Developing Distributed Object Computing Applications with CORBA

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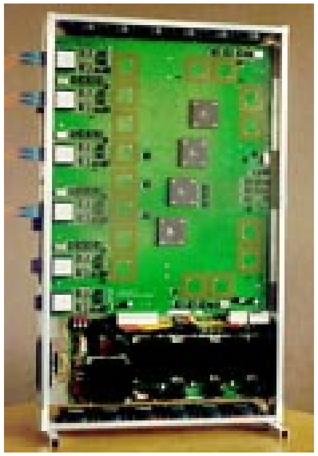
Motivation: the Distributed Software Crisis



Symptoms

- ***Hardware*** gets smaller, faster, cheaper
- ***Software*** gets larger, slower, more expensive

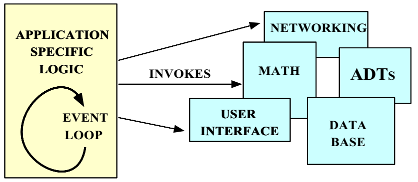
Culprits

- ***Inherent*** and ***accidental*** complexity

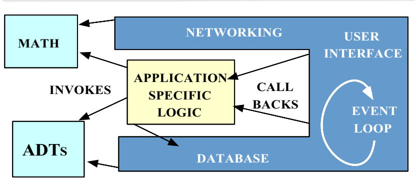
Solution Approach

- ***Components, Frameworks, Patterns, & Architecture***

Techniques for Improving Software Quality and Productivity



(A) CLASS LIBRARY ARCHITECTURE

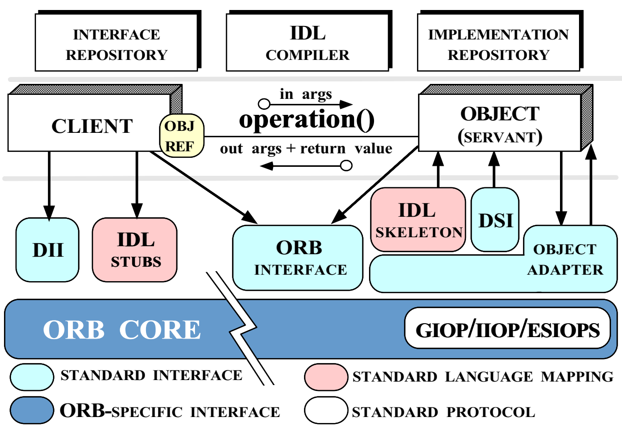


(B) FRAMEWORK ARCHITECTURE

Proven solutions →

- *Components*
  - Self-contained, "pluggable" ADTs
- *Frameworks*
  - Reusable, "semi-complete" applications
- *Patterns*
  - Problem/solution/context
- *Architecture*
  - Families of related patterns and components

Overview of CORBA Middleware Architecture

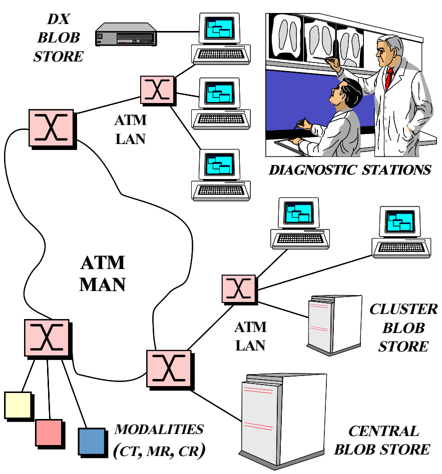


www.cs.wustl.edu/∼schmidt/corba.html

Goals of CORBA

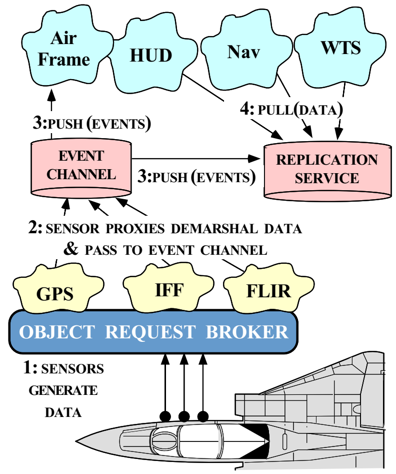
- Simplify distribution by automating
  - Object location & activation
  - Parameter marshaling
  - Demultiplexing
  - Error handling
- Provide foundation for higher-level services

Applying CORBA to Medical Imaging



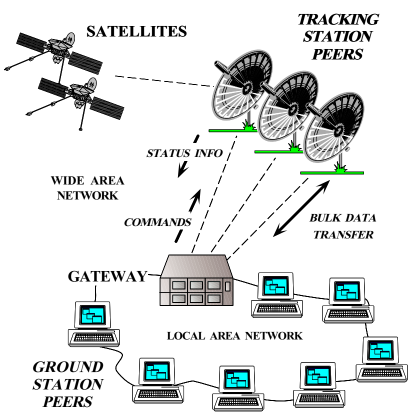
- **Domain Challenges**
  - Large volume of “Blob” data
    - *e.g.*, 10 to 40 Mbps
  - “Lossy compression” isn’t viable
  - Prioritization of requests
- **URLs**
  - ∼schmidt/COOTS-96.ps.gz
  - ∼schmidt/av_chapter.ps.gz
  - ∼schmidt/NMVC.html

Applying CORBA to Real-time Avionics



- **Domain Challenges**
  - Real-time periodic processing
  - Complex dependencies
  - Very low latency
- **URLs**
  - ∼schmidt/JSAC-98.ps.gz
  - ∼schmidt/TAO-boeing.html

Applying CORBA to Global PCS



- **Domain Challenges**
  - Long latency satellite links
  - High reliability
  - Prioritization
- **URL**
  - ∼schmidt/TAPOS-95.ps.gz

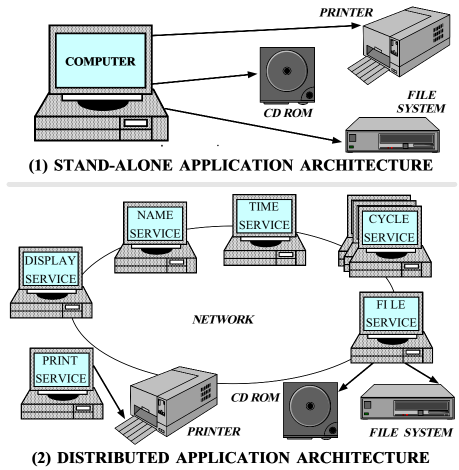
Tutorial Outline

- Motivation
- Example CORBA Applications
- Coping with Changing Requirements
- Overview of CORBA Architecture
- Evaluations and Recommendations

Motivation for COTS Middleware

- It is hard to develop distributed applications whose components collaborate *efficiently*, *reliably*, *transparently*, and *scalably*
- To help address this challenge, the Object Management Group (OMG) is specifying the *Common Object Request Broker Architecture* (CORBA)
- OMG is a consortium of ~1,000 computer companies
  - Sun, HP, DEC, IBM, IONA, Inprise, Cisco, Motorola, Boeing, etc.
- The latest version of the CORBA spec is now available
  - www.omg.org/library/c2indx.html

Sources of Complexity for Distributed Applications



- **Inherent complexity**
  - Latency
  - Reliability
  - Partitioning
  - Ordering
  - Security
- **Accidental Complexity**
  - Low-level APIs
  - Poor debugging tools
  - Algorithmic decomposition
  - Continuous re-invention

Sources of Inherent Complexity

- *Inherent complexity* results from fundamental challenges in the distributed application domain
- Key challenges include
  - Addressing the impact of latency
  - Detecting and recovering from partial failures of networks and hosts
  - Load balancing and service partitioning
  - Consistent ordering of distributed events

Sources of Accidental Complexity

- *Accidental complexity* results from limitations with tools and techniques used to develop distributed applications
- Key limitations include
  - Lack of type-safe, portable, re-entrant, and extensible system call interfaces and component libraries
  - Inadequate debugging support
  - Widespread use of *algorithmic* decomposition
  - Continuous rediscovery and reinvention of core concepts and components

Motivation for CORBA

- Simplifies application interworking
  - CORBA provides higher level integration than traditional *untyped TCP bytestreams*
- Benefits for distributed programming similar to OO languages for non-distributed programming
  - *e.g.*, encapsulation, interface inheritance, polymorphism, and exception handling
- Provides a foundation for higher-level distributed object collaboration
  - *e.g.*, ActiveX and the OMG Common Object Service Specification (COSS)

CORBA Quoter Example

```
int main (void)
{
  // Use a factory to bind
  // to a Quoter.
  Quoter_var quoter =
    bind_quoter_service ();

  const char *name =
    "ACME ORB Inc.";

  CORBA::Long value =
    quoter->get_quote (name);
  cout << name << " = "
       << value << endl;
}
```

- Ideally, a distributed service should look just like a non-distributed service
- Unfortunately, life is harder when errors occur...

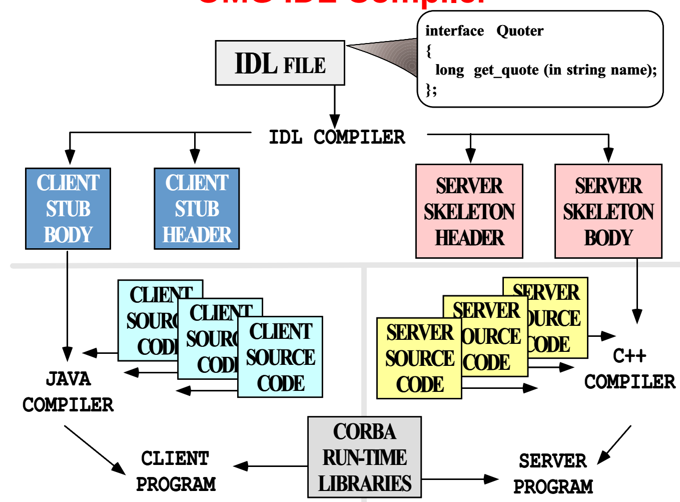
CORBA Quoter Interface

```
// IDL interface is like a C++
// class or Java interface.
interface Quoter
{
  exception Invalid_Stock {};

  long get_quote
    (in string stock_name)
    raises (Invalid_Stock);
};
```

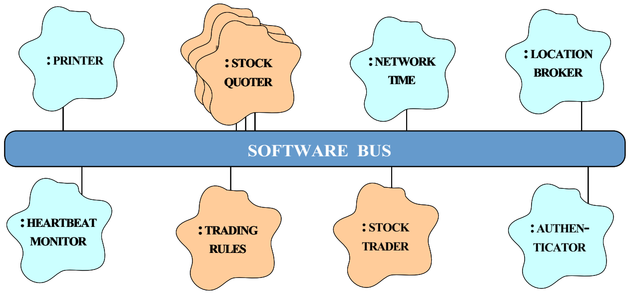
- We write an OMG IDL interface for our Quoter
  - Used by both clients and servers

Using OMG IDL promotes *language/platform independence*, *location transparency*, *modularity*, and *robustness*

