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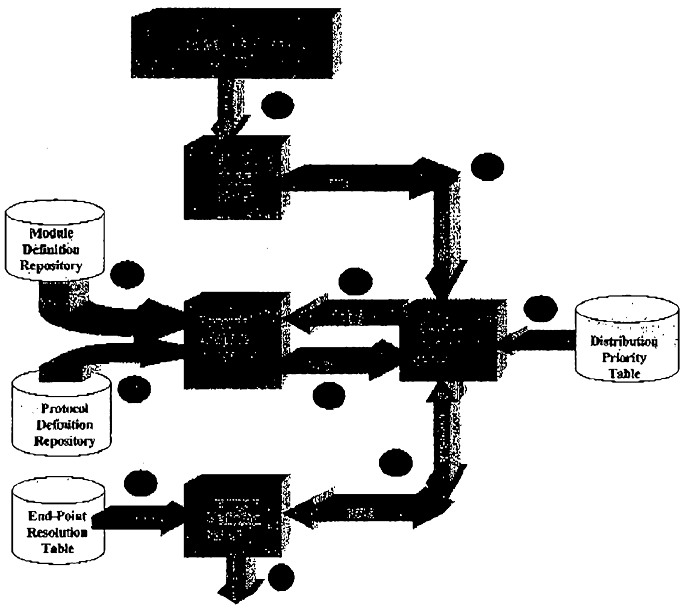
Module Definition Repository
Protocol Definition Repository
End-Point Resolution Table
Distribution Priority Table

(57) **Abstract:** A method of flow of an outbound communication to another module with interface using a broker which is able to review all data structures, regardless of complexity, as being comprised of a finite set of primitive data types (e.g. integer, float etc.) and with reference to the repository determine a mechanism for reading and writing these types to enable processing of structures of arbitrary complexity, wherein the rules and mechanisms for reading these basic types are defined by the protocol and once the rules are captured allow processing of any message over this protocol.

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MIDDLEWARE BROKER

This invention relates to a middleware broker for middleware. In particular it relates to a data transfer means between various protocol systems to provide an integrated system.

Background

Middleware is a software layer that aims to provide the glue between interacting components in a distributed computing environment. There is a variety of middleware types: among others, synchronous procedural RPC (Remote Procedure Call) oriented middleware, such as DCE-RPC, and asynchronous MOM (Message-Oriented-Middleware) based products, such as IBM's MQ-Series; transaction-oriented middleware include BEA's TUXEDO and IBM's CICS; more recently, object-based middleware, the best known of these being OMG's CORBA, Microsoft's DCOM and Java/RMI. Systems based on one of these methods are not directly protocol-level compatible with systems based on another. For example, a CORBA client is not plug-compatible with a DCOM server, even if both run on an NT platform. Although both systems are based on an object model, the implementations of these object-based systems are quite different.

The current corporate climate has placed pressure on many organisations to expand or to become part of larger existing networks. Companies are taking-over or merging with others, and small companies increasingly have had to join global networks to compete locally (e.g. "small companies, global networks"). The resulting super-organisations typically include a mix of generally incompatible IT systems, which need to be integrated to fully exploit the new structures. The problem of protocol-level systems integration is compounded if both companies use different operating environments. For example, a large company may use an IBM mainframe, while a smaller one uses Windows-based PCs. Ideally, the middleware should provide a pipeline to transparently support this communication. However, integration with legacy systems still requires significant amounts of coding.

The different approaches to inter-operability can bc classified as:

- Handcrafted Solutions: It consists of writing ad-hoc software to implement each interoperation requirement. Although this approach is widely applicable, and very commonly used, it is labour-intensive and requires considerable expertise not always available. Such approaches are also difficult to maintain over time.

- Proprietary approaches (commercial EAI products): Usually result in the user being locked-in with a proprietary solution.
- Architectural approaches: Provide mainly a high level modelling view of systems, and are not of much practical benefit to the low level systems integrator. Certainly, they do not allow for any automated protocol-level integration.
- Specific middleware approach: Systems such as ASTER [14] provide an API that allows different protocols to be translated to CORBA. (i.e. ASTER relies on a single middleware, CORBA, to provide all remote (RPC) and component services.)

Protocol-level integration of legacy systems with other systems has been reported to be a major challenge with no obvious general solutions. Low-level systems integration is difficult, because application semantics must be addressed and low-level manual data marshalling is often required.

Direct translation between two different formats or, more generally, two different protocols is the oldest method of achieving data interchange. By writing custom computer source code that is later compiled and installed on the target platform, it is possible to achieve interoperability between two different data formats. If the source code is carefully tuned by someone very skilled in the art, the resulting translator will be a high-performance one. However, it will not work if any change in data format or protocol occurs, and will require additional programming and installation effort to adapt to any such change. Direct translation can offer excellent performance, but it is even less flexible than the static adapters used by "middleware" systems.

Instead of a static adapter or custom-coded direct translator, it is the use of some kind of data or protocol description that can offer greater flexibility and, thereby, connectivity. U.S. Pat. No.5,826,017 to Holzmann (the Holzmann implementation) generically describes a known apparatus and method for communicating data between elements of a distributed system using a general protocol. The apparatus and method employs protocol descriptions written in a device-independent protocol description language. A protocol interpretation means or protocol description language interpreter executes a protocol to interpret the protocol description. Each entity in a network must include a protocol apparatus that enables communication via a general protocol for any protocol for which there is a protocol description. The general protocol includes a first general protocol message which includes a protocol description for a specific protocol. The protocol apparatus at a respective entity or node in a network which receives the first protocol message employs a protocol description language interpreter to interpret the included protocol description and thereby execute the specific protocol.

One known but not commonly known automated approach is that proposed by Dashofy *et al* who investigated using various off-the-shelf middleware products to build bridges or connectors for distributed systems. They present their views from a software architecture perspective, restricted to the C2 architectural model. They have built software connectors that are specific to four middleware packages, Q, Polylith, RMI, and ILU. This means that to add support for another middleware package, a new specific connector (program) would need to be developed. Commercial tools such as those provided by commercial Enterprise Application Integration (EAI) products are similarly restricted.

A recently published granted US patent document is US 6,772,413 which discloses a high level transformation method and apparatus for converting data formats in the context of network applications, among other places. A flexible transformation mechanism is provided that facilitates generation of translation machine code on the fly. A translator is dynamically generated by a translator compiler engine. The translator compiler engine implemented according to the present invention uses a pair of formal machine-readable format descriptions (FMRFDs) and a corresponding data map (DMAP) to generate executable machine code native to the translator platform CPU. When fed an input stream, the translator generates an output stream by executing the native object code generated on the fly by the translator compiler engine. In addition, the translator may be configured to perform a bi-directional translation between the two streams as well as translation between two distinct protocol sequences.

However this document discloses a translation method by generating a set of executable machine instructions for direct processing, said executable machine instructions being generated as a function of a data segment mapping, input format description and output format description, said executable machine instructions to translate an input data stream directly into an output data stream. Further the disclosure is primarily aimed at XML formats. This system is highly data bit intensive and therefore is primarily only suitable for repetitive processing of a single known protocol to another single known protocol.

It is an object of the invention to provide an easier and flexible approach to provide a middleware broker for middleware protocols, as well as for legacy systems.

It is also an object of the invention to provide protocol-level inter-operability which supports a wide range of protocols, including legacy systems and could allow new protocol support to be added with no impact on existing systems (i.e. protocols can be changed (added or removed) without re-compilation of application software).

In accordance with the invention there is provided a system of intercommunication including the steps of:

defining the structure of one or more protocols used in communication and storing said structure in a library;

at run time analysing an input communication and determining an appropriate input structure of protocol of the input communication from the library and analysing the path of the intended output communication and determining an appropriate output structure of protocol of the output communication from the library;

providing a dynamic marshaller for processing at run time and sending the information in accordance with the identified output structure from the corresponding relevant sections of the identified input structure;

wherein the system allows ready communication between various protocols.

The system can include the library having a predefined conversion of the structure of one or more protocols to the structure of another of the one or more protocols.

The dynamic marshaller can provide buffering or addressing as required.

The system also provides for the dynamic marshaller to include definable predefined processing steps of corresponding relative sections of the identified output structure to the identified input structure.

It can therefore be seen that the predefined processing steps can be protocol neutral such that an end user can define the processing steps in a generic manner and the dynamic marshaller undertakes the required manipulation of the data in any communication based on the predefined processing step of the relevant section of the communication protocol structure. This provides a required effect regardless of the protocols of communication. The end user therefore need not be aware of the details of the protocol languages to enable a required manipulation. In particular there can be user defined or third party defined modules can be invoked at particular points during marshalling and un-marshalling (message processing).

In accordance with the invention there is provided a method of intercommunication of middleware including the steps of:

providing a table of initial definition of structure characteristics, including format and parameter data types, of one or more protocols;

converting said one or more structure protocol definitions into a selected format;

storing said one or more structure protocol definitions in said selected format in one or more repositories;

at run time assessing the incoming message and selecting an appropriate structure protocol definition to be used from the table and using the selected format of the converted structure protocol definition to communicate.

It can be seen that the method does not undertake a full conversion but instead, before the time of the message, a structure of the protocol has been defined and the data and information in the form of the protocol structure can be readily communicated in a protocol structure format that would be understood by the receiver.

The invention also provides a method of flow of an outbound communication to another module with interface including the steps of:

assessing the application of the outbound communication to determine and select a protocol to try from a table of protocols in a priority arrangement;

using the selected protocol to determine the format and arguments for the outbound communication;

using the protocol definitions stored to prepare the outbound communication for the particular middleware or application service;

providing required buffer;

determining which protocol to use for transmission;

looking up table of end-point resolutions to determine the communication parameters required to communicate with the selected transmission protocol;

attempting to communicate with the designated host using the appropriate communication parameters; and

if communication with the selected protocol fails selecting the next protocol to try from the table of protocols in the priority arrangement.

The invention also provides a method of flow of an inbound communication from another module with interface including the steps of:

receiving inbound message in the protocol that it was sent;

looking up table to determine whether the message needs marshalling into another protocol before passing the inbound communication to the target application on the local system;

if message needs marshalling into another protocol, determining the preferred protocol from a table according to priority;

determining the format and arguments for the inbound communication;

using stored protocol definitions for the selected protocol to prepare the inbound communication for the target middleware or application service;

buffering the inbound communication as required;

determining protocol to use for transmission.

determining local end point of the target application on the local system; and

at run time passing the inbound communication to the target application on the local system.

It can be seen that the invention provides an easier and flexible approach in which rules and middleware characteristics are specified in a repository, for the system broker to provide the connection and transformation for the middleware protocols, as well as for legacy systems. In particular it is not necessary to have a converter at either end of the communication. Further it is not necessary for there to be two way communication in order to ensure the receiver knows what format is arriving, instead the conversion due to the relevant structure format correlations allows ready flow of data from one input protocol to form readable by output protocol.

It should be noted that protocols are specified in a language neutral machine independent definition language. The language specifies the structure of messages and the parameter templates to establish a connection and exchange messages.

In one form of the invention the language neutral machine independent definition is compiled into binary modules known as protocol implementation modules (PIMs) and transport interface modules (TIMs). The TIMs contain the communication partameters.

These PIMs and TIMs are loaded at runtime and executed by interpreters (virtual machines). PIMs are processed by the dynamic adaptive marshaller (DAM) and the TIMs are handled by the transport mediation server (TMS). Both of these modules are controlled by the message distribution server (MDS). The MDS is also responsible for any interface mapping that is required. It uses either the processed request or response message and a mapping definition. The actual mapping is performed by a mapper module under the direction and control of the MDS.

In one preferred form of the invention the middleware broker is The Ubiquitous Broker Environment (the TUBE system). TUBE allows any defined interface to be marshaled across any defined protocol. This is achieved using existing clients and servers. There are no code changes. The protocol may be switched from A to … at runtime without requiring a stop/start of the application or TUBE runtime. The mode of the interaction may also be switched from say synchronous to asynchronous without operational impact. The client is oblivious to the change. In other words TUBE can make a synchronous protocol asynchronous and visa-versa. TUBE implements protocols using loadable modules called Protocol Implementation Modules (PIMs).

The major premise behind TUBE is that all data structures, regardless of complexity, are comprised of a finite set of primitive data types (e.g. integer, float etc.). Once we have a mechanism for reading and writing these types, we are able to process structures of arbitrary complexity. The rules and mechanisms for reading these basic types are defined by the protocol. Therefore, once we capture these rules we can process any message over this protocol.

For example CORBA uses an encoding known as CDR (Common Data Representation) for reading and writing basic data types. Once we have the rules of CDR or a callable library that implements the rules of CDR, we are able to process CDR-based (CORBA) messages. All we now have to do is define the structure of a CORBA request and response message.

This allows users or third-parties to create new protocols and drop them directly into their environment. The protocol does not even have to be physically implemented in a client or a server. A TUBE PIM on one side can act as the client and another PIM can act as a server on the target side. This enables use of the protocol *without any coding.* For example, an existing client using protocol XX is able to make a call to a server using XX. Without disruption to either client or server TUBE can intercept the XX message, convert it to the new protocol and send it across to the receiving node. At the receiving end, TUBE can convert back to protocol XX and pass to the original server. This allows users "to play" with protocols before actually implementing (or rewriting) existing clients or servers.

What if we want to add a new middleware? Let's say a bank wants to develop its own internal, secure middleware. They don't want to change all their client-side source code. Let us assume that the server-side has already been modified to support the new middleware. For the remainder of this discussion we shall refer to this new middleware as OSM (Our Secure Middleware) and to the existing middleware as XX. OSM requires that its payload be encrypted using its own crypto algorithm. The clients are still making calls via XX and are unaware of this requirement. OSM also introduces a new transport layer that is also encrypted. Without re-writing all the client code to use the new OSM APIs, How can the bank achieve integration?

