Distributed Systems

- 48 - Communication Basics
- 49 - NFS
- 50 - AFS
- GFS

Communication Basics

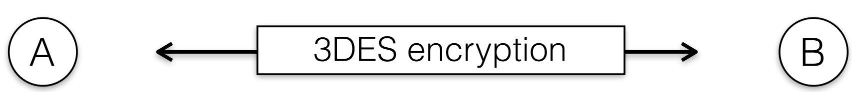
- Building distributed systems
  - all components fail
  - communication fails
  - how to build systems that *rarely* fail from components that do?
- Issues:
  - performance
    - especially with interconnects much slower than buses
  - security
    - systems span users, domains
    - the Internet is scary
  - communication
    - what are the right primitives?
    - what are the right types of applications?

Communication

"progress and correctness of distributed consensus algorithms is impossible to prove in asynchronous environments" - *FLP theorem*

- communication is fundamentally unreliable
  - packet loss
  - packet corruption
  - packet delays
- maybe don't rely on reliability
  - maybe add encryption to the link!
  - but….

End-to-End Argument *crypto is always good, right?*



- example of *end-to-end argument* says:
  - provided encryption might not be good enough
    - 3DES is ancient, maybe want to use *AES*, *blowfish*
  - provided encryption might be too expensive
    - might not need encryption at all, just adds overhead
  - app semantics might be needed
    - different app messages might have different needs
- but strong semantics in underlying layers *do* help

Distributed Systems *reliable communication layers*

- Need to be able to detect and recover from packet loss:
  - *acknowledge* (“ack”) receipt of a messaage

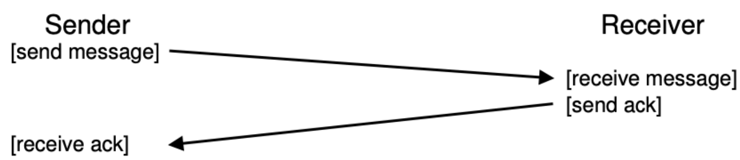


Figure 48.3: **Message Plus Acknowledgment**

Distributed Systems *reliable communication layers*

- Need to be able to detect and recover from packet loss:
  - *acknowledge* (“ack”) receipt of a messaage
- What if we don’t get the ack? How do we even know we don’t get the ack?

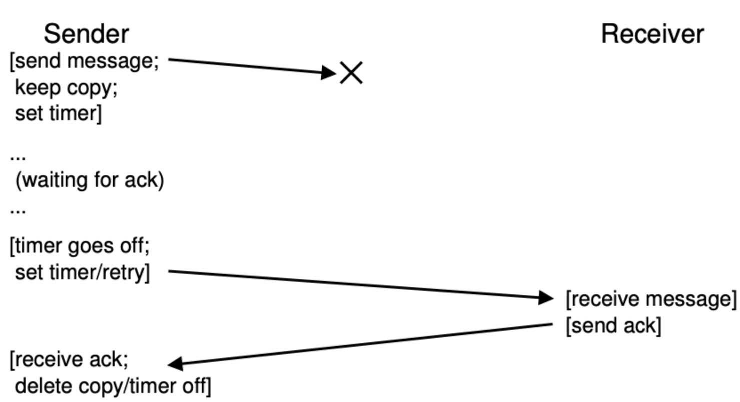
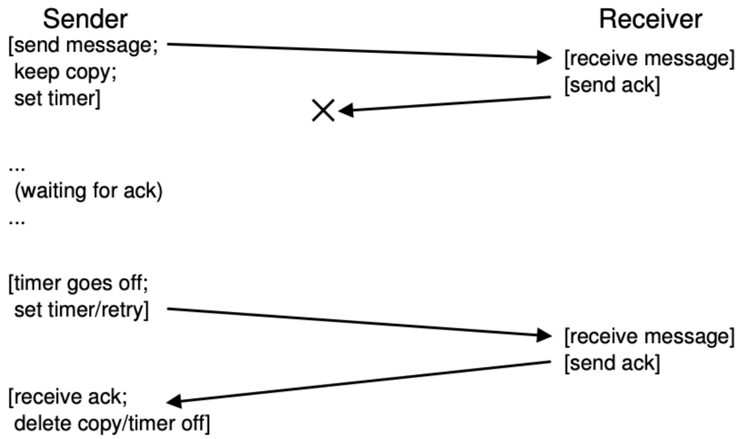


Figure 48.4: **Message Plus Acknowledgment: Dropped Request**

Distributed Systems *reliable communication layers*

- Need to be able to detect and recover from packet loss:
  - *acknowledge* (“ack”) receipt of a messaage
- What if we don’t get the ack? How do we even know we don’t get the ack?



Is this ok?

…no.

