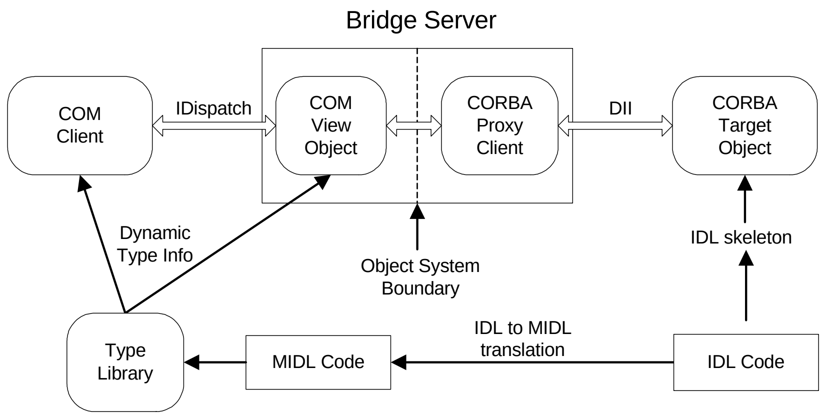


Figure 20 Architectural Model Dynamic CORBA_COM Bridge

The CORBA_COM bridge is the second leg of the two-way, late-bound bridge between the two object systems. The bridge server acts as a middleman between COM clients and the target CORBA objects. Again the bridge server plays a dual role: to the COM client it plays the role of a COM server, and to the CORBA target object it plays the role of a CORBA client. Communication between COM client and COM View object is conducted via IDispatch. CORBA client/server communication is conducted via DII. The target object's IDL code is translated into MIDL code and subsequently compiled to create the type library, which serves as the source for type information about the target object, for the client and the bridge. The CORBA_COM bridge also provides a bootstrapping object that enables the client to create the view object of the target. The COM client binds statically to the bootstrapping object and calls CreateObject() to create a view of the target object.

CHAPTER 7

PERFORMANCE TESTING

Differences in performance are an important characteristic when comparing static and dynamic bound bridges. The tests described in this chapter were designed to quantify the differences in performance for the two styles of bridges. As a control, measurements were also taken for clients accessing the test object of their own object system via static and dynamic invocation.

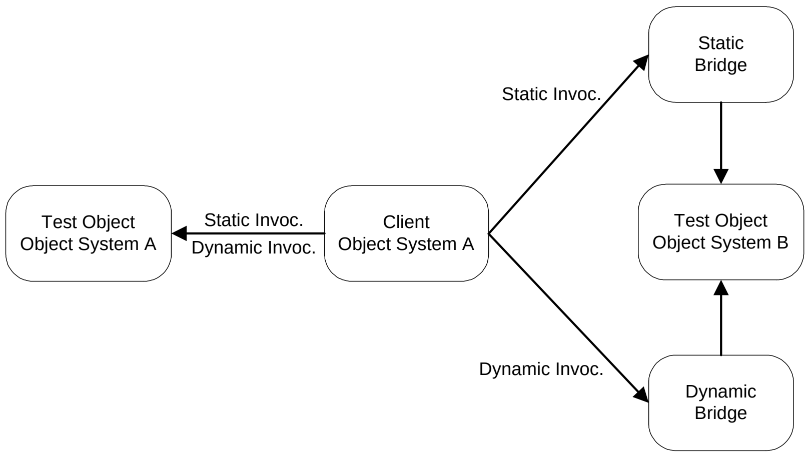


Figure 21 Performance Test Plan

Figure 21 shows a graphical representation of the measurements that were taken to determine the bridges' relative performance, including the time required to make direct calls to objects in the clients' own object systems. The test plan in Figure 21 was applied to both COM and CORBA clients. The effects of co-location[7] of clients with test object

[7] Collocation means that client process, server process, and bridge process all execute on the same host.

server and bridge server were also assessed, using two series of measurements. For one series the client was co-located and in a second series the client was remote, with respect to the object server and the bridge server. Bridge servers and test object servers were co-located in both series. The resulting test-matrix from the above stated conditions is as follows:

	Native object static invocation	Native object dynamic invocation	Foreign object static invocation	Foreign object dynamic invocation
Co-located COM Client				
Co-located CORBA Client				
Remote COM Client				
Remote CORBA Client				

Figure 22 Test Matrix

7.1 Test Procedure

The test-system used for the co-located client test has an AMD CPU clocked at 800MHz, with 512 MB of RAM, and runs Windows 2000 as its operating system. The test objects are implemented as servers running in separate processes from the client's process, as out-of-proc servers in COM terminology. For the remote client test series, a host with a Cyrix 333MHz CPU, 256MB RAM, and Windows 2000 was used. The network link between the two hosts was a 10Mbit/s Ethernet connection.

The measure for performance used in these tests is call execution time. Measuring call execution time in a non real-time operating system like Windows 2000 requires a significant number of repetitions to achieve statistical significance. Each test run consists of 1000 calls, made to the BasicMath interface's Add function. The call takes two in parameters of type short, and returns one out parameter of type long. Each test run was repeated ten times.

Execution time was measured with a high-resolution counter implemented in hardware. The Win32 API counter-access functions used for this study included *QueryPerformanceFrequency()* and *QueryPerformanceCounter()*. The counter frequency was 3.58 MHz, giving it a resolution of 0.28μs.

