Prof. Dr.-Ing. Stefan Deßloch
AG Heterogene Informationssysteme
Geb. 36, Raum 329
Tel. 0631/205 3275
dessloch@informatik.uni-kl.de

Technische Universität Kaiserslautern

Chapter 4
Remote Procedure Calls and Distributed Transactions

Outline

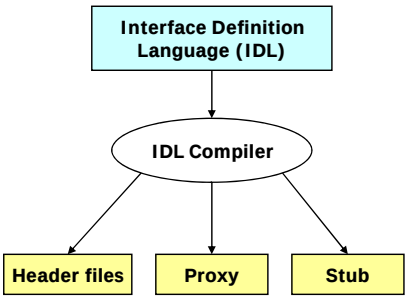
- Remote Procedure Call
  - concepts
    - IDL, principles, binding
  - variations
    - remote method invocation
      - example: Java RMI
    - stored procedures
- Distributed Transaction Processing
  - transactional RPC
  - X/Open DTP
- Summary

Communication and Distributed Processing

- Distributed (Information) System
  - consists of (possibly autonomous) subsystems
  - jointly working in a coordinated manner
- How do subsystems communicate?
  - **Remote Procedure Calls (RPC)**
    - transparently invoke procedures located on other machines
  - Peer-To-Peer-Messaging
  - Message Queuing
- Transactional Support (ACID properties) for distributed processing
  - Server/system components are Resource Managers
  - (Transactional) Remote Procedure Calls (TRPC)
  - Distributed Transaction Processing

Remote Procedure Call (RPC)

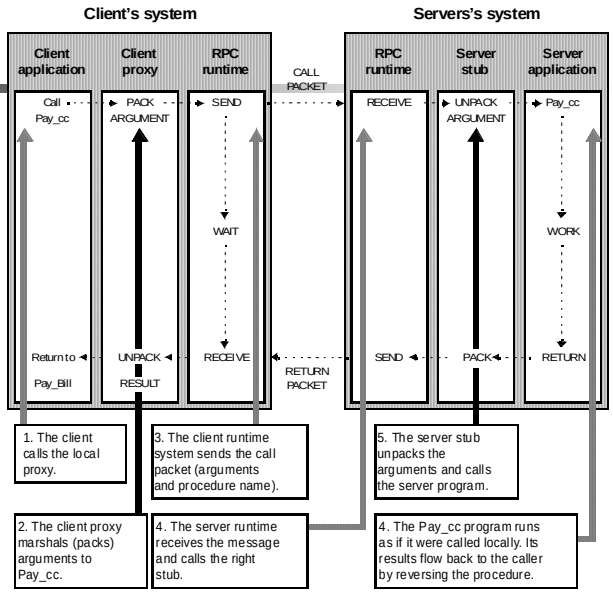
- Goal: Simple programming model for distributed applications
  - based on procedure as an invocation mechanism for distributed components
- Core mechanism in almost every form of middleware
- Distributed programs can interact (transparently) in heterogeneous environments
  - network protocols
  - programming languages
  - operating systems
  - hardware platforms
- Important concepts
  - Interface Definition Language (IDL)
  - Proxy (Client Stub)
  - Stub (Server Stub)



How RPC Works

- Define an interface for the remote procedure using an IDL
  - abstract representation of procedure
    - input and output parameters
  - can be independent of programming languages
- Compile the interface using IDL-compiler, resulting in
  - client stub (proxy)
  - server stub (skeleton)
  - auxiliary files (header files, ...)
- Client stub (proxy)
  - compiled and linked with client program
  - client program invokes remote procedure by invoking the (local) client stub
  - implements everything to interact with the server remotely
- Server stub (skeleton)
  - implements the server portion of the invocation
  - compiled and linked with server code
  - calls the actual procedure implemented at the server

RPC



Binding in RPC

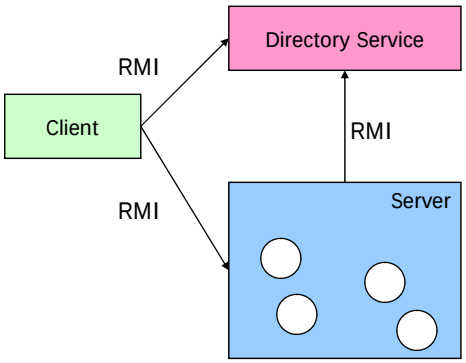
- Before performing RPC, the client must first locate and *bind* to the server
  - create/obtain an (environment-specific) *handle* to the server
  - encapsulates information such as IP address, port number, Ethernet address, ...
- Static binding
  - handle is "hard-coded" into the client stub at compile-time
  - advantages: simple and efficient
  - disadvantages: client and server are tightly coupled
    - server location change requires recompilation
    - dynamic load balancing across multiple (redundant) servers is not possible
- Dynamic binding
  - utilizes a name and directory service
    - based on logical names, signatures of procedures
    - server registers available procedure with the N&D server
    - client asks for server handle, uses it to perform RPC
    - requires lookup protocol/API
  - may be performed inside the client stub (automatic binding) or outside
  - opportunities for load balancing, more sophisticated selection (traders)
- *Location transparency* usually means that a remote procedure is invoked just like a local procedure
  - Binding process for remote and local procedures usually differ

