Distributed systems

Lecture 1: Introduction to distributed systems; RPC

Lent 2014

Dr Robert N. M. Watson

(With thanks to Dr Steven Hand)

1

Recommended Reading

- "***Distributed Systems: Concepts and Design***", (5th Ed) Coulouris et al, Addison-Wesley 2012
- "***Distributed Systems: Principles and Paradigms***" (2nd Ed), Tannenbaum et al, Prentice Hall, 2006
- "***Operating Systems, Concurrent and Distributed S/W Design***", Bacon & Harris, Addison-Wesley 2003
  - or "***Concurrent Systems***", (2nd Ed), Jean Bacon, Addison-Wesley 1997

2

What are Distributed Systems?

- A set of discrete computers ("nodes") which cooperate to perform a computation
  - Operates "as if" it were a single computing system
- Examples include:
  - Compute clusters (e.g. CERN, HPCF)
  - BOINC (aka SETI@Home and friends)
  - Distributed storage systems (e.g. NFS, Dropbox, …)
  - The Web (client/server; CDNs; and back-end too!)
  - Peer-to-peer systems such as Tor
  - Vehicles, factories, buildings (?)

3

Concurrent systems reminder

- Foundations of concurrency: processor(s), threads
- Mutual exclusion: locks, semaphores, monitors, etc.
- Producer-consumer, active objects, message passing
- Races, deadlock, livelock, starvation, priority inversion
- Transactions, ACID, isolation, serialisability, schedules
- 2-phase locking, rollback, time-stamp ordering (TSO), optimistic concurrency control (OCC)
- Durability, write-ahead logging, recovery
- Lock-free algorithms, transactional memory
- Operating system case study

These problems were not difficult enough, distributed systems add:
loss of global visibility, loss of global ordering; new failure modes

Distributed Systems: Advantages

- **Scale and performance**
  - Cheaper to buy 100 PCs than a supercomputer…
  - … and easier to incrementally scale up too!
- **Sharing and Communication**
  - Allow access to shared resources (e.g. a printer) and information (e.g. distributed FS or DBMS)
  - Enable explicit communication between machines (e.g. EDI, CDNs) or people (e.g. email, twitter)
- **Reliability**
  - Can hopefully continue to operate even if some parts of the system are inaccessible, or simply crash

