CS416 – Filesystem (NFS)

NFS

NFS allows a system to access files over a network

- One of many distributed file systems
- Extremely successful and widely used

NFS Challenges

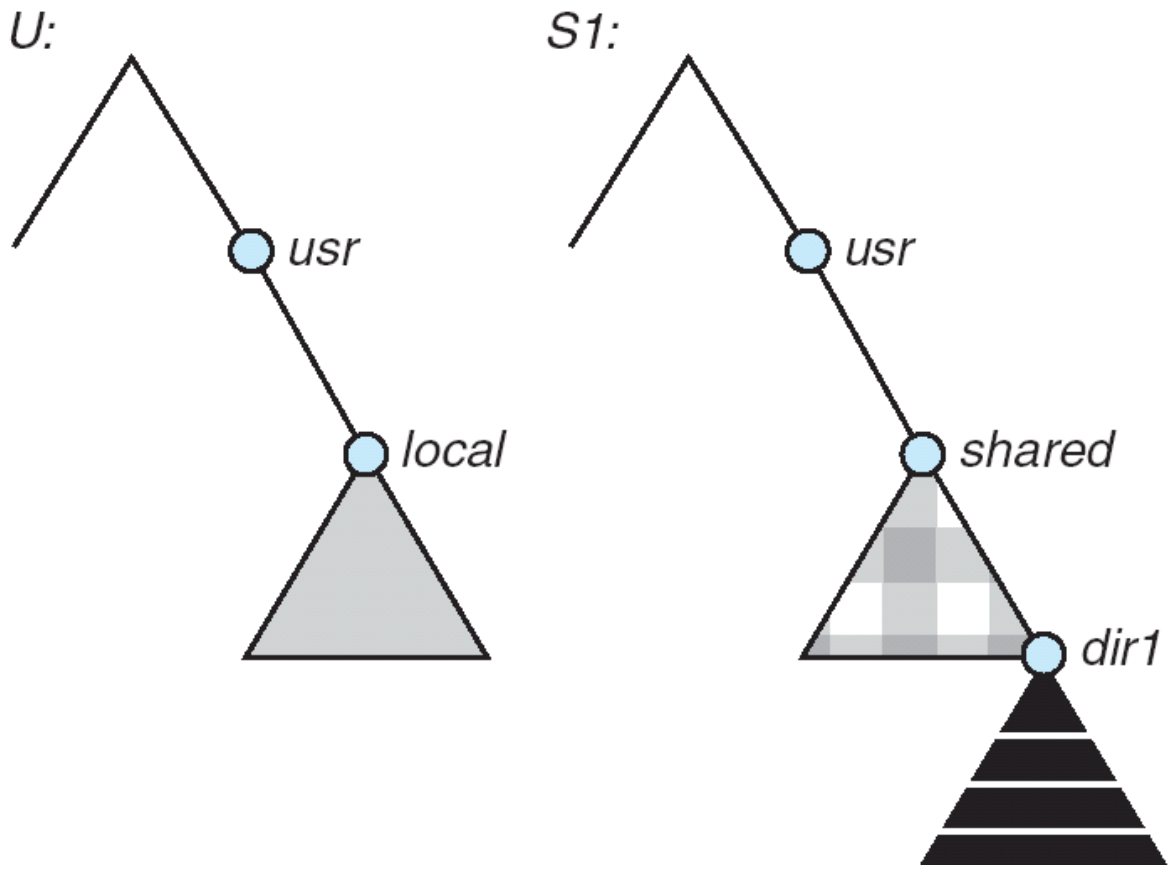
Development of LANs made it really attractive to provide shared file systems to all machines on a network

- Login to any machine and see the same set of files
- Install software on a single server that all machines can run
- Let users collaborate on shared set of files (before CVS!)

Why might this be hard to do???

- Clients and servers might be running different OS
- Clients and servers might be using different CPU architecture with differing byte ordering (*endianess*)
- Client or server might crash independently of each other
  - *Must be easy to recover from crashes*
- Potentially very large number of client machines on a network
- Different users might be trying to modify a shared file at the same time
- Transparency: Allow user programs to access remote files just like local files
  - *No special libraries, recompilation, etc.*

Three Independent File Systems



NFS Overview

NFS was developed by Sun Microsystems in the mid-80s

- Networked machines at the time were predominantly UNIX-based workstations
- Various vendors: Sun, DEC, IBM, etc.
- Different CPU architectures and OS implementations
  - *But, all used UNIX filesystem structure and semantics*

