RMI & RPC

CS 475, Spring 2019
Concurrent & Distributed Systems
Why expand to distributed systems?

• Scalability
• Performance
• Latency
• Availability
• Fault Tolerance

“Distributed Systems for Fun and Profit”, Takada
Networks as Abstractions

- A network consists of communication links
- Networks have several “interesting” properties we will look at
  - Latency
  - Failure modes
- What is the abstraction?

Machine 1

Machine 2
3 Layer Abstraction

- The typical network abstraction model has 7 layers
- Take CS 455 if you want to know more about these
- We’ll think about 3 abstraction layers, and really focus on the top one

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>End-to-End layer</td>
<td>Handles packet loss, etc. Translates from application-data to packets, implements a protocol</td>
</tr>
<tr>
<td>Network layer</td>
<td>Figures out where to send packets</td>
</tr>
<tr>
<td>Link layer</td>
<td>Physical links: care about how to deliver packets</td>
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</tbody>
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Today

• Network abstractions - RMI & RPC

• Reminders:
  • Midterm
  • HW3 posted
  • Bug in barrier sync slides (now fixed)
Abstractions

• Using sockets directly is annoying - very low level, likely someone else already figured out a way to solve your problem and their fix is bug free
• High level protocols:
  • FTP, SMTP
  • HTTP (REST, SOAP and other web service stuff)
• For general purpose, lower level:
  • RPC - Remote Procedure Call, and for Java: RMI - Remote Method Invocation
  • Language agnostic: Google ProtocolBuffers
Remote Procedure Calls

• Example: Address book
• We’ll store our address book on a server
• But to simplify writing the code, can we pretend that the address book is stored on the client?
• RPC
  • Client program will think it’s directly talking to the server
  • Server program will think it’s directly talking to the client
  • In reality, there’s a ton of glue in between them
Remote Procedure Calls

AddPerson("Prof Bell", "ENGR 4422");

Address Book
Client Stub

RPC Magic

Address Book
Server Stub

addPerson("Prof Bell", "ENGR 4422");

Client

Server
Remote Procedure Calls

- Magic is (surprise?) really complicated
- Challenges in building RPC will re-occur in almost any distributed system
- What is the alternative?

```java
void sendRequest(String name, String office)
{
    Socket clientSocket = new Socket(ADDRESSBOOK_SERVER, ADDRESSBOOK_PORT);
    DataOutputStream outToServer = new DataOutputStream(clientSocket.getOutputStream());
    BufferedReader inFromServer = new BufferedReader(new InputStreamReader(clientSocket.getInputStream()));
    outToServer.writeBytes("addPerson" + '\n');
    outToServer.writeBytes(name + '\n');
    outToServer.writeBytes(office + '\n');
    clientSocket.close();
}
```
Why use an abstraction

- Ugly boilerplate
- Might have bugs? (Almost definitely)
- Not portable (string encoding)
- Hard to understand and maintain
- Vulnerability-prone
What abstraction to use

• RPC -> use an abstraction all programmers already use
  • E.g. Local Procedure Call (LPC)
    • E.g. just calling functions
• RPC makes transparent whether server is local or remote
• RPC allows applications to become distributed transparently
• RPC makes architecture of remote machine transparent
RPC Challenges

• Calling and called procedures run on different machines, with different address spaces
• And perhaps different languages, environments, or operating systems
• Must convert to local representation of data
• Machines and network can fail
RPC: High Level Approach

![Diagram showing the high-level approach of RPC between Caller Machine and Callee Machine with user code, local calls, and returns.]
RPC: High Level Approach

**Caller Machine**
- User Code
  - local call
  - local return
- User Stub
  - pack args
- RPC Runtime
  - transmit
  - wait
  - receive
  - unpack return

**Callee Machine**
- User Code
  - local call
- User Stub
  - pack args
- RPC Runtime
  - receive
  - transmit
  - work
  - local return
RPC Stubs

• Compiler automatically generates these
• Client stub
  • **Marshals** arguments into machine-independent format
  • Sends request to server
  • Waits for response
  • **Unmarshals** result and returns to caller
• Server stub
  • **Unmarshals** arguments and builds stack frame
  • Calls procedure
  • Server stub **marshals** results and sends reply
Marshalling and Unmarshalling

• How did we decide to send the data?
• How did we decide to encode the data?
• This is marshalling (done poorly)

```java
void sendRequest(String name, String office)
{
    Socket clientSocket = new Socket(ADDRESSBOOK_SERVER, ADDRESSBOOK_PORT);
    DataOutputStream outToServer = new DataOutputStream(clientSocket.getOutputStream());
    BufferedReader inFromServer = new BufferedReader(new InputStreamReader(clientSocket.getInputStream()));
    outToServer.writeBytes("addPerson" + '\n');
    outToServer.writeBytes(name + '\n');
    outToServer.writeBytes(office + '\n');
    clientSocket.close();
}
```
RPC Stubs

• How does the compiler know what to generate?
• Usually there is a formal spec of the calling interface
  • "Interface Definition Language"
• Java: Just any old Interface
• Other RPC systems: specified in a small language similarly (including XML)
RPC: The Good Stuff

- Hides networking details
- Hides marshaling details
- Lets you evolve the protocol separately from the communication path
- Easy to add extra shared features
  - Authentication
  - Naming/location
RPC: The Bad Stuff

