Distributed Computing Paradigms

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Clarifying note

- Some slides from the original presentation have been deleted.
- These slides have been used for teaching purposes only, for *Parallel and Distributed Programming* students studying the *Computer Science and Engineering Degree* at the University of Cádiz during the 2016-2017 academic year.

Paradigms for Distributed Applications

- Paradigm means "a pattern, example, or model." In the study of any subject of great complexity, it is useful to identify the basic patterns or models, and classify the detail according to these models. This paper aims to present a classification of the paradigms for distributed applications.
- Characteristics that distinguish distributed applications from conventional applications which run on a single machine. These characteristics are:
  - *Interprocess communication*: A distributed application require the participation of two or more independent entities (processes). To do so, the processes must have the ability to exchange data among themselves.
  - *Event synchronization*: In a distributed application, the sending and receiving of data among the participants of a distributed application must be synchronized.

Abstractions

- Arguably the most fundamental concept in computer science, abstraction is the idea of *detail hiding*. To quote David J. Barnes[1]:

  > *We often use abstraction when it is not necessary to know the exact details of how something works or is represented, because we can still make use of it in its simplified form. Getting involved with the detail often tends to obscure what we are trying to understand, rather than illuminate it … Abstraction plays a very important role in programming because we often want to model, in software, simplified versions of things that exist in the real world … without having to build the real things.*

- **In software engineering, abstraction is realized with the provision of tools or facilities which allow software to be built without the developer having to be cognizant of some of the underlying complexities.**

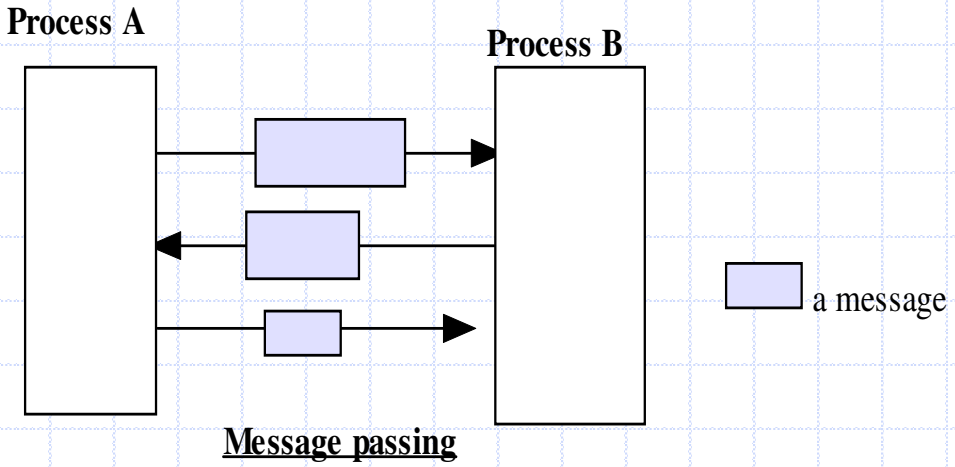
Distributed Application Paradigms

object space
network services, object request broker, mobile agent
remote procedure call, remote method invocation
client-server
message passing

The Message Passing Paradigm

Message passing is the most fundamental paradigm for distributed applications.

- **A process sends a message representing a request.**
- **The message is delivered to a receiver, which processes the request, and sends a message in response.**
- **In turn, the reply may trigger a further request, which leads to a subsequent reply, and so forth. -**