OMG IDL Compiler

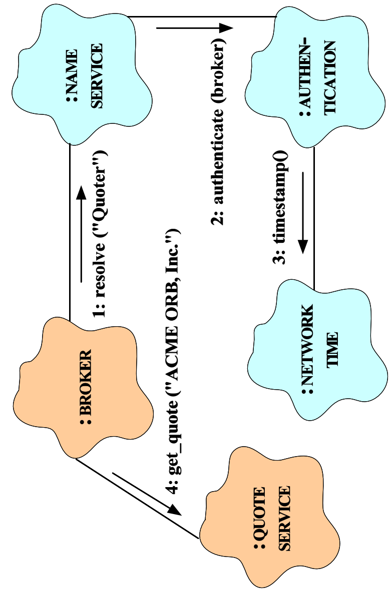


Software Bus



- CORBA provides a communication infrastructure for a heterogeneous, distributed collection of collaborating objects
- Analogous to "hardware bus"

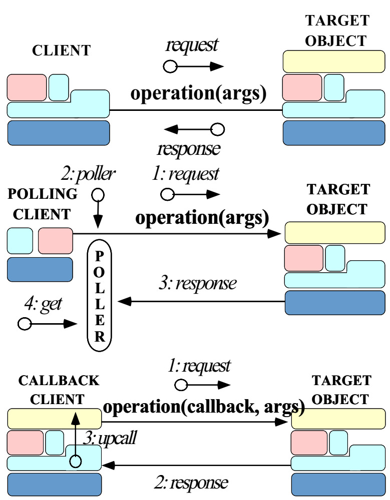
CORBA Object Collaboration



- Collaborating objects can be either remote or local
  - *i.e.*, distributed or collocated
- For this to work transparently the ORB should support *nested upcalls* and *collocation optimizations*

Communication Features of CORBA

- CORBA supports reliable, uni-cast communication
  - *i.e.*, *oneway*, *twoway*, *deferred synchronous*, and *asynchronous*
- CORBA objects can also collaborate in a *client/server*, *peer-to-peer*, or *publish/subscribe* manner
  - *e.g.*, COS Events & Notification Services define a publish & subscribe communication paradigm



Fundamental CORBA Design Principles

- Separation of interface and implementation
  - Clients depend on interfaces, not implementations
- Location transparency
  - Service use is orthogonal to service location
- Access transparency
  - Invoke operations on objects
- Typed interfaces
  - Object references are typed by interfaces
- Support of multiple inheritance of interfaces
  - Inheritance extends, evolves, and specializes behavior

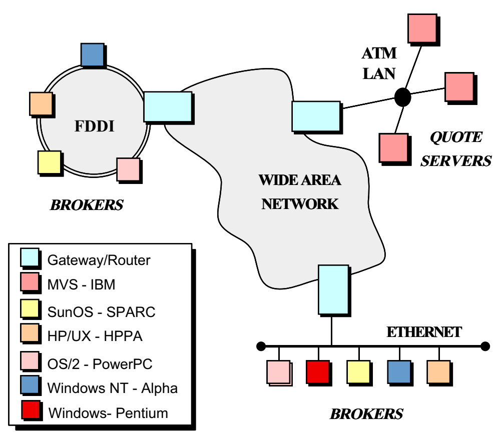
Related Work

- Traditional RPC (*e.g.*, DCE)
  - Only supports "procedural" integration of application services
  - Doesn't provide object abstractions, async message passing, or dynamic invocation
  - Doesn't address inheritance of interfaces
- Windows COM/DCOM/COM+
  - Traditionally limited to desktop applications
  - Does not address heterogeneous distributed computing

Related Work (cont'd)

- Java RMI
  - Limited to Java only
    - ∗ Can be extended into other languages, such as C or C++, by using a bridge across the Java Native Interface (JNI)
  - Well-suited for all-Java applications because of its tight integration with the Java virtual machine
    - ∗ *e.g.*, can pass both object data and code by value
  - However, many challenging issues remain unresolved
    - ∗ *e.g.*, security, robustness, and versioning

CORBA Stock Quoter Application Example



- The quote server(s) maintains the current stock prices
- Brokers access the quote server(s) via CORBA
- Note all the heterogeneity!

Simple OMG IDL Quoter Definition

```
module Stock {
  // Exceptions are similar to structs.
  exception Invalid_Stock {};
  exception Invalid_Factory {};

  // Interface is similar to a C++ class.
  interface Quoter
  {
    long get_quote (in string stock_name)
      raises (Invalid_Stock);
  };

  // A factory that creates Quoter objects.
  interface Quoter_Factory
  {
    // Factory Method that returns a new Quoter
    // selected by name e.g., "Dow Jones,"
    // "Reuters,", etc.
    Quoter create_quoter (in string quoter_service)
      raises (Invalid_Factory);
  };
};
```

Compiling the Interface Definition

- Running the Stock module definition through the IDL compiler generates stubs and skeletons
  - The stub is a *proxy* that marshals parameters on the client
  - The skeleton is an *adapter* that demarshals parameters on the server
- CORBA associates a servant to a generated IDL skeleton using either
  1. The Class form of the Adapter pattern (inheritance) `POA_Stock::Quoter`
  2. The Object form of the Adapter pattern (object composition, *i.e.*, TIE)
     `template <class Impl> class POA_Stock::Quoter_tie`

Revised OMG IDL Quoter Definition

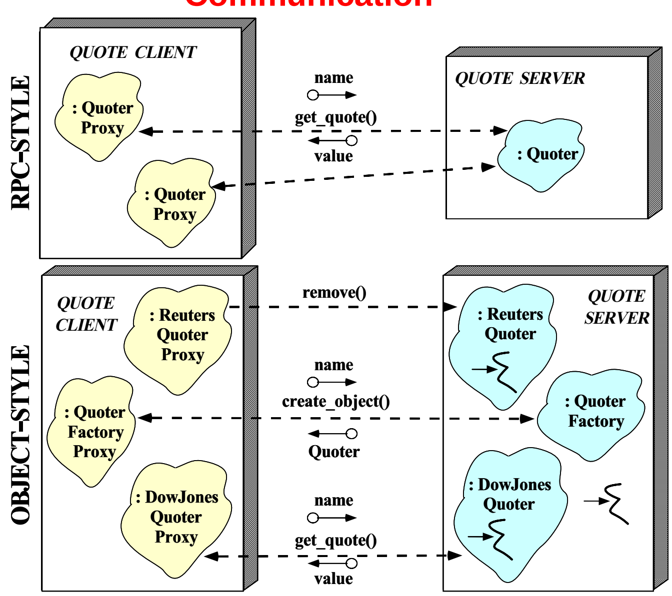
Apply the CORBA Lifecycle Service

```
module Stock {
  exception Invalid_Stock {}; // Similar to structs.

  // Interface is similar to a C++ class.
  interface Quoter : CosLifeCycle::LifeCycleObject
  {
    long get_quote (in string stock_name)
      raises (Invalid_Stock);
    // Inherits:
    // void remove () raises (NotRemovable);
  };

  // Manage the lifecycle of a Quoter object.
  interface Quoter_Factory :
    CosLifeCycle::GenericFactory
  {
    // Returns a new Quoter selected by name
    // e.g., "Dow Jones," "Reuters,", etc.
    // Inherits:
    // Object create_object (in Key k,
    //                       in Criteria criteria)
    // raises (NoFactory, InvalidCriteria,
    //         CannotMeetCriteria);
  };
};
```

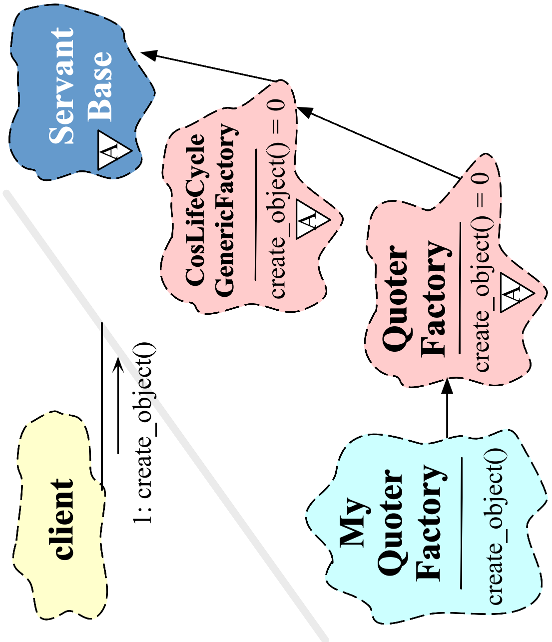

Automatically-Generated Client-side Stubs

```
namespace Stock
{
  class Quoter
    : public virtual CosLifeCycle::LifeCycleObject
      // Quoter also IS-A CORBA::Object.
  {
  public:
    // Proxy interface.
    CORBA::Long get_quote (const char *stock_name);
  };

  class Quoter_Factory
    : public virtual CosLifeCycle::GenericFactory
      // GenericFactory IS-A CORBA::Object.
  {
  public:
    // Proxy Factory method for creation.
    // Inherits:
    // CORBA::Object_ptr create_object
    //   (const CosLifeCycle::Key &factory_key,
    //    const CosLifeCycle::Criteria &criteria)
  };
  // ...
};
```


RPC-style vs. Object-style Communication



The Class Form of the Adapter Pattern



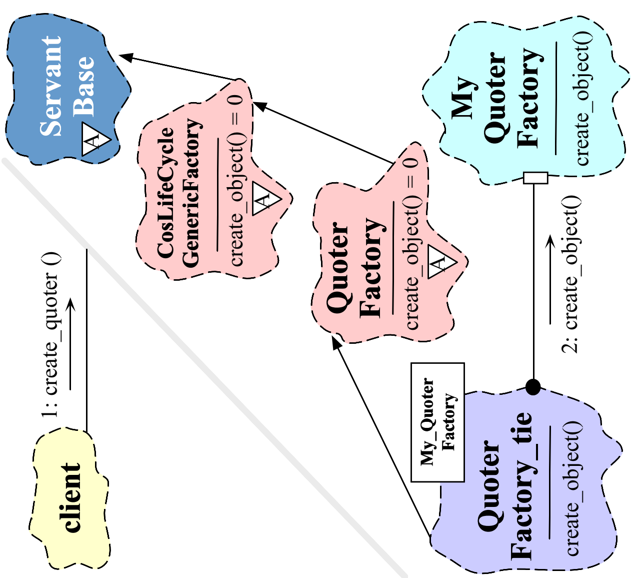
Defining a Servant Using Inheritance

```
class My_Quoter_Factory : public virtual POA_Stock::Quoter_Factory
{
public:
  My_Quoter_Factory (const char *factory_name =
                     "my quoter factory");
  virtual CORBA::Object_ptr // Factory method for creation.
    create_object (const CosLifeCycle::Key &factory_key,
                   const CosLifeCycle::Criteria &the_criteria)
        throw (CORBA::SystemException, QuoterFactory::NoFactory);
};
```

The drawback is that implementations inherit from generated skeletons

- Can create a “brittle” hierarchy and make it hard to integrate with legacy code, *i.e.*, distributing a stand-alone application
- Virtual inheritance is often poorly implemented

The Object Form of the Adapter Pattern



A TIE-based Implementation

```
class My_Quoter_Factory {
public:
  My_Quoter_Factory (const char *factory_name =
                     "my quoter factory");
  // Factory method for creation.
  CORBA::Object_ptr create_object
    (const CosLifeCycle::Key &factory_key,
     const CosLifeCycle::Criteria &the_criteria)
    throw (CORBA::SystemException, QuoterFactory::NoFactory);
};
```

TIE allows classes to become distributed even if they weren’t developed with prior knowledge of CORBA

- There is no use of inheritance and operations need not be virtual!
- However, lifecycle issues can be tricky...

