Distributed Systems
8L for Part IB

Lecture 3

Dr. Robert N. M. Watson

The Story So Far…

- Looking at simple **client/server** interaction, and use of **remote procedure call** (RPC)
  - invoking methods on server over the network
  - middleware generates stub code which can **marshal** / **unmarshal** arguments and replies
  - saw case study of NFS (RPC-based file system)
- In the 1990s started to see OOM
  - Object-oriented middleware (CORBA, DCOM, …)
  - Extends RPC model to remote objects

Java RMI

- 1995: Sun extended Java to allow RMI
  - RMI = **Remote Method Invocation**
- Essentially an OOM scheme for Java with clients, servers and an **object registry**
  - object registry maps from names to objects
  - supports **bind()/rebind()**, **lookup()**, **unbind()**, **list()**
- RMI was designed for Java only
  - no goal of OS or language interoperability
  - hence cleaner design, tighter language integration
  - E.g., distributed garbage collection

3

RMI: New Classes

- **remote class**:
  - one whose instances can be used remotely
  - within home address space, a regular object
  - within foreign address spaces, referenced indirectly via an **object handle**
- **serializable class**: [nothing to do with transactions!]
  - object that can be marshalled/unmarshalled
  - if a serializable object is passed as a parameter or return value of a remote method invocation, the value will be copied from one address space to another
  - (for remote objects, only the object handle is copied)

4

RMI: New Classes

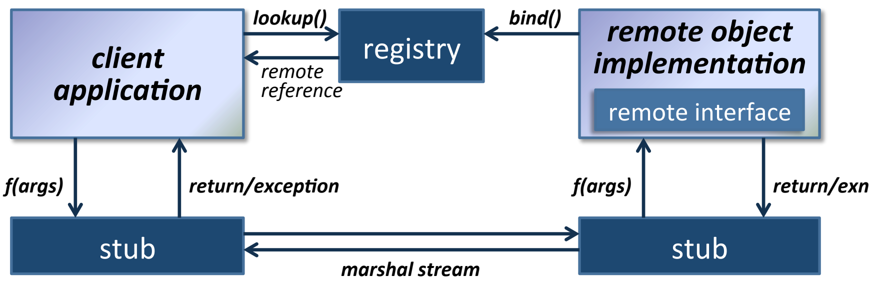
- **remote class**:
  - one whose instances can be used remotely
  - within home address space, a regular object
  - within foreign address spaces, referenced indirectly via an **object handle**
- **serializable class**:
  - object that can be marshalled/unmarshalled
  - if a serializable object is passed as a parameter or return value of a remote method invocation, the value will be copied from one address space to another
  - (for remote objects, only the object handle is copied)

needed for remote objects

needed for parameters

5

RMI: The Big Picture



- Registry can be on server... or one per distributed system
  - client and server can find it via the **LocateRegistry** class
- Objects being serialized are annotated with a URL for the class
  - unless they implement **Remote** => replaced with a remote reference

6

Distributed Garbage Collection

- With RMI, can have local & remote object references scattered around a set of machines
- Build distributed GC by leveraging local GC:
  - When a server exports object O, it creates a skeleton S[O]
  - When a client obtains a remote reference to O, it creates a proxy object P[O], and remotely invokes **dirty(O)**
  - Local GC will track the liveness of P[O]; when it is locally unreachable, client remotely invokes **clean(O)**
  - If server notices no remote references, can free S[O]
  - If S[O] was last reference to O, then it too can be freed
- Like DCOM, server removes a reference if it doesn't hear from that client for a while (default 10 mins)

7

OOM: Summary

- OOM enhances RPC with objects
  - types, interfaces, exceptions, …
- Seen CORBA, DCOM and Java RMI
  - All plausible, and all still used today
  - CORBA most general (language and OS agnostic), but also the most complex: design by committee
  - DCOM is MS-only; being phased out for .NET
  - Java RMI decent starting point for simple distributed systems… but lacks many features
  - (EJB is a modern CORBA/RMI/<stuff> megalith)

8

XML-RPC

- Systems seen so far all developed by large industry, and work fine in the local area…
  - But don't (or didn't) do well through firewalls ;-)
- In 1998, Dave Winer developed XML-RPC
  - Use XML to encode method invocations (method names, parameters, etc)
  - Use HTTP POST to invoke; response contains the result, also encoded in XML
  - Looks like a regular web session, and so works fine with firewalls, NAT boxes, transparent proxies, …

9

XML-RPC Example

XML-RPC Request

```
<?xml version="1.0"?>
<methodCall>
<methodName>util.InttoString</methodName>
 <params>
  <param>
    <value><i4>55</i4></value>
  </param>
 </params>
</methodCall>
```

XML-RPC Response

```
<?xml version="1.0"?>
<methodResponse>
 <params>
  <param>
    <value><string>Fifty Five</string></value>
  </param>
 </params>
</methodResponse>
```

- Client side names method (as a string), and lists parameters, tagged with simple types
- Server receives message (via HTTP), decodes, performs operation, and replies with similar XML
- Inefficient & weakly typed… but simple, language agnostic, extensible, and eminently practical!