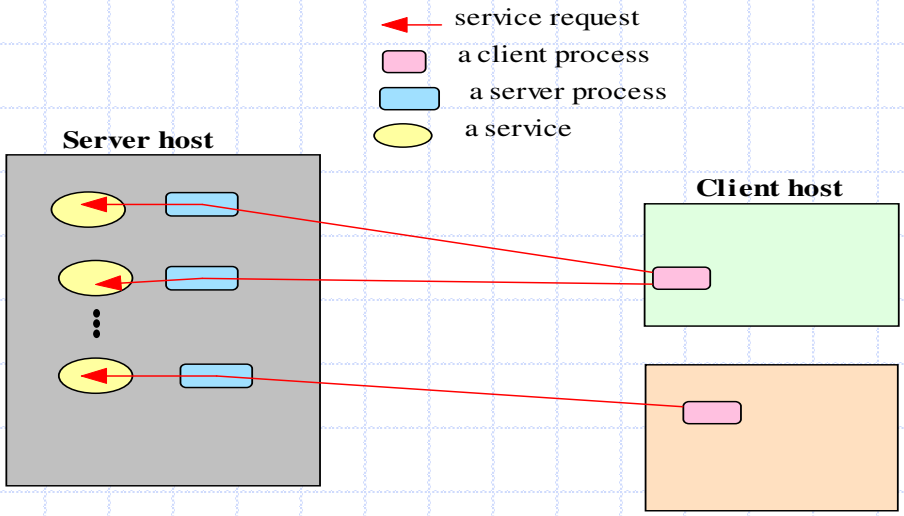
The Message Passing Paradigm - 2

- **The basic operations required to support the basic message passing paradigm are *send*, and *receive*.**
- **For connection-oriented communication, the operations *connect* and *disconnect* are also required.**
- **With the abstraction provided by this model, the interconnected processes perform input and output to each other, in a manner similar to file I/O. The I/O operations encapsulate the detail of network communication at the operating-system level.**
- **The socket application programming interface is based on this paradigm.**
  - **http://java.sun.com/products/jdk/1.2/docs/api/index.html**
  - **http://www.sockets.com/**

The Client-Server Paradigm

Perhaps the best known paradigm for network applications, the client-server[2] model assigns asymmetric roles to two collaborating processes.

One process, the server, plays the role of a service provider which waits passively for the arrival of requests. The other, the client, issues specific requests to the server and awaits its response.



The Client-Server Paradigm, conceptual

The Client-Server Paradigm - 2

- Simple in concept, the client-server model provides an efficient abstraction for the delivery of network services.
- Operations required include those for a server process to listen and to accept requests, and for a client process to issue requests and accept responses.
- By assigning asymmetric roles to the two sides, event synchronization is simplified: the server process waits for requests, and the client in turn waits for responses.
- Many Internet services are client-server applications. These services are often known by the protocol that the application implements. Well known Internet services include HTTP, FTP, DNS, finger, gopher, etc.

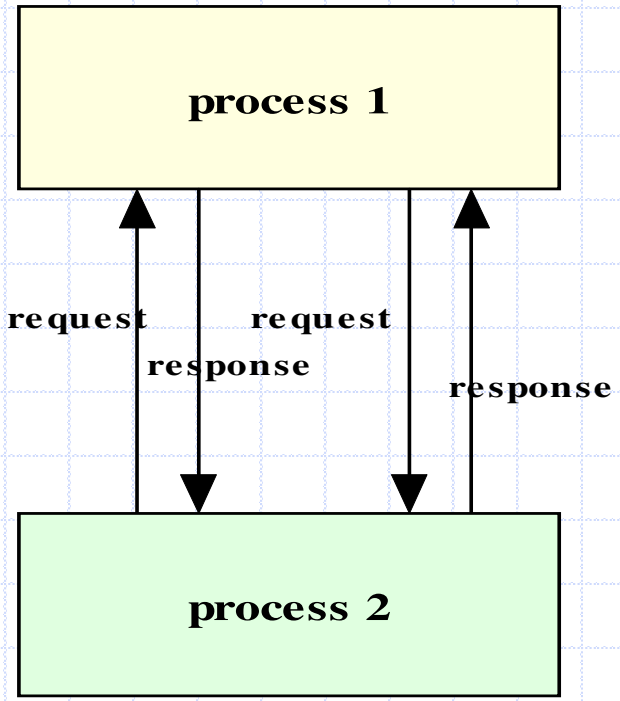
The Peer-to-Peer System Architecture

http://www.peer-to-peerwg.org/whatis/index.html

- In system architecture and networks, peer-to-peer is an architecture where computer resources and services are direct exchanged between computer systems.
- These resources and services include the exchange of information, processing cycles, cache storage, and disk storage for files..
- In such an architecture, computers that have traditionally been used solely as clients communicate directly among themselves and can act as both clients and servers, assuming whatever role is most efficient for the network.