Figure 48.5: **Message Plus Acknowledgment: Dropped Reply**

Distributed Systems *reliable communication layers*

- 48.4 and 48.5 appear the same to the server…
  - but the msg was received in 48.4, and not in 48.5
  - this is bad, as server’s default is to repeat the message, not good if messages are not idempotent
- fix is to include *sequence numbers* in messages
  - receiver could track every number ever seen, but expensive.
- *monotonically increasing* sequence numbers better
  - receiver tracks highest received sequence number
    - acks, but does not execute duplicate messages
    - dealing with out-of-order messages (42, 44, 43, 45…) app-dependent
- Seq numbers important for UDP (unreliable), but TCP uses much more sophisticated approaches under the hood.

Remote Procedure Calls

- turn remote requests into procedure calls to local functions
- need interface definition:

```
interface {
  int func1(int arg1);
  int func2(int arg1, int arg2);
};
```

- *client* stub generator uses interface def to:
  - create a msg buffer
  - pack (*marshal*) request into buffer
  - send to destination
  - synchronously wait for reply
  - unpack (*unmarshal*) return values
  - return return values to caller

- *server* stub generator uses interface def to:
  - unpack (unmarshal) the message
  - call local func w/ arguments
  - pack the return values into a reply buffer
  - send the reply

Remote Procedure Calls

- What about pointers, or other complex data data types?
  - architecture- and language-independent encodings
    - JSON
    - protocol buffers
    - etc.

- What about concurrency in server?
  - want the server to be multi-threaded
  - need to ensure no data races between server stubs and the functions they call

- RPC generally doesn't need reliable communication (TCP)
  - "ack" is not needed, as RPC ("the app") generally returns a response

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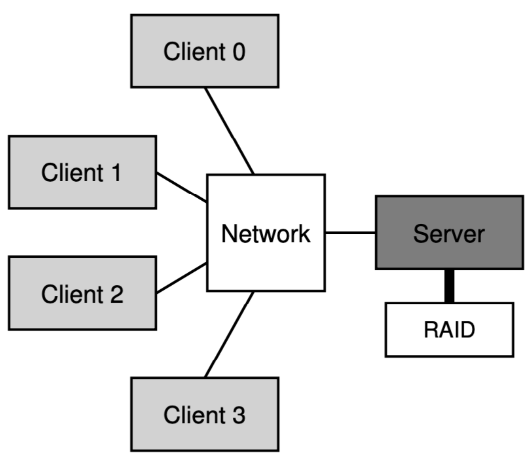
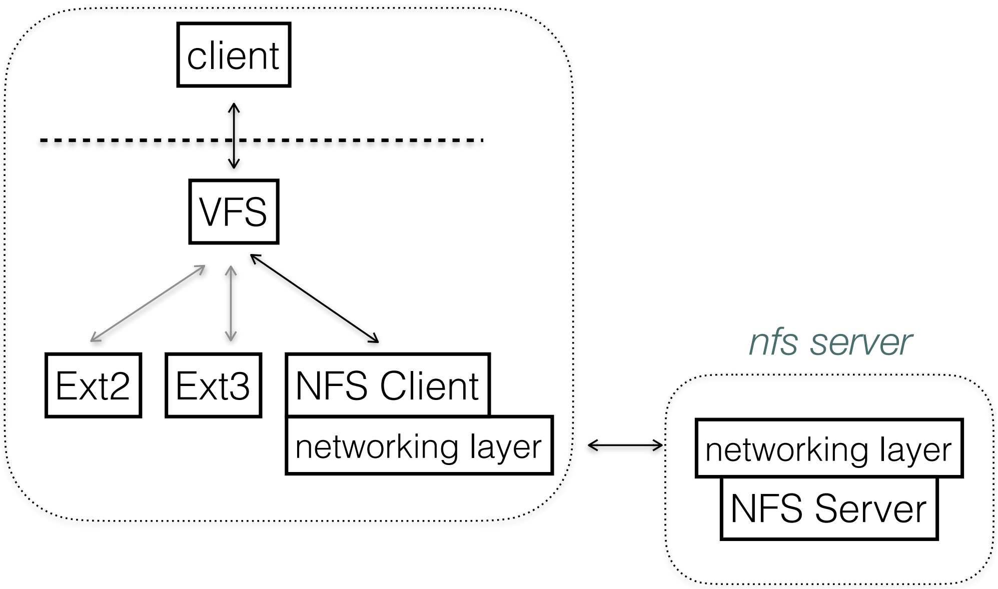
NFS *Sun Microsystems*

- first widely used distributed file system
    - clients diskless
        - easy sharing
        - centralized admin
        - security



NFS

- distributed file system should be *transparent*
  - except possibly in performance
  - client issues same file-system calls as standalone system



