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Chapter 4
Remote Procedure Calls and Distributed Transactions

Outline

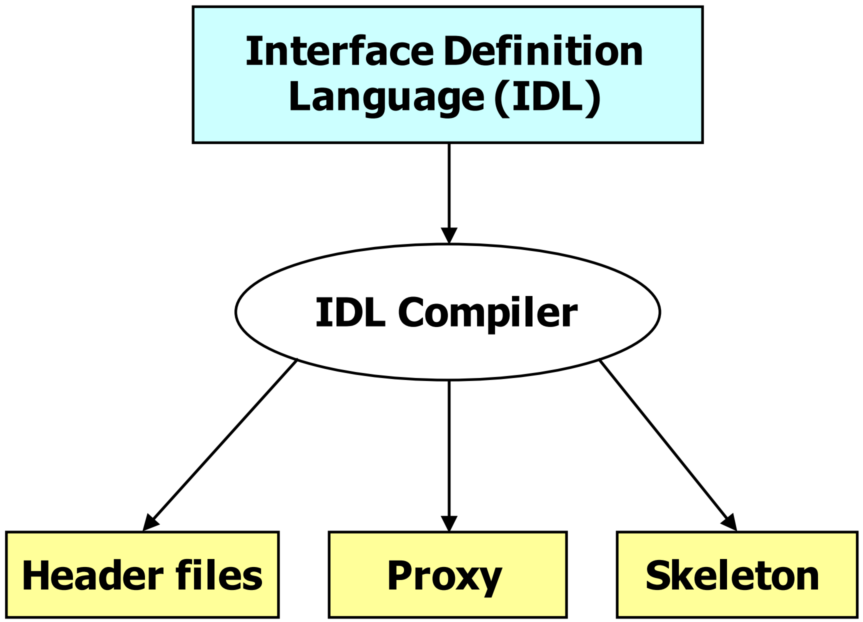
- Remote Procedure Call
  - concepts
    - IDL, principles, binding
  - variations
    - remote method invocation
      - example: Java RMI
    - stored procedures
- Distributed Transaction Processing
  - transactional RPC
  - X/Open DTP
- Summary

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)