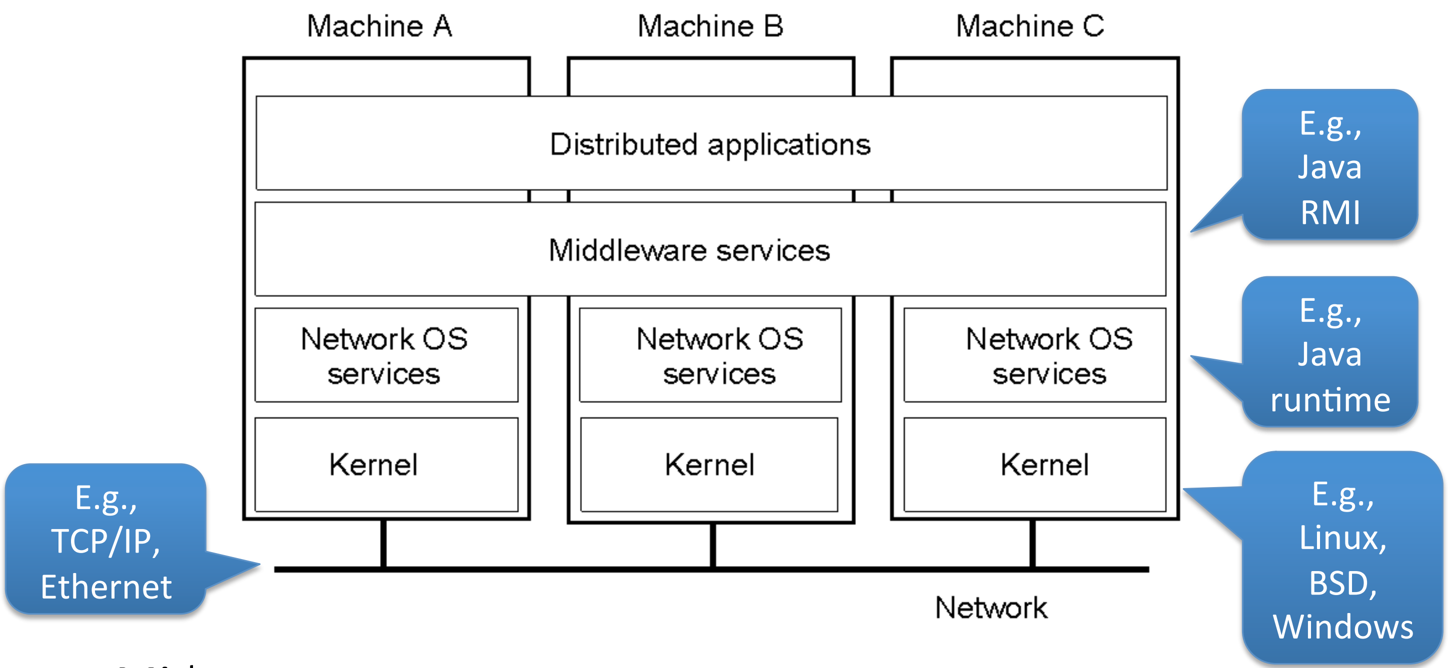
5

Distributed Systems: Challenges

- **Distributed Systems are *Concurrent Systems***
  - Need to coordinate independent execution at each node (c/f first part of course)
- **Failure of any components (nodes, network)**
  - At any time, for any reason
- **Network delays**
  - Can't distinguish congestion from crash/partition
- **No global time**
  - Tricky to coordinate, or even agree on ordering!

6

Middleware



- Middleware layer extends over multiple machines

Transparency & Middleware

- Recall a distributed system should appear "as if" it were executing on a single computer
- We often call this **transparency**:
  - User is unaware of multiple machines
  - Programmer is unaware of multiple machines
- How "unaware" can vary quite a bit
  - e.g. web user probably aware that there's network communication ... but not the number or location of the various machines involved
  - e.g. programmer may explicitly code communication, or may have layers of abstraction: **middleware**

Classic types of Transparency

Transparency	Description
Access	Hide differences in data representation and how a resource is accessed
Location	Hide where a resource is located
Migration	Hide that a resource may move to another location
Relocation	Hide that a resource may be moved to another location while in use
Replication	Hide that a resource may be provided by multiple cooperating systems
Concurrency	Hide that a resource may be simultaneously shared by several competitive users
Failure	Hide the failure and recovery of a resource
Persistence	Hide whether a (software) resource is in memory or on disk

Performance or **scaling transparency** increasingly important

9

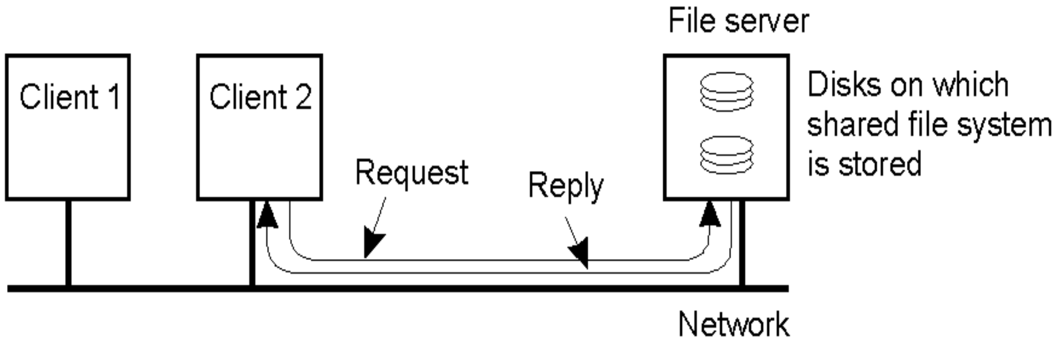
In this Course

- We will look at techniques, protocols & algorithms used in distributed systems
  - in many cases, these will be provided for you by a middleware software suite
  - but knowing how things work will still be useful!
- Assume OS & networking support
  - processes, threads, synchronization
  - basic communication via messages
  - (will see later how assumptions about messages will influence the systems we [can] build)
- Let's start with a simple client-server systems