RPC Variation 1: Distributed Objects

- Basic Idea: Evolve RPC concept for objects
  - application consists of distributed object components
  - object services are invoked using Remote Method Invocation (RMI)
- Utilizes/matches advantages of object-oriented computing
  - object identity
  - encapsulation: object manipulated only through methods
  - inheritance, polymorphism
  - interface vs. implementation
  - reusability

Distributed Objects with Java RMI

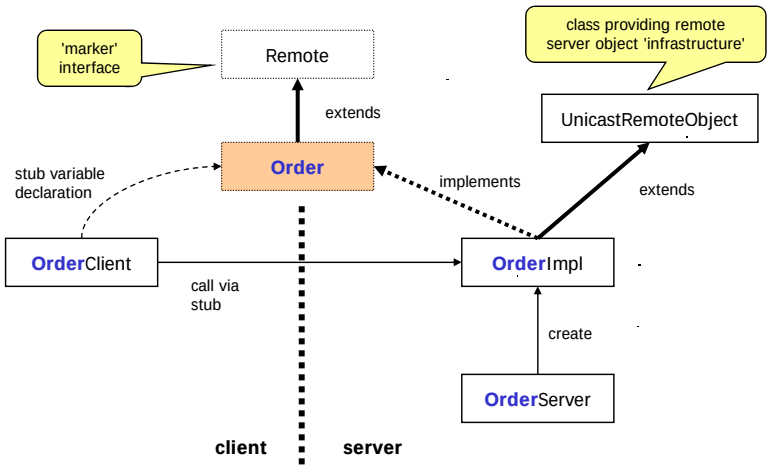
- Mechanism for communication
  - between Java programs
  - between Java programs and applets
  - running in different JVMs, possibly on different nodes
- Capabilities
  - finding remote objects
  - transparent communication with remote objects
  - loading byte code for remote objects



Java RMI – Development

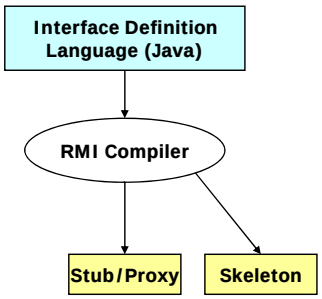
- Java is used as the IDL and development programming language
- Development steps
  1. Defining a remote interface (e.g., *Order*)
  2. Implementing server object class (e.g., *OrderImpl*, which implements *Order*)
     - only application logic; communication infrastructure not "visible"
  3. Implement client object, invocation of remote (server) object
     - locate the remote object using the RMI registry
     - invoke methods on remote object using the remote interface
  4. Provide server code for
     - creating a server object (instantiate server object class)
     - registering the server object with the RMI registry

Example - Class and Interface Relationships



Java RMI – Deployment and Runtime

- Deployment
  - generate stub and skeleton using RMI compiler
  - invoke server code for creating and registering the server object
- Runtime
  - run the client application
  - issuing a server object lookup in the client application will result in transferring a client stub object (implementing the remote interface) to the client application
    - stub class needs to be loaded into JVM on the client, either through local class path or dynamically over the network
  - invoking methods on the remote interface will be carried out using stubs/skeletons as discussed earlier



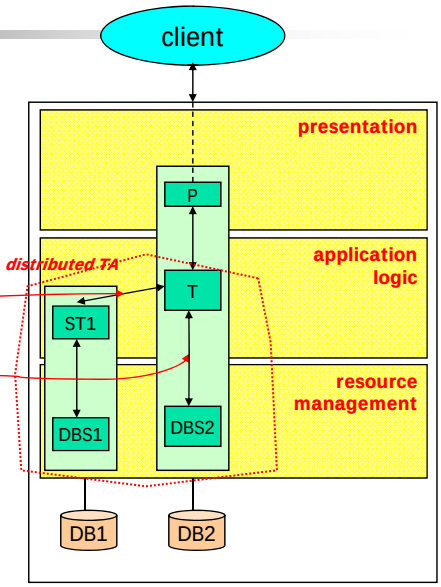
RPC Variation 2: Stored Procedures

- Named persistent code to be invoked in SQL, executed by the DBMS
  - SQL *CALL* statement
- Created directly in a DB schema
- Stored Procedure creation requires
  - header (signature): consists of a name and a (possibly empty) list of parameters.
    - may specify parameter mode: IN, OUT, INOUT
    - may return result sets
  - body (implementation): using SQL procedural extensions or external programming language (e.g., Java)
- Invocation of stored procedures
  - using CALL statement through the usual DB access approaches (e.g., JDBC – see *CallableStatement*)
    - RPC is not transparent!
    - generic invocation mechanism, not stubs/skeletons involved)
  - in the scope of an existing DB connection, active transaction