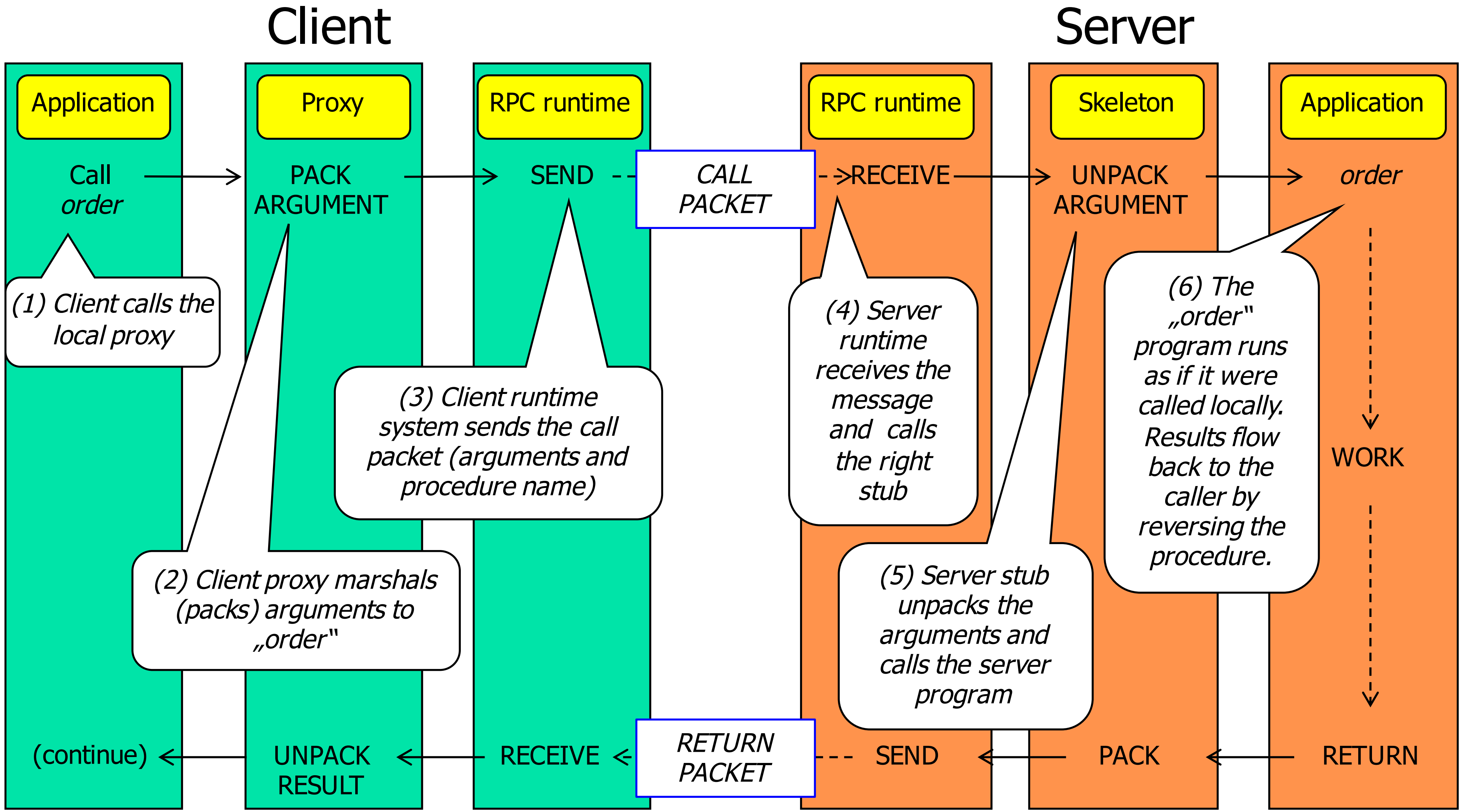
- Goal: Simple programming model for distributed applications
  - based on procedure as an invocation mechanism for distributed components
- Core mechanism in almost every form of middleware
- Distributed programs can interact (transparently) in heterogeneous environments
  - network protocols
  - programming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



Client
Server
Application
Proxy
RPC runtime
RPC runtime
Skeleton
Application
Call
order
PACK
ARGUMENT
SEND
CALL
PACKET
RECEIVE
UNPACK
ARGUMENT
order
(1) Client calls the local proxy
(2) Client proxy marshals (packs) arguments to „order"
(3) Client runtime system sends the call packet (arguments and procedure name)
(4) Server runtime receives the message and calls the right stub
(5) Server stub unpacks the arguments and calls the server program
(6) The „order" program runs as if it were called locally. Results flow back to the caller by reversing the procedure.
WORK
(continue)
UNPACK
RESULT
RECEIVE
RETURN
PACKET
SEND
PACK
RETURN