TUBE provides a middleware definition tool specifically for this purpose. The tool consists of a number of modules, each dedicated to a specific task related to the definition. The first thing that needs to be defined is the payload format. This is defined as a binary sequence. It is also defined that this binary sequence must be obtained by a call-out to an OSM API, which carries-out the encryption.

The API module-name, signature and parameters are obtained in either of two ways; they can be imported from a C-language header or Java class definition, or be specified in the tool. This information is stored temporarily in a meta-language format called PDL (Protocol Definition Language).

The next part of the definition involves the interaction with the OSM transport. This specifies how we get messages into and out of OSM. This operation is divided up into three phases; the method of establishing a connection, the method of conducting a session, and termination actions. These definitions include any API interactions.

When we are satisfied with our definitions, we generate the specification. The specification consists of two parts; protocol implementation and transport interface. The PDL compiler generates these specifications (modules) and stores them in the Protocol Definition Repository (PDR) and Transport Interface Repository (TIR) respectively. Once these have been generated, we specify the end-point information in the End-Point Resolution Table (EPRT) and add OSM to the Distribution Priority Table (DPT), and set it as the preferred protocol for the interface defined in MDR. The interface was already defined in the MDR, only we were using XX rules to marshal any interactions.

If TUBE wasn't aware of the interfaces used over XX, then the IDL compiler would need to be run to import the interface definitions and the XX clients would need to be pointed to a TUBE XX module. This allows TUBE to intercept the client calls, while the clients still believe they are talking to an XX server. The bank can now exchange messages over OSM using its existing XX-based clients. No modules required modification. The only changes were at a configuration level. Anytime an XX-based message is intercepted by TUBE, the OSM-PIM and OSM-TIM are invoked by DAM and TMS respectively to marshal and send messages via OSM.

Before the bank makes the significant investment of actually implementing its "secret" protocol, they would like to test out its robustness and resilience to attack.

They are able to do this using TUBE as the implementation. All they need to implement is the encryption library, which TUBE will call during marshal and un-marshal operations. This way their algorithm remains secret. TUBE is unaware of its detail or structure. It merely handles the (potentially) complex traversal of the interface definitions. Usually these would have to be hand-coded for each interface. TUBE saves the bank a vast amount of work.

With traditional middleware and EAI tools:

- new connectors fully implementing OSM would need to be developed for every interface that
  would be processed.

- New Protocols cannot simply be defined and "virtually" implemented.
- Protocols must be *fully implemented* end-to-end.

Using TUBE the bank is able to:

- test-drive its new protocol before investing in complete implementation
- choose whether or not to physically implement OSM in its servers or clients
- revert back to XX at anytime by a simple configuration change
- set-up redundancy by using TUBE's protocol alias and prioritization features
- enable clients of any protocol (e.g. web-based SOAP clients) to access services

  supplied by OSM. TUBE handles the SOAP to OSM conversion
- future-proof its clients and servers from middleware changes. Coding is only required if the

  bank wishes to change the functionality of its clients or servers.
- *using TUBEs' rule engine may even alleviate that requirement*

TUBE uses a modified IDL style language (Protocol Definition Language or PDL) to define protocols. This PDL definition is compiled into a set of binary op-codes. This collection of op-codes is known as a Protocol Implementation Module (PIM). The Dynamic Adaptive Marshaller (DAM) is a virtual machine, which loads and executes the op-codes in the PIM at run-time. The op-codes in the PIM contain instructions for traversing the interface definitions stored in the Module Definition Repository (MDR). These definitions are obtained by parsing the IDL description for the interface.

Constructs defined in the script, which are not part of the message payload (for example the header) are stored in a run-time variable segment and only used for same-protocol exchanges. The items that constitute the body of the message (as defined in MDR) are stored in an intermediate format known as a TLV (Type, Length, Value) buffer. When marshaling an out-bound (target) message, the values are obtained from the TLV buffer.

In order that the invention is more readily understood an embodiment will be described by way of illustration only with reference to the drawings wherein:

Referring to the drawings and tables there is shown a method of intercommunication of middleware including the steps of providing a table of initial definition of structure characteristics, including format and parameter data types, of one or more protocols; converting said one or more structure protocol definitions into a selected format; storing said one or more structure protocol definitions in said selected format in one or more repositories; and at run time assessing the incoming message and selecting an appropriate structure protocol definition to be used from the table and using the selected format of the converted structure protocol definition to communicate.

As shown in Figure 1 middleware broker of the invention includes The Ubiquitous Broker Environment (the TUBE system) which uses PDL (Protocol Definition Language), and a declarative scripting language (based on OMG-IDL) to define the characteristics of a particular protocol. The TUBE Protocol Definition tool provides a GUI interface for users to produce PDL scripts. This script is then submitted to the PDL compiler, which converts it into an internal format that TUBE can process at runtime. The output of the PDL compiler is stored in the Protocol Definition Repository. The TUBE Interface Description Language (IDL) compiler processes the IDL definition of the interfaces that need to communicate. These files define the format and data types of the parameters passed between clients and servers. TUBE stores this information in its Module Definition Repository. This data in conjunction with the protocol definition (stored in the Protocol Definition Repository) is all that TUBE needs to convert messages between different middleware formats.

The Distribution Priority Table stores the names of the various protocols supported for each interface defined in the Module Definition Repository. These protocols are stored in priority order; that is, starting by the preferred protocol, followed by each subsequent protocol. Each entry in the Distribution Priority Table corresponds to an entry in the End-Point Resolution Table. This table defines the communication parameters necessary to communicate with the interface over the specified protocol. In the case of CORBA, for example, this would be the IOR for a server that implements the desired interface. The information stored here depends entirely on the protocol. These two tables are used in conjunction by TUBE to determine where and how to send messages between different middleware.

Figure 2 shows the main components of the architecture of The Ubiquitous Broker Environment (TUBE). Systems that work through TUBE will use the TUBE API, or use their own middleware API, and have these calls intercepted and processed by TUBE. TUBE consists of four (4) main process components, in addition to its four (4) repositories.

The TUBE server provides the entry-points for the APIs. Both client code and TUBE internal code communicate through the interfaces provided.

The Message Distribution Server (MDS) associates each request for a service with a particular protocol. It reads the Distribution Priority Table to determine which protocol to use to process the message.

The Dynamic adaptive marshaller (DAM) prepares requests for a particular protocol. Given a request from the MDS, it looks-up the definition of marshalling rules for the requested protocol, and the target interface definition in the Module Definition Repository. It then marshals the target interface into the desired protocol, based on the definitions from both repositories. It also un-marshals from the source protocol into an internal protocol-neutral format.

The Transport Mediation Server (TMS) determines the target end-point for the interface from the End-Point Resolution Table. It uses the combination of interface and protocol, such as the IP-address and port number of an ORB, to workout the destination.

The Module Definition Repository (MDR) stores the meta-definition of the particular interface. This includes the interface identifier and the data types of the parameters passed. This information is derived from the IDL for the interface.

The Distribution Priority Table (DPT) provides for each interface defined in the MDR, a list of protocols that can be used to communicate with this interface, stored in priority order.

The Protocol Definition Repository (PDR) stores the marshalling rules for each protocol. These rules are generic for each protocol and not specific to any interface stored in the MDR.

The End-Point Resolution Table (EPRT) stores the target communication address for each interface/protocol combination. This address could be, for example, the IOR for a CORBA server, or a queue definition for MQ series. This table stores the necessary information to send a message to, or communicate with, a defined interface using a particular protocol.

The protocol structure undergoes a language neutral machine independent definition and is compiled into binary modules known as protocol implementation modules (PIMs) and transport interface modules (TIMs). The TIMs contain the communication partameters.

These PIMs and TIMs are loaded at runtime and executed by interpreters (virtual machines). PIMs are processed by the dynamic adaptive marshaller (DAM) and the TIMs are handled by the transport mediation server (TMS). Both of these modules are controlled by the message distribution server (MDS). The MDS is aslso responsible for any interface mapping that is required. It uses either the processed request or response message and a mapping definition. The actual mapping is performed by a mapper module under the direction and control of the MDS.

TUBE uses different data formats internally depending on the situation. In the diagrams the Protocol Independent Data Streams (PIDS) are the format used internally to pass data between the TUBE API, the server and the DAM components. The Protocol Oriented Data streams (PODS) on the other-hand consist of data that has been marshalled into a protocol-specific format (e.g. CORBA) by DAM. These are passed internally between DAM, the MDS, TMS and, if required middleware-specific APIs.

TUBE provides the ability to use either or both synchronous and asynchronous communication modes, and that the desired method can be changed at anytime without system impact. When it is required to switch from one mode to the other, all that is required is to change the configuration. This can be done on a per module/interface basis, even while the system is running. There is no need to shutdown and re-start the broker.

The following scenario depicted in Figure 3 describes the process-flow of an out-bound message through TUBE through the following steps:

1. The application call is passed to the TUBE API via the TUBE server.
2. The TUBE server passes the call to the Message Distribution Server.
3. The Message Distribution Server selects a protocol to try from the Distribution Priority Table.
4. The Message Distribution Server passes the interface/module identifier and the preferred protocol to the Dynamic adaptive marshaller.
5. The Dynamic adaptive marshaller reads the Module Definition Repository to determine the format and arguments for the call.
6. The Dynamic adaptive marshaller uses the protocol definitions stored in the Protocol Definition Repository to prepare the call for the particular middleware or application service.
7. The Dynamic adaptive marshaller passes the marshalled buffer back to the Message Distribution Server.
8. The Message Distribution Server passes the marshalled message to the Transport Mediation Server and tells it which protocol to use for transmission.
9. The Transport Mediation Server reads the End-Point Resolution Table to determine the host and port number required to communicate over this protocol.
10. The Transport Mediation Server attempts to communicate with the designated host using the appropriate communication parameters.

If communication with the preferred protocol fails, TUBE will try each subsequent protocol (in priority order). The application will only receive notification of communication failure once all the listed protocols have been exhausted. If communication succeeds, TUBE sends a positive notification to the application. The way that this occurs depends on the application's relationship with TUBE. If the application has invoked TUBE via the API, then TUBE will return the status directly to the application. If, on the other-hand, TUBE has intercepted an out-bound call made by a proxy or stub, then the status will be given to that module for return to the application.

The scenario shown in Figure 4 describes the process-flow of an in-bound message through TUBE with the following steps:

1. the external call is intercepted by a TUBE module.
2. the interceptor uses the TUBE API to pass the message to the TUBE server, which passes the call to the Message Distribution Server.
3. the TUBE server passes the message to the Message Distribution Server in the protocol that it was received.
4. the Message Distribution Server looks-up the Distribution Priority Table to determine whether the message needs marshalling into another protocol.

Steps 5, 6, 7 and 8 are only executed if the protocol needs to be converted by the Dynamic adaptive marshaller. If not then the message can be passed through to Step 9.

5. The Message Distribution Server passes the interface/module identifier and the preferred protocol to the Dynamic adaptive marshaller.
6. The Dynamic adaptive marshaller reads the Module Definition Repository to determine the format and arguments for the call.
7. The Dynamic adaptive marshaller uses the protocol definitions stored in the Protocol Definition Repository to prepare the call for the particular middleware or application service.
8. The Dynamic adaptive marshaller passes the marshalled buffer back to the Message Distribution Server.
9. The Message Distribution Server passes the (possibly converted) message to the Transport Mediation Server and tells it which protocol to use for transmission.
10. The Transport Mediation Server reads the End-Point Resolution Table to determine how to contact the end-point for this protocol. In this case, it determines that the end-point is local.
11. The Transport Mediation Server then passes the message to the "Target Application" on the local system.

It can be seen that the middleware broker of the invention using The Ubiquitous Broker Environment (TUBE) aims to provide protocol-level inter-operability with the following characteristics:

- Supports a wide range of protocols, including legacy systems.
- Protocol descriptions are to be declared, and developed with a utility tool supplied with TUBE. This allows new protocol support to be added with no impact on existing systems. This effectively provides future-proofing of IT investments. As new protocols emerge, they can be utilised declaratively with very little (if any)

development.

- Protocols can be changed (added or removed) without re-compilation of application software.

From a user perspective, a major advantage of this approach is that application programs don't have to be re-compiled to use TUBE. TUBE is installed, and descriptions of the protocols supported are declared and stored in a protocol definition repository. Applications specify the service that they want by using the API of the service. These calls are intercepted by TUBE, which determines a service provider and marshals the call appropriately. The service providers and the protocols that can satisfy a call are specified for each interface. If the required service is not available through a preferred protocol, then alternative protocols are tried. For example, the default may be CORBA, and calls will target CORBA end-points (e.g. an IOR); however, an alternative may be MQ-Series, which will be tried if a CORBA service cannot be reached. (The onus will be on the systems integrator to specify those protocols that are interchangeable for each interface.)

Unlike some proprietary EAI products, which attempt to control workflow and broadcast (publish) each message on a universal messaging bus, TUBE only communicates with designated end-points. TUBE is capable of broadcasting or publishing to a universal bus, if that is required. Since TUBE will provide fully synchronous or asynchronous methods, the desired communication type may be changed at anytime without system impact. For example, if synchronous behaviour is required from an (essentially) asynchronous middleware platform (e.g. MQ-Series), TUBE will handle the synchronisation through blocking and buffering. If it is then required to go back to purely asynchronous, the application software does not need to change, provided that the protocol is supported for the called interface. This will allow remote modules to be developed independently, and for each to use the middleware that best suits their purposes. There will be no need for independent development groups to be familiar with each other's protocols.

The messaging life-cycle employed depends upon the type of communication mode we are engaged in. If we are engaged in a synchronous mode operation, then we will be in a blocked or waiting state. In the asynchronous mode, we are also waiting but can continue to perform other tasks whilst we wait. We need to be able to handle both modes independently of one another, and also be able to combine them. Let us consider the following example, a client may make a synchronous request on a server using the same protocol as always; the client is unaware that the server implementation has been changed to use asynchronous queuing. We need to hold the synchronous session with the client, which is awaiting a response and is thus blocked. At the same time we must monitor a queue on the server-side and we must wait for a response that could come at anytime. However, we are not blocked, we are waiting to be notified when something is put on the queue. When our response arrives we send it back to the waiting client. This entire process involves more than sending and receiving of the request and response; we must marshal the data to and from the source and target protocols.