The Peer-to-Peer Distributed Computing Paradigm

In the peer-to-peer paradigm, the participating processes play equal roles, with equivalent capabilities and responsibilities (hence the term “peer”). Each participant may issue a request to another participant and receive a response.



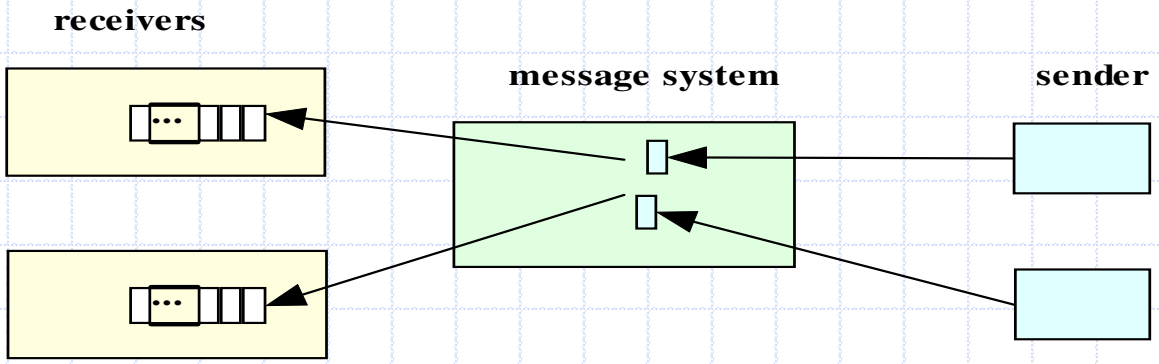
Peer-to-Peer distributed computing

Whereas the client-server paradigm is an ideal model for a centralized network service, the peer-to-peer paradigm is more appropriate for applications such as instant messaging, peer-to-peer file transfers, video conferencing, and collaborative work. It is also possible for an application to be based on both the client-server model and the peer-to-peer model.

A well-known example of a peer-to-peer file transfer service is ***Napster.com*** or similar sites which allow files (primarily audio files) to be transmitted among computers on the Internet. It makes use of a server for directory in addition to the peer-to-peer computing.

The Message System Paradigm

- The Message System or Message-Oriented Middleware (MOM) paradigm is an elaboration of the basic message-passing paradigm.
- In this paradigm, a message system serves as an intermediary among separate, independent processes.
- The message system acts as a switch for messages, through which processes exchange messages asynchronously, in a decoupled manner.
- A sender deposits a message with the message system, which forwards it to a message queue associated with each receiver. Once a message is sent, the sender is free to move on to other tasks.



Two subtypes of message system models

The Point-To-Point Message Model

- In this model, a message system forwards a message from the sender to the receiver's message queue. Unlike the basic message passing model, the middleware provides a message depository, and allows the sending and the receiving to be decoupled. Via the middleware, a sender deposits a message in the message queue of the receiving process. A receiving process extracts the messages from its message queue, and handles each one accordingly.
- Compared to the basic message-passing model, this paradigm provides the additional abstraction for asynchronous operations. To achieve the same effect with basic message-passing, a developer will have to make use of threads or child processes.