Binding in RPC

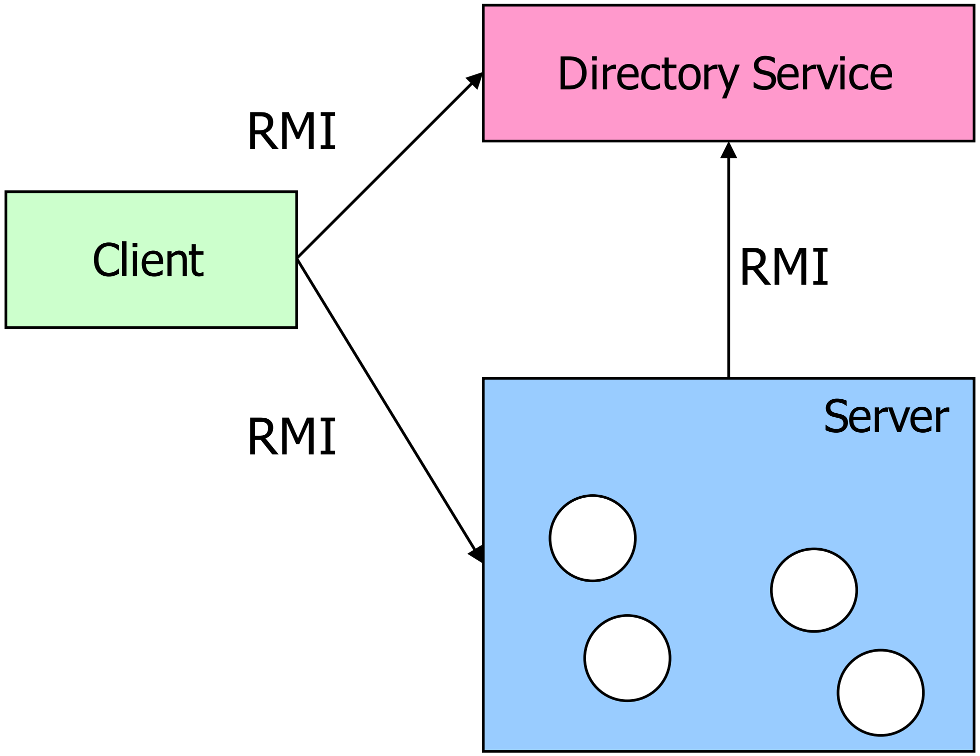
- Before performing RPC, the client must first locate and *bind* to the server
  - create/obtain an (environment-specific) *handle* to the server
  - encapsulates information such as IP address, port number, Ethernet address, …
- Static binding
  - handle is "hard-coded" into the client stub at compile-time
  - 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

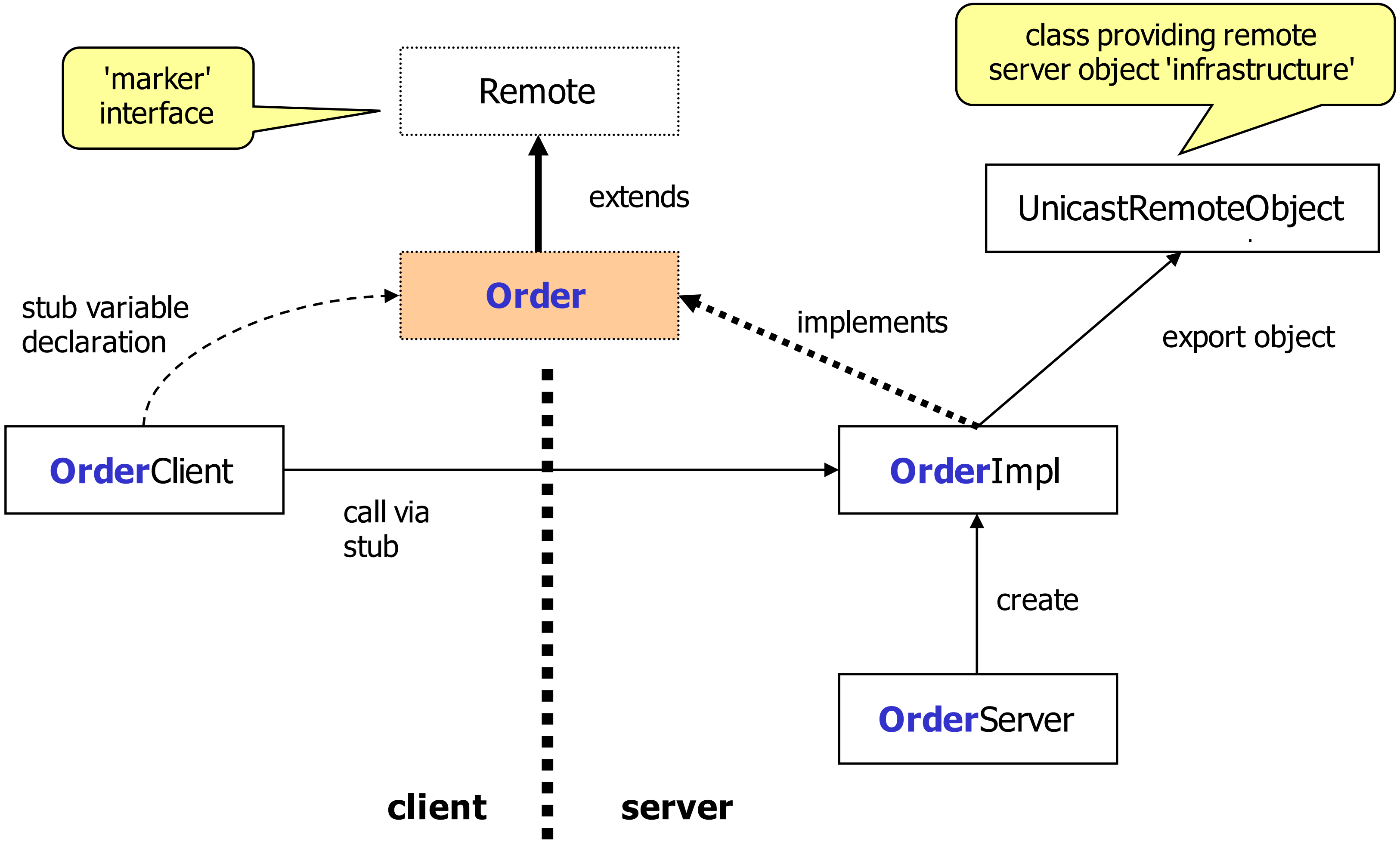
- Mechanism for communication
  - between Java programs
  - between Java programs and applets
  - running in different JVMs, possibly on different nodes
- Capabilities
  - finding remote objects
  - transparent communication with remote objects
  - loading byte code for remote objects