During the marshalling process the message data need to be buffered and copied from the source to the target. Depending on message size, this could be a fast or slow task. If we are brokering a synchronous request over an asynchronous invocation to the server, we will keep the client blocked until we have completely marshalled and sent the request message. The client will continue to remain blocked until we return the response to it.

The component in the TUBE architecture that is responsible for managing the messaging life-cycle and ensuring that clients either; receive the response in synchronous mode or are notified of responses in the asynchronous mode is the Message Distribution Server (MDS). The MDS is the first and last module to handle a message and its subsequent response (assuming a two-way exchange). The MDS is also responsible for determining the target end-point from the DPT and EPRT, and providing that to the other modules via an API. When clients elect to use the TUBE server directly via APIs, the TUBE server creates an instance of MDS to handle the message. The same thing occurs when a protocol interceptor intercepts a message; it uses an instance of MDS to manage the session.

The basic operation of MDS may be described as follows:

- Receive an in-coming message
- Invoke the DAM to un-marshal the source message into protocol-neutral (TLV) format
- Determine the target protocol and end-point from the DPT and EPRT
- Call DAM to marshal from the TLV format into the target format
- Invoke the TMS to perform the actual communication and await the response

There are some situations where the semantics required by a particular protocol cannot be handled by MDS. The job of the MDS is primarily to distribute messages amongst other TUBE components to ensure that they are marshaled and delivered correctly. This generic model would be compromised if we tried to build the logic into MDS to handle these very protocol-specific situations. Instead we relegate these protocol-specific tasks to what we call "Protocol Control Modules". The PCM assists the MDS with higher-level semantics that deviate from the standard synchronous and asynchronous communication modes. An example of this is the LOCATION-FORWARD response received in CORBA.

This response tells the client to resubmit the original request to a new target end-point. We chose not to embed the logic to handle this in MDS. This is a very CORBA-specific situation and it did not make sense to design any specific protocol related operations into MDS. Had we done so, we would have most likely found ourselves adding logic to handle the idiosyncrasies of other protocols. This would endanger MDS of becoming over complicated and difficult to maintain as new protocols were added. A major design goal of MDS, and for that matter all of TUBE, is to be protocol-neutral. The only parts that are intended to be protocol-specific are the PIMs generated from the PDL scripts . The MDS uses the PCM to make higher-level decisions about message processing. The MDS will pass the full request or response to the PCM and will delegate all further processing to it. MDS will wait for the PCM to either submit another request or return a response to the client.

Protocol definition language (PDL) as its name implies is a language (symbolism) for defining protocols. In the same way as IDL defines interfaces, PDL defines protocol structure. The language defines the structure of both request and response messages. When we say it defines the structure, we are referring to the things that we need defined in order to exchange messages with a server on behalf of a client. We discuss earlier in the paper that the purpose of TUBE is as a broker between disparate systems. As a broker, it sometimes needs to convert from one client protocol to another to communicate with a server. We have various types of protocols; we have text-based protocols such as XML, HTTP and SOAP[1]. Then we have binary protocols, some of which are object-based (examples include CORBA, COM and Java-RMI) and others such as DCE-RPC, which are not object-based. Finally, we have the MOM type protocols such as MQ and JMS.

Each protocol wraps or encapsulates the actual message content in different ways. SOAP for example wraps the content in a structure called a SOAP body, and then wraps this in another structure known as a SOAP envelope. In the following discussion, we shall refer to this content as the payload. This is the body of the message as defined for the interface.

To clarify this, let us use our simple math-server definition again; partially reproduced in Figure 5 for convenience of the reader. Figure 6 and Figure 7 show the basic structure of a request and successful response message for an "add" operation of the numbers "1000" and "15" on the mathServer interface. The server may also return an exception or error condition. This is shown in Figure 8, where we assume that the div (divide) operation was called with "1000" and "0". This is an illegal operation and hence the server returns an exception. The exception we have defined is a structure, which contains one member, a string describing the error. It could however be considerably more complex. The example exception shown is protocol-neutral, that is, it does not represent any specific protocol mapping. It is merely illustrative.

Referring to the interface definition above, if we are dealing with a request, our payload will be a math_req structure (see Figure 6). If we are dealing with a response, we will have a math_resp structure (see Figure 7) or some failure indication (see Figure 8). The payload for a message is either the (serialized) input parameters to the operation, or the (serialized) response from the operation, whether successful or not. We know from the above definition how to marshal these structures; we know at least what native types constitute them. What we do not know however, is how to marshal them over a particular protocol. Do we want the integer (int) values converted to text so we can send them in XML? Does the protocol wrap the payload in some other structures, such as headers or trailers? If we only know the structure of the interface, then we cannot broker between protocols. We must know what to add to the message or what to convert[2] so that the target system can receive and process it. We must also know the address (in protocol-specific terms) of the end-point (target). This may be a host name and port number or a queue name or, perhaps a directory name. These are the items of "protocol structure", which PDL is designed to address.

[2] This is not character-set conversion such as ASCII to EBCDIC, rather conversion of numbers to strings and so on.

There are also certain aspects of message structure, which are similar although not the same between protocols. That is, they may contain varying values depending on the protocol, or appear in different places within a message. These items are mandatory for any message exchange regardless of protocol. We refer to such items as TUBE internal variables. These are the variables TUBE uses to keep track of such things (amongst others) as; message lengths, sequence numbers, and whether we are dealing with a request or a response. Table 7 provides details of all these variables. In the discussion that follows, we refer to TUBE internal variables and user variables. User variables are those that only have meaning for the particular protocol. We obtain their value from the EPRT entry for the interface. Although the variable is applicable to the entire protocol, its value is determined on an interface-by-interface basis. In other words, the same variable may have a different value in each EPRT entry. An example of a user-defined variable in an EPRT entry is a CORBA object-key . This identifies the object to instantiate (or invoke) on the target end. We discuss both types of variables and their PDL definition later.

Before this discussion, it is important to gain an understanding of some terms and concepts that we refer to when describing PDL. Of particular importance are code-blocks and op-codes. A code-block, also referred to as a state-block (see Table 2) is a structure consisting of the following elements:

- Op-code
- A target variable to store the result of the operation
- Array of parameters for the operation
- Offsets into other data structures required by the operation

These code-blocks are processed at runtime by a Virtual Machine (VM), which interprets the op-codes and executes the given instruction. We call this VM the DAM (Dynamic adaptive marshaller). We decided that using a VM would enable the addition of functionality to PDL by expanding the range of op-codes.

The op-code is a symbolic value used to determine the operation to be carried-out. For example, the op-code READ_INT instructs the marshaller to read a signed 32-bit numeric value from the input source. Likewise, the op-code WRITE_INT instructs the marshaller to write a signed 32-bit value to the output target.

The PDL is a series of extensions to OMG IDL . The rationale behind extending an existing language is that most software engineers have some exposure to, or knowledge of it. This is mostly the case with IDL. It defines CORBA interfaces and is the description language for Java RMI . OMG IDL itself is an extension of the original DCE RPC IDL . Microsoft also has a language based-on extension to RPC IDL called MIDL (Microsoft Interface Definition Language). It primarily defines C++ COM interfaces . Extending an existing language reduces the learning curve for the users, and shortens the development time for the PDL and supporting tools. An example of PDL is explained later with reference to Figure 20. The example uses CORBA IIOP V1.0 to illustrate in detail:

1. The use of the IDL extensions
2. How the PDL compiler interprets the extensions
3. The op-codes that are emitted

In a later section we discuss the DAM, and show how DAM interprets these op-codes to handle messages.

In the PDL compiler, PDL scripts are not compatible with IDL and therefore standard IDL compilers cannot process them, as they would not recognise the extensions, which would cause parsing errors. We need a special compiler to process PDL. The PDL compiler reads the PDL definition (also referred to as a script or PD) and generates two types of output, a Protocol Interface Module (PIM) and a Transport Interface Module (TIM). There are two PIMs generated for each protocol definition, one for handling requests and the other for handling responses. This simplifies the logic required in both the compiler's code generator and the runtime interpreter (DAM). The DAM loads the appropriate PIM based-on the current message type (i.e. request or response). The PIM is comprised of code-blocks, derived from constructs within the PDL script. For example, for each "struct" keyword encountered in the PD, the compiler generates what we refer to as a code-block. This code-block is a series of instruction blocks. An instruction block consists of op-codes and state definitions, which define operations, variables (internal and user-defined) and initial values. Each op-code and state is (generally) associated with a source or target variable . The Figure 9 diagram illustrates the structure of a PIM.

The PIM header contains information and structures that assist in the loading and processing of the rest of the file. The header is comprised of the fields shown in Figure 10.

We will deal with each of the header elements in turn, and then discuss the other portions of the PIM structure. The entire PIM structure and all the constituent parts are shown in the tables and explained as we encounter them.

1. The File-Identifier is a hexadecimal value, which identifies this file as a valid TUBE PIM. If this value is not found or does not match, then the rest of the file is ignored and the load aborted.

2. The Marshalling class-name specifies the name of the class that implements the TUBE.commsBuffer interface. This is the class that will be used for all reading and writing operations whilst processing this PIM. The actual disk layout of this item is an integer specifying the length of the name string, followed by the string. This string contains the actual name. A length of zero (0) signifies an empty class-name and there is no string following. In this case, the DAM will use a default (internal TUBE) implementation for encoding and decoding of native values.

3. The Constant-Segment stores all constant values. The entries specify a type, the length of the value and the actual value. We always encode the value in a byte array despite the data type. The compiler encodes offsets into this segment into instructions that require access to these values.

4. The Variable-Definition Segment contains information about all the variables defined in the PD. It stores the name, data type and a flag to define the variable as an internal or user-defined variable. If the variable has an initial value specified by an "init" clause (see Table 6), then an index into the CS is also stored.

The Marshalling map, Pre-Marshal map and Post-Marshal maps all have the same basic structure (illustrated in Figure 11). These blocks contain the op-codes and other information necessary to the execution of the operation. The Declarations section of the file contains pointers into these maps for instruction-blocks generated from "declare" (see

Figure 13) statements. These blocks contain all the code required to handle the declared type. We now discuss variable handling and explain these relationships.

When the compiler encounters a simple (native) type in a struct definition, if it specifies an initial value, the compiler generates an entry in the CS and stores an offset to this value in a state-parameter entry (see Table 1). The compiler adds the entry to the state-block it is currently generating. If the variable does not have an initial value, the compiler generates a VDS definition as an empty slot for the value. This slot is a placeholder for the value when it is read-in. It is also the source for the value when writing. Refer to Table 5 for a description of the runtime usage of this entry.

In the case of compound (declared) types, the compiler generates references to two separate code-blocks, one in the reading PIM and one in the writing PIM. These code-blocks have a type of USER-DEFINED and have an entry created in the Declarations section using the name of the structure with either a "_READ" or "_WRITE" appended. This modified name is stored in the CS and the CS index is stored in the definition entry. The PDL compiler patches offsets to the actual code-blocks once it has completely processed the PDL script. The instructions to handle the declared type are generated into the Marshalling map. The first instruction-block for handling this type contains a pointer to the modified name in the CS. This is how the compiler finds the value to patch into the declaration entry. This is also, how the DAM identifies and loads individual code-blocks at runtime.

We write the Constant-Segment to disk in its entirety. It is read-only at runtime. These values never change during the execution of the PIM.

The compiler writes the Variable-Definition Segment to disk in the format shown in Table 4). This is what the DAM reads when loading the PIM. At runtime, we create another structure for storage of variable values for efficiency. We call this runtime-only structure the Variable Value Table (VVT). The layout of the VVT appears in Table 5.

The Variable Value Table stores the values for variables as we read them from the input source. If we are marshalling this value, then we use this entry as the source and write the current value to the output target using either, user-supplied methods or internal (default) handlers. We extract the native type from the Object wrapper for writing and we coerce it from the native value into the wrapper when reading. This casting of native types to and from objects adds some processing overhead, however we compensate for this with the ability to handle all data types in the same manner. Refer to the section on DAM for a more in-depth discussion on runtime variable management.

Figure 12 illustrates a read-octet operation for a target variable, which has an offset of two (2) in the Variable-Definition Segment. If we follow this offset, the VDS entry stores an offset of five (5) into the CS. This is where we find the name of the variable "objectKey". Because this is a USER-DEFINED variable (indicated by the declaration "$objectKey$" in the PDL script in the Figure 20 CORBA example), initially we obtain this value from the EPRT entry for this interface. This entry then remains constant for the life of the PIM, unless explicitly changed by invoking set method or executing a code-block. When we have read the value, it will be stored in offset two (2) of the Variable Value Table (VVT). We create this table only at runtime to manage the storage of actual values, which are not constants. After the read, the entry at offset two (2) contains the value "$OBJECT:myObject". When we marshal this in a request, its value comes from this VVT entry.

In the application of extensions to OMG IDL, table 6 shows the new keywords and constructs introduced to extend OMG IDL. A brief description of each is also given. We expand these descriptions as we work through our CORBA example.

Table 7 describes the internal TUBE variables that may appear in a PDL definition. The entry referred to in the text, unless otherwise noted, is a record in the Variable-Definition Segment.

These are reserved words and are expected enclosed in the '%' character (e.g. %count%). The PDL compiler throws an exception if it encounters any other usage.

We will now examine each section of the PDL script (see Figure 20 CORBA example) in detail. We also assume throughout the discussion that the compiler has built a symbol table and other internal structures during the parsing phase. Our discussion will concentrate on the code generated from these constructs, rather than their actual construction. Most of the examples show the instructions generated for reading. We must note that for each set of read instructions generated, there is also a corresponding set of write instructions emitted.

