Distributed Systems
8L for Part IB

Lecture 2

Dr. Robert N. M. Watson

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Last time

- Distributed systems are everywhere
  - Challenges including concurrency, delays & failures
  - The importance of **transparency**
- Simplest distributed systems are client/server
  - Client sends request as message
  - Server gets message, performs operation, and replies
  - Some care required handling **retry semantics**, timeouts
- One popular client/server model is RPC
  - invoking methods on server over the network
  - **Middleware** generates stub code which can **marshal** / **unmarshal** arguments and replies – e.g. SunRPC/XDR
  - Transparency for the programmer, not just the user

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Case Study: NFS

- **NFS** = **Networked File System** (developed Sun)
  - aimed to provide distributed filing by remote access
- Key design decisions:
  - Distributed file system vs. remote disks
  - Client-server model
  - High degree of transparency
  - Tolerant of node crashes or network failure
- First public version, NFS v2 (1989), did this by:
  - Unix file system semantics (or almost)
  - Integration into kernel (including mount)
  - Simple stateless client/server architecture
- A set of RPC "programs": mountd, nfsd, lockd, statd, ...

Transparency for users and applications, but also NFS programmers: hence SunRPC

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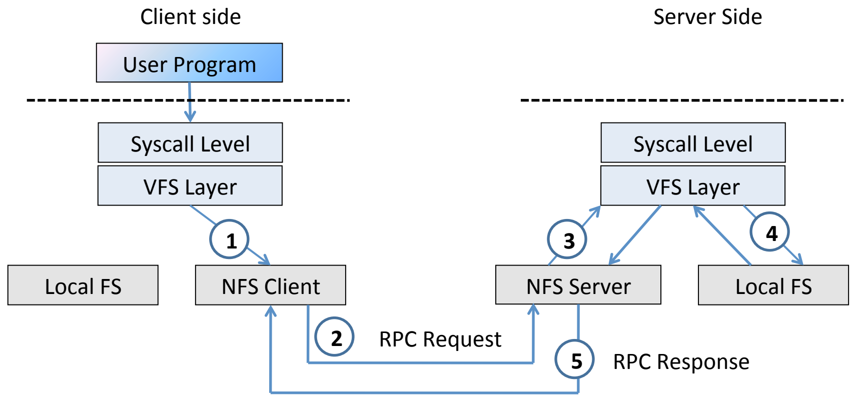
NFS: Client/Server Architecture



- Client uses opaque **file handles** to refer to files
- Server translates these to local inode numbers
- SunRPC with XDR running over UDP (originally)

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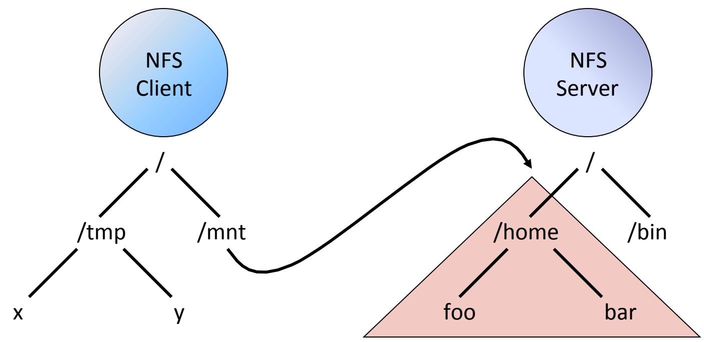
NFS: Mounting



- NFS RPCs are methods on files; file handle is an RPC argument
- Dedicated mount RPC protocol which:
  - Performs authentication (if any);
  - Negotiates any optional session parameters; and
  - Returns root filehandle

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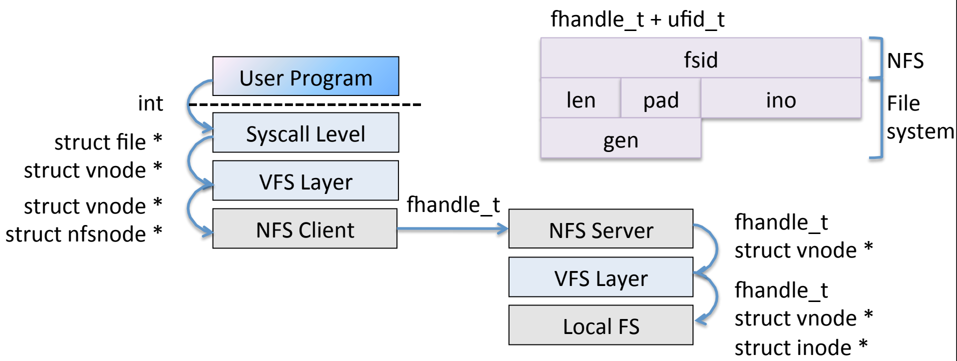
Scoping



