CSE 120
Principles of Operating Systems

Fall 2004

Lecture 14: Remote Procedure Call And Network File System

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Why is RPC Interesting?

- Remote Procedure Call (RPC) is the most common means for remote communication
- It is used both by operating systems and applications
  - NFS is implemented as a set of RPCs
  - DCOM, CORBA, Java RMI, etc., are all basically just RPC
- Someday (soon?) you will most likely have to write an application that uses remote communication (or you already have)
  - You will most likely use some form of RPC for that remote communication
  - So it's good to know how all this RPC stuff works
    - » More "debunking the magic"

Clients and Servers

- The prevalent model for structuring distributed computation is the client/server paradigm
- A server is a program (or collection of programs) that provide a service (file server, name service, etc.)
  - The server may exist on one or more nodes
  - Often the node is called the server, too, which is confusing
- A client is a program that uses the service
  - A client first binds to the server (locates it and establishes a connection to it)
  - A client then sends requests, with data, to perform actions, and the servers sends responses, also with data

Messages

- Initially with network programming, people hand-coded messages to send requests and responses
- Hand-coding messages gets tiresome
  - Need to worry about message formats
  - Have to pack and unpack data from messages
  - Servers have to decode and dispatch messages to handlers
  - Messages are often asynchronous
- Messages are not a very natural programming model
  - Could encapsulate messaging into a library
  - Just invoke library routines to send a message
  - Which leads us to RPC…

Procedure Calls

- Procedure calls are a more natural way to communicate
  - Every language supports them
  - Semantics are well-defined and understood
  - Natural for programmers to use
- Idea: Have servers export a set of procedures that can be called by client programs
  - Similar to module interfaces, class definitions, etc.
- Clients just do a procedure call as it they were directly linked with the server
  - Under the covers, the procedure call is converted into a message exchange with the server

Remote Procedure Calls

- So, we would like to use procedure call as a model for distributed (remote) communication
- Lots of issues
  - How do we make this invisible to the programmer?
  - What are the semantics of parameter passing?
  - How do we bind (locate, connect to) servers?
  - How do we support heterogeneity (OS, arch, language)?
  - How do we make it perform well?

RPC Model

- A server defines the server's interface using an interface definition language (IDL)
  - The IDL specifies the names, parameters, and types for all client-callable server procedures
- A stub compiler reads the IDL and produces two stub procedures for each server procedure (client and server)
  - The server programmer implements the server procedures and links them with the server-side stubs
  - The client programmer implements the client program and links it with the client-side stubs
  - The stubs are responsible for managing all details of the remote communication between client and server

RPC Stubs

- A client-side stub is a procedure that looks to the client as if it were a callable server procedure
- A server-side stub looks to the server as if a client called it
- The client program thinks it is calling the server
  - In fact, it's calling the client stub
- The server program thinks it is called by the client
  - In fact, it's called by the server stub
- The stubs send messages to each other to make the RPC happen "transparently"

RPC Example

Server Interface:
int Add(int x, int y);

Client Program:
…
sum = server->Add(3,4);
…

Server Program:
int Add(int x, int, y) {
return x + y;
}

- If the server were just a library, then Add would just be a procedure call

RPC Example: Call

Client Program:
sum = server->Add(3,4);

Client Stub:
Int Add(int x, int y) {
Alloc message buffer;
Mark as "Add" call;
Store x, y into buffer;
Send message;
}

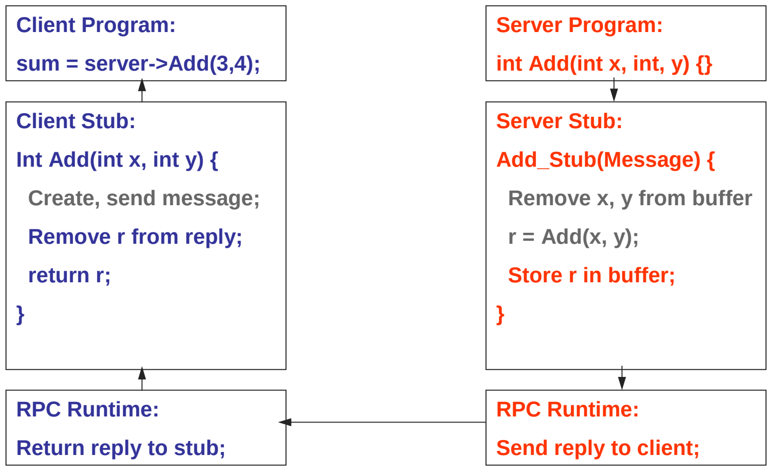
RPC Runtime:
Send message to server;