We begin with the protocol declaration.

```
protocol CORBA
{
```

The first keyword that we encounter is "protocol" followed by the value "CORBA". This tells the compiler to generate the following two filenames:

- CORBA_Req.PIM – defines rules for marshalling requests
- CORBA_Resp.PIM – defines rule for marshalling responses

The "{" character identifies this as the opening of the PD script.

Next, we encounter three "typedef" statements. These behave the same way in PDL as in standard IDL and programming languages such as C and C++. In that, they define an alias for the type. For instance, the following statement;

"typedef sequence<octet, 3> reserved;"

causes the compiler to create a variable named "reserved" and whenever it encounters this variable to point to a code-block. The code-block will define op-codes for reading and writing a sequence of three octets. The definition for GIOP_MAGIC is very similar except that it also generates a four-byte entry in the CS with the value 'G''I''O''P'. Whenever we begin to read a message, we first look for those four bytes and conversely, when writing a message we always write this initial value. The definition for "olist" specifies an octet sequence of unbounded length. The important distinction to note here is that sequences of native items (such as octets) defined with "typedef " do not have their length encoded and neither do we expect to read the length during decoding. If the length is required when reading or writing, we must define this using a "declare" clause (see byteSequence in above) as explained next.

Before we explain the "declare" clause however, we need to skip ahead a little and explain the "bufferFormat" construct and how the DAM uses it in conjunction with the MDR at runtime. The "bufferFormat" definition tells DAM, which code-blocks to use when marshalling the payload. The payload can be made-up of either native types or constructed complex types. The complex types may contain native types and other complex types. We must provide the DAM with marshalling instructions for the following standard constructed types:

- STRING – how to marshall a String
- BYTESEQ – marshall an arbitrary byte sequence
- ARRAY – marshall an array (fixed-size sequence) of native or complex types
- SEQUENCE – marshall a variable-length sequence of native or complex types
- OBJECTDEF – marshall an object definition

The DAM assumes that a message may only be comprised of a combination of those items and native types. If we do not provide these instructions in the PDL, consequently there will be no handlers (code-blocks) generated, as there will be no "declare" clauses to define them. In this case, DAM will use internal marshalling rules, which may or may not be suitable for the particular protocol. For example, an object definition is very protocol specific. If none is given, DAM will simply encode and decode an item defined in MDR as an object, as an un-interpreted array of bytes. If we look at the PDL definition for an "objectDef" in our CORBA example, we can see that if we omitted the "declare" and "bufferFormat" statements, the default behaviour would not be suitable for our protocol[3]. If the PDL compiler encounters multiple bufferFormat statements, it throws an exception and terminates processing.

The next keyword we encounter is "declare". We use this for defining compound or complex types, which may be composed of many native and or other, compound types.

Referring to Figure 13 we are defining a "byteSequence". This will generate op-codes that tell the DAM how to read and write an arbitrary sequence of bytes. We define a reference to an internal TUBE variable "%num_bytes%" (see Table 7: TUBE internal variables). This indicates how many bytes (octets) to read or write next. We then have a reference to an "olist". Next we find the end of this declare clause, signified by "};".

[3] For example, strings would not be null terminated.

The compiler will now create a code-block named "byteSequence_READ" with the op-codes shown in Table 8.

From this point on wherever a reference to "byteSequence" appears, the compiler will encode an instruction to load this code-block and execute it. Any other code-blocks that refer to this code-block will have a flag set that specifies a reference to a "USER-DEFIND" code-block. The instruction (in the referring block) will also have an offset (in the CS) to the name of this block.

Referring to Figure 14, the next declaration we encounter is for an array. This entry specifies how DAM should handle arrays. This is very similar to the byteSequence example, except that we use another special variable "array_size" to keep track of the number of actual entries. An array is a fixed-size sequence. The interpreter derives the upper-limit of the array dimension at runtime by referencing the MDR entry for the particular interface being marshalled. Currently PDL supports only single dimension arrays.

Referring to Figure 15, the declaration for "nString" demonstrates the use of op-codes to add and subtract constant values to and from those currently being processed. The "+ 1" tells the compiler that we always have one extra byte than the actual string length. Here we read the length of the string including the null byte, and then we must subtract one (1) from it. This is so we do not consume the null as part of the string. We read it separately and discard it. Conversely, when we are writing the string, we first add one (1) to the length and write it. We then write the string itself, and finally we write the null byte.

The compiler generates the code-block as per Table 9.

Referring to Figure 16, the "objectDef" declaration illustrates the usage of declared types within declared types.

Table 10 illustrates the resultant code-block.

The interpreter executes the instructions above whenever an "object" definition is encountered in the payload and the value being marshalled is defined as an "object" type in the MDR. The statement "OBJECT=objectDef;" in the bufferFormat clause defines this association.

The "bufferFormat" clause is the next construct that we encounter. As we have already explained the bufferFormat clause above, we will not repeat it here.

Referring to Figure 17 the next significant construct we encounter is the "control" statement. The compiler writes the op-codes generated here (see Table 11) into the Pre-Marshal map. These are loaded and executed just before marshalling the payload. When the interpreter encounters the special op-code START_PAYLOAD, it will search for a pre-marshal map. If none is found, then the DAM will traverse the payload according to the MDR definition for the interface being processed. Otherwise, if there is a map present we invoke a module to handle the tests.

The statement above tells the compiler to generate some branching op-codes based-on the value of the internal variable reply_status. When the value of reply_status is read from the input at runtime it is examined and tested for the values: 0, 1, 2 and 3. The value determines what action to take for encoding or decoding the payload. After executing the appropriate action, we exit this module and return to the main interpreter code. According to the rules specified above, we will execute the following process:

If the value is zero (0) we push a false onto the stack. This indicates that we will follow the MDR definition for the interface and marshall the values accordingly. In this case, the module returns a Boolean false. If it is not zero (0) we then perform a test for one (1), and if this is true we follow the definition of the exception for this operation (as defined) in the MDR. Unlike the case for zero above where we return false, for MDR-defined exceptions we return true to indicate that it is not the standard payload; although, we are still following an MDR definition. Otherwise, we test for two (2), and if this is true, we push the name of the code-block defined as "systemException_READ" and return it. Finally, we test for a value of three (3). If this is true, we load the name of the "objectDef_READ" code-block and return. If none of the defined values exists, the DAM throws a marshalling exception.

In summary, the module that performs the "control" instructions returns one of three values to the main interpreter. It returns false if we are marshalling the payload by following the MDR representation, or it returns true if we must handle the payload differently. A string value indicates that this module has pushed the name of a USER_DEFINED code-block (that was defined with the declare clause) onto the stack. The main interpreter loop will load and execute this code-block. After marshalling the payload, the interpreter will search for a Post-Marshal map.

Table 11 shows op-codes for processing "control" clause. Unlike the control clause for pre-marshal maps, there is no keyword to indicate the start of a post-marshalling map[4]. The compiler will always generate code to write-out the body (payload) length after marshalling the payload. Therefore wherever the variable %buffer_length% is encountered this tells the compiler that this is the payload length. We initially marshal the length as zero (0) and then we re-write it with the correct value after marshalling the body.

Referring to Figure 18, statements that contain the buffer_length variable, such as the one shown, automatically cause the compiler to create a post-marshalling block. This block contains instructions to save the current point in the buffer, calculate the new position, write the length and return to the current position.

Table 12 shows post marshal maop for CORDA message.

Next, we encounter the "external" clause. This defines the full class-name (including packages) of the class that the interpreter is to call for marshalling native types. Because CORBA uses CDR encoding for primitive data, the default TUBE codec is not suitable. Therefore, we define our own special class to handle the CDR padding of the bytes that the PIM reads or writes. We only need to define this class once in the PDL. From then on, it will be available for marshalling any defined interface across this protocol. For example, when the PIM contains a READ_INT op-code, the DAM will call MYORB.marshaller.CDRBuffer.read_int() to obtain the value. Conversely, when we encounter WRITE_INT, we call MYORB.Marshaller.CDRBuffer.write_int(value) to output the value. This clause causes the compiler to populate the Marshalling class-name member of the PIM header (see Figure).

[4] We may introduce one or more if we feel it would add flexibility to PDL.

The final construct we shall deal with in this example is the "endPoint" definition. It appears in PDL as follows:

```
endPoint : "TCP"
{
//
// These are transport and protocol-specific items
//
"host";                          // This is the host for the object
"port";                          // This is the port on the host
};
```

The value following the ":" is transport for the protocol, in this case "TCP" for IIOP. The DAM must find these values in the EPRT entry for this interface. The compiler generates code into the TIM for loading and using these values. As the definition for this endpoint defines the use of TCP/IP, the TIM will use these values to create a sockets-based connection to the defined host on the designated port. We cover the operation of TIMs in more detail in the section on the Transport Mediation Server (TMS).

In the next section, we will continue with our CORBA example and show how parts of the message may be re-marshalled.

The Dynamic adaptive marshaller (DAM) is the name we have given to the VM, or interpreter, which executes the PIMs that we discussed in the previous section. As the name suggests, this component must dynamically adapt to the protocol that it needs to marshal. Before we discuss the DAM in detail however, it is important to understand the two (2) types of invocation modes (i.e. the ways we invoke DAM).

We can invoke DAM in either of the following ways:

- Via a Protocol Control Module (PCM)
- Via the Message Distribution Server (MDS)

Both invocations actually occur via MDS, however in the case of a PCM, the MDS first routes to the PCM, which then invokes the DAM. In the other case, the MDS invokes the DAM directly.

Firstly, we must discuss the role of the Message Distribution Server (MDS) in the message processing cycle. We assume throughout the discussion, that we are processing a synchronous (two-way) message.

When a request is intercepted by a protocol listener, the listener creates an instance of MDS and passes it the message. The MDS will then attempt to create an instance of a Protocol Control Module (discussed below) using the Java Reflection API. If the creation is successful, MDS hands the request to the PCM and takes no further part in the process until the PCM returns the response. Whereas, if the creation fails: MDS passes the request to DAM and waits for DAM to return a protocol-neutral representation of the request (a TLV buffer). The MDS will now look-up the DPT to ascertain the target protocol. The MDS passes the TLV buffer back to DAM for marshalling into the target protocol. After DAM returns the marshalled request, MDS passes the message to TMS for transmission to the target end-point. The MDS now waits for TMS to return the response. When MDS receives the response, it carries out the reverse of the above procedure; it uses DAM to convert the response from the target protocol into the source protocol. The MDS returns the marshalled response to the listener.

A Protocol Control Module (PCM) is a piece of software written by a user. This module provides higher-level protocol semantics than those required for marshalling. As an example, consider our CORBA PDL definition (see
). In this script, we have a "control" clause, which is a switch statement that controls what sort of message payload we are dealing with. The decision as to what to do with this payload after marshalling and return belongs to the PCM. The PCM implements the same switch logic as that specified in the control clause with the addition of logic to handle the resultant payload. To further clarify this we will again give an example based on our CORBA PDL using a response message. The PCM must decide what to do with this response based on the value of the reply_status field of the message.

One of the values specified for reply_status in the control clause is a three (3), which signifies that the response payload is a CORBA object-reference (defined as objectDef). To a CORBA client or server the value of three (3) actually means more than the type of response payload; it means the response is a LOCATION-FORWARD response <*CORBA spec.*>. This indicates that we should re-marshal the original request and submit it to the object whose reference is contained in the response message. We believe an attempt to support the specification of this logic in PDL would result in an overly complex language. That is why we have chosen to delegate these higher-level semantics to a user-supplied module. The PDL still provides support for the marshalling of the various payload types, without however attempting to interpret their meaning. That is, the decision whether or not to re-submit the request to the new object is left to the PCM. The DAM API provides methods for retrieval and population of various fields within the message by name. Therefore, the PCM makes a request of DAM to re-marshall the request using the new object-reference received in the response. We must emphasise that only one PCM is required for a given protocol, and this can manage any message for any defined interface handled by this protocol. Using a CORBA LOCATION-FORWARD response message, the PCM performs the following steps (illustrated in Figure 19):

1. Receive the original request from MDS
2. Invoke DAM to marshal the request
3. Invoke TMS to send the request and wait for a reply
4. Receive the response from TMS
5. Invoke DAM to un-marshal the response
6. Make a decision of what to do based-on the reply_status in the response
   If the PCM decides to re-submit the request
   - Use DAM APIs to set appropriate fields in the request with new values
   - Return to step 2.
7. Return the response to MDS for subsequent return to client

The main difference between the MDS direct invocation of DAM and the PCM invocation is that MDS does not attempt to interpret any of the messages. The MDS simply routes the messages to the other components.

Once we invoke DAM either, directly from MDS or via a PCM it must dynamically adapt to the source protocol of the in-bound message, and to the target protocol of the out-bound message. The MDS or PCM will tell DAM what protocol the in-coming message is encoded in. The DAM will then search the Protocol Definition Repository (PDR) for a request PIM that implements the un-marshalling rules for the particular protocol. The DAM will throw an exception if it does not find the required PIM.

Once the source PIM is located, it is loaded and DAM checks the header for external class declarations. If we find any, DAM creates an instance of the classes using the Java Reflection API. We recall from our discussion in that these classes must implement TUBE-defined interfaces. This allows DAM to handle different buffer types and encoding schemes uniformly. Users are free to wrap or implement any underlying methods or formats that they choose. The DAM calls pre-defined method signatures to read and write the different native data types. Therefore, if a user requires compression or encryption and does not want to reveal the algorithm in the PDL definition, they can implement the algorithm in their commsBuffer class. This way the details remain hidden, whilst still taking advantage of DAM and a PIM to perform the actual traversal of the interface and its data structures. This applies to any interface, regardless of complexity. Provided we define the interface in the MDR, DAM and the PIM ensure encoding of the message as per the rules specified in the PDL definition for the protocol. The fact that we encrypt the values with a proprietary algorithm does not interfere with the encoding and de-coding process. We feel that this is a very powerful feature of the TUBE approach to message processing; special protocol handling code only needs to be written once, not for every interface. This allows optimal re-use of code and uniform treatment of all interfaces over the protocol.