- Something interesting is going on with names
  - Each layer is aware only certain **scopes**
  - Layers translate namespaces when transitioning
  - Contents of names between layers are often opaque
- **Pure** vs **impure names** (Needham)

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NFS is *Stateless*

- Key NFS design decision to ease fault recovery
  - Obviously, file systems aren't stateless, so…
- Stateless means:
  - Doesn't keep any record of current clients
  - Doesn't keep any record of current open files
- Hence server can crash + reboot, and clients shouldn't have to do anything (except wait ;-)
- Clients can crash, and server doesn't need to do anything (no cleanup etc)

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Implications of Stateless-ness

- No "open" or "close" operations
  - use **lookup(<pathname>)**
- No implicit arguments
  - e.g. cannot support **read(fd, buf, 2048)**
  - Instead use **read(fh, buf, offset, 2048)**
- Note this also makes operations **idempotent**
  - This use of SunRPC gives **at-least-once** semantics
  - Tolerate message duplication in network, RPC retries
- Challenges in providing Unix FS semantics…

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Semantic Tricks (and Messes)

- rename() is fundamentally non-idempotent
  - Servers-side "cache" recent RPC replies for replay
- unlink() tricky – what if you discard a file that a client has "open"?
  - Local semantics require files to persist even after last unlink()
  - NFS client translates unlink() to rename(): **silly rename**
  - Only works on same client (not server delete, or another client)
  - NFS file handles contain an **inode generation number** - ESTALE
- Stateless file ***locking*** seems impossible
  - Add two other daemons: **rpc.lockd** and **rpc.statd**
  - Server reboot => **rpc.lockd** contacts clients
  - Client reboot => server's **rpc.statd** tries contact

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Performance Problems

- Neither side knows if other is alive or dead
  - All writes must be synchronously committed on server before it returns success
- Very limited client caching…
  - Risk of inconsistent updates if multiple clients have file open for writing at the same time
- These two facts alone meant that NFS v2 had truly ***dreadful*** performance

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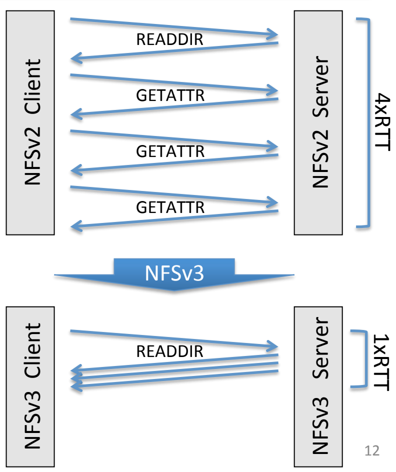
NFS Evolution

- NFS v3 (1995): mostly minor enhancements
  - Scalability
    - Remove limits on path- and file-name lengths
    - Allow 64-bit offsets for large files
    - Allow large (>8KB) transfer size negotiation
  - Explicit asynchrony
    - Server can do asynchronous writes (write-back)
    - Client sends explicit **commit** after some #writes
    - Timestamps piggybacked on most server replies allowing clients to manage read cache validity: **close-to-open consistency**
  - Optimized operations (**readdirplus**, **symlink**)
- But had *major* impact on performance

NFSv3 readdirplus

```
drwxr-xr-x  55 al565    al565     12288 Feb  8 15:47 al565/
drwxr-xr-x 115 am21     am21      49152 Feb 10 18:19 am21/
drwxr-xr-x 214 atm26    atm26     36864 Feb  1 17:09 atm26/
```

- NFSv2 behaviour for "ls –l"
  - readdir() triggers NFS_READDIR to request names and handles
  - stat() on each file triggers one NFS_GETATTR RPC
- NFS3_READDIRPLUS returns a names, handles, and attributes
  - Eliminates a vast number of round-trip times
- Principle: mask network latency by **batching synchronous operations**



NFS Evolution (2)

- NFS v4 (2003): major rethink
  - **Single *stateful* protocol** (including mount, lock)
  - TCP (or at least reliable transport) only
  - Explicit **open** and **close** operations
  - Share reservations
  - Delegation
  - Arbitrary compound operations
  - Many lessons learned from AFS (later in term)
- Now starting to see deployment…

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Improving over SunRPC

- SunRPC (now "ONC RPC") very successful but
  - Clunky (manual program, procedure numbers, etc)
  - Limited type information (even with XDR)
  - Hard to scale beyond simple client/server
- One improvement was OSF DCE (early 90's)
  - Another project that learned from AFS
  - DCE = "Distributed Computing Environment"
  - Larger middleware system including a distributed file system, a directory service, and DCE RPC
  - Deals with a collection of machines – a **cell** – rather than just with individual clients and servers

