Last Class: RPCs

- RPCs make distributed computations look like local computations

- Issues:
  - Parameter passing
  - Binding
  - Failure handling

Today:

- Lightweight RPCs

- Remote Method Invocation (RMI)
  - Design issues
Lightweight RPCs

• Many RPCs occur between client and server on same machine
  – Need to optimize RPCs for this special case => use a lightweight RPC mechanism (LRPC)

• Server $S$ exports interface to remote procedures

• Client $C$ on same machine imports interface

• OS kernel creates data structures including an argument stack shared between $S$ and $C$

Lightweight RPCs

• RPC execution
  – Push arguments onto stack
  – Trap to kernel
  – Kernel changes mem map of client to server address space
  – Client thread executes procedure (OS upcall)
  – Thread traps to kernel upon completion
  – Kernel changes the address space back and returns control to client

• Called “doors” in Solaris
**Doors**

![Door Diagram]

- Which RPC to use? - run-time bit allows stub to choose between LRPC and RPC

**Other RPC Models**

- Asynchronous RPC
  - Request-reply behavior often not needed
  - Server can reply as soon as request is received and execute procedure later

- Deferred-synchronous RPC
  - Use two asynchronous RPCs
  - Client needs a reply but can’t wait for it; server sends reply via another asynchronous RPC

- One-way RPC
  - Client does not even wait for an ACK from the server
  - Limitation: reliability not guaranteed (Client does not know if procedure was executed by the server).
Asynchronous RPC

a) The interconnection between client and server in a traditional RPC
b) The interaction using asynchronous RPC

Deferred Synchronous RPC

- A client and server interacting through two asynchronous RPCs
Remote Method Invocation (RMI)

- RPCs applied to objects, i.e., instances of a class
  - **Class**: object-oriented abstraction; module with data and operations
  - Separation between interface and implementation
  - Interface resides on one machine, implementation on another
- RMIs support system-wide object references
  - Parameters can be object references

Distributed Objects

- When a client binds to a distributed object, load the interface ("proxy") into client address space
  - Proxy analogous to stubs
- Server stub is referred to as a skeleton
Proxies and Skeletons

• Proxy: client stub
  – Maintains server ID, endpoint, object ID
  – Sets up and tears down connection with the server
  – [Java:] does serialization of local object parameters
  – In practice, can be downloaded/constructed on the fly (why can’t this be done for RPCs in general?)

• Skeleton: server stub
  – Does deserialization and passes parameters to server and sends result to proxy

Binding a Client to an Object

(a) Example with implicit binding using only global references

```c
Distr_object* obj_ref;
obj_ref = ...;
obj_ref-> do_something();  // Implicitly bind and invoke a method
```

(b) Example with explicit binding using global and local references

```c
Distr_object objPref;
Local_object* obj_ptr;
obj_ref = ...;
obj_ptr = bind(obj_ref);
objc_ptr -> do_something();  // Explicitly bind and obtain a pointer to the local proxy
```

a) (a) Example with implicit binding using only global references
b) (b) Example with explicit binding using global and local references
Parameter Passing

- Less restrictive than RPCs.
  - Supports system-wide object references
  - [Java] pass local objects by value, pass remote objects by reference

DCE Distributed-Object Model

a) Distributed dynamic objects in DCE.
b) Distributed named objects
Java RMI

• Server
  – Defines interface and implements interface methods
  – Server program
    • Creates server object and registers object with “remote object” registry

• Client
  – Looks up server in remote object registry
  – Uses normal method call syntax for remote methods

• Java tools
  – Rmiregistry: server-side name server
  – Rmic: uses server interface to create client and server stubs

Java RMI and Synchronization

• Java supports Monitors: synchronized objects
  – Serializes accesses to objects
  – How does this work for remote objects?

• Options: block at the client or the server

• Block at server
  – Can synchronize across multiple proxies
  – Problem: what if the client crashes while blocked?

• Block at proxy
  – Need to synchronize clients at different machines
  – Explicit distributed locking necessary

• Java uses proxies for blocking
  – No protection for simultaneous access from different clients
  – Applications need to implement distributed locking
Message-oriented Transient Communication

- Many distributed systems built on top of simple message-oriented model
  - Example: Berkeley sockets

![Diagram of socket primitives](image)

Berkeley Socket Primitives

<table>
<thead>
<tr>
<th>Primitive</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socket</td>
<td>Create a new communication endpoint</td>
</tr>
<tr>
<td>Bind</td>
<td>Attach a local address to a socket</td>
</tr>
<tr>
<td>Listen</td>
<td>Announce willingness to accept connections</td>
</tr>
<tr>
<td>Accept</td>
<td>Block caller until a connection request arrives</td>
</tr>
<tr>
<td>Connect</td>
<td>Actively attempt to establish a connection</td>
</tr>
<tr>
<td>Send</td>
<td>Send some data over the connection</td>
</tr>
<tr>
<td>Receive</td>
<td>Receive some data over the connection</td>
</tr>
<tr>
<td>Close</td>
<td>Release the connection</td>
</tr>
</tbody>
</table>
Message-Passing Interface (MPI)

• Sockets designed for network communication (e.g., TCP/IP)
  – Support simple send/receive primitives
• Abstraction not suitable for other protocols in clusters of workstations or massively parallel systems
  – Need an interface with more advanced primitives
• Large number of incompatible proprietary libraries and protocols
  – Need for a standard interface
• Message-passing interface (MPI)
  – Hardware independent
  – Designed for parallel applications (uses transient communication)
• Key idea: communication between groups of processes
  – Each endpoint is a \((\text{groupID}, \text{processID})\) pair

### MPI Primitives

<table>
<thead>
<tr>
<th>Primitive</th>
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</tr>
</thead>
<tbody>
<tr>
<td>MPI_bsend</td>
<td>Append outgoing message to a local send buffer</td>
</tr>
<tr>
<td>MPI_send</td>
<td>Send a message and wait until copied to local or remote buffer</td>
</tr>
<tr>
<td>MPI_ssend</td>
<td>Send a message and wait until receipt starts</td>
</tr>
<tr>
<td>MPI_sendrecv</td>
<td>Send a message and wait for reply</td>
</tr>
<tr>
<td>MPI_isend</td>
<td>Pass reference to outgoing message, and continue</td>
</tr>
<tr>
<td>MPI_issend</td>
<td>Pass reference to outgoing message, and wait until receipt starts</td>
</tr>
<tr>
<td>MPI_recv</td>
<td>Receive a message; block if there are none</td>
</tr>
<tr>
<td>MPI_irecv</td>
<td>Check if there is an incoming message, but do not block</td>
</tr>
</tbody>
</table>