The DAM uses the source PIM to un-marshal the in-bound message into an internal protocol-neutral format known as TLV (Type, Length and Value). The next step in the process is to determine the target protocol. We achieve this by using MDS APIs to look-up the Distribution Priority Table (DPT) and determine, which protocol has the highest priority. The DAM creates a request marshalling PIM for the target protocol. The DAM then uses values from the TLV to populate values within the target PIM.

TUBE's major objective to provide brokerage between different types of middleware is implemented by storing interaction rules in PIMs and TIMs. The major categories of information required by TUBE to mediate between disparate middleware are:

- On-the-wire protocol and payload format.
- Communications sessions. The communication sessions are further decomposed into a number of operations. These are: session-establishment (hand-shaking), session-management and session-termination. Each in-turn may require further de-composition, depending on the middleware in question. For example, session-management may involve simply sending data, or sending data and waiting for a

response. The exact nature of the interaction depends on several factors: the target middleware, the session type (one-way or two-way) and the invoking application (interface) requirements.

As discussed, the Module Definition Repository holds the definition of the interface. This is necessary because there is likely to be an impedance mismatch between the two middleware interfaces, such as for example, with CORBA, which is object-based, as opposed to MQ that is message-based. The interface definition may need to be altered to reflect this. If `MathServer` is MQ-based, whereas its clients are CORBA-based, method calls in CORBA must be properly mapped to MQ messages to ensure that the correct operation is performed by the receiving end.
The `MathServer` IDL defines four methods: `add`, `sub`, `mul` and `div`. To specify the operation to MQ, we encode the parameters using information from the MDR. If the information were sent as is (i.e. with only `math_req` encoded), the MQ server would not know which operation to perform. Therefore, the IDL needs to be modified to reflect what MQ requires as established by the MQ server team. For example, let us assume that the MQ team established the following COBOL definition for the `MathServer` interface.

```
01 MATH_REQ.
       03     OP_CODE       PIC X VALUE SPACES.
              88    ADD_OP        VALUE 'A'.
              88    SUB_OP        VALUE 'S'.
              88    MUL_OP        VALUE 'M'.
              88    DIV_OP        VALUE 'D'.
       03     NUM1          PIC 9(4) VALUE 0.
       03     NUM2          PIC 9(4) VALUE 0.

01 MATH_RESP.
       03     RESP_NUM      PIC 9(4) VALUE 0.
```

We assume for the remainder of the discussion that the server has been changed from CORBA to MQ-based and that the clients remain CORBA-based.

The data structures math_req and math_resp are almost the same, except for the op_code in the request structure. The client development team creates the IDL shown below.

```
interface MathServer
{
          struct math_req
          {
                    char op_code;
                    int num1;
                    int num2;
          };

          struct math_resp
          {
                    int resp_num;
          };

// methods for each operation
struct resp_num add(in struct math_req);
struct resp_num sub(in struct math_req);
struct resp_num mul(in struct math_req);
struct resp_num div(in struct math_req);
};
```

It is worth noting that:

- The interface remains largely un-altered
- The request and response parameters have not changed
- None of the object-oriented properties of the client interface has been violated
- Simply the op_code member has been added to the request structure.

We may now use this interface with object-based and non-object based systems.

If the IDL were left in its original state, the CORBA call obj->add(10, 9) would be encoded by TUBE into an MQ message as method-name serialised-parameters, for example:

```
    add 10 9// spaces between values are for readability only
```

This is the default behaviour based on the IDL definition. The onus is on the systems integrator (the client development team in this case) to ensure that the definitions match. Conversely, if the call was being marshalled from an MQ message to a CORBA call and the IDL were in its original state, TUBE would not be able to determine which method to call. This is because TUBE only receives a sequence of bytes representing the math_req structure, and therefore there is no way that the operation can be determined from the original math_req structure. The necessary information is just not there. Using the new IDL, a mapping is defined that instructs TUBE to use the op_code member of the request structure to determine the method to call on the CORBA object. There is still, however, a missing a link between the op_code value and the actual method-name. Therefore, a mapping definition such as the following is defined:

```
<FieldMap action="operation">
<Field    name="math_req.op_code"    offset="0"    type="byte"
len="1">
<XForm Map="A,add M,mul D,div S,sub" />
</Field>
</FieldMap>
```

The XML (fragment above shows that to derive a method-name, we use either:

- A byte from offset zero (0) in the in-bound buffer, and then map it according to the rules defined by the XML tag XForm. This is used when only a buffer of bytes is available, such in an MQ or JMS BytesMessage.
- The op_code member of the math_req structure. This is used where the structure of the buffer (a SOAP message for example) is known, and then map it according to the rules defined by the XML tag XForm. This shows, for example, that an 'A' is mapped to "add".

The following example shows a complete translation from an in-bound MQ client request to a CORBA-based object request to illustrate the mapping process. We use the add operation with the decimal numbers 1000 and 15 respectively.

MQ Message Buffer (Hexadecimal, little-endian) as extracted by MQ PIM

```
00000 -- 41 ------------- ASCII character 'A'
00001 -- e8 03 00 00 ---- Decimal number 1000
00005 -- 0f 00 00 00 ---- Decimal number 15
```

Using the rules defined in the XML shown above we derive the method name add from the byte at offset zero in this buffer. We now show how the CORBA PIM marshals these values into the CORBA GIOP request buffer. (The PIM actually receives an intermediate representation of the buffer, which is not shown here for brevity.)

GIOP Header

```
00000 -- 47 49 4f 50 -- GIOP
00004 -- 01 01 -------- IIOP version = 1.1
00006 -- 01 ----------- Byte Order = Little-Endian
00007 -- 00 ----------- Message Type = Request
00008 -- 3c 00 00 00 -- Message Length = 60 bytes (octets)
```

Request Header

```
00012 -- 00 00 00 00 -- NULL (zero-length) Service Context List
00016 -- 01 00 00 00 -- Request-id = 1
00020 -- 01 ----------- Response Expected = true  //  two-way call
00021 -- 00 00 00 ----- 3 Reserved octets
```

Object Key

```
00024 -- 13 00 00 00 -- Length of Object Key (octet sequence) = 19
octets
00028 -- 2f 31 35 3332 2f 31 30 34 35 32 37 31 32 38 39 2f 5f 30
         00      /1532/1045271289/_0.
```

Operation and parameters

```
00048 -- 04 00 00 00 -- Length of Method Name = 4
00052 -- 61 64 64 00 -- NULL terminated string = "add"
00056 -- 00 00 00 00 -- NULL (zero-length) Requesting Principal
00060 -- 41 ----------- op_code = 'A'
00061 -- 00 00 00 ----- CDR padding for alignment of 4
                        byte boundary for long value.
00064 - e8 03 00 00 --- Decimal number 1000
00068 -- 0f 00 00 00 -- Decimal number 15
```

The following excerpt from the EPRT (End-Point Resolution Table) for the `MathServer` interface shows the specification for the remote object key at offset 28 in the example above.

```
<Interface Name="MathServer" Mode="Synch" >
<CORBA ObjectKey="/1532/1045271289/_0" Host="192.168.1.3" Port="1978" endian="1"/>
</Interface>
```

The CORBA TIM uses the Host and Port values to establish communication with the remote ORB, and the CORBA PIM uses the `ObjectKey` value to ensure that the correct object is invoked at the end-point.

Once the IDL definition is complete, the IDL is submitted to the TUBE IDL compiler, which populates the Module Definition Repository with the interface information. This information is protocol-independent. That is, the same MDR definition is used to marshal CORBA, MQ or any other supported middleware protocol. The protocol marshalling rules are already contained in the relevant PIMs and the transport (communication-level) interactions are defined in TIMs.

We will now present a detailed example of the items discussed and as shown in Figure 20. A PDL definition of CORBA using IIOP V1.0 is shown. The PDL script and each construct and data member are shown and how the PDL compiler processes them. We will use symbolic names to represent op-code and offset values. The actual numeric values are not relevant to our discussion and we feel that symbolic names are easier to understand.

It should be understood that the above description is of a preferred embodiment and included as illustration only. It is not limiting of the invention. Clearly variations of the middleware broker and method of intercommunication would be understood by a person skilled in the art without any inventiveness and such variations are included within the scope of this invention.

CLAIMS

1. A protocol-level middleware inter-operability system which supports a wide range of communication protocols, including legacy systems, the middleware inter-operability system having

a. an input for receiving communication message in a communication protocol;

b. a repository in which general rules and middleware characteristics are specified, to provide the connection and transformation for middleware protocols, as well as for legacy systems to allow exchange of said communication message;

c. a broker which is able to review all data structures, regardless of complexity, as being comprised of a finite set of primitive data types and with reference to the repository determine a mechanism for reading and writing these types to enable processing of structures of arbitrary complexity, wherein the rules and mechanisms for reading these basic types are defined by the protocol and once the rules are captured allow processing and exchange of any communication message over this protocol, and wherein the broker uses a modified IDL style language (Protocol Definition Language or PDL) to define protocols, the PDL definition being compiled into a set of binary op-codes known as a Protocol Implementation Module (PIM), the op-codes in the PIM containing instructions for traversing the interface definitions stored in the repository with the definitions obtained by parsing the IDL description for the interface and including a Dynamic Adaptive Marshaller (DAM) which is a virtual machine, which loads and executes the op-codes in the PIM at run-time

d. a dynamic marshaller for the conversion based on the rules determined by the broker due to the relevant structure format correlations to allow ready flow of data from one input protocol to be readable by output protocol; and

e. an output in a language neutral machine independent definition language specifying the structure of communication messages and the parameter templates to establish a connection and to exchange the communication messages;

wherein the system provides the interface definitions of the selected communication protocol and allows the communication messages to be sent and understood at the receiver and further allows new protocol support to be added without impact on existing systems and without re-compilation of application software.

2. The system of claim 1 wherein a middleware definition tool for this purpose consists of a number of modules, each dedicated to a specific task related to the definition of mechanism for reading and writing data types.

3. A method of intercommunication across communication protocols including the steps of:

a. defining the structure of one or more protocols used in communication using a Protocol Definition Language, compiling this structure into a byte-code structure and storing said result structure in a library;

b. at run time analysing an input communication and determining an appropriate input structure of protocol of the input communication from the library and analysing the path of the intended output communication and determining an appropriate output structure of protocol of the output communication from the library;

c. providing a dynamic marshaller for processing of the byte-code structure at run time and sending the information in accordance with the identified output structure from the corresponding relevant sections of the identified input structure;

d. providing an output in a language neutral machine independent definition language specifying the structure of communication messages and the parameter templates to establish a connection and to exchange the communication messages;

e. providing ability to define new encoders and decoders using said Protocol Definition Language or to specify external pre-existing encoders and decoders using said Protocol Definition Language; and

f. providing ability to define new transport mechanisms or specify external pre-existing transport mechanisms using said Protocol Definition Language;

g. wherein the method allows ready communication between various communication protocols and middleware systems.

4. A method of intercommunication according to claim 3 including the library having a predefined conversion of the structure of one or more protocols to the structure of another of the one or more protocols.

5. A method of intercommunication according to claim 3 or 4 wherein the dynamic marshaller provides buffering and/or addressing as required.

6. A method of intercommunication according to any one of claims 3 to 5 also providing for the dynamic marshaller to include definable predefined processing steps of corresponding relative sections of the identified output structure to the identified input structure.

7. A method of intercommunication according to claim 6 wherein the dynamic marshaller is able to review all data structures, regardless of complexity, as being comprised of a finite set of primitive data types and with reference to the repository determine a mechanism for reading and writing these types to enable processing of structures of arbitrary complexity, wherein the rules and mechanisms for reading these

basic types are defined by the protocol and once the rules are captured allow processing of any message over this protocol.

8. A method of intercommunication according to any one of claims 6 or 7 wherein the predefined processing steps are protocol neutral such that an end user output defines the processing steps in a generic manner and the dynamic marshaller undertakes the required manipulation of the data in any communication based on the predefined processing step of the relevant section of the communication protocol structure so as to provide a required effect regardless of the protocols of communication.

9. A method of intercommunication according to any one of claims 3 to 8 wherein the language neutral machine independent definition is compiled into binary modules known as protocol implementation modules (PIMs) and transport interface modules (TIMs) which contain the communication parameters, and wherein the PIMs and TIMs are loaded at runtime and executed by interpreters (virtual machines) with the PIMs processed by a dynamic adaptive marshaller (DAM) and the TIMs handled by a transport mediation server (TMS) and both of these modules are controlled by a message distribution server (MDS) which is also responsible for any interface mapping that is required and uses either the processed request or response message and a mapping definition with the actual mapping being performed by a mapper module under the direction and control of the MDS.

10. A method of intercommunication of middleware including the steps of:

a. providing a table of initial definition of structure characteristics, including format and parameter data types, of one or more protocols;

b. converting said one or more structure protocol definitions into a selected format;

c. storing said one or more structure protocol definitions in said selected format in one or more repositories;

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d. at run time assessing the incoming message and selecting an appropriate structure protocol definition to be used from the table and using the selected format of the converted structure protocol definition to communicate;

e. including a user or third-parties to create new further protocols and inserting directly into the conversion environment wherein a broker PIM on one side can act as the client and another PIM can act as a server on the target side enabling use of the protocol without any coding wherein a message in one communication protocol can be intercepted, the message converted to the new protocol and sent across to the receiving node where it can be can converted back to original protocol and pass to the original server;

wherein before run time of a message, a structure of the protocol has been defined and the data and information in the form of the protocol structure can be readily communicated in a protocol structure format that would be understood by the receiver.

11. The method of intercommunication of middleware of claim 10 wherein the data structures are reviewed, regardless of complexity, and assessed as comprised of a finite set of primitive data types and a mechanism determined for reading and writing these types, to process structures of arbitrary complexity, with the rules and mechanisms for reading these basic types defined by the protocol and wherein after capturing the rules any message can be processed over this protocol by defining the structure of a request and response message on said communication protocol.