7.2 Data Analysis and Results

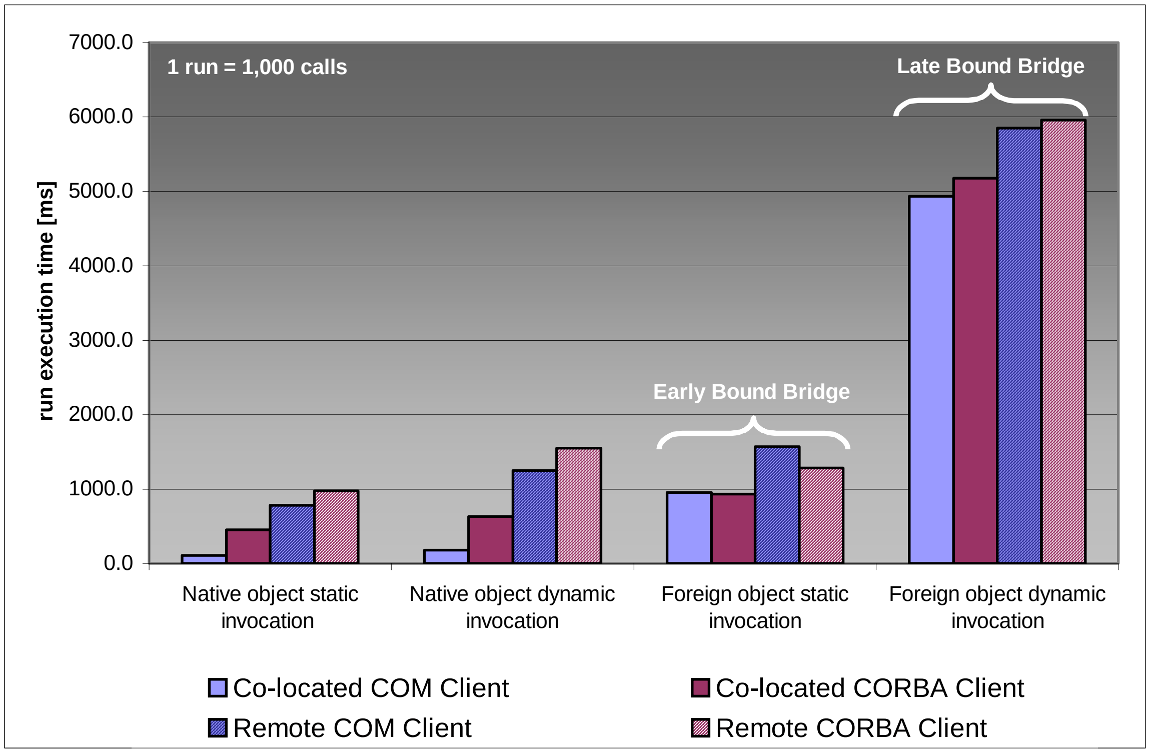


Figure 23 Test Results Summary

The data collect during the test runs can be found in Appendix K. The median for each series of ten measurements was calculated to serve as the representative figure for that series. Figure 23 plots the medians for each run, giving a comprehensive overview of all measurements taken.

7.2.1 Performance Test Results

To determine the relative performance for the two types of bridges, and also for static vs. dynamic invocation on native objects, ratios were calculated between the respective contestants.

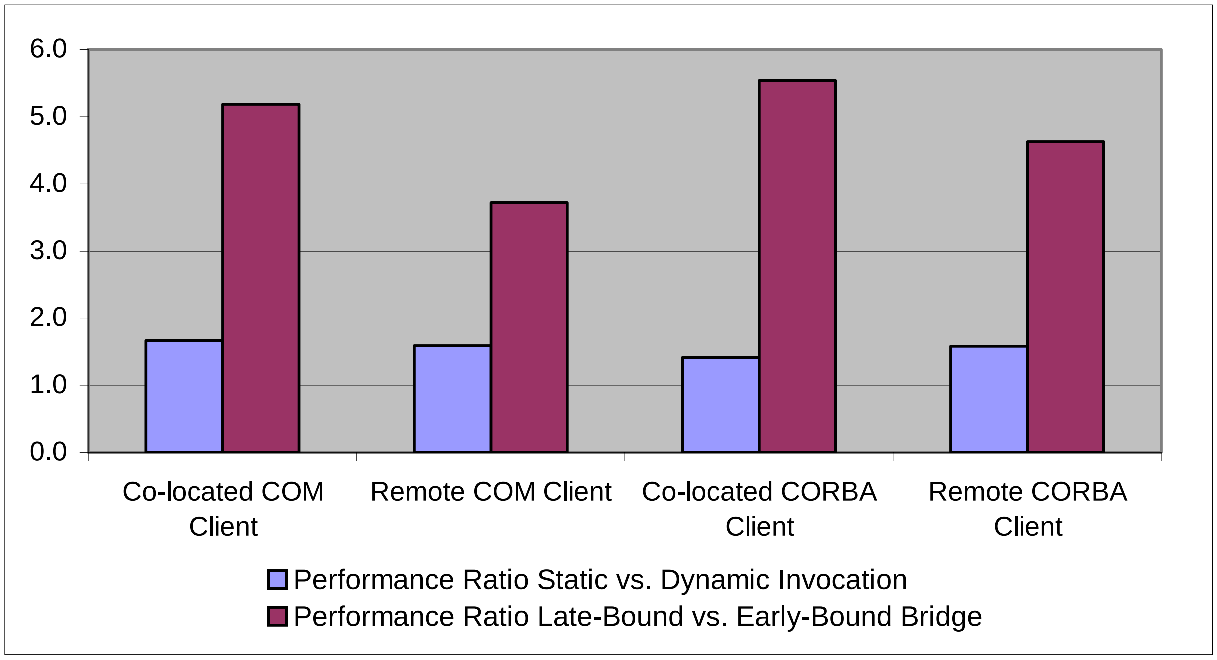


Figure 24 Bridge Performance Test Results

As expected the plot of the ratios in Figure 24 shows that a late bound bridge is significantly slower than an early bound bridge. The invocation of an object via a late bound bridge is on the order of five times slower than the invocation via a static bridge. This is not surprising as the overhead for parameter marshalling is significant. For the remote clients the performance of the late bound bridges was a little better because network latency started to impact the measurements. With increasing network traffic delays, network latencies would tend to dominate communications time, lessening the performance disadvantage of a late bound bridge. This would lead to the conclusion that for remote clients the style of bridge used becomes less important as the distance to the bridge and object host increases.

The plot of the ratio static invocation vs. dynamic also shows the expected behavior, which is that dynamic invocation is slower than static invocation. However, the difference here is far less pronounced—a factor of circa 1.5 to 1.7—than for the bridge performance. Therefore the impact of network latency is not as easily detectable in the ratio dynamic vs. static invocation.

Another observation that can be made is that COM native object invocations are substantially faster than CORBA invocations. COM client *dynamic* invocations on native objects are even faster than CORBA client *static* invocations on native objects. The relative slowness of CORBA invocations could be a function of CORBA's more complex object model, which requires deeper nested calls. However, it could also be caused by the MICO implementation model, which is based on a highly modular—and presumably less streamlined—design.