Server Program:
int Add(int x, int, y) {}

Server Stub:
Add_Stub(Message) {
Remove x, y from buffer
r = Add(x, y);
}

RPC Runtime:
Receive message;
Dispatch, call Add_Stub;

RPC Example: Return



RPC Marshalling

- Marshalling is the packing of procedure parameters into a message packet
- The RPC stubs call type-specific procedures to marshal (or unmarshal) the parameters to a call
  - The client stub marshals the parameters into a message
  - The server stub unmarshals parameters from the message and uses them to call the server procedure
- On return
  - The server stub marshals the return parameters
  - The client stub unmarshals return parameters and returns them to the client program

RPC Binding

- Binding is the process of connecting the client to the server
- The server, when it starts up, exports its interface
  - Identifies itself to a network name server
  - Tells RPC runtime its alive and ready to accept calls
- The client, before issuing any calls, imports the server
  - RPC runtime uses the name server to find the location of a server and establish a connection
- The import and export operations are explicit in the server and client programs
  - Breakdown of transparency

RPC Transparency

- One goal of RPC is to be as transparent as possible
  - Make remote procedure calls look like local procedure calls
- We have seen that binding breaks transparency
- What else?
  - Failures – remote nodes/networks can fail in more ways than with local procedure calls
    - » Need extra support to handle failures well
  - Performance – remote communication is inherently slower than local communication
    - » If program is performance-sensitive, could be a problem

Network File System

- We have talked about file systems and RPC
- We'll now look at a file system that uses RPC
- Network File System (NFS)
  - Protocol for remote access to a file system
    - » Does not implement a file system per se
    - » Remote access is transparent to applications
  - File system, OS, and architecture independent
    - » Originally developed by Sun
    - » Although Unix-y in flavor, explicit goal to work beyond Unix
  - Client/server architecture
    - » Local file system requests are forwarded to a remote server
    - » These requests are implemented as RPCs

Mounting

- Before a client can access files on a server, the client must mount the file system on the server
  - The file system is mounted on an empty local directory
  - Same way that local file systems are attached
  - Can depend on OS (e.g., Unix dirs vs NT drive letters)
- Servers maintain ACLs of clients that can mount their directories
  - When mount succeeds, server returns a file handle
  - Clients use this file handle as a capability to do file operations
- Mounts can be cascaded
  - Can mount a remote file system on a remote file system

NFS Protocol

- The NFS protocol defines a set of operations that a server must support
  - Reading and writing files
  - Accessing file attributes
  - Searching for a file within a directory
  - Reading a set of directory links
  - Manipulating links and directories
- These operations are implemented as RPCs
  - Usually by daemon processes (e.g., nfsd)
  - A local operation is transformed into an RPC to a server
  - Server performs operation on its own file system and returns

Statelessness

- Note that NFS has no open or close operations
- NFS is stateless
  - An NFS server does not keep track of which clients have mounted its file systems or are accessing its files
  - Each RPC has to specify all information in a request
    - » Operation, FS handle, file id, offset in file, sequence #
- Robust
  - No reconciliation needs to be done on a server crash/reboot
  - Clients detect server reboot, continue to issue requests
- Writes must be synchronous to disk, though
  - Clients assume that a write is persistent on return
  - Servers cannot cache writes

Consistency

- Since NFS is stateless, consistency is tough
  - NFS can be (mostly) consistent, but limits performance
  - NFS assumes that if you want consistency, applications will use higher-level mechanisms to guarantee it
- Writes are supposed to be atomic
  - But performed in multiple RPCs (larger than a network packet)
  - Simultaneous writes from clients can interleave RPCs (bad)
- Server caching
  - Can cache reads, but we saw that it cannot cache writes

Consistency (2)

- Client caching can lead to consistency problems
  - Caching a write on client A will not be seen by other clients
  - Cached writes by clients A and B are unordered at server
  - Since sharing is rare, though, NFS clients usually do cache
- NFS statelessness is both its key to success and its Achilles' heel
  - NFS is straightforward to implement and reason about
  - But limitations on caching can severely limit performance
    - » Dozens of network file system designs and implementations that perform much better than NFS
  - But note that it is still the most widely used remote file system protocol and implementation

RPC Summary

- RPC is the most common model for communication in distributed applications
  - "Cloaked" as DCOM, CORBA, Java RMI, etc.
  - Also used on same node between applications
- RPC is essentially language support for distributed programming
  - What else have we seen use language support?
- RPC relies upon a stub compiler to automatically generate client/server stubs from the IDL server descriptions
  - These stubs do the marshalling/unmarshalling, message sending/receiving/replying
- NFS uses RPC to implement remote file systems

Next Time

- Tue 11/30: Research talk
- Thu 12/02: Final review