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DCE RPC versus SunRPC

- Quite similar in many ways
  - Interfaces written in Interface Definition Notation (IDN), and compiled to skeletons and stubs
  - NDR wire format: little-endian by default (woot!)
  - Can operate over various transport protocols
- Better security, and **location transparency**
  - Services identified by 128-bit “Universally” Unique identifiers (UUIDs), generated by uuidgen
  - Server registers UUID with cell-wide directory service
  - Client contacts directory service to locate server… which supports service move, or replication

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Object-Oriented Middleware

- Neither SunRPC / DCE RPC good at handling types, exceptions, or polymorphism
- Object-Oriented Middleware (OOM) arose in the early 90s to address this
  - Assume programmer is writing in OO-style
  - Provide illusion of ‘remote object’ which can be manipulated just like a regular (local) object
  - Makes it easier to program (e.g. can pass a dictionary object as a parameter)

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CORBA (1989)

- First OOM system was CORBA
  - Common Object Request Broker Architecture
  - specified by the OMG: Object Management Group
- OMA (Object Management Architecture) is the general model of how objects interoperate
  - Objects provide services.
  - Clients makes a request to an object for a service.
  - Client doesn't need to know where the object is, or anything about how the object is implemented!
  - Object interface must be known (public)

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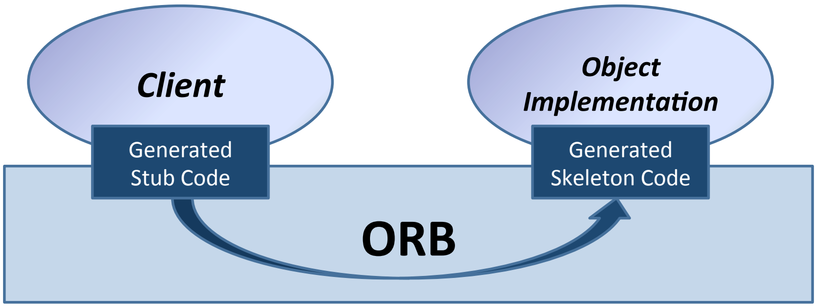
Object Request Broker (ORB)

- The ORB is the core of the architecture
  - Connects clients to object implementations
  - Conceptually spans multiple machines (in practice, ORB software runs on each machine)



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Invoking Objects

- Clients obtain an **object reference**
  - Typically via the **naming service** or **trading service**
  - (Object references can also be saved for use later)
- Interfaces defined by CORBA IDL
- Clients can call remote methods in 2 ways:
  1. **Static Invocation**: using stubs built at compile time (just like with RPC)
  2. **Dynamic Invocation**: actual method call is created on the fly. It is possible for a client to discover new objects at run time and access the object methods

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CORBA IDL

- Definition of language-independent remote interfaces
  - **Language mappings** to C++, Java, Smalltalk, …
  - Translation by IDL compiler
- Type system
  - *basic types*: long (32 bit), long long (64 bit), short, float, char, boolean, octet, any, …
  - *constructed types*: struct, union, sequence, array, enum
  - *objects* (common super type **Object**)
- Parameter passing
  - **in**, **out**, **inout** (= send remote, modify, update)
  - basic & constructed types passed by value
  - objects passed by reference

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CORBA Pros and Cons

- CORBA has some unique advantages
  - Industry standard (OMG)
  - Language & OS agnostic: mix and match
  - Richer than simple RPC (e.g. interface repository, implementation repository, DII support, …)
  - Many additional services (trading & naming, events & notifications, security, transactions, …)
- However:
  - Really really complicated / ugly / buzzwordy
  - Poor interoperability, at least at first
  - Generally to be avoided unless you need it!

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Microsoft DCOM (1996)

- An alternative to CORBA:
  - MS had invested in COM (object-oriented local IPC scheme) so didn't fancy moving to OMA
- Service Control Manager (SCM) on each machine responsible for object creation, invocation, ...
  - essentially a lightweight 'ORB'
- Added remote operation using MSRPC:
  - based on DCE RPC, but extended to support objects
  - augmented IDL called MIDL: DCE IDL + objects
  - requests include interface pointer IDs (IPIDs) to identify object & interface to be invoked

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DCOM vs. CORBA

- Both are language neutral, and object-oriented
- DCOM supports **objects with multiple interfaces**
  - but not, like CORBA, multiple inheritance of interfaces
- DCOM handles **distributed garbage collection**:
  - remote objects are reference counted (via explicit calls)
  - ping protocol handles abnormal client termination
- DCOM is widely used (e.g. SMB/CIFS, RDP, ...)
- But DCOM is MS proprietary (not standard)...
  - and no support for exceptions (return code based)..
  - and lacks many of CORBAs services (e.g. trading)
- Deprecated today in favor of .NET

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