Another perspective on the collected data can be gained by plotting the percentage to which the network latencies contribute to the overall measured run times. The bars in Figure 25 were calculated from:

NWL = (RCET – CCET) / RCET * 100

RCET = Remote Client Execution Time

CCET = Collocate Client Execution Time

NWL = Network Latency Weight

The plot of NWL in Figure 25 shows that roughly 75% of a call to a remote COM client is due to network latency, with 25% due to target-object processing. Static as well as dynamic invocations appear to encounter the same network latencies. The proportion of the network latency is relatively large because invocations on native objects are relatively fast. Invocations via the bridges show the weight of network access times as less significant since call processing time is relatively long compared to network access time.

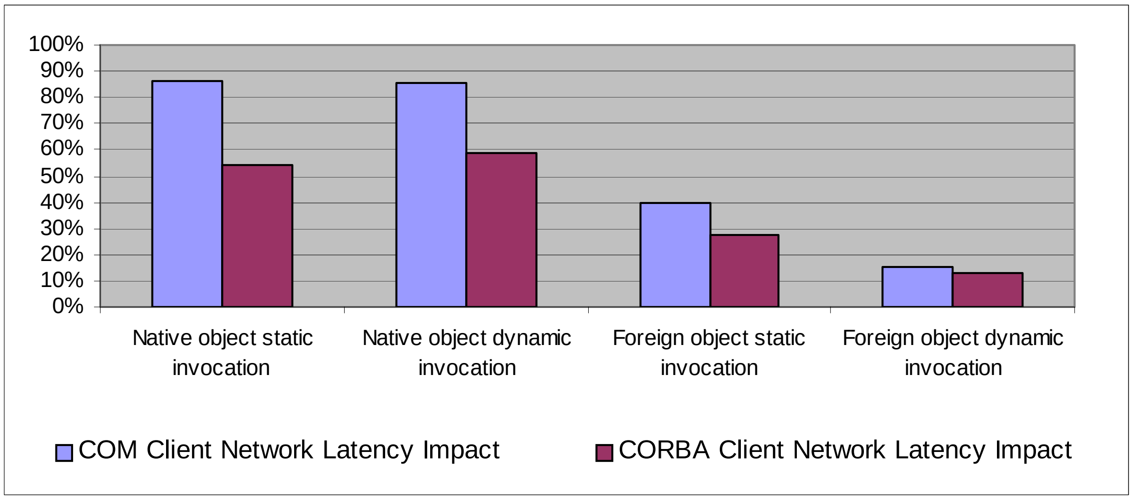


Figure 25 Network Communication Delays

CHAPTER 8

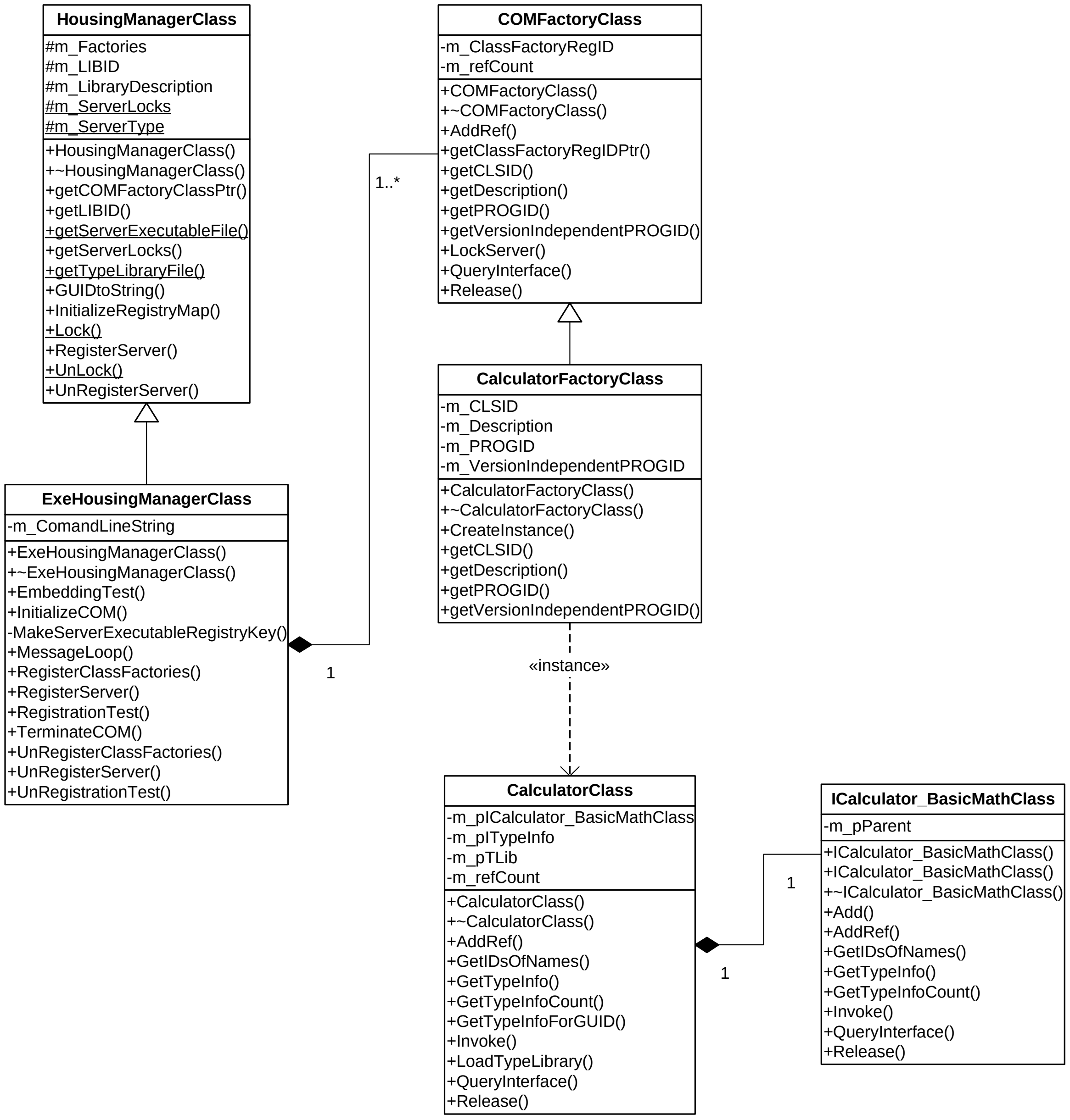
FINAL ASSESMENT AND CONCLUSION

This thesis has presented an analysis of the time needed to bridge between the COM and CORBA object systems. An early bound bridge has been shown to be faster in handling invocations than a late bound bridge, due to the availability of type information at compile time. However, this speed advantage comes at the cost of flexibility. An early bound bridge is specifically build for certain kinds of objects, excluding any objects the bridge's developer did not anticipate. The construction of an early bound bridge always requires the translation of a target object's interface description code into the equivalent of the client object system. The translation process could be improved by the creation of a cross-compiler between MIDL and IDL: a tool that translated the interface definitions, and possibly even generated the code for a bridge object, thus providing a static bridge with the advantages of a late bound bridge.