NFS *actually NFSv2*

"a distributed system is one where a machine I've never heard of goes down and I can't read my email"

- Leslie Lamport: Turing Award Winner for his work on distributed systems

- NFS goals:
  - simple and fast file recovery
  - *stateless* protocol : *server keeps no client state*
    - server scales well
    - client crashes transparent
    - server crashes transparent
    - client must maintain all state the the server needs for any communication

NFS *actually NFSv2*

- file handle : uniquely describe file or directory
  - volume ID
  - inode number
  - generation number (inumbers get re-used)

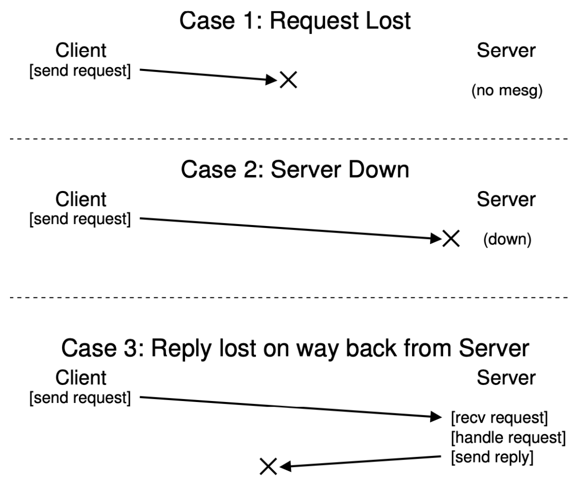
NFSPROC_GETATTR	file handle returns: attributes
NFSPROC_SETATTR	file handle, attributes returns: –
NFSPROC_LOOKUP	directory file handle, name of file/dir to look up returns: file handle
NFSPROC_READ	file handle, offset, count data, attributes
NFSPROC_WRITE	file handle, offset, count, data attributes
NFSPROC_CREATE	directory file handle, name of file, attributes –
NFSPROC_REMOVE	directory file handle, name of file to be removed –
NFSPROC_MKDIR	directory file handle, name of directory, attributes file handle
NFSPROC_RMDIR	directory file handle, name of directory to be removed –
NFSPROC_READDIR	directory handle, count of bytes to read, cookie returns: directory entries, cookie (to get more entries)

NFS *reading a file :*

Client	Server
fd = open("/foo", ...); Send LOOKUP (rootdir FH, "foo")	
	Receive LOOKUP request look for "foo" in root dir return foo's FH + attributes
Receive LOOKUP reply allocate file desc in open file table store foo's FH in table store current file position (0) return file descriptor to application	
read(fd, buffer, MAX); Index into open file table with fd get NFS file handle (FH) use current file position as offset Send READ (FH, offset=0, count=MAX)	
	Receive READ request use FH to get volume/inode num read inode from disk (or cache) compute block location (using offset) read data from disk (or cache) return data to client
Receive READ reply update file position (+bytes read) set current file position = MAX return data/error code to app	
read(fd, buffer, MAX); Same except offset=MAX and set current file position = 2*MAX	
read(fd, buffer, MAX); Same except offset=2*MAX and set current file position = 3*MAX	
close(fd); Just need to clean up local structures Free descriptor "fd" in open file table (No need to talk to server)	

NFS *server failures*

- server crashes / restarts, knowing nothing about clients
  - because most client requests are *idempotent*
    - lookups, reads don't change server state
    - writes contain data and exact offset to write to
- client handles all timeouts in the same way



NFS *performance*

- client-side caching
  - read file data (and metadata) cached by client
  - all good unless the file changes on the server
- client-side write buffers
  - coalescing
  - aggregating disparate messages

- However : cache consistency!

NFS *cache consistency*

Problems:

- update visibility
  - C_1 writes `foo.c`, but does not immediately push to server
  - C_2 reads, sees old version
  - C_1 flushes to server
- stale cache
  - C_2 reads again, still sees old version (`foo.c` locally cached)

Fixes:

- close-to-open consistency
  - every open guaranteed to see every prior write to the server
    - must validate cache (GETATTR)
    - but maybe not all the time

NFS consistency is weak…   (so are most other FSs)

NFS *server caching*

- tons of memory
  - wants to use it for disk cache   (satisfy reads)
  - wants to use it for write buffer   (quickly ack writes)
    - what could go wrong?
- server could ack a write before writing to disk!
  - say file initially has three 4k blocks of data:

```
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
yyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyy
zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz
```

  - client overwrites with:

```
write(aaa…, 0)., write(bbb…, 4k), write(ccc…, 8k):
```

    - server crashes after acking second block, before writing:

```
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
yyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyyy <--- oops
cccccccccccccccccccccccccccccccccccccccccccc
```

  - client never evens knows that the server crashed