Java RMI – Development

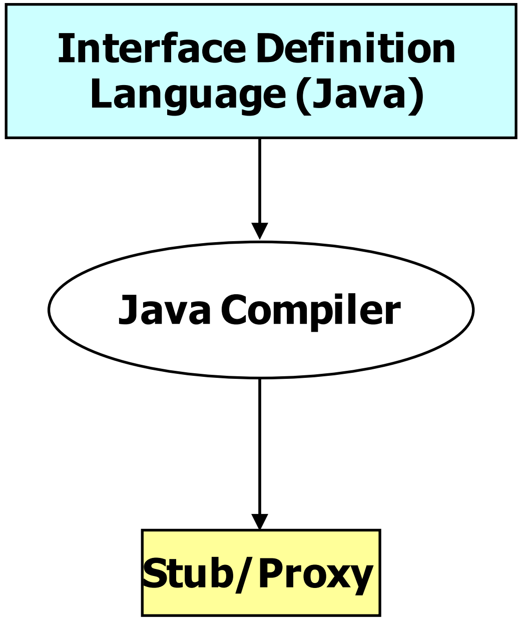
- Java is used as the IDL and development programming language
- Development steps
  1. Defining a remote interface (e.g., *Order*)
     - methods capable of throwing *RemoteExceptions*
  2. Implementing server object class (e.g., *OrderImpl*, which implements *Order*)
     - only application logic; 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
     - handle *RemoteExceptions*
  4. Provide server code for
     - creating a server object (instantiate server object class)
     - exporting and registering the server object with the RMI registry

Example - Class and Interface Relationships



Java RMI – Deployment and Runtime

- Deployment
  - generate stub using Java 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*)
    - location-transparency is provided, but RPC itself is not transparent!
    - generic invocation mechanism, no stubs/skeletons involved)
  - in the scope of an existing DB connection, active transaction