A late bound bridge has been shown to be on the order of five times slower than an early bound bridge. Yet a late bound bridge has the advantage of being universally applicable. The all-purpose characteristic of a late bound bridge is rooted in the fact that it uses runtime type information for call marshalling. The creation of runtime type information also requires the translation of interface description code, but no static bridge objects must be generated to use the target object. Instead, the type information is stored in interface repositories that are accessed by bridges at runtime to discover type information. Late bound bridges are more appealing from a bridge user’s perspective as they don’t require the building of any special code.

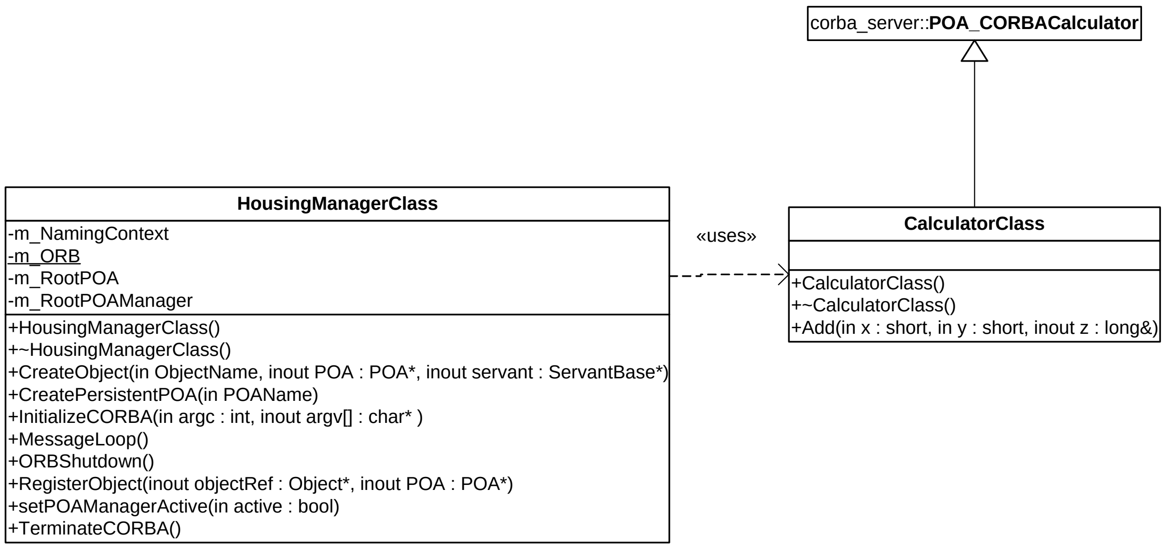
APPENDIX A

COM Test Object Server Class Diagram



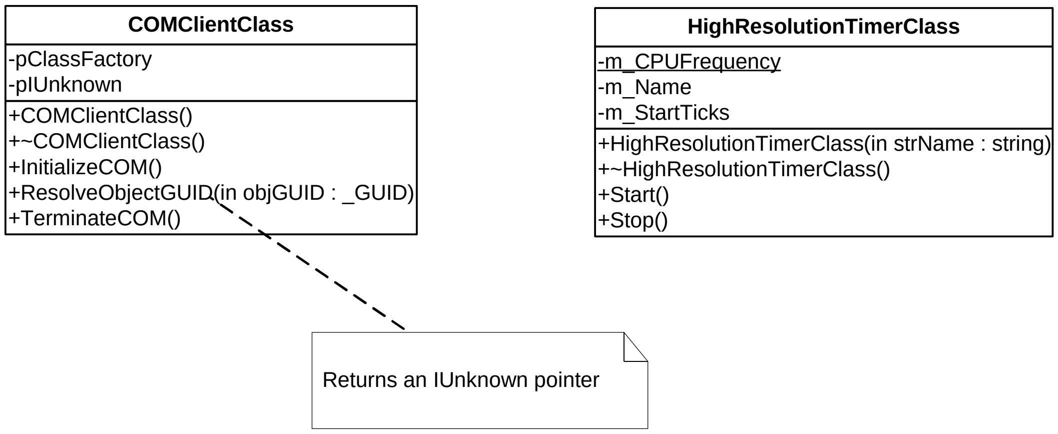
APPENDIX B

CORBA Test Object Server Class Diagram

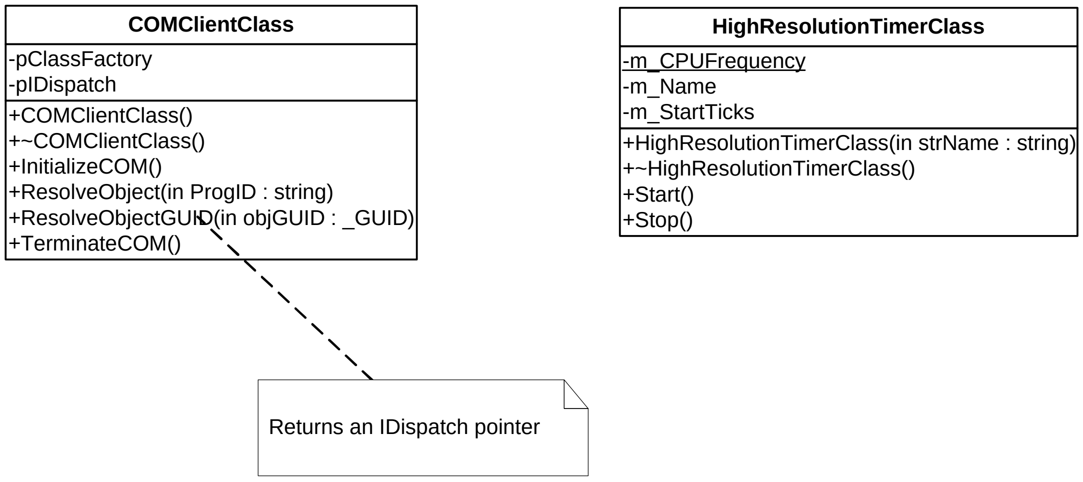

corba_server::POA_CORBACalculator
HousingManagerClass
-m_NamingContext
-m_ORB
-m_RootPOA
-m_RootPOAManager
+HousingManagerClass()
+~HousingManagerClass()
+CreateObject(in ObjectName, inout POA : POA*, inout servant : ServantBase*)
+CreatePersistentPOA(in POAName)
+InitializeCORBA(in argc : int, inout argv[] : char*)
+MessageLoop()
+ORBShutdown()
+RegisterObject(inout objectRef : Object*, inout POA : POA*)
+setPOAManagerActive(in active : bool)
+TerminateCORBA()
«uses»
CalculatorClass
+CalculatorClass()
+~CalculatorClass()
+Add(in x : short, in y : short, inout z : long&)