10

Client-Server Model

- 1970s: development of LANs
- 1980s: standard deployment involves small number of **servers**, plus many **workstations**
  - Servers: always-on, powerful machines
  - Workstations: personal computers
- Workstations request 'service' from servers over the network, e.g. access to a shared file-system:



11

Request-Reply Protocols

- Basic scheme:
  - Client issues a request message
  - Server performs operation, and sends reply
- Simplest version is **synchronous**:
  - client blocks awaiting reply
- Example: HTTP 1.0
  - Client (browser) sends "GET /index.html"
  - Web server fetches file and returns it
  - Browser displays HTML web page

We will also talk about **asynchronous** communication models

12

Handling Errors & Failures

- **Errors** are **application-level** things => easy ;-)
  - E.g. client requests non-existent web page
  - Need special reply (e.g. "404 Not Found")
- **Failures** are **system-level** things, e.g.:
  - lost message, client/server crash, network down,...
- To handle failure, client must timeout if it doesn't receive a reply within a certain time T
  - On timeout, client can **retry** request
  - (Q: what should we set T to?)

13

Retry Semantics

- Client could timeout because:
  1. Request was lost
  2. Request was sent, but server crashed on receipt
  3. Request was sent & received, and server performed operation (or some of it?), but crashed before replying
  4. Request was sent & received, and server performed operation correctly, and sent reply … which was then lost
  5. As #4, but reply has just been delayed for longer than T
- For read-only stateless requests (like HTTP GET), can retry in all cases, but what if request was an order with Amazon?
  - In case #1, we probably want to re-order… and in case #5 we want to wait for a little bit longer, and otherwise we … erm?
- Worse: we don't know what case it actually was!

14

Ideal Semantics

- What we want is **exactly-once** semantics:
  - Our request occurs once no matter how many times we retry (or if the network duplicates our messages)
- E.g. add a unique ID to every request
  - Server remembers IDs, and associated responses
  - If sees a duplicate, just returns old response
  - Client ignores duplicate responses
- Pretty tricky to ensure exactly-once in practice
  - e.g. if server explodes ;-)

15

Practical Semantics

- In practice, protocols guarantee one of:
- **All-or-nothing** (atomic) semantics
  - Use scheme on previous page; persistent log
  - (similar idea to transaction processing).
- **At-most-once** semantics
  - Request carried out once, or not at all
  - If no reply, we don't know which outcome it was
  - e.g. send one request; give up on timeout
- **At-least-once** semantics
  - Retry on timeout; risk operation occurring again
  - Ok if the operation is read-only, or **idempotent**