RPCs and Transactions

- Example scenario for T: debit/credit
  - T invokes debit procedure (ST1), modifying DB1
  - T performs credit operation on DBS2, modifying DB2
- Need transactional guarantees for T
- Program structure of T

  BOT
  CALL debit(...)
  CONNECT (DB2)
  UPDATE ACCOUNTS SET ...
  DISCONNECT
  EOT
- Requires coordination of distributed transaction
  - based on 2PC

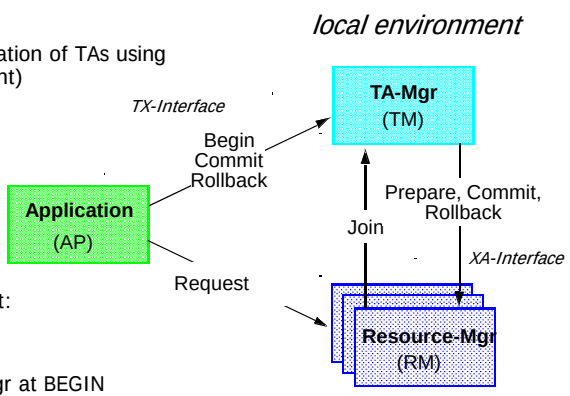


Transactional RPC (TRPC)

- Servers are resource managers
- RPCs are issued in the context of a transaction
  - demarcation (BOT, EOT) usually happens on the client
- TRPC-Stub
  - like RPC-Stub
  - additional responsibilities for TA-oriented communication
- TRPC requires the following additional steps
  - binding of RPC to transactions using TRID
  - notifying TA-Mgr about RM-Calls if performed through RPC (register participant of TA)
  - binding processes to transactions: failures (crashes) resulting in process termination should be communicated to the TA-Mgr

X/OPEN – Standard for Distributed TA Processing

- Resource Manager
  - recoverable
  - supports external coordination of TAs using 2PC protocol (XA-compliant)
- TA-Mgr
  - coordinates, controls RMs
- Application Program
  - demarcates TA (TA-brackets)
  - invokes RM services
    - e.g., SQL-statements
  - in distributed environment: performs (T)RPCs
- Transactional Context
  - TRID generated by TA-Mgr at BEGIN
  - established at the client
  - passed along (transitively) with RM-requests, RPCs

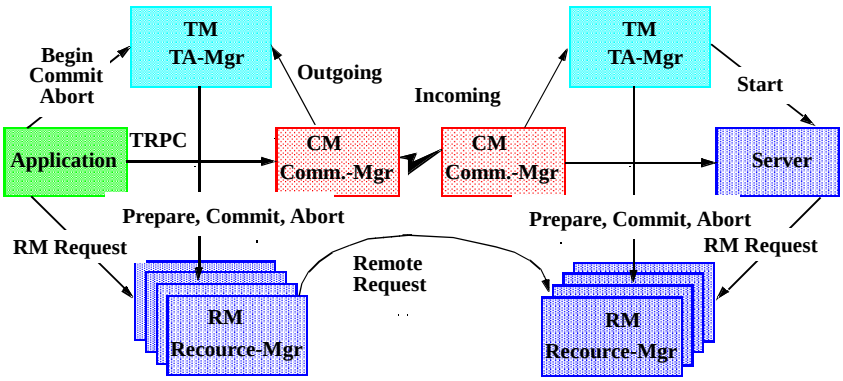


Interactions in a Local Environment

1. AP -> TM: begin() – establishes transaction context, global TRID
2. TM -> RM: start() – TM notifies frequently used RMs about the new global transaction, so that RM can associate future AP requests with the TRID
3. AP -> RM: request – the RM
   1. first registers with the TM to join the global transaction (unless it was already notified in (2) above), then
   2. processes the AP request
4. AP -> TM: commit() (or rollback) – TM will interact with RMs to complete the transaction using the 2PC protocol

A thread of control is associated with at most one TRID at a time. An AP request is implicitly associated with a TRID through the current thread.