APPENDIX C

COM Early Bound Client Class Diagram

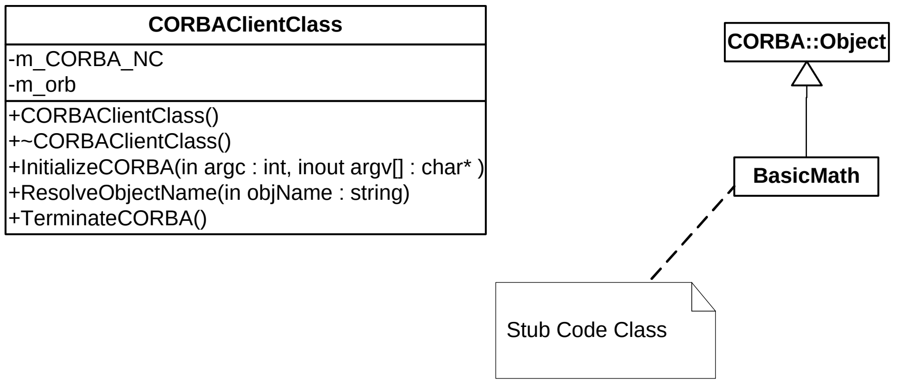


COM Late Bound Client Class Diagram

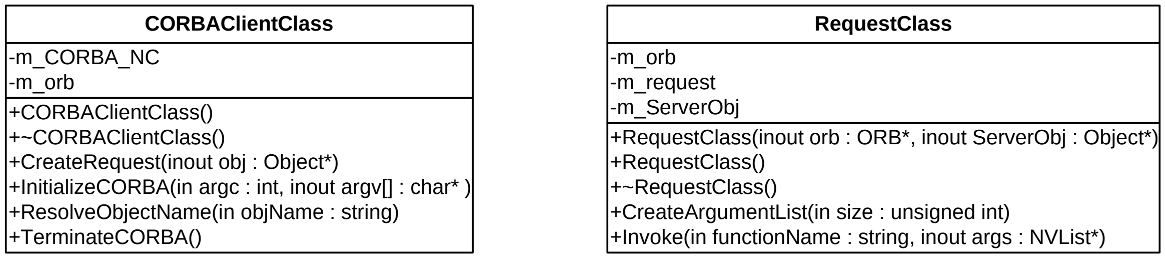


APPENDIX D

CORBA Early Bound Client Class Diagram

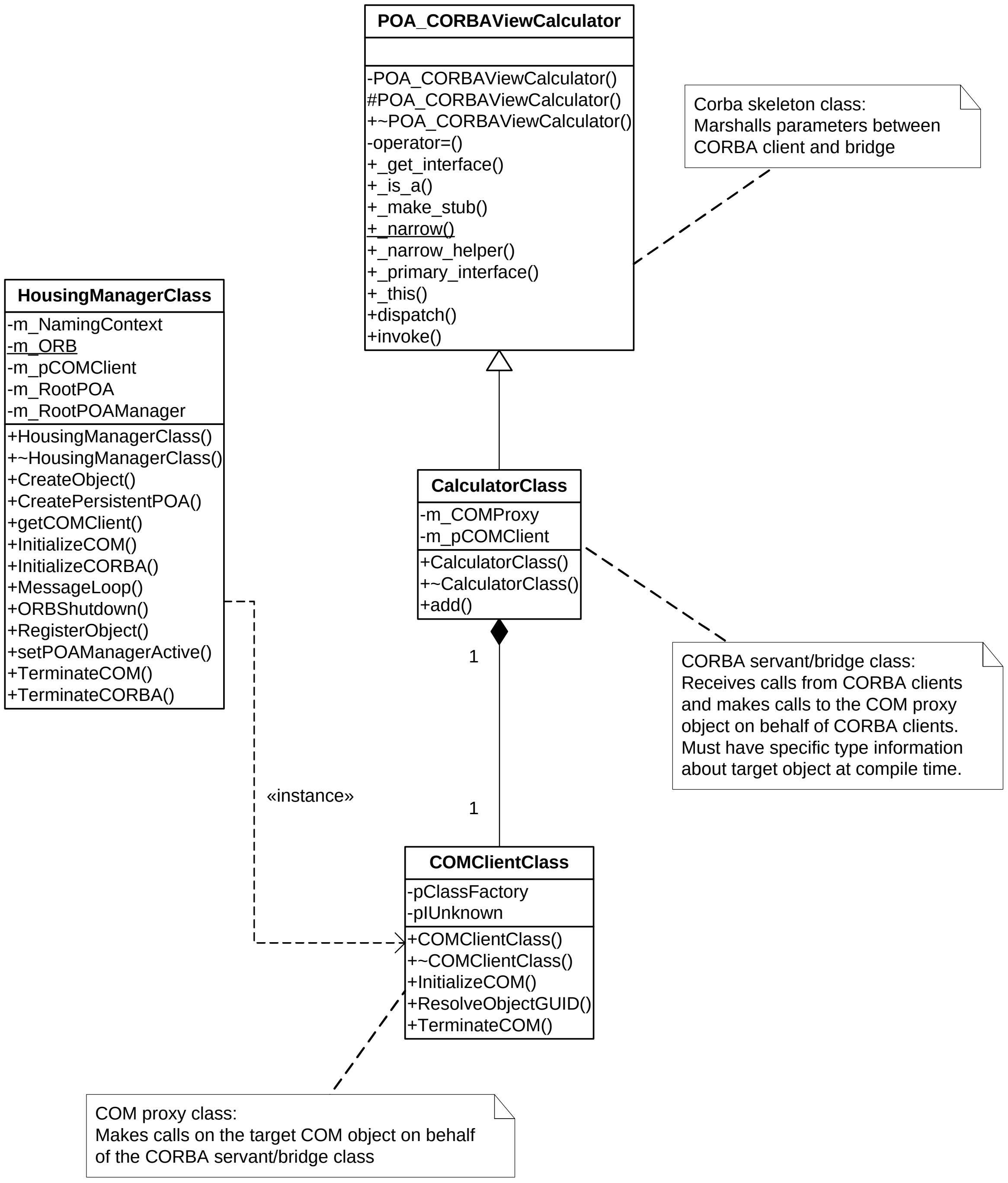


COM Late Bound Client Class Diagram


CORBAClientClass
-m_CORBA_NC
-m_orb
+CORBAClientClass()
+~CORBAClientClass()
+CreateRequest(inout obj : Object*)
+InitializeCORBA(in argc : int, inout argv[] : char*)
+ResolveObjectName(in objName : string)
+TerminateCORBA()
RequestClass
-m_orb
-m_request
-m_ServerObj
+RequestClass(inout orb : ORB*, inout ServerObj : Object*)
+RequestClass()
+~RequestClass()
+CreateArgumentList(in size : unsigned int)
+Invoke(in functionName : string, inout args : NVList*)

APPENDIX E

Early Bound COM_CORBA Bridge Class Diagram



APPENDIX F