Server state required to suppress retries/ duplicates

Server state not required

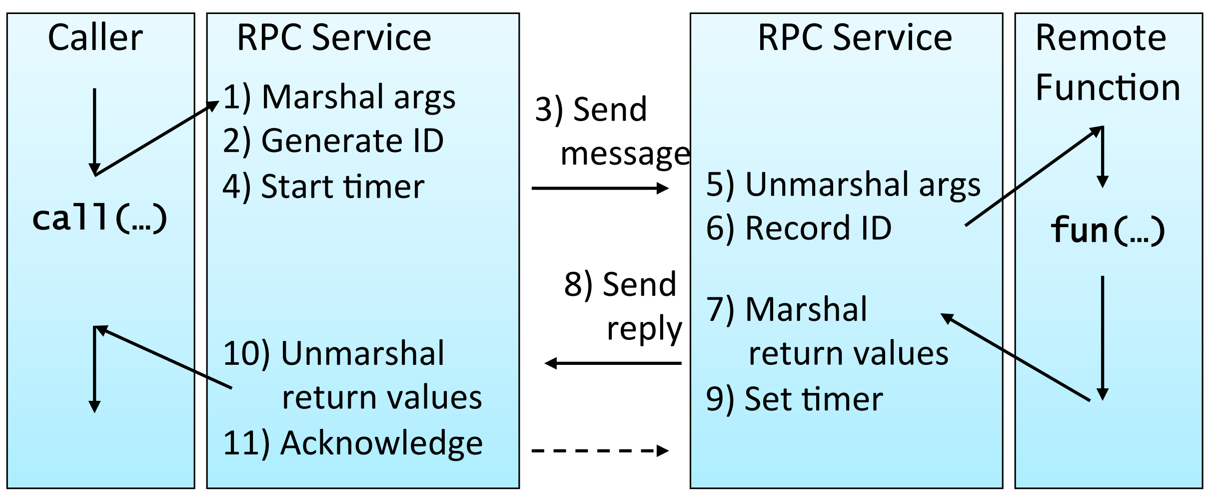
16

Remote Procedure Call (RPC)

- Request/response protocols are useful – and widely used – but rather clunky to use
  - e.g. need to define the set of requests, including how they are represented in network messages
- A nicer abstraction is **remote procedure call**
  - Programmer simply invokes a procedure…
  - …but it executes on a remote machine (the server)
  - RPC subsystem handles message formats, sending & receiving, handling timeouts, etc
- Aim is to make distribution (mostly) transparent
  - Certain failure cases wouldn't happen locally
  - Distributed and local function call performance different

Marshalling Arguments

- RPC is integrated with the programming language
  - Some additional magic to specify things are remote
- RPC layer **marshals** parameters to the call, as well as any return value(s), e.g.



IDLs and Stubs

- To marshal, the RPC layer (on both sides!) must know:
  - how many arguments the procedure has,
  - how many results are expected, and
  - the types of all of the above
- The programmer must specify this by describing things in an **interface definition language (IDL)**
  - In higher-level languages, this may already be included as standard (e.g. C#, Java)
  - In others (e.g. C), IDL is part of the middleware
- The RPC layer can then automatically generate **stubs**
  - Small pieces of code at client and server (see previous)
  - May also provide authentication, encryption
  - Provides integrity, confidentiality

19

Example: SunRPC

- Developed mid 80's for Sun Unix systems
- Simple request/response protocol:
  - Server registers one or more "programs" (services)
  - Client issues requests to invoke specific procedures within a specific service
- Messages can be sent over any transport protocol (most commonly UDP/IP and later TCP/IP)
  - Requests have a unique transaction id which can be used to detect & handle retransmissions
  - *At-least-once* semantics
  - Various types of *access transparency* including byte-order

20

XDR: External Data Representation

- SunRPC used **XDR** for describing interfaces:

```
// file: test.x
program test {
  version testver {
    int get(getargs) = 1;   // procedure number
    int put(putargs) = 2;   // procedure number
  } = 1;                    // version number
} = 0x12345678;             // program number
```

- **rpcgen** generates [un]marshaling code, stubs
  - Single arguments… but recursively convert values
  - Some support for following pointers too
- Data on the wire always in big-endian format (oops!)

21

Using SunRPC

1. Write XDR, and use rpcgen to generate skeleton code
2. Fill in blanks (i.e. write client and server moving), compile code
3. Run server program & register with **portmapper**
   - holds mappings from { prog#, ver#, proto } -> port
   - (on Linux/UNIX, try "/usr/sbin/rpcinfo -p")
   - **Portmapper** is itself an RPC service on a **well-known port**
4. Server process will then listen(), awaiting clients
5. When a client starts, client stub calls clnt_create
   - Sends { prog#, ver#, proto } to portmapper on server, and gets reply with appropriate port number to use
   - Client now invokes remote procedures as needed
6. Later versions integrated with GSS to provide authentication and encryption – e.g., via Kerberos

22

Next time

- The Network File System (NFS)
- Object-Oriented Middleware (OOM)