The Publish/Subscribe Message Model

- **In this model, each message is associated with a specific topic or event. Applications interested in the occurrence of a specific event may subscribe to messages for that event. When the awaited event occurs, the process publishes a message announcing the event or topic. The middleware message system distributes the message to all its subscribers.**
- **The publish/subscribe message model offers a powerful abstraction for multicasting or group communication. The *publish* operation allows a process to multicast to a group of processes, and the *subscribe* operation allows a process to listen for such multicast.**

Toolkits based on the Message-System Paradigm

- The MOM paradigm has had a long history in distributed applications.
- Message Queue Services (MQS) have been in use since the 1980's.
- The IBM MQ*Series[6] is an example of such a facility.

  http://www-4.ibm.com/software/ts/mqseries/
- Other existing support for this paradigm are
  - Microsoft's Message Queue (MSQ),

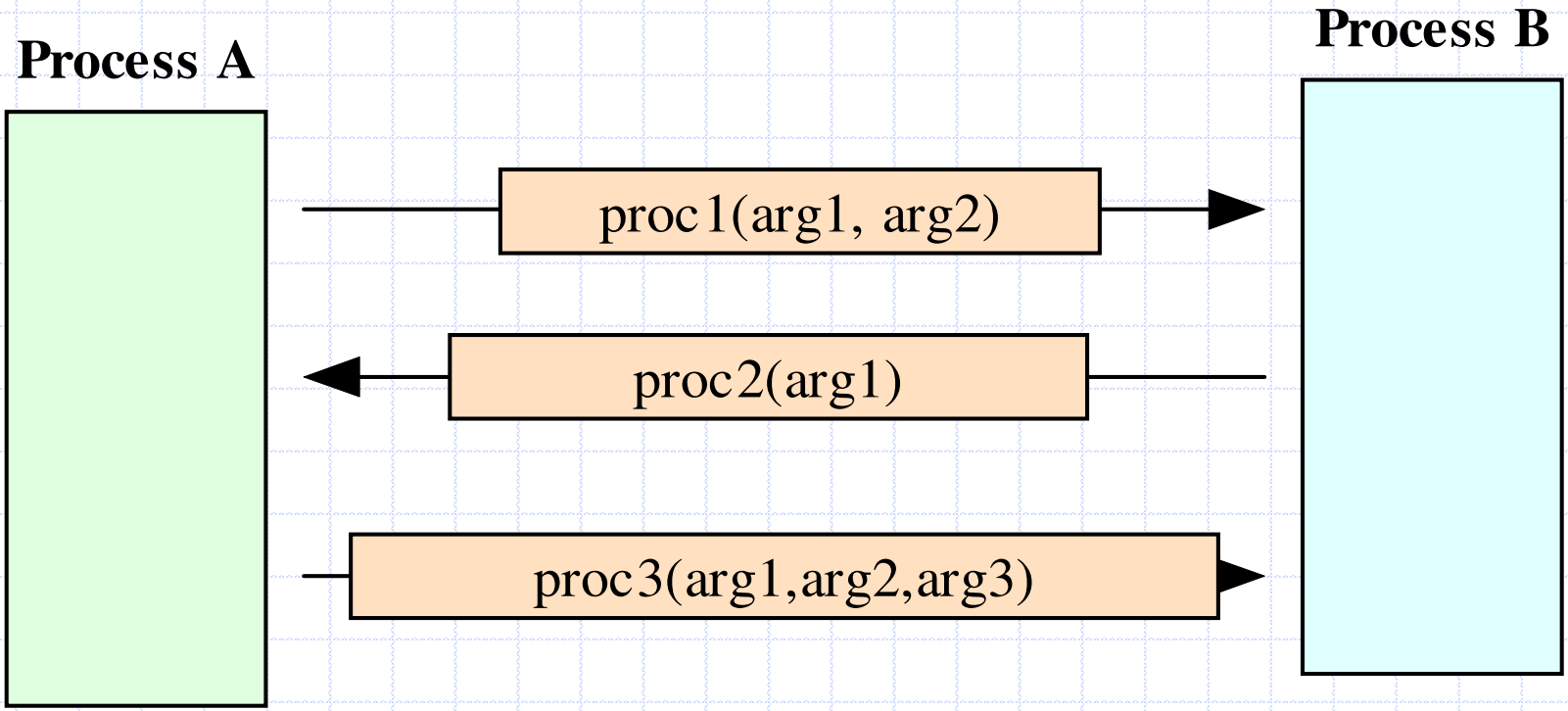
    http://msdn.microsoft.com/library/psdk/msmq/msmq_overview_4ilh.htm
  - Java's Message Service