MIDL Code of the Target COM Object

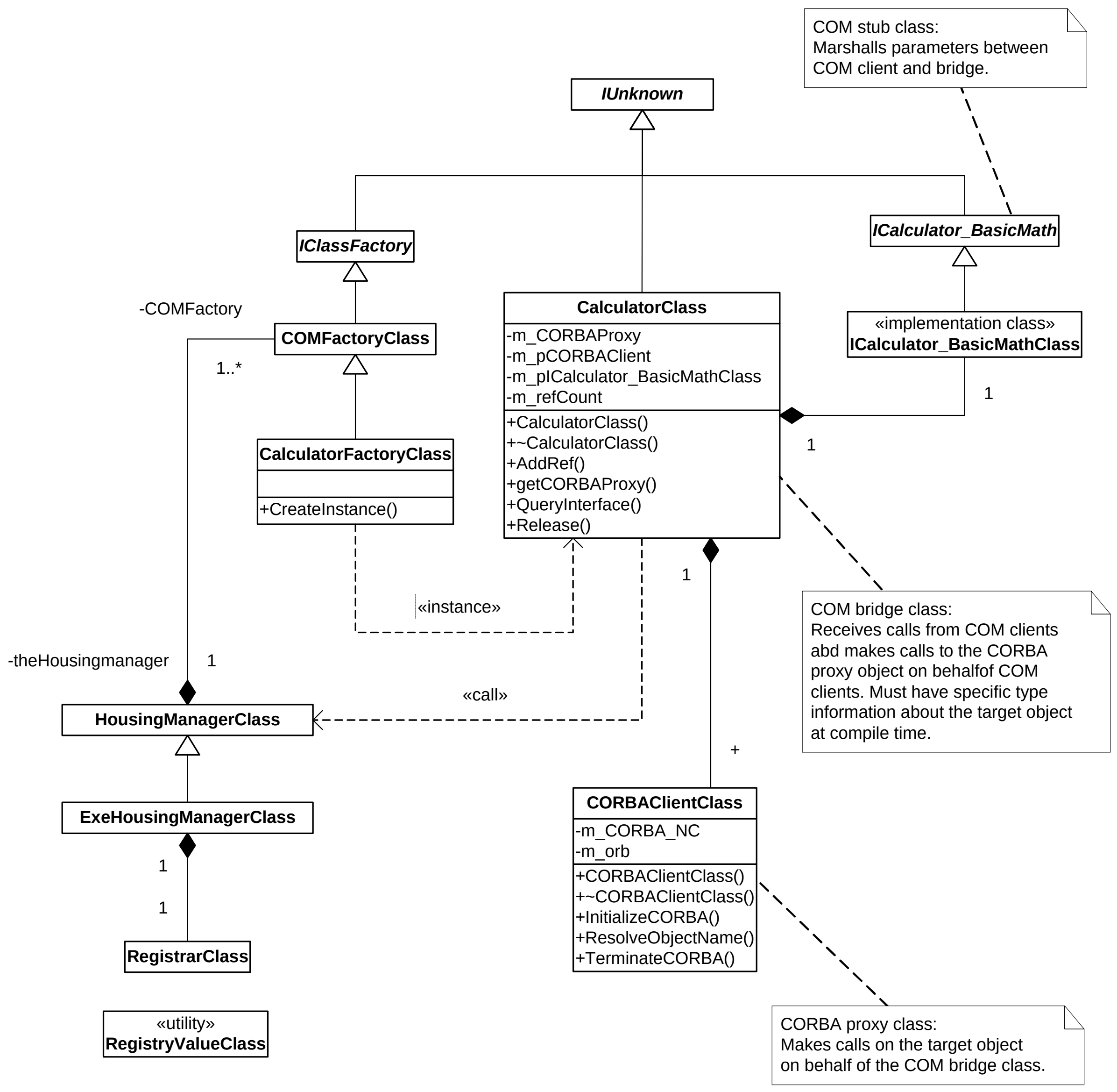
```
import "oaidl.idl";

[
      object,
      uuid(51BEE260-CBF9-4f57-86CA-217A7EA2DC71),
      oleautomation
]

interface ICalculator_BasicMath:IUnknown
{
      HRESULT add( [in] short x, [in] short y, [out] long* z );
};

[
      uuid(B11E5D95-F527-4de8-8F60-065513920635), //LIBID
      version(1.0), helpstring("COM Calculator Library")
]
library COMCalculatorLibrary
{
      importlib("stdole32.tlb");
      [uuid(9FD7A036-D00B-4907-A460-D1212ED68E69)] //CLSID
      coclass COMCalculator
      {
            [default] interface ICalculator_BasicMath;
      };
};
```

MIDL to IDL Translation for the CORBA View of the Target Object

```
interface BasicMath {
      void add( in short x, in short y, out long z );
};

interface CORBAViewCalculator : BasicMath
{
};
```