12. A method of flow of an outbound communication to another module with interface including the steps of:

i. assessing the application of the outbound communication to determine and select a protocol to try from a table of protocols in a priority arrangement;

ii. using the selected protocol to determine the format and arguments for the outbound communication;

iii. using the protocol definitions stored to prepare the outbound communication for the particular middleware or application service;

iv. providing required buffer;

v. determining which protocol to use for transmission;

vi. looking up table of end-point resolutions to determine the communication parameters required to communicate with the selected transmission protocol;

vii. attempting to communicate with the designated host using the appropriate communication parameters; and

viii. if communication with the selected protocol fails selecting the next protocol to try from the table of protocols in the priority arrangement.

13. A method of flow of an outbound communication to another module with interface according to claim 12 using a broker which is able to review all data structures, regardless of complexity, as being comprised of a finite set of primitive data types and with reference to the repository determine a mechanism for reading and writing these types to enable processing of structures of arbitrary complexity, wherein the rules and mechanisms for reading these basic types are defined by the protocol and once the rules are captured allow processing of any message over this protocol

14. A method of flow of an inbound communication from another module with interface including the steps of:

i. receiving inbound message in the protocol that it was sent;

ii. looking up table to determine whether the message needs marshalling into another protocol before passing the inbound communication to the target application on the local system;

iii. if message needs marshalling into another protocol, determining the preferred protocol from a table according to priority;

iv. determining the format and arguments for the inbound communication;

v. using stored protocol definitions for the selected protocol to prepare the inbound communication for the target middleware or application service;

vi. buffering the inbound communication as required;

vii. determining protocol to use for transmission.

viii. determining local end point of the target application on the local system; and

ix. at run time passing the inbound communication to the target application on the local system.

15. A method of flow of an inbound communication from another module with interface according to claim 14 using a broker which is able to review all data structures, regardless of complexity, as being comprised of a finite set of primitive data types and with reference to the repository determine a mechanism for reading and writing these types to enable processing of structures of arbitrary complexity, wherein the rules and mechanisms for reading these basic types are defined by the protocol and once the rules are captured allow processing of any message over this protocol

16. A method of flow of an inbound communication from another module with interface according to claim 14 or 15 in which rules and middleware characteristics are specified in a repository, for the system broker to provide the connection and transformation for the middleware protocols, as well as for legacy systems and wherein it is not necessary to have a converter at either end of the communication and further it is not necessary for there to be two way communication in order to ensure the receiver knows what format is arriving, instead the conversion due to the relevant structure format correlations allows ready flow of data from one input protocol to form readable by output protocol.

17. A programmable semiconductor device programmed to perform the steps of the method as defined in any one of claims 3 to 13.

18. A method of intercommunication substantially as hereinbefore described with reference to the drawings.

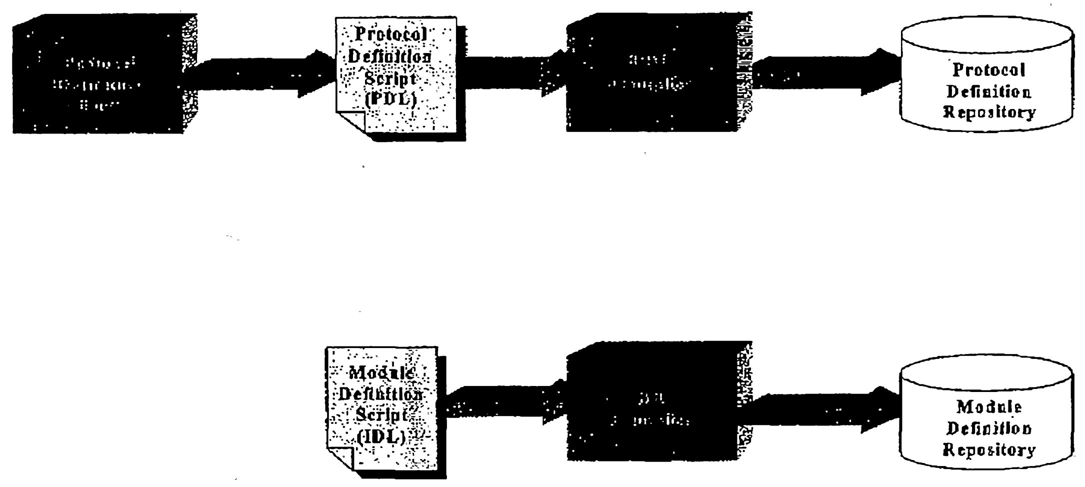

Protocol Definition Script (PDL)
Protocol Definition Repository
Module Definition Script (IDL)
Module Definition Repository

Figure 1 TUBE Build-time processing

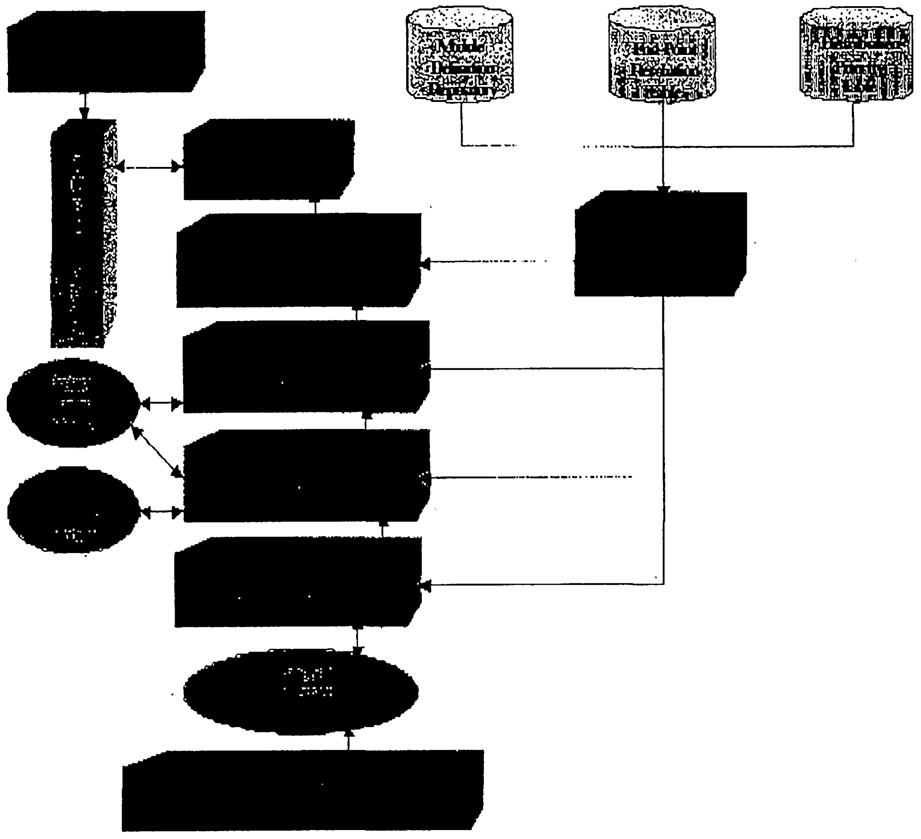


Figure 2 TUBE Component Architecture

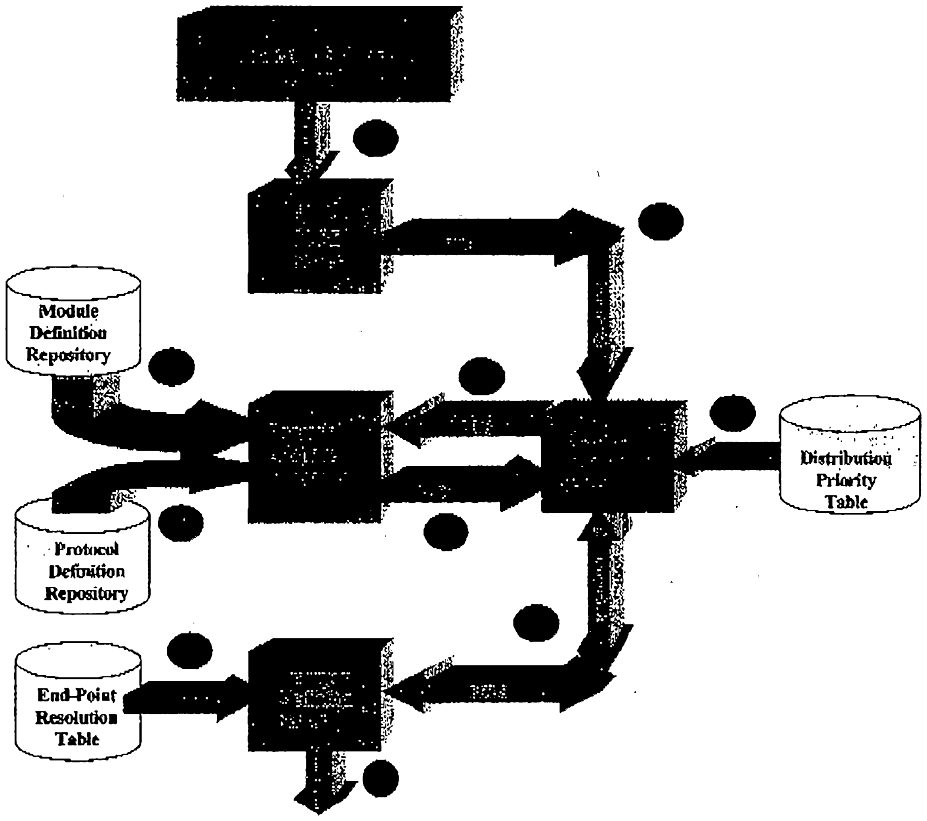

Module Definition Repository
Protocol Definition Repository
Distribution Priority Table
End-Point Resolution Table

Figure 3 TUBE Out-bound message scenario

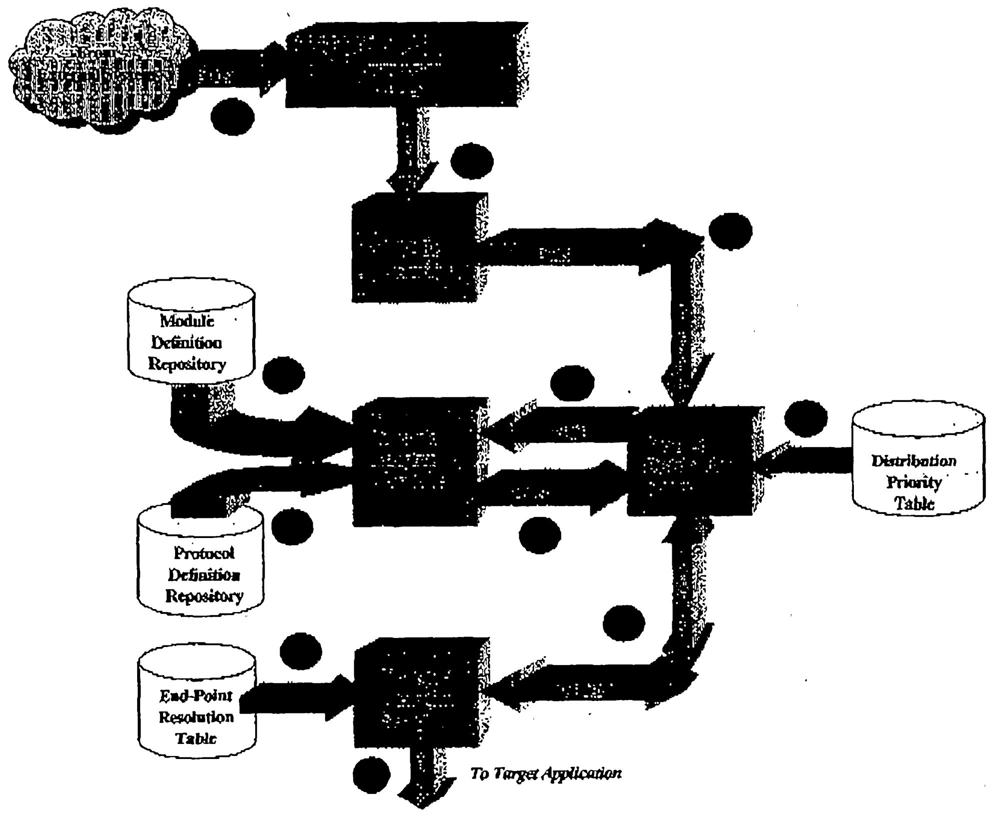

Module Definition Repository
Protocol Definition Repository
Distribution Priority Table
End-Point Resolution Table
To Target Application

Figure 4 TUBE in-bound message scenario

```
interface mathServer
{
  // request structure
  struct math_req
  {
    char op;
    int   num1;
    int   num2;
   };

  // response structure
  struct math_resp
  {
    int   ret_num;
  };


  // define the exception
  exception mathException
  {
    string error_text;
  };

   // methods (services, functions, operations)
   struct math_resp add(in math_req mr) raises (mathException);
   struct math_resp div(in math_req mr) raises (mathException);
......
// Remainder omitted for brevity

};
```

Figure 5: Fragment of mathServer IDL

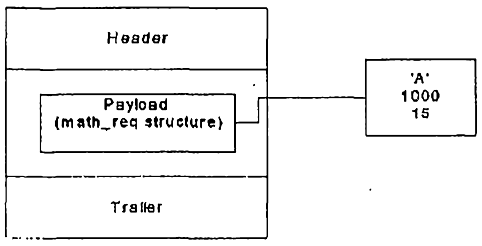


Figure 6: Structure of request message (highlighting payload)

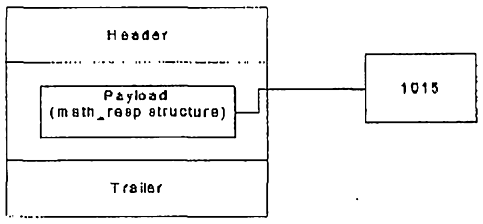


Figure 7: Structure of a successful response message (highlighting payload)

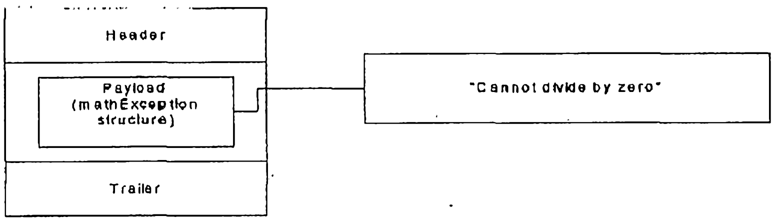


Figure 8:Structure of an unsuccessful response message with an exception as payload

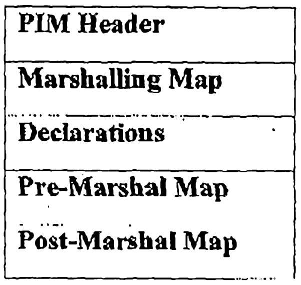


Figure 9: Structure of a PIM

Field	**Description**
File-identifier	This identifies this file as a valid PIM
Marshalling class-name	The name of a class specified in an external clause. This can be empty.
Constant-Segment (CS)	Contains all constant values.
Variable-Definition Segment (VDS)	Contains information about all variables defined in PD.