RPCs and Transactions

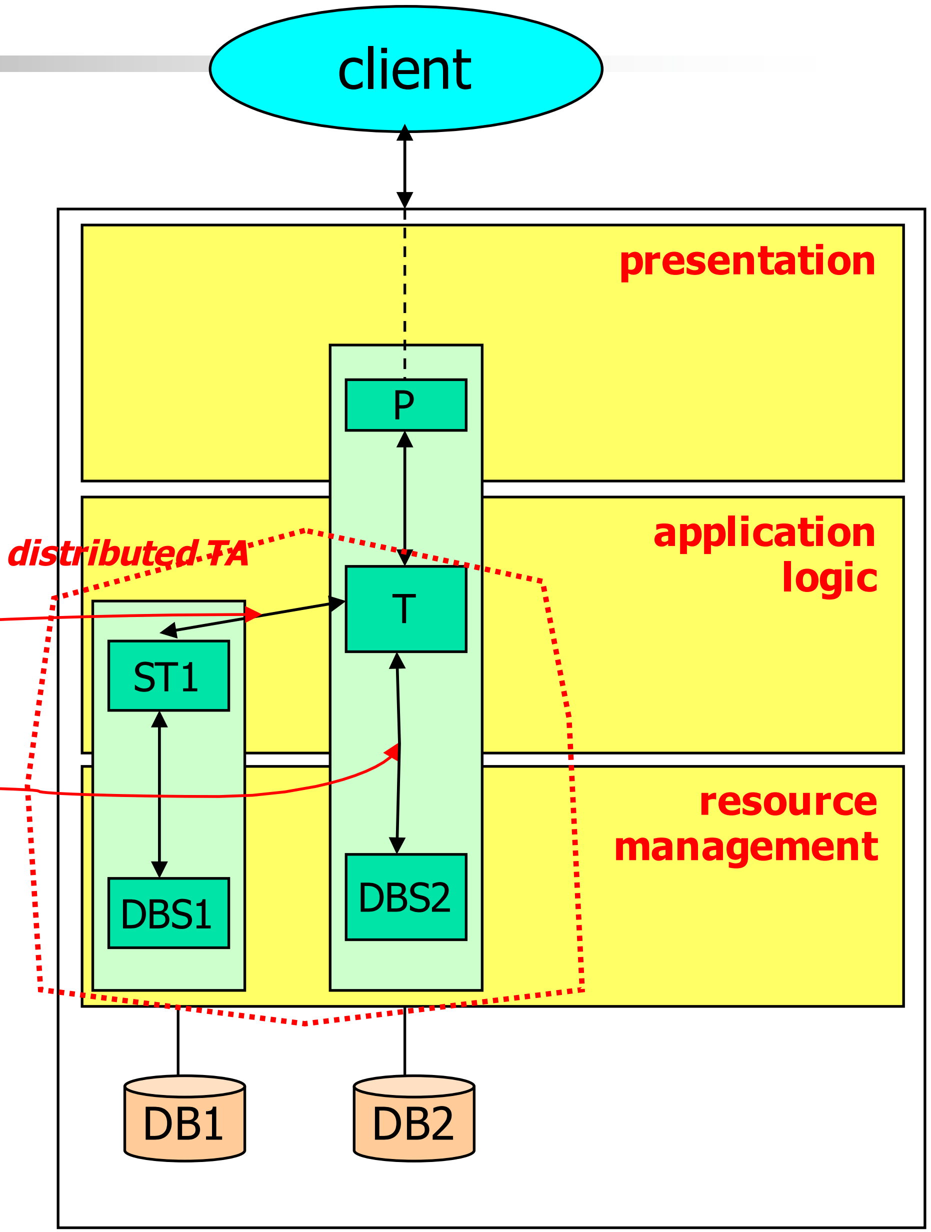
- Example scenario for T: debit/credit
  - T invokes debit procedure (ST1), modifying DB1
  - T performs credit operation on DBS2, modifying DB2
- Need transactional guarantees for T
- Program structure of T

  BOT

  CALL debit(…)