APPENDIX G

Early Bound CORBA_COM Bridge Class Diagram



APPENDIX H

IDL Code of the Target CORBA Object

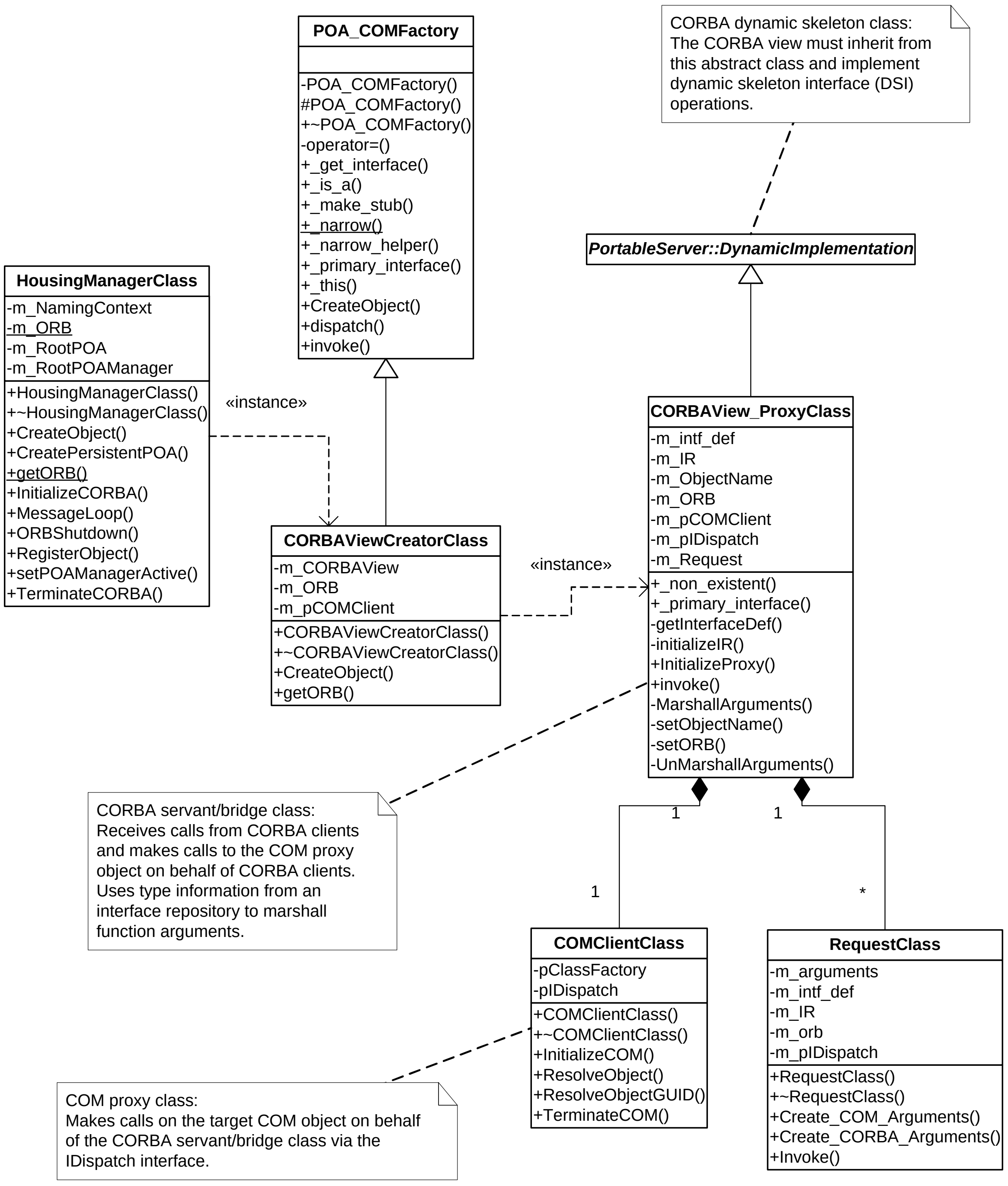
```
interface BasicMath {
      void Add( in short x, in short y, out long z );
};

interface CORBACalculator : BasicMath
{
};
```

IDL to MIDL Translation for the COM View of the Target Object

```
import "oaidl.idl";

[
      object,
      uuid(0A597D75-FCCD-4f93-A4F0-FAC890A2CEE5),
      oleautomation
]

interface ICalculator_BasicMath:IUnknown
{
      HRESULT Add([in] short x, [in] short y, [out] long* z);
};


[
      uuid(C2648F1C-3DD1-4da9-A076-42F7E269035C), //LIBID
      version(1.0), helpstring("COMView Calculator Library")
]
library COMViewCalculatorLibrary
{
      importlib("stdole32.tlb");
      [uuid(0528DA48-23B1-4da7-8DBC-AD5BC6081C7E)] //CLSID
      coclass COMViewCalculator
      {
            [default] interface ICalculator_BasicMath;
      };
};
```