    http://developer.java.sun.com/developer/technicalArticles/Networking/messaging/

Remote Procedure Call

- As applications grew increasingly complex, it became desirable to have a paradigm which allows distributed software to be programmed in a manner similar to conventional applications which run on a single processor.
- The Remote Procedure Call (RPC) model provides such an abstraction. Using this model, interprocess communications proceed as procedure, or function, calls, which are familiar to application programmers.
- A remote procedure call involves two independent processes, which may reside on separate machines. A process, *A*, wishing to make a request to another process, *B*, issues a procedure call to *B*, passing with the call a list of argument values. As in the case of local procedure calls, a remote procedure call triggers a predefined action in a procedure provided by process *B*. At the completion of the procedure, process *B* returns a value to process *A*.

Remote Procedure Call - 2



Remote Procedure Call - 3

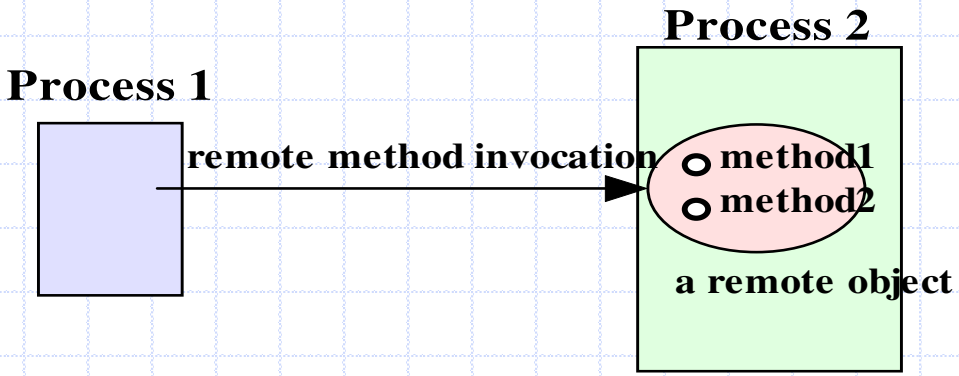
- RPC allows programmers to build network applications using a programming construct similar to the local procedure call, providing a convenient abstraction for both interprocess communication and event synchronization.
- Since its introduction in the early 1980s, the Remote Procedure Call model has been widely in use in network applications.
- There are two prevalent APIs for Remote Procedure Calls.
  - The *Open Network Computing Remote Procedure Call*, evolved from the RPC API originated from Sun Microsystems in the early 1980s.
  - The *Open Group Distributed Computing Environment* (DCE) RPC.
- Both APIs provide a tool, *rpcgen*, for transforming remote procedure calls to local procedure calls to the stub.

The Distributed Objects Paradigms

- The idea of applying object orientation to distributed applications is a natural extension of object-oriented software development.
- Applications access objects distributed over a network.
- Objects provide methods, through the invocation of which an application obtains access to services.
- Object-oriented paradigms include:
  - Remote method invocation (RMI)
  - Network services
  - Object request broker
  - Object spaces

Remote Method Invocation (RMI)

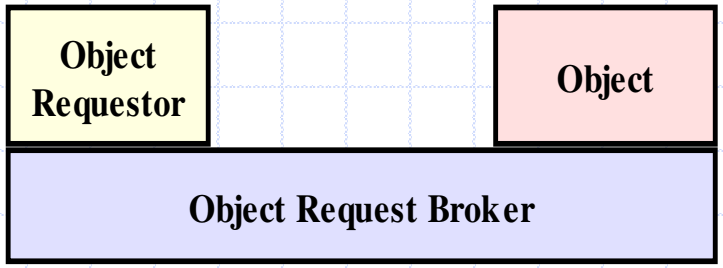
- Remote method invocation is the object-oriented equivalent of remote method calls.
- In this model, a process invokes the methods in an object, which may reside in a remote host.
- As with RPC, arguments may be passed with the invocation.



