CSE 451: Operating Systems
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Module 19
Remote Procedure Call (RPC)

Ed Lazowska
lazowska@cs.washington.edu
Allen Center 570

Client/Server communication

- The prevalent model for structuring distributed computation is the client/server paradigm
  - a server is a program (or collection of programs) that provides a service to other programs
    - e.g., file server, name server, web server, mail server …
    - server/service may span multiple nodes (clusters)
      - often, nodes are called servers too
      - e,g., the web server runs on a Dell server computer
  - a client is a program that uses the service
    - the client first binds to the server
      - locates it, establishes a network connection to it
    - the client then sends requests (with data) to perform actions, and the server sends responses (with data)
      - e.g., web browser sends a “GET” request, server responds with a web page
- TCP/IP is the transport, but what is the higher-level programming model?

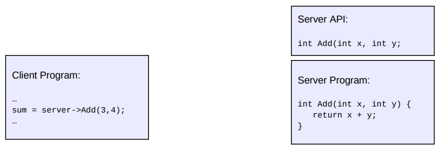
Messages

- Initially, people hand-coded messages to send requests and responses
  - message is a stream of bytes – “op codes” and operands
- Lots of drawbacks
  - need to worry about message format
  - have to pack and unpack data from messages
  - servers have to decode messages and dispatch to handlers
  - messages are often asynchronous
    - after sending one, what do you do until response comes back?
  - messages aren’t a natural programming model

Procedure calls

- Procedure calls are a natural way to structure multiple modules inside a single program
  - every language supports procedure calls
  - semantics are well-defined and well-understood
  - programmers are used to them
- “Server” (called procedure) exports an API
- “Client” (calling procedure) calls the server procedure’s API
- Linker binds the two together

Procedure call example


Client Program:

```
…
sum = server->Add(3,4);
…
```

Server API:

```
int Add(int x, int y;
```

Server Program:

```
int Add(int x, int y) {
   return x + y;
}
```

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

Remote Procedure Call (RPC)

- Traditional procedure call syntax and semantics across a network
- The most common means used for remote communication in client/server systems
- Used both by operating systems and applications
  - NFS is implemented as a set of RPCs
  - HTTP is essentially RPC
  - DCOM, CORBA, Java RMI, etc., are just RPC systems
- Someday you, too, will likely have to write an application that uses remote communication
  - you’ll likely model your remote communication on RPC

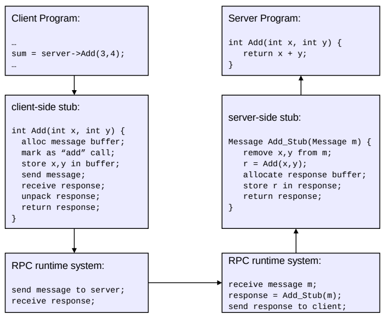
RPC

- Use procedure calls as the model for distributed (remote) communication
  - have servers export a set of procedures that can be called by client programs
    - similar to library API, class definitions, etc.
  - clients do a local procedure call, as though they were directly linked with the server
    - under the covers, the procedure call is converted into a message exchange with the server
    - ***largely invisible to the programmer!***

RPC issues

- There are a bunch of hard issues:
  - how do we make the “remote” part of RPC invisible to the programmer?
    - and is that a good idea?
  - what are the semantics of parameter passing?
    - what if we try to pass by reference?
  - how do we bind (locate/connect-to) servers?
  - how do we handle heterogeneity?
    - OS, language, architecture, …
  - how do we make it go fast?

RPC example invocation



Client Program:

```
…
sum = server->Add(3,4);
…
```

client-side stub:

```
int Add(int x, int y) {
  alloc message buffer;
  mark as “add” call;
  store x,y in buffer;
  send message;
  receive response;
  unpack response;
  return response;
}
```

RPC runtime system:

```
send message to server;
receive response;
```

Server Program:

```
int Add(int x, int y) {
   return x + y;
}
```

server-side stub:

```
Message Add_Stub(Message m) {
   remove x,y from m;
   r = Add(x,y);
   allocate response buffer;
   store r in response;
   return response;
}
```

RPC runtime system:

```
receive message m;
response = Add_Stub(m);
send response to client;
```

Topics:
- interface description
- stubs
- stub generation
- parameter marshalling
- binding
- runtime system
- error handling
- performance
- thread pools

RPC model

- A server defines the service interface using an interface definition language (IDL)
  - the IDL specifies the names, parameters, and types for all client-callable server procedures
    - example: ASN.1 in the OSI reference model
    - example: Sun’s XDR (external data representation)
- A “stub compiler” reads the IDL declarations and produces two stub procedures for each server procedure
  - the server programmer implements the service’s 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 manage all of the details of remote communication between client and server using the RPC runtime system

RPC stubs

- A client-side stub is a procedure that looks to the client as if it were a callable server procedure
  - it has the same API as the server’s implementation of the procedure
  - a client-side stub is just called a “stub” in Java RMI
- A server-side stub looks like a caller to the server
  - it looks like a hunk of code that invokes the server procedure
  - a server-side stub is called a “skeleton” or “skel” in Java RMI
- The client program thinks it’s invoking the server
  - but it’s calling into the client-side stub
- The server program thinks it’s called by the client
  - but it’s really called by the server-side stub
- The stubs send messages to each other, via the runtime, to make the RPC happen transparently

RPC marshalling

- Marshalling is the packing of procedure parameters into a message packet
  - the RPC stubs call type-specific procedure to marshal or unmarshal the parameters of an RPC
    - the client stub marshals the parameters into a message
    - the server stub unmarshals the parameters and uses them to invoke the service’s procedure
  - on return:
    - the server stub marshals the return value
    - the client stub unmarshals the return value, 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 that it is 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 the server and establish a connection
- The import and export operations are explicit in the server and client programs
  - a slight breakdown in transparency
    - more to come…

RPC transparency

- One goal of RPC is to be as transparent as possible
  - make remote procedure calls look like local procedure calls
  - we've seen that binding breaks this transparency
- What else breaks transparency?
  - failures: remote nodes/networks can fail in more ways than with local procedure calls
    - network partition, server crash
    - need extra support to handle failures
    - server can fail independently from client
      - "partial failure": a big issue in distributed systems
      - if an RPC fails, was it invoked on the server?
  - performance: remote communication is inherently slower than local communication
    - if you're not aware you're doing a remote procedure call, your program might slow down an awful lot…

RPC and thread pools

- What happens if two client threads (or client programs) simultaneously invoke the same server procedure using RPC?
  - ideally, two separate threads will run on the server
  - so, the RPC run-time system on the server needs to spawn or dispatch threads into server-side stubs when messages arrive
    - is there a limit on the number of threads?
    - if so, does this change semantics?
    - if not, what if 1,000,000 clients simultaneously RPC into the same server?