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 $C$

• 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
• 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;  //Declare a systemwide object reference
obj_ref = ...;         // Initialize the reference to a distributed object
obj_ref-> do_something();  // Implicitly bind and invoke a method
```

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

```c
Distr_object obj_ref;  //Declare a systemwide object reference
Local_object* obj_ptr;  //Declare a pointer to local objects
obj_ref = ...;         // Initialize the reference to a distributed object
obj_ptr = bind(obj_ref);  // Explicitly bind and obtain a pointer to the local proxy
obj_ptr -> do_something();  //Invoke a method on 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

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 (groupID, 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>MPIIssend</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>