The Remote Method Call Paradigm

The Object Request broker Paradigm

- In the object broker paradigm , an application issues requests to an *object request broker* (ORB), which directs the request to an appropriate object that provides the desired service.
- The paradigm closely resembles the remote method invocation model in its support for remote object access. The difference is that the object request broker in this paradigm functions as a middleware which allows an application, as an object requestor, to potentially access multiple remote (or local) objects.
- The request broker may also function as an mediator for heterogeneous objects, allowing interactions among objects implemented using different APIs and /or running on different platforms.



The Object Request broker Paradigm - 2

- This paradigm is the basis of the Object Management Group's CORBA (Common Object Request Broker Architecture) architecture.

  http://www.corba.org/

- Tool kits based on the architecture include:
  - Inprise's Visibroker http://www.inprise.com/visibroker/
  - Java's Interface Development Language (Java IDL)

    http://java.sun.com/products/jdk/idl/
  - Orbix's IONA, and TAO from the Object Computing, Inc.

    http://www.corba.org/vendors/pages/iona.html

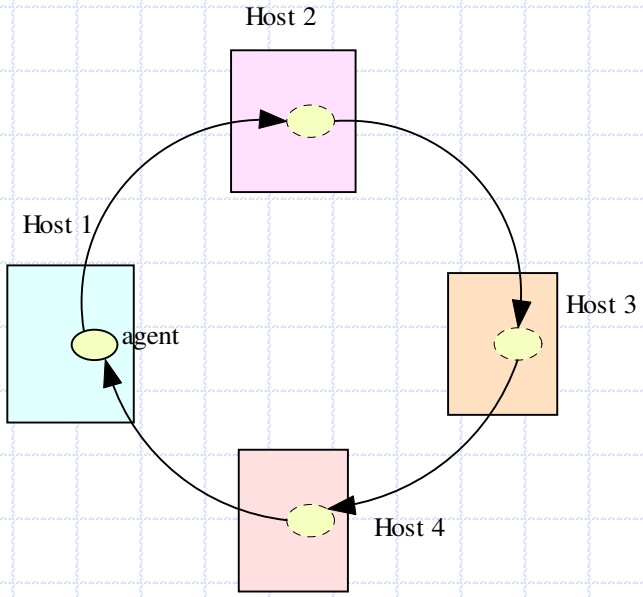
Component-based Technologies

- Component-based technologies such as Microsoft's COM, Microsoft DCOM, Java Bean, and Enterprise Java Bean are also based on distributed-object paradigms, as components are essentially specialized, packaged objects designed to interact with each other through standardized interfaces.
- In addition, *application servers,* popular for enterprise applications, are middleware facilities which provide access to objects or components.

  IBM's WebSphere, http://www.as400.ibm.com/products/websphere/docs/as400v35/docs/admover.html

The Mobile Agent Paradigm

- A mobile agent is a transportable program or object.
- In this model, an agent is launched from an originating host.
- The agent travels from host to host according to an itinerary that it carries.
- At each stop, the agent accesses the necessary resources or services, and performs the necessary tasks to accomplish its mission.



The Mobile Agent Paradigm - 2

- The paradigm offers the abstraction for a transportable program or object.
- In lieu of message exchanges, data is carried by the program/object as the program is transported among the participants.
- Commercial packages which support the mobile agent paradigm include:
  - Mitsubishi Electric ITA's Concordia system

    http://www.meitca.com/HSL/Projects/Concordia/Welcome.html

    IBM's Aglet system.

    http://www.trl.ibm.co.jp/aglets/