  CONNECT (DB2)
  UPDATE ACCOUNTS SET …
  DISCONNECT

  EOT
- Requires coordination of distributed transaction
  - based on 2PC

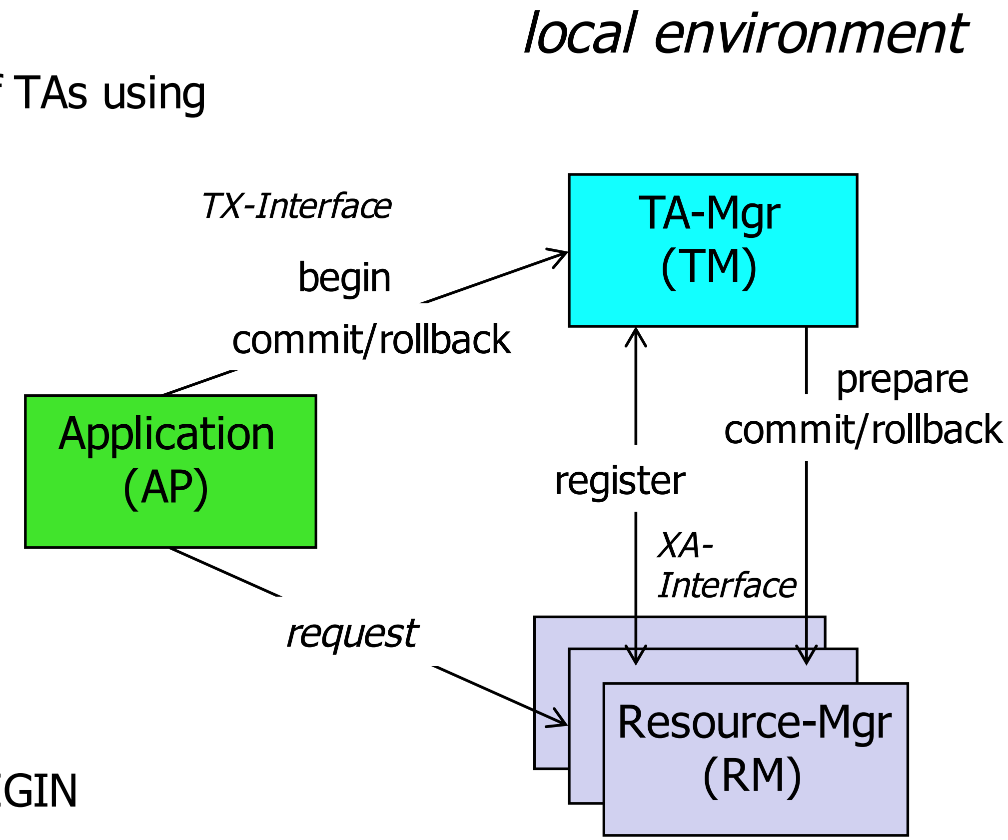


Transactional RPC (TRPC)