Registering `My_Quoter_Factory` with the Naming Service

```
extern CosNaming::NamingContext_ptr
       name_context;

My_Quoter_Factory::My_Quoter_Factory
  (const char *factory_name)
{
  CosNaming::Name name;
  name.length (1);
  name[0].id = factory_name;
  name[0].kind = "object impl";

  // Obtain object reference and
  // register with the POA.
  Quoter_Factory_var qf = this->_this ();

  // Export our object reference to the
  // naming context.
  name_context->bind (name, qf.in ());
};
```

Real code should handle exceptions...

Defining a Servant Using TIE

```
namespace POA_Stock
{
  template <class Impl>
  class Quoter_Factory_tie : public Quoter_Factory { /* ... */ };
  // ...
```

```
typedef POA_Stock::Quoter_Factory_tie<My_Quoter_Factory>
   MY_QUOTER_FACTORY;
```

We generate a typedef and a servant that places an implementation pointer object within the TIE class:

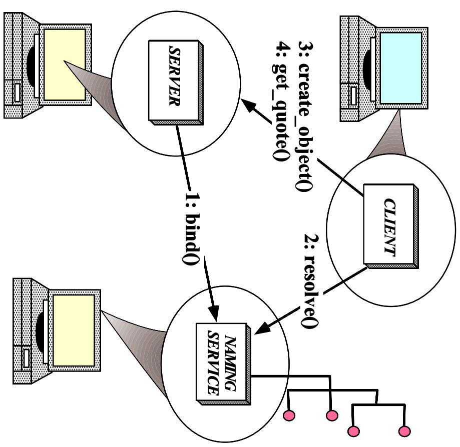
```
MY_QUOTER_FACTORY factory (new My_Quoter_Factory);
```

All operation calls via the TIE class are then delegated to the implementation object

Implementing `My_Quoter_Factory`

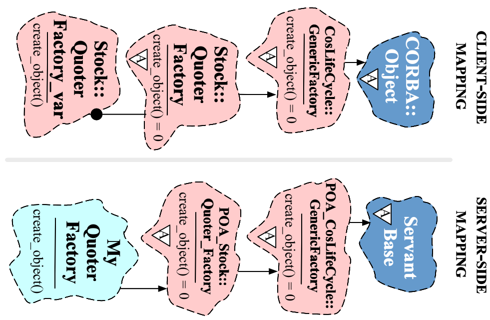
```
CORBA::Object_ptr
My_Quoter_Factory::create_object
  (const CosLifeCycle::Key &factory_key,
   const CosLifeCycle::Criteria &the_criteria)
{
  POA_Stock::Quoter *quoter;

  // Perform Factory Method selection of
  // the subclass of Quoter.
  if (strcmp (factory_key.id.in (),
              "Dow Jones") == 0)
    quoter = new Dow_Jones_Quoter;
  // ...
  else if (strcmp (factory_key.id.in (),
                   "My Quoter") == 0)
    // Dynamically allocate a My_Quoter object.
    quoter = new My_Quoter;
  else
    // Raise exception.
    throw Quoter_Factory::NoFactory ();

  // Create a Stock::Quoter_ptr, register
  // the servant with the default_POA, and
  // return the new Object Reference.
  return quoter->_this ();
};
```


Using the CORBA Naming Service



- **Purpose**
  - Maps sequences of strings to object references
- **Implementation**
  - `Naming Context` can be a hierarchically nested graph
  - Written using ACE `Hash Maps`

POA IDL Mappings



- The client-side mapping inherits all interfaces from the `Object` interface
  - Similar to Java
- The server-side mapping inherits all Servants from `ServantBase`
- Note that older versions of CORBA may not support this standard

The Main Server Program

Uses *persistent activation* mode

```
int main (int argc, char *argv[])
{
  ORB_Manager orb_manager (argc, argv);

  const char *factory_name = "my quoter factory";

  // Create the servant, which registers with
  // the rootPOA and Naming Service implicitly.
  My_Quoter_Factory factory (factory_name);

  // Could use the TIE approach and explicitly
  // register the servant with the POA, i.e.:
  // MY_QUOTER_FACTORY factory
  //   (new My_Quoter_Factory (factory_name));
  // orb_manager.activate (&factory);

  // Block indefinitely waiting for incoming
  // invocations and dispatch upcalls.
  orb_manager.run ();
  // After run() returns, the ORB has shutdown.
}
```


OMG IDL Mapping Rules

- The CORBA specification defines mappings from CORBA IDL to various programming languages
  - *e.g.*, C++, C, Smalltalk, Java, COBOL
- Mapping OMG IDL to C++
  - Each `module` is mapped to a class or namespace
  - Each `interface` is mapped to a class
  - Each operation is mapped to a C++ method with appropriate parameters
  - Each read/write attribute is mapped to a pair of get/set methods
    - * A read-only attribute is only mapped to a single get method
  - An `Environment` is defined to carry exceptions in languages that lack this feature

Server Initialization Wrapper Facades

```
class ORB_Manager {
public:
  // Initialize the ORB manager.
  ORB_Manager (int argc, char *argv[]) {
    orb_ = CORBA::ORB_init (argc, argv, 0);
    CORBA::Object_var obj =
      orb_->resolve_initial_references ("RootPOA");
    poa_ =
      PortableServer::POA::_narrow (obj.in ());
    poa_manager_ = poa_->the_POAManager ();
  }

  // Register <servant> with the <poa_>.
  int activate (PortableServer::Servant servant) {
    return poa_->activate_object (servant);
  }
  // ORB Accessor.
  CORBA::ORB_ptr orb (void) { return orb_.in (); }

  // Run the main ORB event loop.
  int run (void) {
    poa_manager_->activate ();
    return orb_->run ();
  }
private:
  CORBA::ORB_var orb_;
  PortableServer::POA_var poa_;
  PortableServer::POA_Manager_var poa_manager_;
```

Binding a Client to a CORBA Object

- Several steps:
  1. Client uses `resolve_initial_references` and "Interoperable Naming Service" to obtain a `NamingContext`
     – This is the standard ORB "bootstrapping" mechanism
  2. Client then uses `NamingContext` to obtain desired object reference
  3. The client then invokes operations via object reference
- Object references can be passed as parameters to other remote objects
  – This supports various types of "factory" patterns

A Client Program

```
int main (int argc, char *argv[])
{
  // Manages refcounts.
  Stock::Quoter_var quoter;

  try { // Use a factory to bind to any quoter.
    Stock::Quoter_Factory_var qf =
      bind_service<Stock::Quoter_Factory>
        ("my quoter factory", argc, argv);
    if (CORBA::is_nil (qf.in ())) return -1;
    const char *stock_name = "ACME ORB Inc.";
    CosLifeCycle::Key key; key.length (1);
    key[0].id = "My Quoter";

    // Find a quoter and invoke the call.
    CORBA::Object_var obj = qf->create_object (key);
    quoter = Stock::Quoter::_narrow (obj);
    CORBA::Long value =
      quoter->get_quote (stock_name);
    cout << stock_name << " = " << value << endl;
    // Destructors of *_var release memory.
  } catch (Stock::Invalid_Stock &) {
    cerr << stock_name << " not valid" << endl;
  } catch (...) { /* Handle exception... */ }
  quoter->remove ();
}
```


Programming with Object References

- Object references are represented by different generated types
  – `_ptr` → C++ pointer to object reference
    * Requires programmer management of reference ownership via `_duplicate` and `_release`
  – `_var` → Auto pointer to object reference
    * Internally manages reference ownership
  – `_out` → eases passing out parameters between client and server
    * Never used directly by user

Obtaining an Object Reference via the Naming Service

```
static CORBA::ORB_ptr orb;
extern CosNaming::NamingContext_ptr name_context;

template <class T> typename T::_ptr_type /* trait */
bind_service (const char *n, int argc, char *argv[])
{
  CORBA::Object_var obj; // "First time" check.
  if (CORBA::is_nill (name_context)) {
    // Get reference to name service.
    orb = CORBA::ORB_init (argc, argv, 0);
    obj = orb->resolve_initial_references
      ("NameService");
    name_context =
      CosNaming::NamingContext::_narrow (obj);
    if (CORBA::is_nil (name_context)) return 0;
  }
  CosNaming::Name svc_name;
  svc_name.length (1); svc_name[0].id = n;
  svc_name[0].kind = "object impl";
  // Find object reference in the name service.
  obj = name_context->resolve (svc_name);

  // Narrow to the T interface and away we go!
  return T::_narrow (obj);
}
```

Coping with Changing Requirements

- New Quoter features
  - Format changes to extend functionality
  - New interfaces and operations
- Improving existing Quoter features
  - Batch requests
- Leveraging new ORB features
  - Asynchronous Method Invocations (AMI)
  - Server location independence (requires smart ORB)

New Formats

For example, percentage that stock increased or decreased since start of trading day, volume of trades, etc.

```
module Stock
{
  // ...

  interface Quoter
  {
    long get_quote (in string stock_name,
                    out double percent_change,
                    out long trading_volume)
      raises (Invalid_Stock);
  };
};
```

Note that even making this simple change would involve a great deal of work for a sockets-based solution...