- Latency
- Pointer transfers
- Failures
Local Procedure Call - Failures

• Local code calls `addPerson`

• What can happen?
  • LPC returns (OK, can see return value/error code)
  • LPC doesn’t return (OK, know it’s still running)
Shared Fate

- Two methods/threads/processes running on the same computer generally have **shared fate**
- They will either both crash, or neither will crash
RPC Failures

• If our client makes an RPC request, but hasn’t heard back yet, how do we know what happened?
RPC Failures

- If we haven't heard back from the server yet, possibilities are:
  - Server never received request
  - Server received request and crashed
  - Server received request, processed it, crashed
  - Server received requested, processed it, sent response but never received it
Split Brain

- When two machines in a distributed system can’t talk to each other, they might start believing different things
- Two sides can not reconcile view of world because they can’t talk to each other
- We call this a *split brain* problem
Split brain: Client thinks `addPerson` didn’t succeed, server did complete it though!
Split Brain in RPC

This gets even worse when you consider more complicated semantics

Who has the lock?
RPC Semantics

• No matter what we do, if we want RPC, we have networks, networks might have timeouts/failures
• How do we handle the potential for split brain?
  • If we don't hear a response, just freeze?
• What can the abstraction guarantee?
  • Leak some of this complexity through
RPC Semantics: Exactly once delivery

- Can our RPC abstraction guarantee call is sent and processed exactly once?
- In general, not possible:
  - Server can crash at any point
  - Never will know exactly what happened
RPC Semantics: At least once

• RPC system might guarantee **at least once** delivery
• Client library keeps track of unconfirmed messages
• If message is not confirmed, keep re-sending
• Works fine for **idempotent** requests (requests that can be repeated with no side effect)
RPC Semantics: At most once

- RPC system might guarantee at most once delivery
- Client library re-sends if it doesn’t hear an ACK
- Client library adds message IDs
- Server library keeps track of received message IDs
- Problems?
  - Server needs to perpetually track received IDs
RPC - Implementation Issues

- Performance is the usual issue:
  - When do you generate the stubs?
  - How do you patch in the stubs?
  - What data is copied from client to server?
- Environmental concerns:
  - What if client/server are very different (OS/language)?
Java RMI

• Synchronous (client method doesn’t return until server completes)
• At most once delivery
• Hence, in the event of a communication failure, an exception is thrown on your client
• Implications:
  • Client code needs to be aware that failures might happen (and exception might be thrown)
  • Client code needs to have some plan to handle when a message fails to get through (application specific)
Java RMI

- Threading model:
  - What happens when there are multiple simultaneous RMI requests to the same server?
  - RMI creates a *thread pool*, a set of threads ready to handle each request
    - Subsequent calls from the same client might or might not use the same thread
    - Subsequent calls from other clients might use the same thread as others
- Implications:
  - Can process multiple requests simultaneously
  - Need to be cognizant of thread safety
public interface AddressBook extends Remote {
    public LinkedList<Person> getAddressBook() throws RemoteException;

    public void addPerson(Person p) throws RemoteException;
}

AddressBook book = new AddressBookServer();
AddressBook stub = (AddressBook) UnicastRemoteObject.exportObject(book, 0);
Registry registry = LocateRegistry.createRegistry(port);
registry.rebind("AddressBook", stub);

Registry registry = LocateRegistry.getRegistry("localhost", 9000);
AddressBook addressBook = (AddressBook) registry.lookup("AddressBook");
Java RMI

- Registration of a server makes it possible for a client to locate the server and bind to it.
- Server location is done in two steps:
  - Locate the server’s machine.
  - Locate the server on that machine.
Split Brain in RPC

This gets even worse when you consider more complicated semantics

Who has the lock? How do we handle this?
Split Brain in RPC

This gets even worse when you consider more complicated semantics

Who has the lock? How do we handle this?
Sidebar: Heartbeat Protocols

- Allow client/server to remain aware of each other’s status
- For HW3: does client still have locks (client checking server, server checking client)

Client

```
lock("foo")
```

```
OK, stamp = 1
Hi, I’m stamp 1, still have foo
```

Server

```
Hmm, I guess server is gone, maybe lock is not valid
```

CRASH!
Sidebar: Heartbeat Protocols

- Allow client/server to remain aware of each other's status
- For HW3: does client still have locks (client checking server, server checking client)

Client

lock(“foo”)

OK, stamp = 1

Hi, I’m stamp 1, still have foo

OK

CRASH!

Server

Hmm, I guess foo is no longer locked
Sidebar: Heartbeat Protocols

- We call these time-limited locks **leases**
- What does a lease guarantee?
  - If no network failures
    - Locks that are relinquished when client crashes
  - If network failures/delays:
    - Nothing
RPC Summary

• Expose RPC properties to client, since you cannot hide them
• Application writers have to decide how to deal with partial failures
• Consider: E-commerce application vs. game
Summary

• Procedure calls
  • Simple way to pass control and data
  • Elegant transparent way to distribute application
  • Not only way…
• Hard to provide true transparency
  • Failures
  • Performance
  • Memory access
  • Etc.
• How to deal with hard problem: give up and let programmer deal with it
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