- 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



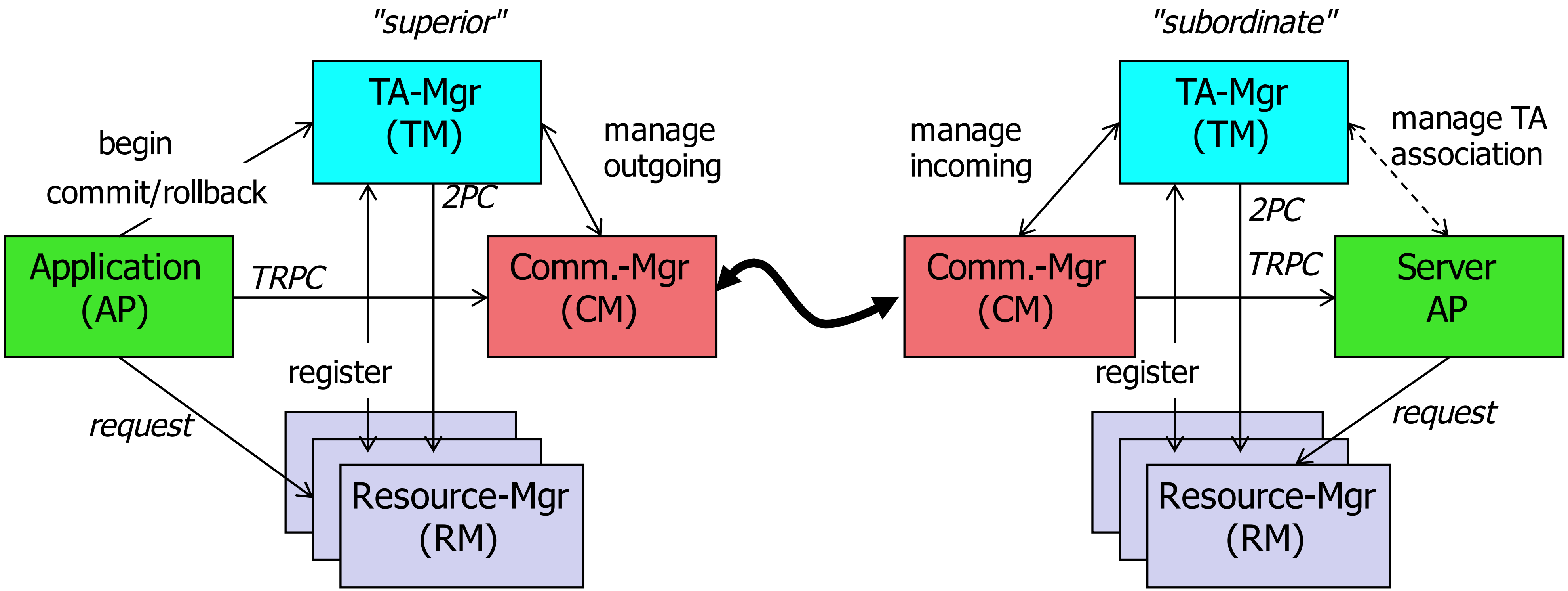
Interactions in a Local Environment

1. AP -> TM: begin – establishes transaction context, global id (TRID) for ToC
   1. TM -> RM static registration – TM notifies frequently used RMs about the new global transaction, RM can associate future AP requests from ToC with the TRID
2. AP -> RM: *request* – the RM
   1. first dynamically registers with the TM to join the global transaction for ToC (unless RM uses static registration), then
   2. processes the AP request
3. AP -> TM: commit, rollback – TM will interact with RMs to complete the transaction using the 2PC protocol (prepare, commit/rollback)

Thread of Control (ToC)

- entity, with all its context (resources, etc.) that is in control of the processor (e.g., an OS-thread)
- is associated with at most one TRID at a time (but a global TA can have multiple ToCs). An AP request is implicitly associated with a TRID through the current ToC.

X/OPEN DTP – Distributed Environment



- Communication Manager (CM)
  - provides transactional RPC support
  - works with TMs on both sides to help manage global transactions
- Remote TM assumes role of subordinate TM
  - hierarchical 2PC processing

Interactions in a Distributed Environment

- Application issues a (transactional) RPC (TRPC)
  1. local CM interacts with local TM to manage the outgoing TA
     - TM notes TRID as extending to the remote system
     - TM notes local CM to be included in commit processing (2PC)
     - local TM becomes the "superior" TA-Manager (later initiates 2PC)
  2. local CM communicates RPC and transactional context to remote CM
  3. remote CM interacts with remote TM to manage the incoming TA
     - CM establishes TRID with remote TM, which becomes the "subordinate" for this TRID
     - CM asks TM to associate TRID with ToC in which (remote) server application will run
     - TM performs static registration with remote RMs for TRID
     - CM (server stub) invokes server AP
  4. server AP may issue (remote) RM requests (might cause dynamic RM registration as usual)
- Application issues a commit (or rollback)
  1. superior TM drives hierarchical 2PC processing, involving local CM just like RMs
  2. local CM relays prepare/commit/rollback calls to remote CM, which in turn relays them to subordinate (remote) TM
  3. subordinate TM coordinates with remote RMs for each phase