Adding Features Unobtrusively

Interface inheritance allows new features to be added without breaking existing interfaces

```
module Stock
{
  // ...
  interface Quoter { /* ... */ };

  interface Stat_Quoter : Quoter // a Stat_Quoter IS-A Quoter
  {
    long get_stats (in string stock_name,
                    out double percent_change,
                    out long trading_volume)
      raises (Invalid_Stock);
  };
};
```

Note that there are no changes to the existing `Quoter` interface

New Interfaces and Operations

For example, adding a trading interface

```
module Stock {
  // Interface Quoter_Factory and Quoter same as before.
  interface Trader {
    void buy  (in string name,
               inout long num_shares,
               in long max_value) raises (Invalid_Stock);
    void sell (in string name,
               inout long num_shares,
               in long min_value) raises (Invalid_Stock);
  };
  interface Trader_Factory { /* ... */ };
};
```

Multiple inheritance is also useful to define a full service broker:

```
interface Full_Service_Broker : Stat_Quoter, Trader {};
```

Batch Requests

Improve performance for multiple queries or trades

```
interface Batch_Quoter : Stat_Quoter
{ // Batch_Quoter IS-A Stat_Quoter
  typedef sequence<string> Names;
  struct Stock_Info {
    string name;
    long value;
    double change;
    long volume;
  };
  typedef sequence<Stock_Info> Info;
  exception No_Such_Stock { Names stock; };

  void batch_quote (in Names stock_names,
                    out Info stock_info) raises (No_Such_Stock);
};
```


Limitations with Workarounds for CORBA's Lack of Asynchrony

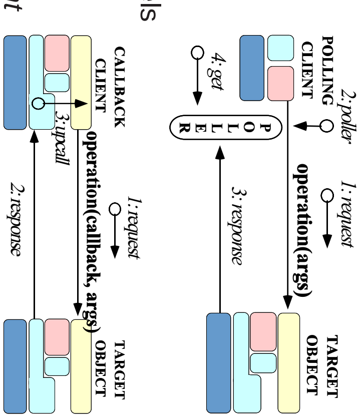
- *Synchronous method invocation* (SMI) multi-threading
  - Often non-portable, non-scalable, and inefficient
- Oneway operations
  - Best-effort semantics are unreliable
  - Requires *callback* objects
  - Applications must match callbacks with requests
- Deferred synchronous
  - Uses DII, thus *very* hard to program
  - Not type-safe

Motivation for Asynchronous Method Invocations (AMI)

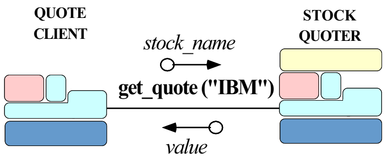
- Early versions of CORBA lacked support for asynchronous two-way invocations
- This omission yielded the following drawbacks
  1. Increase the number of client threads
     - *e.g.*, due to synchronous two-way communication
  2. Increase the end-to-end latency for multiple requests
     - *e.g.*, due to blocking on certain long-delay operations
  3. Decrease OS/network resource utilization
     - *e.g.*, inefficient support for bulk data transfers

OMG Solution → CORBA Messaging Specification

- Defines *QoS Policies* for the ORB
  - Timeouts
  - Priority
  - Reliable one-ways
- Specifies two *asynchronous method invocation* (AMI) models
  1. Poller model
  2. Callback model
- Standardizes *time-independent invocation* (TII) model
  - Used for store/forward routers



AMI Callback Overview



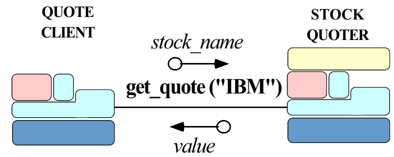
Quoter IDL Interface:

```
module Stock {
 interface Quoter {
   // Two-way operation to
   // get current stock value.
   long get_quote
     (in string stock_name);
 };
 // ...
}
```

Implied-IDL for client-side:

```
module Stock {
  // ReplyHandler.
  interface AMI_QuoterHandler
    : Messaging::ReplyHandler {
     // Callback method.
     void get_quote (in long q);
   };

 interface Quoter {
   // Two-way synchronous operation.
   long get_quote (in string stock_name);

   // Two-way asynchronous operation.
   void sendc_get_quote
      (AMI_QuoterHandler handler,
       in string stock);
  };
};
```


Example: Synchronous Client



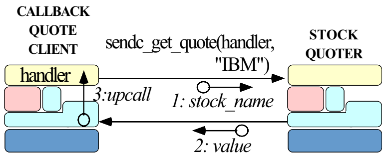
IDL-generated stub:

```
CORBA::ULong
Stock::Quoter::get_quote
  (const char *name)
{
  // 1. Setup connection
  // 2. Marshal
  // 3. Send request
  // 4. Get reply
  // 5. Demarshal
  // 6. Return
};
```

Application:

```
// NASDAQ abbreviations for ORB vendors.
static const char *stocks[] =
{
  "IONAY" // IONA Orbix
  "INPR"  // Inprise VisiBroker
  "IBM"   // IBM Component Broker
}
// Set the max number of ORB stocks.
static const int MAX_STOCKS = 3;

// Make synchronous two-way calls.
for (int i = 0; i < MAX_STOCKS; i++) {
  CORBA::Long value =
    quoter_ref->get_quote (stocks[i]);
  cout << "Current value of "
       << stocks[i] << " stock: "
       << value << endl;
}
```


Example: AMI Callback Client



Asynchronous stub:

```
void
Stock::Quoter::sendc_get_quote
       (AMI_QuoterHandler_ptr,
        const char *name)
{
 // 1. Setup connection
 // 2. Store reply handler
 //    in POA
 // 3. Marshal
 // 4. Send request
 // 5. Return
};
```

Reply Handler Servant:

```
class My_Async_Stock_Handler
 : public POA_Stock::AMI_QuoterHandler {
public:
 My_Async_Stock_Handler (const char *s)
   : stock_ (CORBA::string_dup (s))
 { }
 ~My_Async_Stock_Handler (void) { }

 // Callback method.
 virtual void get_quote (CORBA::Long q)
 {
   cout << stock_ << " stock: "
        << q << endl;
    // Decrement global reply count.
    reply_count--;
  }

private:
  CORBA::String_var stock_;
};
```


Example: AMI Callback Client (cont'd)

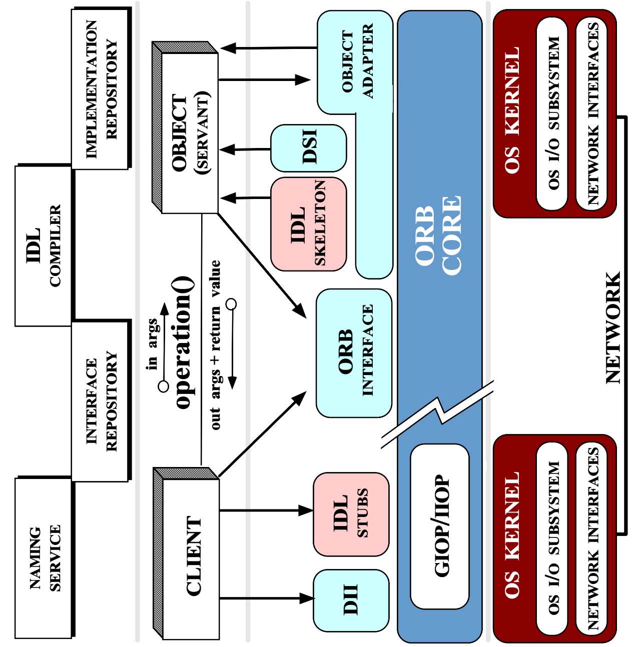
```
// Global reply count
int reply_count = MAX_STOCKS;

// Servants.
My_Async_Stock_Handler *
  handlers[MAX_STOCKS];

// Objrefs.
Stock::AMI_QuoterHandler_var
  handler_refs[MAX_STOCKS];

int i;

// Initialize ReplyHandler
// servants.
for (i = 0; i < MAX_STOCKS; i++)
 handlers[i] = new
 My_Async_Stock_Handler (stocks[i]);
```

```
// Initialize ReplyHandler object refs.
for (i = 0; i < MAX_STOCKS; i++)
  handler_refs[i] =
    handlers[i]->_this ();

// Make asynchronous two-way calls
// using the callback model.
for (i = 0; i < MAX_STOCKS; i++)
  quoter_ref->sendc_get_quote
    (handler_refs[i],
     stocks[i]);

// ...

// Event loop to receive all replies.
while (reply_count > 0)
  if (orb->work_pending ())
    orb->perform_work ();
  else
    ...
```

Additional Information on AMI

- See Asynchronous Messaging specification
  - www.cs.wustl.edu/~schmidt/CORBA-docs/00-02-05.pdf.gz
- See Vinoski's CACM article on CORBA 3.0 for more info.
  - www.cs.wustl.edu/~schmidt/vinoski-98.pdf.gz
- See our papers on AMI
  - www.cs.wustl.edu/~schmidt/report-doc.html
  - www.cs.wustl.edu/~schmidt/ami1.ps.gz
  - www.cs.wustl.edu/~schmidt/ami2.ps.gz
- See TAO release to experiment with working AMI examples
  - `$TAO_ROOT/examples/AMI/`

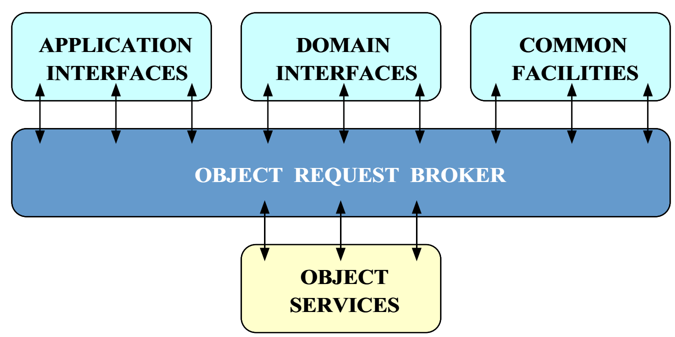
CORBA ORB Architecture



Overview of CORBA Components

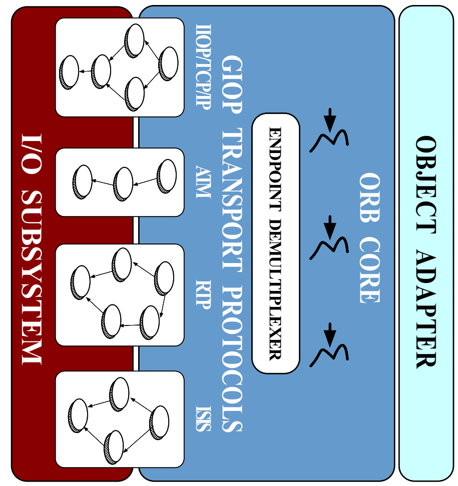
- The CORBA specification contains several components:
  - Object Request Broker (ORB) Core
  - Interoperability Spec (GIOP and IIOP)
  - Interface Definition Language (IDL)
  - Programming language mappings for IDL
  - Static Invocation Interface (SII)
  - Dynamic Invocation Interface (DII)
  - Static Skeleton Interface (SSI) and Dynamic Skeleton Interface (DSI)
  - Portable Object Adapter (POA)
  - Interface and Implementation Repositories

OMA Reference Model Interface Categories



The Object Management Architecture (OMA) Reference Model describes the interactions between various CORBA components and layers

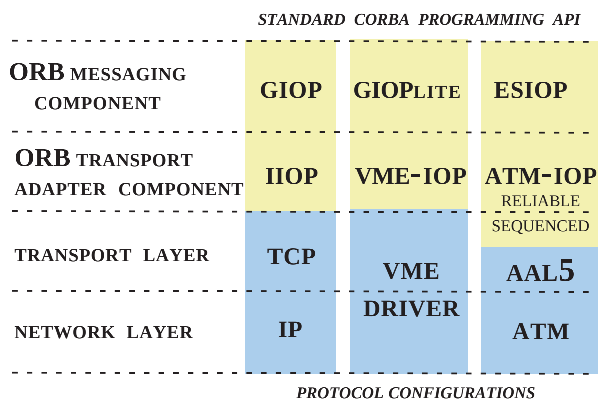
Overview of the ORB Core



Features

- Connection/memory management
- Request transfer
- Endpoint demuxing
- Concurrency control

CORBA Interoperability Protocols



- GIOP
  - Enables ORB-to-ORB interoperability
- IIOP
  - Works directly over TCP/IP, no RPC
- ESIOPs
  - *e.g.*, DCE, DCOM, wireless, etc.