X/OPEN DTP – Distributed Environment



- Outgoing TRPC: CM acts like a RM, notifies local (superior) TM that TA involves remote RMs
- Incoming TRPC: CM notifies local (subordinate) TM about incoming global TA
- Superior TM will drive hierarchical 2PC over remote TM/RMs through CM

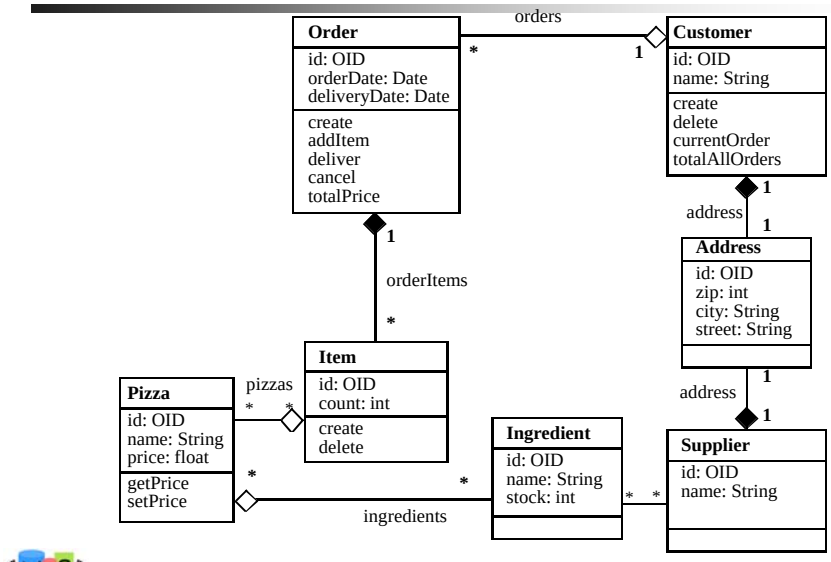
Summary

- Remote Procedure Call
  - important core concept for distributed IS
  - RPC model is based on
    - interface definitions using IDL
    - client stub (proxy), server stub (skeleton) for transparent invocation of remote procedure
    - binding mechanism
- RPC Variations
  - Remote Method Invocation
    - supported in object-based middleware (e.g., CORBA, Enterprise Java)
  - Stored Procedures
- Transaction support for RPCs
  - distributed transaction processing guarantees atomicity of global TA
  - transactional RPC
  - X/Open DTP as foundation for standardized DTP
    - variations/enhancements appear in object-based middleware (CORBA OTS, Java JTA/JTS)

Appendix

JAVA RMI EXAMPLE

Example Scenario: Pizza-Service



Example – Remote Service Interface

```
import java.rmi.*;
import java.util.Date;
public interface Order extends Remote {
        public void addItem(int pizzaId, int number)
                                        throws RemoteException;
        public Date getDeliveryDate() throws
                        RemoteException;
        public Date setDeliveryDate (Date newDate) throws
        RemoteException;
...
        }


...
import java.rmi.*;
import java.rmi.server.UnicastRemoteObject;
import java.util.*;
```

Example – Server Class Implementation

```
...
public class OrderImpl
        extends UnicastRemoteObject
        implements Order {
                private Vector fItems;
                private Date fDeliveryDate;
                public OrderImpl(String name) throws RemoteException {
                  super();
                  try {
                     Naming.rebind(name, this);
                     fItems = new Vector();
                     fDeliveryDate = null;
                      }
                  catch (Exception e) {
                     System.err.println("Output: " + e.getMessage());
                     e.printStackTrace();
                                }
                        }
...
```

'export' Order object for accepting requests

register with name server

Example – Server Class (continued)

```
...
public void addItem(int pizzaId, int number )
                throws RemoteException {
                // assuming class Item is known
                Item item = new  Item(pizzaId, number);
                fItems.addElement(item);
                        }
                ... // Impl. of other methods          }
```

Example – Server

```
...
import java.rmi.*;
import java.server.*;
public class OrderServer {
      public static void main(String args[]) {
        try {
          OrderImpl order = new OrderImpl("my_order");
          System.out.println("Order server is running");
              }
        catch (Exception e) {
          System.err.println("Exception: " + e.getMessage());
          e.printStackTrace();
                    }
              }
      }
```

remote object name (later used in client lookup)

Example – Client Program

```
...
import java.rmi.*;
public class OrderClient {
      public static void Main(String args[]) {
      try {
              Order order = (Order)
                  Naming.lookup("/my_order");
              int pizzaId = Integer.parseInt(args[0]);
              int number = Integer.parseInt(args[1]);
              order.addItem(pizzaId, number);
                    }
      catch (Exception e) {
              System.err.println("system error: " + e);
                    }
              }
      }
```

returns an instance of the stub class (generated from the remote Order interface)

Example – Compile, Generate Stub, Run

- Compile:
  javac Order.java OrderImpl.java OrderClient.java OrderServer.java
- Generate stub and skeleton code:
  rmic OrderImpl
- Administrative steps:
  - Start directory server: ***rmiregistry***
  - Start RMI-Servers: ***java OrderServer***
  - Run clients: ***java OrderClient***