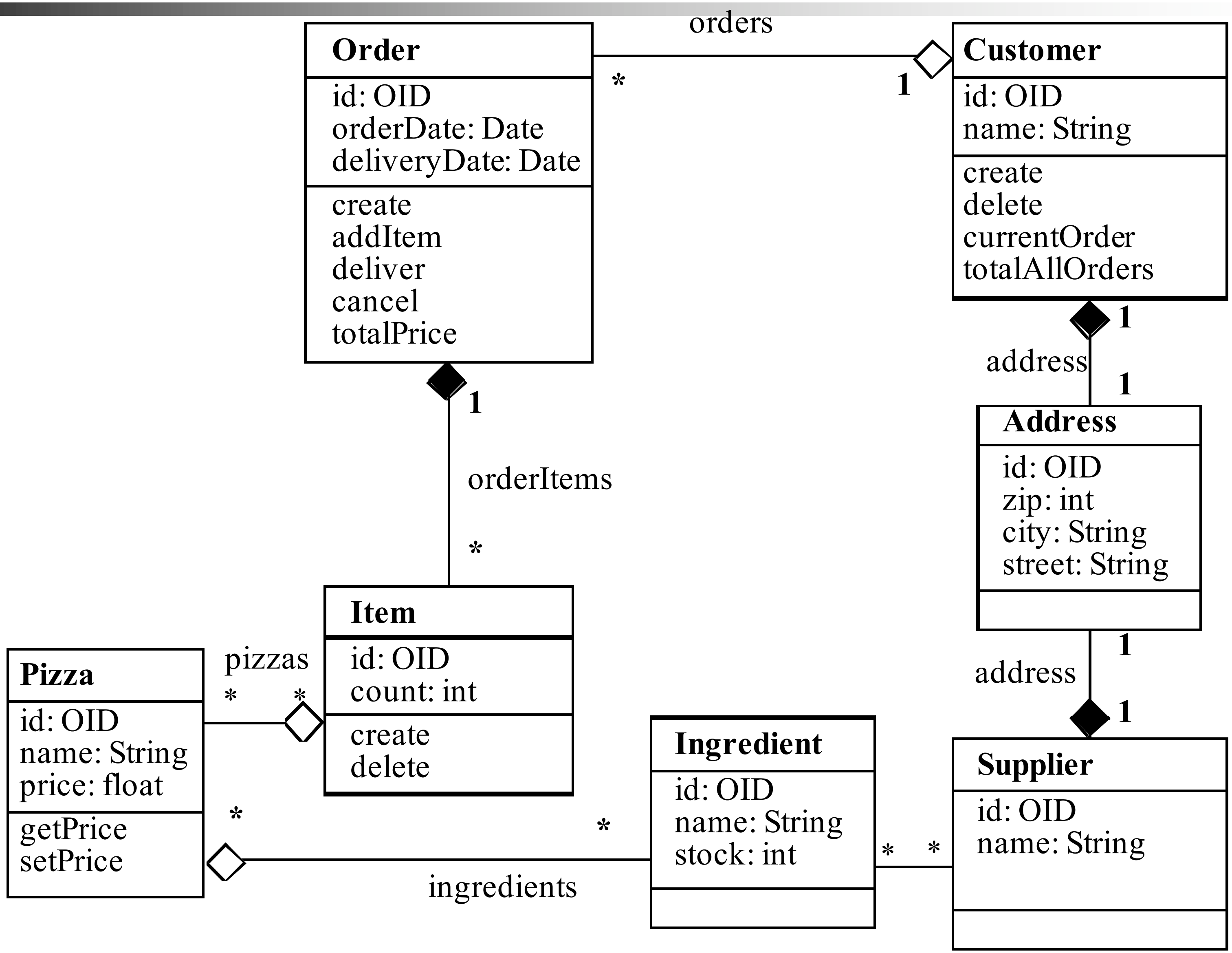
Summary

- 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;
…
        }
```

Example – Server Class Implementation

```
   ...
   import java.rmi.*;
   import java.rmi.registry.LocateRegistry
   import java.rmi.registry.Registry
   import java.rmi.server.UnicastRemoteObject;
   import java.util.*;
...
   public class OrderImpl
         implements Order {
                  private Vector fItems;
                  private Date fDeliveryDate;
                  public OrderImpl(String name) throws RemoteException {
                     super();
                     try {
                        Order stub =
                           (Order) UnicastRemoteObject.exportObject(this, 0);
                        Registry Naming = LocateRegistry.getRegistry();
                        Naming.rebind(name, stub);
                        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 {
        Registry Naming = Locate Registry.getRegistry(args[0]);
        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 – will also generate stubs:

  javac Order.java OrderImpl.java OrderClient.java OrderServer.java
- Administrative steps:
  - Start directory server: ***rmiregistry***
  - Start RMI-Servers: ***java OrderServer***
  - Run clients: ***java OrderClient***