GIOP Overview

- Common Data Representation (CDR)
  - Transfer syntax mapping OMG-IDL data types into a bi-canonical low-level representation
    - * Supports variable byte ordering and aligned primitive types
- Message transfer
  - Request multiplexing, *i.e.*, shared connections
  - Ordering constraints are minimal, *i.e.*, can be asynchronous
- Message formats
  - Client: `Request`, `CancelRequest`, `LocateRequest`
  - Server: `Reply`, `LocateReply`, `CloseConnection`
  - Both: `MessageError`

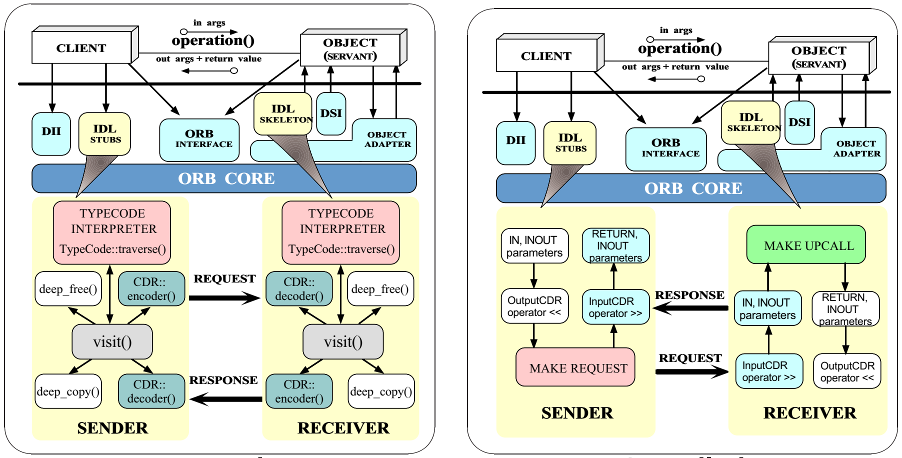
Example GIOP Format

```
module GIOP {
  enum MsgType {
    Request, Reply, CancelRequest,
    LocateRequest, LocateReply,
    CloseConnection, MessageError
  };

  struct MessageHeader {
    char magic[4];
    Version GIOP_version;
    octet byte_order; // Fragment bit in 1.1.
    octet message_type;
    unsigned long message_size;
  };

  struct RequestHeader {
    IOP::ServiceContextList service_context;
    unsigned long request_id;
    // Reliable one-way bits in 1.2
    boolean response_requested;
    sequence<octet> object_key;
    string operation;
    Principal requesting_principal;
  };
  // ...
```

IIOP Overview

- IIOP adds to GIOP semantics for TCP/IP connection management
- IIOP bundled with Netscape 4.0
- Inter-ORB Engine available from SunSoft
  - ftp://ftp.omg.org/pub/interop/iiop.tar.Z
- TAO is originally based on SunSoft IIOP
  - However, TAO adds *many* enhancements and optimizations
    - www.cs.wustl.edu/∼schmidt/JSAC-99.ps.gz
    - www.cs.wustl.edu/∼schmidt/TAO.html

Interpreted vs. Compiled (De)marshaling



Interpretive Compiled

Interface Definition Language (IDL)

- Motivation
  - Developing flexible distributed applications on heterogeneous platforms requires a strict separation of *interface* from *implementation(s)*
- Benefits of using an IDL
  - Ensure platform independence → *e.g.*, Windows NT to UNIX
  - Enforce modularity → *e.g.*, separate concerns
  - Increase robustness → *e.g.*, eliminate common network programming errors
  - Enable language independence → *e.g.*, COBOL, C, C++, Java, etc.

Related IDLs

- Many IDLs are currently available, *e.g.*,
  - OSI ASN.1
  - OSI GDMO
  - SNMP SMI
  - DCE IDL
  - Microsoft's IDL (MIDL)
  - OMG IDL
  - ONC's XDR
- However, many of these are *procedural* IDLs
  - These are more complicated to extend and reuse since they don't support inheritance

CORBA Interface Definition Language (IDL)

- OMG IDL is an object-oriented interface definition language
  - Used to specify interfaces containing *operations* and *attributes*
  - OMG IDL support interface inheritance (both single and multiple inheritance)
- OMG IDL is designed to map onto multiple programming languages
  - *e.g.*, C, C++, Smalltalk, COBOL, Modula 3, DCE, Java, etc.
- OMG IDL is similar to Java `interfaces` and C++ abstract classes

Application Interfaces

- Interfaces described using OMG IDL may be application-specific, *e.g.*,
  - Databases
  - Spreadsheets
  - Spell checker
  - Network manager
  - Air traffic control
  - Documents
  - Medical imaging systems
- Objects may be defined at any level of granularity
  - *e.g.*, from fine-grained GUI objects to multi-megabyte multimedia "Blobs"

OMG IDL Features

- OMG IDL is similar to Java `interfaces` or C++ abstract classes
  - It is not a complete programming language, however, since it only defines *interfaces*
- OMG IDL supports the following features:
  - `modules` and `interfaces`
  - Operations and Attributes
  - Single and multiple inheritance
  - Basic types (*e.g.*, `double`, `long`, `char`, etc).
  - Arrays and `sequence`
  - `struct, enum, union, typedef`
  - `consts`
  - `exceptions`

OMG IDL Differences from C++ and Java

- No control constructs
- No data members
- No pointers
- No constructors or destructors
- No overloaded operations
- No `int` data type
- Contains parameter passing modes
- Unions require a tag
- Different String type
- Different Sequence type
- Different exception interface
- No templates
- `oneway` call semantics
- `readonly` keyword

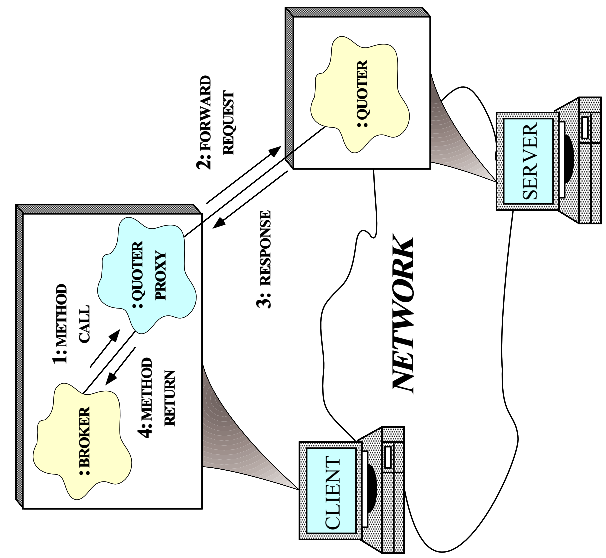
Static Invocation Interface (SII)

```
// Get object reference.
Quoter_var quoter = // ...

const char *name =
  "ACME ORB Inc.";

CORBA::Long value =
  quoter->get_quote (name);
cout << name << " = "
     << value << endl;
```

- The common way to use OMG IDL is the “Static Invocation Interface” (SII)
- All operations are specified in advance and are known to client via *stubs*
  - Stubs marshal operation calls into request messages

Primary advantages of SII are *simplicity*, *typesafety*, and *efficiency*

Stubs use the Proxy Pattern



Intent: provide a surrogate for another object that controls access to it

Dynamic Invocation Interface (DII)

- A less common programming API is the “Dynamic Invocation Interface” (DII)
  - Enables clients to invoke operations on objects that aren’t known until run-time
    - *e.g.*, MIB browsers
  - Allows clients to “push” arguments onto a request stack and identify operations via an ASCII name
    - Type-checking via meta-info in “Interface Repository”
- The DII is more flexible than the SII
  - *e.g.*, it supports *deferred synchronous* invocation
- However, the DII is also more complicated, less typesafe, and inefficient

An Example DII Client

```
// Get Quoter reference.
Stock::Quoter_var quoter_ref = // ...
CORBA::Long value;

// Create request object.
CORBA::Request_var request =
  quoter_ref->_request ("get_quote");

// Add parameter.
request->add_in_arg () <<= "IONAY";
request->set_return_type (CORBA::_tc_long);

// Call method.
request->invoke ();

// Retrieve/print value.
if (request->return_value () >>= value)
  cout << "Current value of IONA stock: "
       << value << endl;
```

This example is *much* more complicated and inefficient than simply using SII...

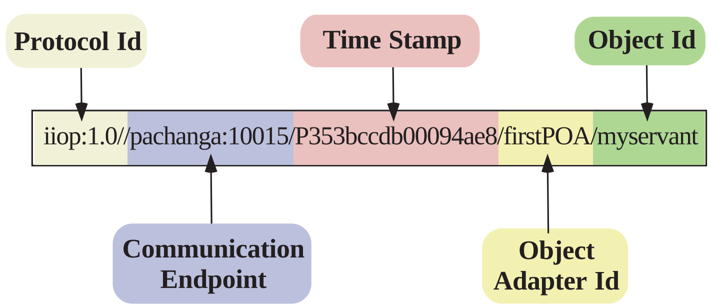
Static and Dynamic Skeleton Interface

- The Static Skeleton Interface (SSI) is generated automatically by the IDL compiler
  - The SII performs the operation demuxing/dispatching and parameter demarshaling
- The Dynamic Skeleton Interface (DSI) provides analogous functionality for the server-side that the DII provides on the client-side
  - It is defined primarily to build ORB “Bridges”
  - The DSI lets server code handle arbitrary invocations on CORBA objects

Object References

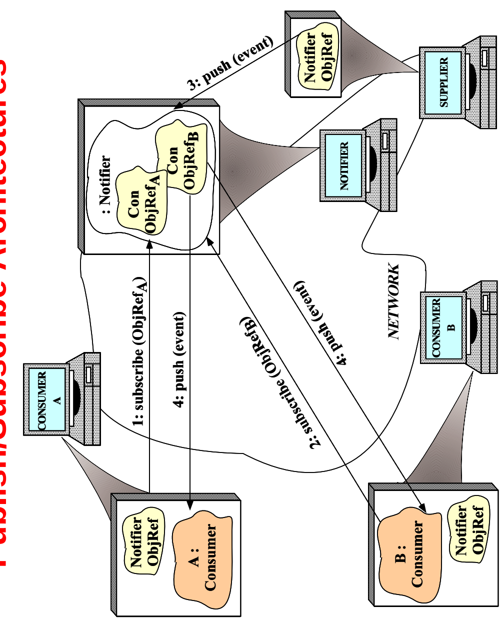
- An “object reference” is an opaque handle to an object
  - It identifies the object’s location
- Object references may be passed among processes on separate hosts
  - The underlying CORBA ORB will correctly convert object references into a form that can be transmitted over the network
  - The ORB provides the receiver with a pointer to a proxy in its own address space
    - ∗ This proxy refers to remote object implementation
- Object references are a powerful feature of CORBA
  - *e.g.*, supports *peer-to-peer* interactions and *distributed callbacks*