10

SOAP & Web Services

- XML-RPC was a victim of its own success
- WWW consortium decided to embrace it, extend it, and generally complify it up
  - SOAP (**Simple Object Access Protocol**) is basically XML-RPC, but with more XML bits
  - Support for namespaces, user-defined types, multi-hop messaging, recipient specification, …
  - Also allows transport over SMTP (!), TCP & UDP
- SOAP is part of the **Web Services** world
  - As complex as CORBA, but with more XML ;-)

11

Moving away from RPC

- SOAP 1.2 defined in 2003
  - Less focus on RPC, and more on moving XML messages from A to B (perhaps via C & D)
- One major problem with all RPC schemes is that they were synchronous:
  - Client is blocked until server replies
  - Poor responsiveness, particularly in wide area
- 2006 saw introduction of AJAX
  - **A**synchronous **Ja**vascript with **X**ML
  - Chief benefit: can update web page without reloading
- Examples: Google Maps, Gmail, Google Docs, …

12

REST

- AJAX still does RPC (just asynchronously)
- Is a procedure call / method invocation really the best way to build distributed systems?
- **Representational State Transfer** (REST) is an alternative 'paradigm' (or a throwback?)
  - Resources have a name: URL or URI
  - Manipulate them via PUT (insert), GET (select), POST (updated) and DELETE (delete)
  - Send state along with operations
- Very widely used today (Amazon, Flickr, Twitter)

13

Client-Server Interaction: Summary

- Server handles requests from client
  - Simple request/response protocols (like HTTP) useful, but lack language integration
  - RPC schemes (SunRPC, DCE RPC) address this
  - OOM schemes (CORBA, DCOM, RMI) extend RPC to understand objects, types, interfaces, exns, …
- Recent WWW developments move away from traditional RPC/RMI:
  - Avoid explicit IDLs since can slow evolution
  - Enable asynchrony, or return to request/response

14

Clocks

- Distributed systems need to be able to:
  - order events produced by concurrent processes;
  - synchronize senders and receivers of messages;
  - serialize concurrent accesses to shared objects; and
  - generally coordinate joint activity
- This can be provided by some sort of “clock”:
  - **physical clocks** keep time of day
    - (must be kept consistent across multiple nodes – why?)
  - **logical clocks** keep track of event ordering
- Relativity can’t be ignored: think satellites

15

Physical Clock Technology

- Quartz Crystal Clocks (1929)
  - resonator shaped like a tuning fork
  - laser-trimmed to vibrate at 32,768 Hz
  - standard resonators accurate to 6ppm at 31°C... so will gain/lose around 0.5 seconds per day
  - stability better than accuracy (about 2s/month)
  - best resonators get accuracy of ~1s in 10 years
- Atomic clocks (1948)
  - count transitions of the caesium 133 atom
  - 9,192,631,770 periods defined to be 1 second
  - accuracy is better than 1 second in 6 million years...

16

Coordinated Universal Time (UTC)

- Physical clocks provide 'ticks' but we want to know the actual time of day
  - determined by astronomical phenomena
- Several variants of universal time
  - **UT0**: mean solar time on Greenwich meridian
  - **UT1**: UT0 corrected for polar motion; measured via observations of quasars, laser ranging, & satellites
  - **UT2**: UT1 corrected for seasonal variations
  - **UTC**: civil time, tracked using atomic clocks, but kept within 0.9s of UT1 by occasional leap seconds

17

Computer Clocks

- Typically have a real-time clock
  - CMOS clock driven by a quartz oscillator
  - battery-backed so continues when power is off
- Also have range of other clocks (PIT, ACPI, HPET, TSC, ...), mostly **higher frequency**
  - free running clocks driven by quartz oscillator
  - mapped to real time by OS at boot time
  - programmable to generate interrupts after some number of ticks (~= some amount of real time)

18

Operating system use of clocks

- OSes use time for many things
  - Periodic events – e.g., time sharing, statistics, at, cron
  - Local I/O functions – e.g., peripheral liveness; entropy
  - Network protocols – e.g., TCP DELACK, retries, keep-alive
  - Cryptographic certificate/ticket generation, expiration
  - Performance profiling and sampling features
- “Ticks” trigger interrupts
  - Historically, timers at fixed intervals (e.g., 100Hz)
  - Now, “tickless”: timer reprogrammed for next event
  - Saves energy, CPU resources – especially as cores scale up

Which of these require “physical time” vs “logical time”?
What will happen to each if the real-time clock drifts or steps due to synchronisation?

19

The Clock Synchronization Problem

- In distributed systems, we’d like all the different nodes to have the same notion of time, but
  - quartz oscillators oscillate at slightly different frequencies (time, temperature, manufacture)
- Hence clocks tick at different rates:
  - create ever-widening gap in perceived time
  - this is called **clock drift**
- The difference between two clocks at a given point in time is called **clock skew**
- Clock synchronization aims to minimize clock skew between two (or a set of) different clocks

20

Clock Skew and Clock Drift

08:00:00

February 18, 2012
08:00:00

08:00:00

NB: Steve Hand’s watches, not mine.

21

Clock Skew and Clock Drift

08:01:24

Skew = *84 seconds*
Drift = *84s / 34 days*
= +2.47s per day

March 23, 2012
08:00:00

08:01:48

Skew = *108 seconds*
Drift = *108s / 34 days*
= +3.18s per day

22