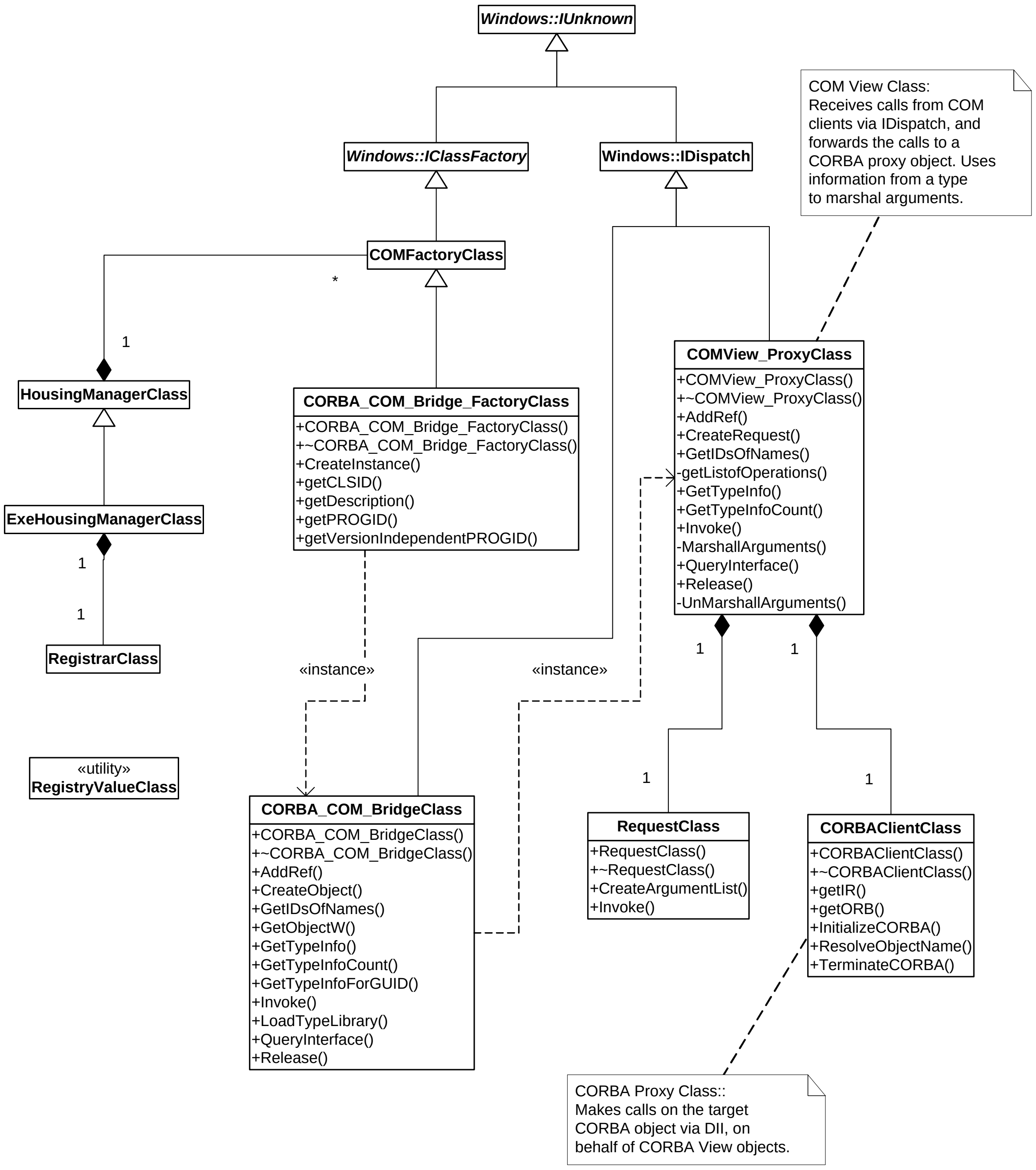
APPENDIX I

Late Bound COM_CORBA Bridge Class Diagram



APPENDIX J

Late Bound CORBA_COM Bridge Class Diagram



APPENDIX K

Test Data

COM Client Co-located

test run number	COM object static invocation	COM object dynamic invocation	CORBA object static invocation	CORBA object dynamic invocation
1	110.4	182.0	949.2	4929.1
2	110.7	181.1	949.6	4942.3
3	109.3	183.4	952.9	4941.8
4	109.9	182.4	949.6	4922.8
5	110.1	182.6	953.2	4939.2
6	109.1	189.0	951.8	4938.9
7	109.5	182.3	951.0	4944.4
8	109.3	182.0	957.8	4931.6
9	109.6	182.5	955.3	4927.1
10	109.1	182.1	954.4	4935.1
Median	109.6	182.4	952.4	4937.0

CORBA Client Co-located

test run number	CORBA object static invocation	CORBA object dynamic invocation	COM object static invocation	COM object dynamic invocation
1	457.3	635.7	930.2	5155.1
2	448.5	633.6	942.0	5167.2
3	448.9	630.6	951.5	5177.1
4	449.5	632.8	935.7	5169.7
5	448.1	707.7	941.0	5183.1
6	448.5	635.7	935.9	5189.4
7	449.1	629.1	941.1	5178.6
8	453.0	633.5	934.4	5221.3
9	453.0	633.7	933.3	5192.3
10	450.1	624.8	936.0	5196.1
Median	449.3	633.6	936.0	5180.9

COM Client Remote

test run number	COM object static invocation	COM object dynamic invocation	CORBA object static invocation	CORBA object dynamic invocation
1	866.8	1272.9	1578.1	5856.9
2	797.9	1284.0	1571.5	5850.9
3	812.5	1254.2	1576.2	5852.3
4	791.2	1265.8	1565.3	5857.3
5	798.8	1259.0	1587.6	5836.3
6	772.8	1245.6	1562.1	5823.0
7	776.3	1240.5	1571.8	5849.4
8	774.3	1239.1	1577.1	5844.1
9	771.8	1230.7	1559.1	5828.0
10	776.5	1244.4	1563.3	5853.7
Median	783.9	1249.9	1571.7	5850.2

CORBA Client Remote

test run number	CORBA object static invocation	CORBA object dynamic invocation	COM object static invocation	COM object dynamic invocation
1	994.5	1651.1	1468.0	5943.3
2	997.1	1551.0	1302.2	5953.7
3	984.4	1553.8	1297.2	5933.0
4	989.0	1528.5	1299.0	5957.6
5	968.7	1532.9	1287.3	5963.6
6	970.3	1537.2	1282.3	5954.1
7	979.4	1555.4	1282.2	6003.6
8	973.2	1544.1	1286.3	5970.9
9	971.3	1540.7	1281.9	5979.6
10	970.0	1547.1	1273.1	6211.8
Median	976.3	1545.6	1286.8	5960.6

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VITA

EDWIN KRAUS

Personal Data:	Date of Birth: January 20, 1970
	Place of Birth: Mediasch, Romania
	Marital Status: Single
Education:	Public High-school, Bochum, Germany
	Professional School, Bochum Germany; major in Electronics 1991
	FH-Bochum, Bochum, Germany; Bachelor in Mechatronics (Electrical/Mechanical Engineering & Computer Science), 1997
	East Tennessee State University, Johnson City, Tennessee; Information Science, M.S. 2003
Professional Experience:	Nokia Electronics, Bochum, Germany; Technician, 1987-1991
	University of Bochum, Bochum, Germany; Student Assistant, department of physics, 1995
	OVAKO Ajax, York, South Carolina; Engineering Intern 1996
	Siemens Energy&Automation, Johnson City, Tennessee; Process Engineer, since 1997
Honors and Awards:	Member of Upsilon Pi Epsilon
	Member of Phi Kappa Phi