Object Reference in URL Format



- Transient object reference

Using Object References for Publish/Subscribe Architectures



Note the use of the Observer pattern

Event Receiver Interface

```
struct Event {
  string topic_; // Used for filtering.
  any value_; // Event contents.
};

interface Consumer
{
  // Inform the Consumer
  // event has occurred.
  void push (in Event event);

  // Disconnect the Consumer
  // from the Notifier.
  void disconnect (in string reason);
};
```

A `Consumer` is called back by the Notifier

Notifier Interface

```
interface Notifier {
  // = For Consumers.
  // Subscribe the Consumer to receive
  // events that match filtering_criteria
  // applied by the Notifier.
  void subscribe
    (in Consumer consumer,
     in string filtering_criteria);
  // Unsubscribe the Consumer.
  void unsubscribe (in Consumer consumer);

  // = For Suppliers.
  // Push the Event to all the consumers
  // who have subscribed and who match
  // the filtering criteria.
  void push (in Event event);
};
```

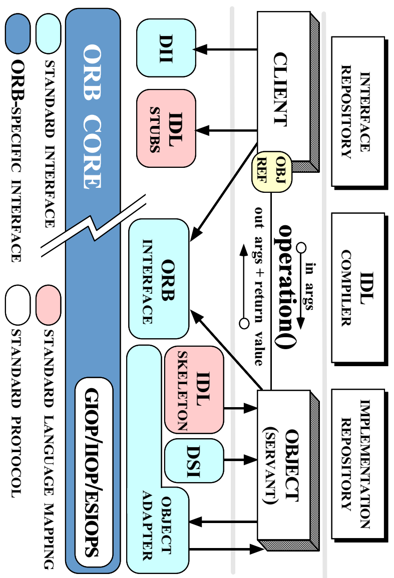
A Notifier publishes `Events` to subscribed Consumers

Notifier Implementation

```
class My_Notifier { // C++ pseudo-code
public:
  void subscribe (Consumer_ptr consumer,
                  const char *fc) {
    insert <consumer> into
    <consumer_set_> with <fc>.
  }
  void unsubscribe (Consumer_ptr consumer) {
    remove <consumer> from <consumer_set_>.
  }
  void push (const Event &event) {
    foreach <consumer> in <consumer_set_>
      if (event.topic_ matches <consumer>.filter_criteria)
        <consumer>.push (event);
  }
private: // e.g., use an STL map.
  map <string, Consumer_ptr> consumer_set_;
};
```

- The Notifier maintains a table of object references to Consumers

Advanced CORBA Features

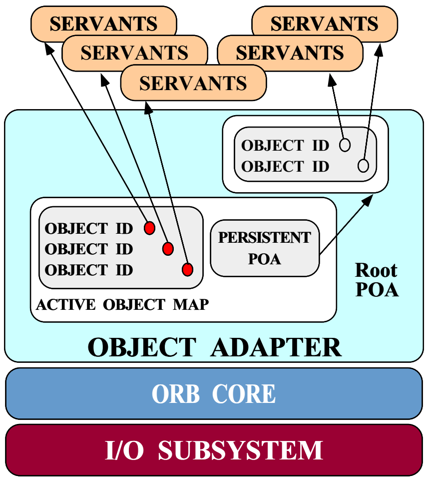


www.cs.wustl.edu/~schmidt/corba.html

Features

- Portable Object Adapter
- Multi-threading
- Implementation Repository
- CORBA Component Model

Overview of the Portable Object Adapter (POA)



POA Features

- Creates object refs
- Activates and deactivates objects
- Etherealizes and incarnates servants
- Maps requests to servants

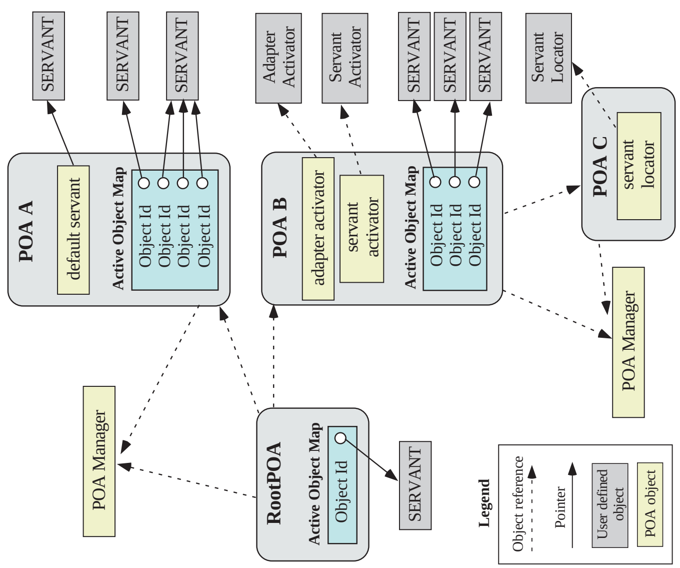
The POA is very important for certain applications

- *e.g.*, telecom MIBs, enterprise servers

Design Goals of the Portable Object Adapter

- Servants that are portable between ORBs
- Objects with persistent & transient identities
- Transient objects with minimal programming effort and overhead
- Transparent activation & deactivation of servants
- Implicit and explicit servant activation
- A single servant can support multiple object identities
- Multiple (nested) instances of the POA in a server process
- POA behavior is dictated by creation policies
- Servants can inherit from skeletons or use DSI

The POA Architecture



POA Components

- Client: Makes requests on an object through one of its references
- Server: Computational context for servants
  - Generally, a server corresponds to a process
  - Client and server are “roles” - a program can play both roles
- Object: A CORBA programming entity with an identity, an interface, and an implementation
- Servant: A programming language entity that implements requests on one or more objects
- Policy: Specifics the characteristics of a POA or child POA

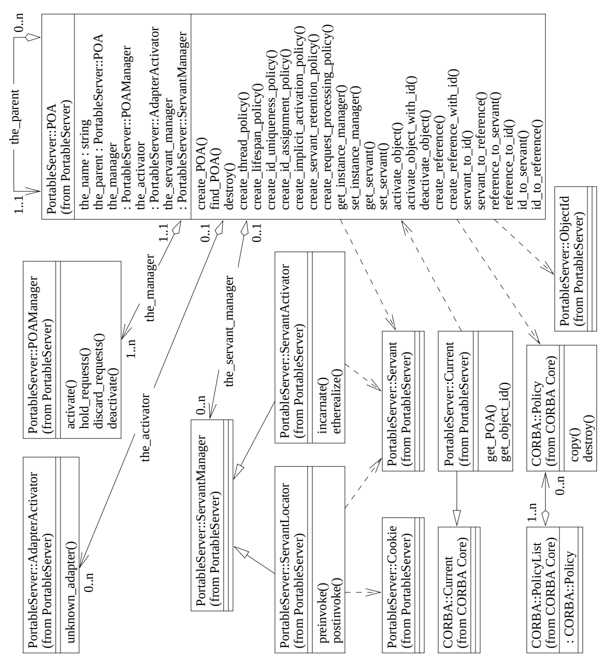
POA Components (cont'd)

- Object Id: A value that is used by the POA and by the implementation to identify a particular CORBA object
  - Object Id values may be assigned by the POA, or by the user implementation
  - Object Id values are hidden from clients, encapsulated by references
  - Object Ids have no standard form; they are managed by the POA as uninterpreted octet sequences
- Object Reference: Encapsulates an Object Id, a POA identity, and transport profiles
- POA: A namespace for Object Ids and a namespace for child POAs
  - Nested POAs form a hierarchical name space for objects in servers

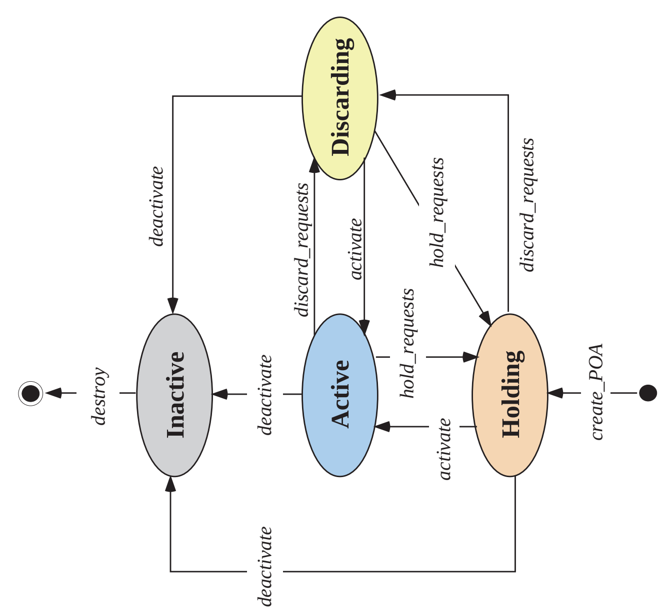
POA Components (cont'd)

- POA Manager: Encapsulates the processing state of associated POAs
  - Can dispatch, hold, or discard requests for the associated POAs and deactivate POA(s)
- Servant Manager: Two kinds of callback objects used to incarnate and etherealize servants on demand
  - `ServantActivator` → first time
  - `ServantLocator` → one time
- Adapter Activator: Callback object used when a request is received for a child POA that does not exist currently
  - The adapter activator can then create the required POA on demand

POA Architecture in UML



POA Manager Processing States



Getting the Root POA

```
// ORB is ''locality constrained''
CORBA::ORB_var orb = CORBA::ORB_init (argc, argv);

// Root POA is the default POA (locality constrained)
CORBA::Object_var obj =
  orb->resolve_initial_references ("RootPOA");

// Type-safe downcast.
PortableServer::POA_var root_POA
  = PortableServer::POA::_narrow (obj.in ());

// Activate the POA.
PortableServer::POA_Manager_var poa_manager =
  root_POA->the_POAManager ();
poa_manager->activate ();
```


Creating a Child POA

```
CORBA::PolicyList policies (2);

policies[0] = root_POA->create_id_assignment_policy
  (PortableServer::IdAssignmentPolicy::USER_ID);

policies[1] = root_POA->create_lifespan_policy
  (PortableServer::LifespanPolicy::PERSISTENT);

PortableServer::POA_ptr child_poa =
  root_POA->create_POA
             ("child_poa",
              PortableServer::POAManager::_nil (),
              policies);
```


Explicit Activation with POA-assigned Object Ids

```
// IDL
interface Quoter /* ... */
{
  long get_quote (in string stock_name)
    raises (Invalid_Stock);
};

// Auto-generated for use by servants.
class My_Quoter : public virtual POA_Stock::Quoter
{
public:
  // ...
  CORBA::Long get_quote (const char *stock_name);
};

My_Quoter *quoter = new My_Quoter;
PortableServer::ObjectId_var oid =
  poa->activate_object (quoter);
PortableServer::POA_Manager_var poa_manager =
  poa->the_POAManager ();
poa_manager->activate ();
orb->run ();
```