Figure 10: Structure of a PIM Header

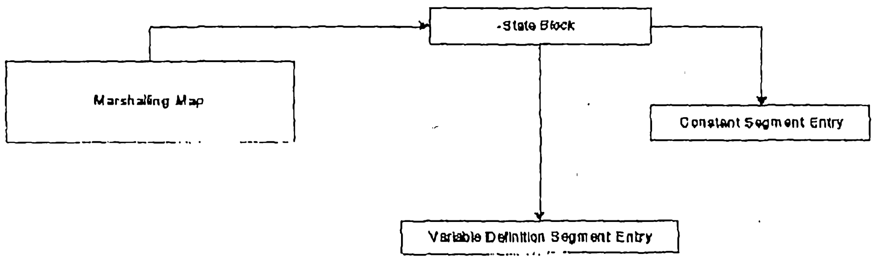
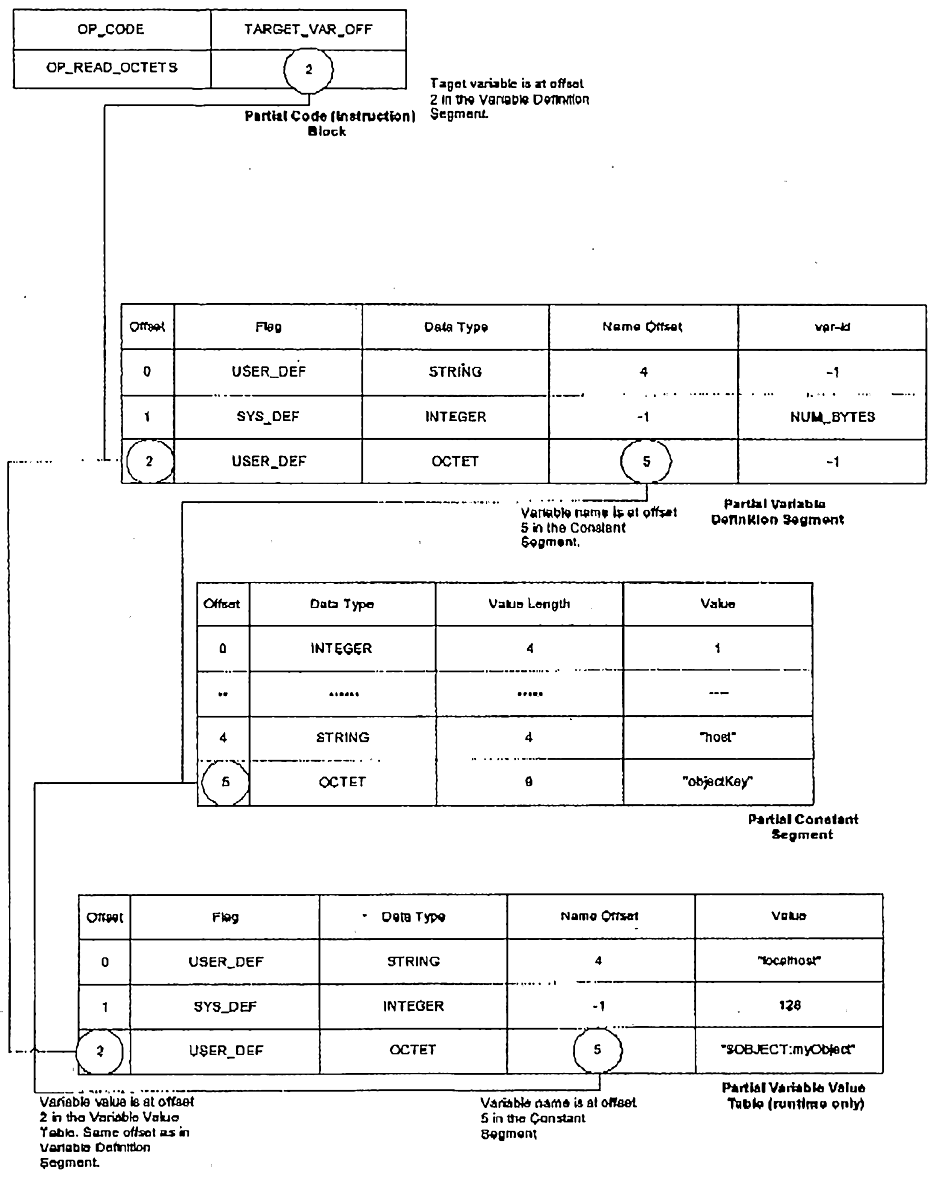


Figure 11 : Structure of a Marshalling Map



Tagot variable is at offset 2 in the Variable Definition Segment.
Partial Code (Instruction) Block
Variable name is at offset 5 in the Constant Segment.
Partial Variable Definition Segment
Partial Constant Segment
Variable value is at offset 2 in the Variable Value Table. Same offset as in Variable Definition Segment.
Variable name is at offset 5 in the Constant Segment
Partial Variable Value Table (runtime only)

OP_CODE	TARGET_VAR_OFF
OP_READ_OCTETS	2

Offset	Flag	Data Type	Name Offset	var-id
0	USER_DEF	STRING	4	-1
1	SYS_DEF	INTEGER	-1	NUM_BYTES
2	USER_DEF	OCTET	5	-1

Offset	Data Type	Value Length	Value
0	INTEGER	4	1
..	......	.....	---
4	STRING	4	"host"
5	OCTET	9	"objectKey"

Offset	Flag	Data Type	Name Offset	Value
0	USER_DEF	STRING	4	"localhost"
1	SYS_DEF	INTEGER	-1	128
2	USER_DEF	OCTET	5	"$OBJECT:myObject"

Figure 12: Mapping op-code target to variable value

```
declare byteSequence
        {
        int %num_bytes%;          // no of bytes in olist
        olist bytes;
                                              };
```

Figure 13: declaration of a byteSequence

```
declare array
        {
        int %array_size%;         // no of items in sequence, arrays don't have this encoded
                                  // although, we can calculate it at runtime
        olist bytes;              // actual sequence of items (can be simple or complex)
                                              };
```

Figure 14: declaration for an array

```
        declare nString
        {
         int %num_bytes% + 1;          // length of string_bytes (incl. null)
         olist string_bytes;           // the actual bytes of the string
         init octet null_byte = 0;     // the terminating null
        };
```

Figure 15: declaration of a null terminated string

```
        declare objectDef
        {
         nString repo_id;                // repository-id of object
         int    profile_count;           // number of profiles in reference
         int    profile_id;              // id of profile
         int    length;                  // length of following stream
         short  version;                 // IIOP version for this profile
         nString host;                   // Host for this object
         short  port;                    // Port for this object
         byteSequence object_key;        // Object key – includes length and byte[]
        };
```

Figure 16: declaration of an object reference

```
control
        {
          switch(%reply_status%)
          {
             case 0:
```

```
            buffer = body;                      // follow MDR
        case 1:
            buffer = USER_EXCEPTION;            // follow Exception in MDR
        case 2:
            buffer = systemException;           // use declared structure
        case 3:
            buffer = objectDef;                 // use declared structure
    }
};
```

Figure 17: The control clause

```
// Response message
        struct GIOPRespMessage
        {
         GIOPHdr hdr;
         int        %buffer_length%;        // the length of the following buffer (body)
         GIOPRespBody body;
                                        };
```

Figure 18: Response message declaration showing buffer_length variable

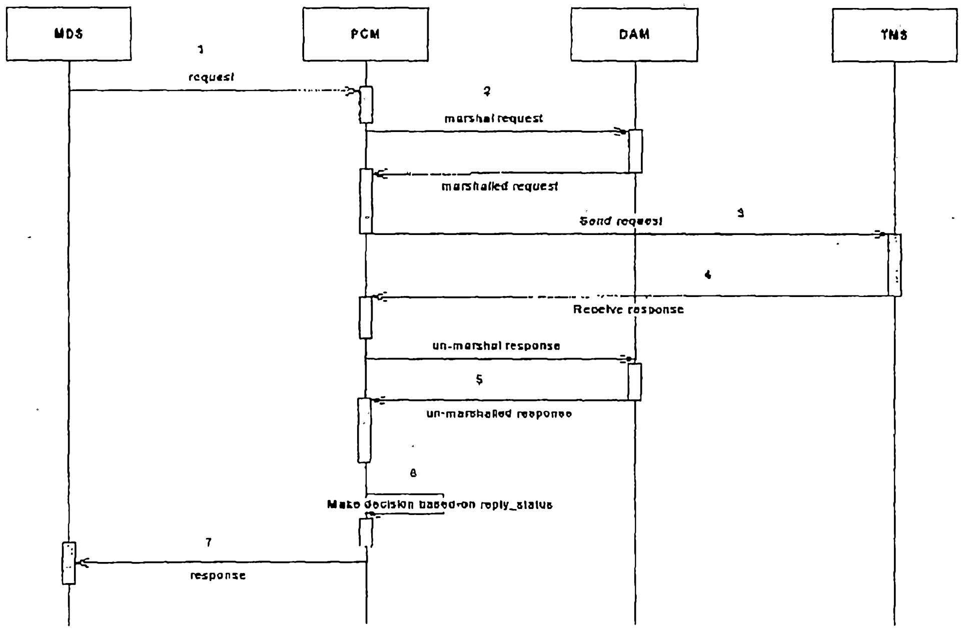


Figure 19: The process of invoking DAM from a PCM

```
// ******************************************************************************
// Items surrounded in % symbols are :
//              internal TUBE variables (eg. buffer length - %buffer_length%)
// Items surrounded in $ symbols are :
//              user-defined variables (eg. ObjectKey --> $ObjectKey$)
//
//              The user-defined variables are expected to be found in either;
//                      - The End Point Resolution Table (EPRT)
//                      - The XFORM map for protocol mapping rules (different to
//                        marshalling rules)
//
// The generated PIM will look in both of these repositories and generate a
// runtime error if the name is not found.
//
// ******************************************************************************

protocol CORBA
{
        typedef sequence<octet, 3> reserved;
        typedef sequence<octet> olist;
        typedef sequence<octet, 4> GIOP_MAGIC;
        //
        // This is an arbitrary sequence of bytes
        // This is referenced in the bufferFormat
        // statement below.
        //
        declare byteSequence
        {
         int %num_bytes%;          // no of bytes in olist
         olist bytes;
        };

        //
        // An idl sequence<..., size>
        // This is a bounded (fixed-size) sequence
        // The only difference between an array and a sequence
        // is that arrays don't have a length encoded because
        // their size is fixed!
        // This is referenced in the bufferFormat
        // statement below.
        //
        declare array
        {
         int %array_size%;         // no of items in sequence, arrays don't have this encoded
                                   // although, we can calculate it at runtime
         olist bytes;              // actual sequence of items (can be simple or complex)
        };


        //
        // An idl sequence<...>
        // This is an un-bounded sequence (see array above for a bounded sequence)
        // This is referenced in the bufferFormat
        // statement below.
        //
```

```
declare sequence
{
 int %sequence_size%;   // no of items to read/write
 olist bytes;           // the items as defined in IDL
};

//
// CORBA uses a hybrid (between C & Pascal) String structure
// The length precedes the bytes (as in Pascal) and the String is zero (null) terminated (as in C)
// Therefore the number of bytes to write and read is always one more than the actual string
// length.
//
// define an nString – a null terminated string
//
declare nString
{
int %num_bytes% + 1;          // length of string_bytes (incl. null)
 olist string_bytes;          // the actual bytes of the string
 init octet null_byte = 0;    // the terminating null
};

//
// declare a CORBA Object Reference
//
declare objectDef
{
 nString repo_id;             // repository-id of object
 int     profile_count;             // number of profiles in reference
 int     profile_id;                // id of profile
 int     length;                    // length of following stream
 short   version;             // IIOP version for this profile
 nString host;                      // Host for this object
 short   port;                      // Port for this object
 byteSequence object_key;           // Object key – includes length and byte[]
};

//
// define how to handle a (CORBA) System Exception (ref. CORBA spec.)
//
declare systemException
{
 nString exc_repoid;          // repository-id of Exception
 int minor_code;              // minor-code
 int completion_status;       // completion-status
};


//
// This is how to treat a buffer - payload
// This item is referenced using the keyword "buffer"
// in any subsequent declarations below
// This declaration statement can only appear once!!!!
//
bufferFormat
{
 STRING = nString;            // marshall a string
 BYTESEQ = byteSequence;      // marshall a buffer of bytes
 ARRAY = array;              // marshall a sequence<..., size>
 OBJECT=objectDef;           // an Object definition
                             // all other items are assumed to be native or constructed
                             // from those above
 SEQUENCE=sequence;          // marshall an un-bounded sequence (sequence<...>)
};


//
// The following control clause uses the reply_status member of the request body
// to perform some decision-making. The payload in the response message may be
// either of four (4) different types depending on the value of reply_status.
//      0 - normal payload as per MDR definition of operation
//      1 - a USER defined EXCEPTION as defined in the MDR entry
//      2 - a SYSTEM EXCEPTION of a fixed format
//      3 - an OBJECT_REFERENCE as encoded for a
//      LOCATION_FORWARD response (see CORBA spec.)
//
control
{
  switch(%reply_status%)
  {
    case 0:
       buffer = body;                   // follow MDR
    case 1:
       buffer = USER_EXCEPTION;         // follow Exception in MDR
    case 2:
       buffer = systemException;        // use declared structure
    case 3:
       buffer = objectDef;              // use declared structure
  }
};

//
// The "external" clause defines our own CDR marshalling class.
// This class implements interface TUBE.commsBuffer and supplies methods to marshall
// native data types using CDR encoding (refer to CORBA spec).
// When we have to marshall an int. The DAM will call read_int or write_int on this
// class
//
external
{
  class = "MYORB.marshaller.CDRBuffer";            // the full classname
};

// Define a Request
Request
{
 GIOPReqMessage message;
};

// Request message
struct GIOPReqMessage
{
 GIOPHdr hdr;
 int %buffer_length%;           // the length of the following buffer (body)
 GIOPReqBody body;
```

```
};

// Common GIOP header
struct GIOPHdr
{
 init GIOP_MAGIC GIOPId = "GIOP";        // 'G''I''O''P' - first 4 bytes
 init octet majver = 1;                  // major version, default 1
 init octet minver = 0;                  // minor version, default 0
 init octet flags = %endian%;            // the endian-ness of the host
 init octet msg_type = %isResponse%;     // built-in flag determines message type
};

//
// This is how a service context is encoded
//
declare ServiceContext
{
 int context_id;
 byteSequence contextData;
};


// This is a list (sequence) of service contexts – will generate a loop wrapper
// around the declared code-block
typedef sequence<ServiceContext> contextList;

// Request body
struct GIOPReqBody
{
 contextList clist;             // sequence of ServiceContexts
 int     %request_id%;          // request-id
 octet   %expect_resp%;         // do we expect a response
 reserved res;                  // 3 reserved bytes
 byteSequence $objectKey$;      // another byte sequence
 nString %operation%;           // declared type (NULL terminated string)
 byteSequence req_principal;    // another byte sequence
 buffer params;                 // a buffer, which can contain various
                                // parameters (native/constructed) follows MDR format
                                // uses bufferFormat clause above

};

// Define a Response
Response
{
  GIOPRespMessage response;
};

// Response message
struct GIOPRespMessage
{
 GIOPHdr hdr;
 int     %buffer_length%;       // the length of the following buffer (body)
 GIOPRespBody body;
};

// Response body
```

```
          struct GIOPRespBody
          {
           contextList clist;               // a byte sequence of the form <length><bytes....>
           int      %request_id%;           // request-id
           int      %reply_status%;         // a reply code, identifies the response format
           buffer response;                 // a buffer, which can contain various
                                            // parameters (native/constructed) follows MDR format
                                            // uses bufferFormat clause above
          };

          //
          // These are values that are encoded into the EPRT
          // The generated TIM will look for these items in the EPRT entry
          //
          endPoint : "TCP"                  // The transport (eg. TCP, HTTP, JMS etc)
          {
          //
          // These are transport and protocol-specific items
          //
          "host";                                 // This is the host for the object
          "port";                                 // This is the port on the host
          };
};
```