Explicit Activation With User-assigned Object Ids

```
// Create a new servant object.
My_Quoter *quoter = new My_Quoter;

// Create a new Object ID for the object.
PortableServer::ObjectId_var oid =
  PortableServer::string_to_ObjectId ("my quoter");

// Activate the object with the new Object ID.
poa->activate_object_with_id (oid.in (),
                              quoter);
PortableServer::POA_Manager_var poa_manager =
  poa->the_POAManager ();
poa_manager ()->activate ();
// Run the ORB's event loop.
orb->run ();
```

Servant Activator Definition

```
typedef ServantBase *Servant;

// Skeleton class
namespace POA_PortableServer
{
  class ServantActivator :
    public virtual ServantManager
  {
    // Destructor.
    virtual ~ServantActivator (void);

    // Create a new servant for <id>.
    virtual Servant incarnate
      (const ObjectId &id,
       POA_ptr poa) = 0;

    // <servant> is no longer active in <poa>.
    virtual void etherealize
      (const ObjectId &,
       POA_ptr poa,
       Servant servant,
       Boolean remaining_activations) = 0;
  };
}
```

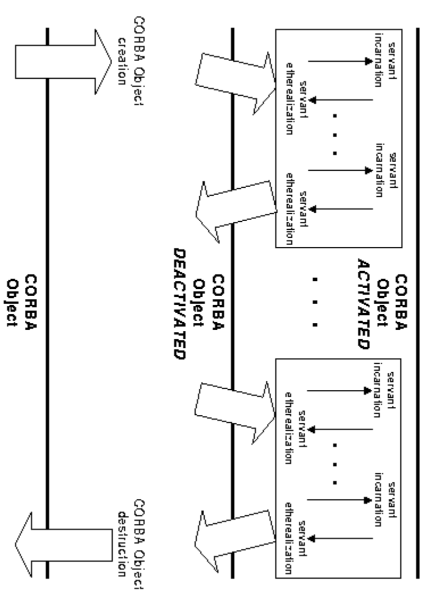

Creating References Before Activation

```
PortableServer::ObjectId_var oid =
  PortableServer::string_to_ObjectId ("my quoter");
CORBA::Object_var obj =
  poa->create_reference_with_id (oid.in (),
                                 "IDL:Quoter:1.0");
// Insert into a name context.
name_context->bind (svc_name, obj.in ());

// ...later...

My_Quoter *quoter = new My_Quoter;
poa->activate_object_with_id (oid.in (), quoter);
```


Custom ServantActivator Definition and Creation

```
// Implementation class.
class My_Quoter_Servant_Activator :
  public POA_PortableServer::ServantActivator
{
  Servant incarnate (const ObjectId &oid,
                     POA_ptr poa) {
    String_var s =
      PortableServer::ObjectId_to_string (oid);

    if (strcmp (s.in (), "my quoter") == 0)
      return new My_Quoter;
    else
      throw CORBA::OBJECT_NOT_EXIST ();
  }

  void etherealize
    (const ObjectId &oid,
     POA_ptr poa,
     Servant servant,
     Boolean remaining_activations) {
    if (remaining_activations == 0)
      delete servant;
  }
};
```


Request Lifecycle for POA



Servant Locator Definition

```
typedef ServantBase *Servant;

// Skeleton class
namespace POA_PortableServer
{
  class ServantLocator :
    public virtual ServantManager
  {
    // Destructor.
    virtual ˜ServantLocator (void);

    // Create a new servant for <id>.
    virtual PortableServer::Servant preinvoke
      (const PortableServer::ObjectId &id,
       PortableServer::POA_ptr poa,
       const char *operation,
       PortableServer::Cookie &cookie) = 0;

    // <servant> is no longer active in <poa>.
    virtual void postinvoke
      (const PortableServer::ObjectId &id,
       PortableServer::POA_ptr poa,
       const char *operation,
       PortableServer::Cookie cookie,
       PortableServer::Servant servant) = 0;
  };
}
```


Custom ServantLocator Definition and Creation

```
// Implementation class.
class My_Quoter_Servant_Locator :
  public POA_PortableServer::ServantLocator {
  Servant preinvoke
    (const PortableServer::ObjectId &oid,
     PortableServer::POA_ptr poa,
     const char *operation,
     PortableServer::Cookie &cookie) {
    CORBA::String_var str =
      PortableServer::ObjectId_to_string (oid);
    Object_State state = database_lookup (str);
    if (val == -1)
      throw CORBA::OBJECT_NOT_EXIST ();
    return new My_Quoter (state);
  }

  void postinvoke
    (const PortableServer::ObjectId &id,
     PortableServer::POA_ptr poa,
     const char *operation,
     PortableServer::Cookie cookie,
     PortableServer::Servant servant) {
    database_update (servant);
    delete servant;
  }
};
```

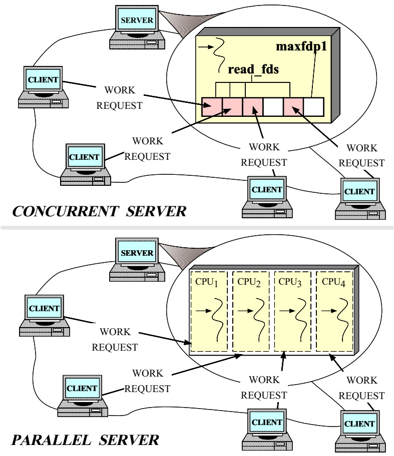

Registering Servant Locators

```
PortableServer::ObjectId_var oid =
  PortableServer::string_to_ObjectId ("my quoter");
CORBA::Object_var obj =
  poa->create_reference_with_id (oid.in (),
                                 "IDL:Quoter:1.0");
// Insert into a name context.
name_context->bind (svc_name, obj.in ());

My_Quoter_Servant_Locator *quoter_locator =
  new My_Quoter_Servant_Locator;

// Locality constrained.
ServantLocator_var locator = quoter_locator->_this ();
poa->set_servant_manager (locator.in ());
PortableServer::POA_Manager_var poa_manager =
  poa->the_POAManager ();
poa_manager ()->activate ();
orb->run ();
```


Additional Information on the POA

- See POA specification for some examples:
  - One Servant for all Objects
  - Single Servant, many objects and types, using DSI
- See Vinoski/Henning book for even more examples
- See Schmidt/Vinoski C++ Report columns
  - www.cs.wustl.edu/~schmidt/report-doc.html
- See TAO release to experiment with working POA examples
  - `$TAO_ROOT/examples/POA/`

Motivation for Concurrency in CORBA



- *Leverage hardware/software*
  - *e.g.*, multi-processors and OS thread support
- *Increase performance*
  - *e.g.*, overlap computation and communication
- *Improve response-time*
  - *e.g.*, GUIs and network servers
- *Simplify program structure*
  - *e.g.*, sync vs. async

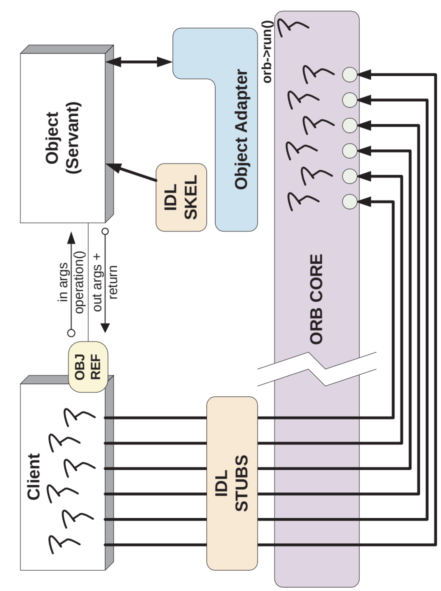
Threading in TAO

- An application can choose to ignore threads and if it creates none, it need not be thread-safe
- TAO can be configured with various concurrency strategies:
  - *Thread-per-Connection*
  - *Thread Pool*
  - *Thread-per-Endpoint*
- TAO also provides many locking strategies
  - TAO doesn't automatically synchronize access to application objects
  - Therefore, applications must synchronize access to their own objects

TAO Multi-threading Examples

- Each example implements a concurrent CORBA stock quote service
  - Show how threads can be used on the server
- The server is implemented in two different ways:
  1. *Thread-per-Connection* → Every client connection causes a new thread to be spawned to process it
  2. *Thread Pool* → A fixed number of threads are generated in the server at start-up to service all incoming requests
- Note that clients are unaware which concurrency model is being used...

TAO's Thread-per-Connection Concurrency Architecture



Pros
- Simple to implement and efficient for long-duration requests

Cons
- Excessive overhead for short-duration requests
- Permits unbounded number of concurrent requests

Thread-per-Connection Quoter Implementation

Implementation of multi-threaded Quoter callback invoked by the CORBA skeleton

```
long My_Quoter::get_quote (const char *stock_name)
{
  Guard<Thread_Mutex> guard (lock_);

  // Increment the request count.
  ++My_Quoter::req_count_;

  // Obtain stock price (beware...).
  long value = Quote_Database::instance ()->
                 lookup_stock_price (stock_name);

  if (value == -1)
    // Skeleton handles exceptions.
    throw Stock::Invalid_Stock ();

  return value;
}
```


Thread-per-Connection Main Program

The server creates a single Quoter factory and waits in ORB's event loop

```
int main (void)
{
  ORB_Manager orb_manager (argc, argv);

  const char *factory_name = "my quoter factory";

  // Create the servant, which registers with rootPOA and Naming Service implicitly.
  My_Quoter_Factory factory (factory_name);

  // Block indefinitely waiting for incoming invocations and dispatch upcalls.
  orb_manager.run ();

  // After run() returns, the ORB has shutdown.
}
```

The ORB's `svc.conf` file

```
static Resource_Factory "-ORBResources global -ORBReactorType select_mt"
static Server_Strategy_Factory "-ORBConcurrency thread-per-connection"
```


Thread Pool

- This approach creates a thread pool to amortize the cost of dynamically creating threads
- In this scheme, before waiting for input the server code creates the following:
  1. A `Quoter_Factory` (as before)
  2. A pool of threads based upon the command line input
- Note the use of the ACE spawn_n method for spawning multiple pool threads

Thread-per-Connection Quoter Interface

Implementation of the `Quoter` IDL interface

```
// Maintain count of requests.
typedef u_long COUNTER;

class My_Quoter
{
public:
  // Constructor.
  My_Quoter (const char *name);

  // Returns the current stock value.
  long get_quote (const char *stock_name);

private:
  // Serialize access to database.
  Thread_Mutex lock_;

  // Maintain request count.
  static COUNTER req_count_;
};
```

Thread Pool Configuration

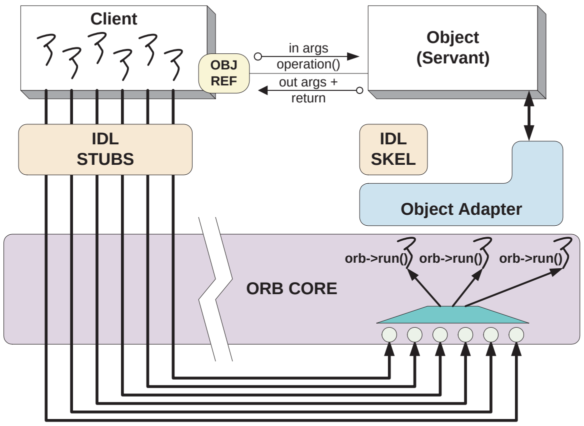
The `run_orb` adapter function

```
void run_orb (void *arg)
{
  try {
    CORBA::ORB_ptr orb =
      ACE_reinterpret_cast (CORBA::ORB_ptr, arg);

    // Block indefinitely waiting for incoming
    // invocations and dispatch upcalls.
    orb->run ();

    // After run() returns, the ORB has shutdown.
  } catch (...) { /* handle exception ... */ }
}
```

The ORB's `svc.conf` file

```
static Resource_Factory "-ORBReactorType tp"
```


TAO's Thread Pool Concurrency Architecture



Pros

- Bounds the number of concurrent requests
- Scales nicely for multi-processor platforms, *e.g.*, permits load balancing

Cons

- May Deadlock

Additional Information on CORBA Threading

- See Real-time CORBA 1.0 specification
  - www.cs.wustl.edu/~schmidt/RT-ORB-std-new.pdf.gz
- See our papers on CORBA Threading
  - www.cs.wustl.edu/~schmidt/CACM-arch.ps.gz
  - www.cs.wustl.edu/~schmidt/RT-perf.ps.gz
  - www.cs.wustl.edu/~schmidt/COOTS-99.ps.gz
  - www.cs.wustl.edu/~schmidt/orc.ps.gz
  - www.cs.wustl.edu/~schmidt/report-doc.html
- See TAO release to experiment with working threading examples
  - `$TAO_ROOT/tests/`

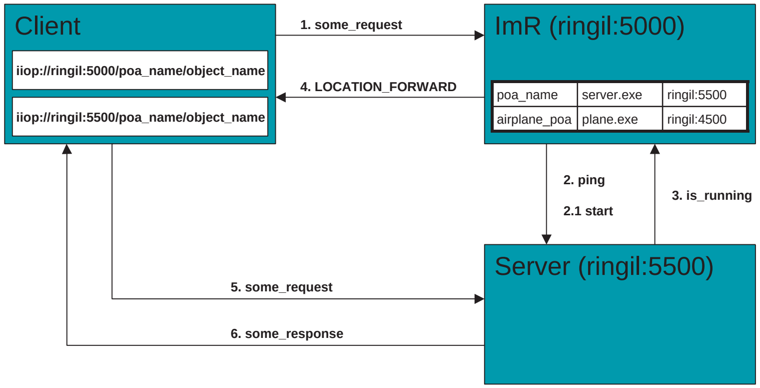
Thread Pool Main Program

```
int main (int argc, char *argv[])  {
  try {
    ORB_Manager orb_manager (argc, argv);

    const char *factory_name = "my quoter factory";

    // Create the servant, which registers with
    // the rootPOA and Naming Service implicitly.
    My_Quoter_Factory factory (factory_name);

    int pool_size = // ...

    // Create a thread pool.
    ACE_Thread_Manager::instance ()->spawn_n
      (pool_size,
       &run_orb,
       (void *) orb_manager.orb ());
    // Block indefinitely waiting for other
    // threads to exit.
    ACE_Thread_Manager::instance ()->wait ();

    // After run() returns, the ORB has shutdown.
    } catch (...) { /* handle exception ... */ }
}
```

Implementation Repository

- Allows the ORB to activate servers to process operation invocations
- Store management information associated with objects
  - *e.g.*, resource allocation, security, administrative control, server activation modes, etc.
- Primarily designed to work with *persistent* object references
- From client's perspective, behavior is portable, but administrative details are highly specific to an ORB/OS environment
  - *i.e.*, not generally portable

Typical Implementation Repository Use-case



Server Activation via Implementation Repository

- If the server isn't running when a client invokes an operation on an object it manages, the Implementation Repository automatically starts the server
- Servers can register with the Implementation Repository
  - *e.g.*, in TAO

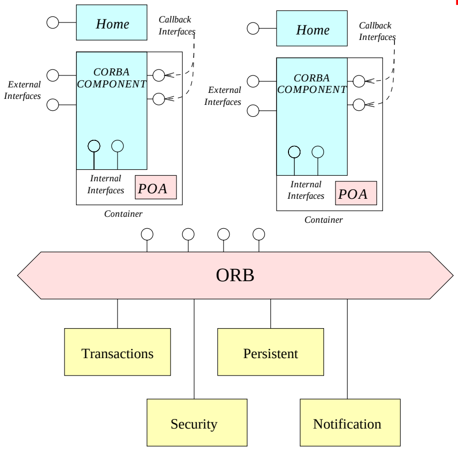
```
% tao_imr add airplane_poa -c "plane.exe"
```

- Server(s) may be installed on any machine
- Clients may bind to an object in a server by using the Naming Service or by explicitly identifying the server

Server Activation Modes

- An idle server will be automatically launched when one of its objects is invoked
- TAO's Implementation Repository supports four types of activation
  1. *Normal* $\rightarrow$ one server, started if needed but not running
  2. *Manual* $\rightarrow$ one server, will not be started on client request, *i.e.*, pre-launched
  3. *Per-client call* $\rightarrow$ one server activiated for each request to the Implementation Repository
  4. *Automatic* $\rightarrow$ like normal, except will also be launched when the Implementation Repository starts

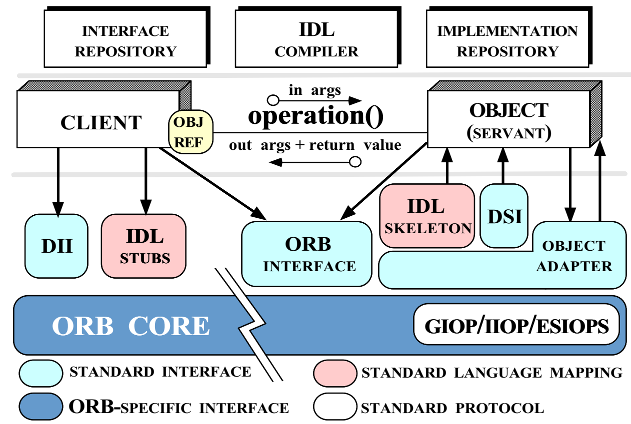
The CORBA Component Model



~schmidt/CBSE.ps.gz

- **Features**
  - Navigation among interfaces supported by components
  - Standardized system-component interaction
  - Standardized component life-cycle management
  - Component interconnections
  - Standardized component configuration
  - Standardized ORB services interfaces

Evaluating CORBA



www.cs.wustl.edu/~schmidt/corba.html

Criteria

- Learning curve
- Interoperability
- Portability
- Feature Limitations
- Performance

Learning Curve

- CORBA introduces the following:
  1. New concepts
     - *e.g.*, object references, proxies, and object adapters
  2. New components and tools
     - *e.g.*, interface definition languages, IDL compilers, and object-request brokers
  3. New features
     - *e.g.*, exception handling and interface inheritance
- Time spent learning this must be amortized over many projects

Interoperability

- The first CORBA 1 spec was woefully incomplete with respect to interoperability
  - The solution was to use ORBs provided by a single supplier
- CORBA 2.x defines a useful interoperability specification
  - Later extensions deal with portability issues for server-side
    - *i.e.*, the POA spec
- Most ORB implementations now support IIOP or GIOP robustly...
  - However, higher-level CORBA services aren't covered by ORB interoperability spec...

Portability

- To improve portability, the latest CORBA specification standardizes
  - IDL-to-C++ language mapping
  - Naming service, event service, lifecycle service
  - ORB initialization service
  - Portable Object Adapter API
  - Servant mapping
- Porting applications from ORB-to-ORB will be limited, however, until conformance tests become common-place
  - www.opengroup.org/testing/testsuites/vsorb.htm
- Moreover, CORBA spec doesn't really handle concurrency in a portable manner

Feature Limitations

- Standard CORBA doesn't yet address all the "inherent" complexities of distributed computing, *e.g.*,
  - *Latency*
  - *Causal ordering*
  - *Deadlock*
- It does address
  - *Service partitioning*
  - *Fault tolerance*
  - *Security*

Feature Limitations (cont'd)

- Many ORBs do not yet support passing objects-by-value (OBV)
  - However, CORBA 2.3 OBV spec. defines a solution for this
- Most ORBs still support only the following semantics:
  - Object references are passed by-reference
    - ∗ However, all operations are routed to the originator
  - C-style structures and discriminated unions may be passed by-value
    - ∗ However, these structures and unions do *not* contain any methods
- Until OBV spec is ubiquitous, objects can be passed by value using hand-crafted "factories"

Feature Limitations (cont'd)

- Many ORBs do not yet support AMI and/or standard CORBA timeouts
  - However, these capabilities are defined in the OMG Messaging Specification
- Most ORBs do not yet support fault tolerance
  - This was standardized by the OMG recently, however
  - www.omg.org/techprocess/meetings/schedule/Fault_Tolerance_RFP.html
- Versioning is supported in IDL via `pragmas`
  - Unlike Sun RPC or DCE, which include in language

Performance Limitations

- Performance may not be as good as hand-crafted code for some applications due to
  - Additional remote invocations for naming
  - Marshaling/demarshaling overhead
  - Data copying and memory management
  - Endpoint and request demultiplexing
  - Context switching and synchronization overhead
- Typical trade-off between extensibility, robustness, maintainability → *micro-level efficiency*
- Note that a well-crafted ORB may be able to automatically optimize *macro-level efficiency*

CORBA Implementations

- Many ORBs are now available
  - Orbix2000 from IONA
  - Visibroker from Inprise
  - BEA Web Logic Enterprise
  - Component Broker from IBM
  - eORB from Vertel, ORB Express from OIS, and HighComm from Highlander/Inprise
  - Open source ORBs → TAO, ORBacus, onmiORB, and MICO
- In theory, CORBA facilitates vendor-independent and platform-independent application collaboration
  - In practice, heterogeneous ORB interoperability and portability still an issue...

CORBA Services

- Other OMG documents (*e.g.*, COSS) specify higher level services
  - Naming service
    - Mapping of convenient object names to object references
  - Event service
    - Enables decoupled, asynchronous communication between objects
  - Lifecycle service
    - Enables flexible creation, copy, move, and deletion operations via factories
- Other CORBA services include transactions, trading, relationship, security, concurrency, property, A/V streaming, etc.

Summary of CORBA Features

- CORBA specifies the following functions to support an Object Request Broker (ORB)
  - Interface Definition Language (IDL)
  - A mapping from IDL onto C++, Java, C, COBOL, etc.
  - A Static Invocation Interface, used to compose operation requests via proxies
  - A Dynamic Invocation Interface, used to compose operation requests at run-time
  - Interface and Implementation Repositories containing meta-data queried at run-time
  - The Portable Object Adapter (POA), allows service programmers to interface their code with an ORB

Concluding Remarks

- Additional information about CORBA is available on-line at the following WWW URLs
  - Doug Schmidt's CORBA page
    - www.cs.wustl.edu/~schmidt/corba.html
  - OMG's WWW Page
    - www.omg.org/
  - CETUS CORBA Page
    - www.cetus-links.org/oo_corba.html
  - LANL's OMG Page
    - www.acl.lanl.gov/CORBA