Figure 20 a PDL definition of CORBA using IIOP V1.0. First, we will show the PDL script and then examine in detail, each construct and data member and show how the PDL compiler processes them.

Type	Name	Description
Integer	Type	Type of this variable.
Integer	Use	Usage of this variable. Add or subtract from another value or use value as-is.
Integer	value_offset	Offset to constant value of this variable in CS.

Table 1: State Parameter entry

Type	Name	Description
Integer	op_code	Specifies the action to perform.
Integer	target_var	Target variable indicates the variable to use as the source or target for this operation.
State param	state_param	A state parameter entry for this op-code.
Integer	handler_offset	Offset to "declared" type handler map.
Integer	handler_name	Offset of handler name in CS.

Table 2: Structure of a (Code) State-Block

Type	Name	Description
Integer	Type	Type of constant.
Integer	length	Length of constant value.
Byte[]	Name	Name of constant.
Byte[]	Value	Constant value.

Table 3: Format of Constant Segment Entry

Type	Name	Description
Integer	Flag	Flag to indicate if this is a system or user-defined variable.
Integer	Type	Type of this variable.
Integer	name_offset	Offset to name of this variable in CS.
Integer	var_id	Symbolic identifier for this variable. This is –1 for a user-defined variable.

Table 4: Format of Variable-Definition Segment Entry

Type	Name	Description
Integer	flag	Flag to indicate if this is a system or user-defined variable.
Integer	type	Type of this variable.
Integer	name_offset	Offset to name of this variable in CS.
Object	var_value	The current value of this variable. This may be initially empty until we read the value.

Table 5: In-memory layout of Variable Value Table

Keyword	**Description**
Protocol	Signifies the beginning of a PDL script. This replaces the module or interface keywords found in IDL.
Request	Defines the structure of a request message.
Response	Defines the structure of a response message.
%var%	Represents an internal TUBE variable. There are several of these explained in Table 7below. An example is %operation%, which represents the operation or method to invoke on an object-based interface. It may be empty; its value depends on the protocol.
init	Defines a variable of the specified type with an initial value. Refer to the Variable-Definition Segment discussion below *<sec. ref.>*. As an example, we want to define an integer variable mynum and initialise it to the value one (1); we would write "init int mynum=1;".
control	Specifies a field in the message to use as a switch (decision making) value. This allows us to handle different types of payload depending on the value of this field. For instance, we may receive an exception rather than the expected return value. The CORBA example below demonstrates this usage.
buffer var	Signals the start of the payload (as defined in the interface) within the message. The compound (complex) types defined by "declare" statements can be marshalled and un-marshalled from this position in the message. The processing follows the MDR definition. The only exception to this is if some condition specified in a "control" clause has been met, and this specified the execution of another code-block. Specifies a user-defined variable. We retrieve the values for these variables at marshal time from the EPRT *<sec. ref.>*. During un-marshalling we read them from the input stream. In either case, the value is stored in the Variable-Definition Segment entry. An example of a user-defined variable is a CORBA object-key, we define it as follows: "byteSequence $objectKey$". This means when we reach this point in the message, read a byteSequence structure and assign its value to the variable "objectKey".
struct declare	This is not strictly an extension to the syntax, rather a usage of the keyword struct. We use this to define individual parts of the message, such as header, body or trailer. Each struct declaration causes the generation of a CODE_BLOCK (see **Error! Reference source not found.**). This allows different parts of the message to be handled out-of sequence. Where it may be necessary to re-marshal only some values. We explain this fully in the DAM CORBA example. Define marshalling rules for a particular compound (complex) type.

Keyword	Description
bufferFormat	Defines how to encode/decode declared types encountered in the payload (refer to **Error! Reference source not found.**).
endPoint	Defines the communications end-point in protocol-specific terms.
external	Defines an external class that will provide marshalling functions for this protocol and communication management functions. If there are no external classes defined, TUBE will use its own to carry out these operations. The specified classes must implement specific TUBE defined interfaces. These classes may be used as wrappers around vendor-specific or home-grown APIs.
sequence	This is not an extension. It causes the generation of a looping wrapper around the CODE_BLOCK, which marshals the defined type. This is closely associated to the %count% (internal) variable, which holds the value of the loop count. TUBE must know from this definition, at what point and from where in the message, to read this value. In the case of marshalling, TUBE will write this value into this point in the message. The encoding of the specified sequence then follows.

Table 6: Extensions to OMG IDL

Variable	Description		
		Marshalling	**Un-marshalling**
endian	Defines the endian representation of the target host.	Value obtained from EPRT entry.	Value stored for reference only.
buffer_length	Specifies the overall length of the payload.	Encoded after payload.	Read before payload.
request_id	Ensures processing in correct sequence.	Read from entry and encoded.	Stored in entry.
isResponse	Determines if this is a response message.	Read from entry and encoded.	Stored in entry.
operation	Specifies the method to invoke. Only applies to protocols that support methods[1].	Read from entry and encoded or obtained from an *XFORM* map.	Stored in entry.
		Marshalling	**Un-marshalling**
expect_resp	Specifies if this is a two-way invocation.	Read from entry and encoded.	Stored in entry.

Variable	Description		
num_bytes	The number of bytes in the next set of bytes.	Read from entry and used to write next block of bytes.	Stored in entry and used to read next block of bytes.
reply_status	The status of the communication session. Only applies to responses.	Read from entry and encoded. The value is protocol-specific.	Stored in entry.
target_tlv	Read/Write the valuc from a TLV entry. We use the TLV primarily for payload processing.	Read from TLV entry and encoded.	Stored in TLV entry.
count	Internally created when we encounter "sequence" in PDL.	Written at the start of a loop wrapper.	Read from stream at expected start of a loop.
array_size	Internally created when an item is defined as an ARRAY	Value obtained from MDR entry.	Value obtained from MDR entry.
sequence_size	The size (in elements) of the sequence to read/write	Read from entry and encoded.	Written from entry.

Table 7: TUBE internal variables

OP-Code	Source / Target variable	Comment
READ_INT		Read an integer from input
PUSH	Put on top of value stack	
POP	Get value on top of value stack	
ASSIGN_TO	NUM_BYTES	Assign value to internal NUM_BYTES
GET_FROM	NUM_BYTES	Retrieve NUM_BYTES
READ_OCTETARRAY		Read NUM_BYTES octets
PUSH		Put octet array on top of value stack. Caller will POP and retrieve value.
END_BLOCK		End of this code-block

Table 8: op-codes generated for reading a byteSequence

OP-Code	Source / Target variable	Comment
READ_INT		Read an integer from input
SUB PUSH	Subtract a value from the offset into the CS from the value just read Put on top of value stack	We have an offset to the value "1" in the CS. We now have value - 1
USER_DEFINED		A declared code block
POP	Get value on top of value stack	
ASSIGN_TO	NUM_BYTES	Assign value to NUM_BYTES
GET_FROM	NUM_BYTES	Retrieve NUM_BYTES
READ_OCTETARRAY		Read NUM_BYTES octets
PUSH		Put octet array on top of value stack. Caller will POP and retrieve value.
READ_OCTET		Read null byte
END_BLOCK		End of this code-block

Table 9: op-codes for reading a null terminated string

OP-Code	Source / Target variable	Comment
USER_DEFINED		A declared code-block
LOAD_BLOCK	repo_id	Load and execute the block named "nString_READ" and place the value in the variable "repo_id"
READ_INT	profile_count	Read an integer and assign it to the variable "profile_count"
READ_INT	profile_id	Read an integer and assign it to the variable "profile_id"
READ_INT	length	Read an integer and assign it to the variable "length"
READ_SHORT	version	Read a short and assign it to the variable "version"
LOAD_BLOCK	host	Load and execute the block named "nString_READ" and place the value in the variable "host"
READ_SHORT	port	Read a short and assign it to the variable "port"

OP-Code	Source / Target variable	Comment
LOAD_BLOCK	object_key	Load and execute the block named "byteSequence_READ" and place the value in the variable "object_key"
END_BLOCK		End of this code-block

Table 10: op-codes for reading an object reference

OP-Code	Source / Target variable	Comment
TEST_EQ	REPLY_STATUS	Test if reply_status == 0
JUMP	LABEL_0	The test returns true. Jump to the given label.
TEST_EQ	REPLY_STATUS	Test if reply_status == 1
JUMP	LABEL_1	The test returns true. Jump to the given label.
TEST_EQ	REPLY_STATUS	Test if reply_status == 2
JUMP	LABEL_2	The test returns true. Jump to the given label.
TEST_EQ	REPLY_STATUS	Test if reply_status == 3
JUMP	LABEL_3	The test returns true. Jump to the given label.
PUSH	Exception	All tests failed. Push an Exception value onto the stack. This causes the interpreter to throw an exception.
JUMP	LABEL_4	Jump to the last label.
LABEL_0		
PUSH	False	Push a false value onto the stack. This is the return value. Therefore, we follow the MDR.
JUMP	LABEL_4	Jump to the last label.
LABEL_1		This is an MDR-defined Exception.
PUSH	True	Return true
LABEL_2		
PUSH	"systemException_READ"	Push the name of the block to decode a system exception.
JUMP	LABEL_4	Jump to the last label.

OP-Code	Source / Target variable	Comment
JUMP	LABEL_4	Jump to the last label.
LABEL_3		
PUSH	"objectDef_READ"	Push the name of the block to decode an object definition.
JUMP	LABEL_4	Jump to the last label.
LABEL_4		Return value on top of stack.

Table 11: Op-codes for processing "control" clause

OP-Code	Source / Target variable	Comment
SAVEPOS	BUFFER_POS	Save current buffer position.
SETPOS	BUFFER_POS (POS=8)	Set the buffer position to the value of the constant at the offset given by the parameter.
SUBTRACT	A constant value of "12" from the buffer length. Header length (8) + length of integer (4) = 12.	Subtract the length of the header + the length of the integer from the buffer_length to give only payload length.
WRITE_INT	BUFFER_LENGTH	Write-out the value of the internal variable buffer_length
GETPOS	BUFFER_POS	Get the saved buffer position.
SETPOS	BUFFER_POS	Set the buffer position to the saved value.

Table 12: Post-Marshal map for CORBA message

OP-Code	Description	Comments
READ_OCTET	Read a single octet (byte) from a source.	
WRITE_OCTET	Write a single octet (byte) to a target	
JUMP	Jump to the given LABEL	
LABEL	The target of a JUMP instruction.	
LOOP	The start of a looping sequence.	
LOOP_END	The end of a looping sequence.	
Etc.		

OP-Code	Description	Comments

Table 13: PDL Op-codes