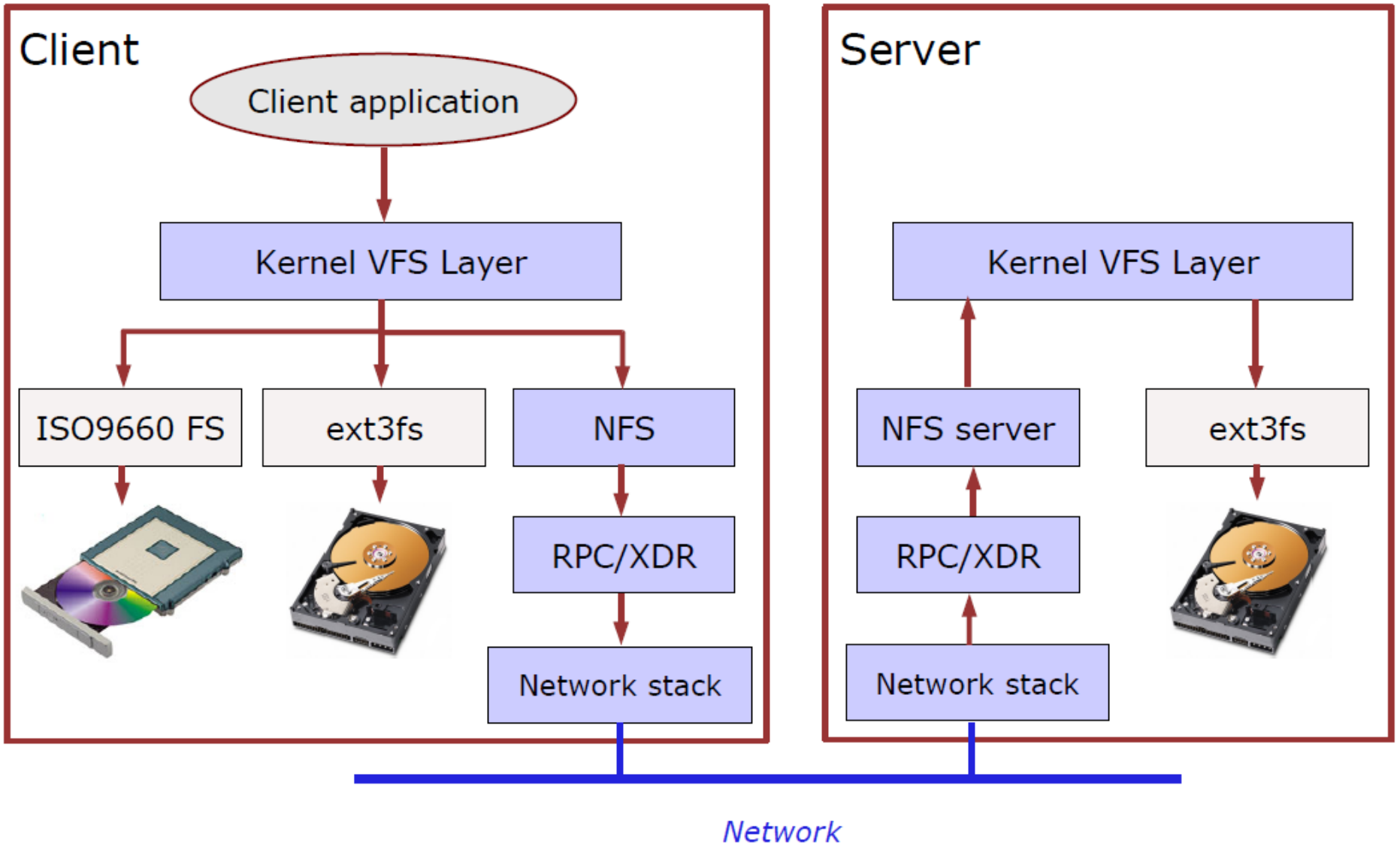
NFS is based on *Remote Procedure Call (RPC)*

- Allows a client machine to invoke a function on a server machine, over a network
- Client sends a message with the function arguments
- Server replies with a message with the return value.

External Data Representation (XDR) to represent data types

- Canonical network representation for ints, longs, byte arrays, etc.
- Clients and servers must translate parameters and return values of RPC calls into XDR before shipping on the network
  - *Otherwise, a little-endian machine and a big-endian machine would disagree on what is meant by the stream of bytes "fe 07 89 da" interpreted as an "int"*

NFS Design


Client
Client application
Kernel VFS Layer
ISO9660 FS
ext3fs
NFS
RPC/XDR
Network stack
Server
Kernel VFS Layer
NFS server
ext3fs
RPC/XDR
Network stack
Network

Stateless Protocol

The NFS protocol is *stateless*

- The server maintains no information about individual clients!
- This means that NFS does not support any notion of “opening” or “closing” files
  - *Each client simply issues read and write requests specifying the file, offset in the file, and the requested size*

Advantages?

-
-
-

Disadvantages?

-
-
-

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Advantages:

- Server doesn't need to keep track of open/close status of files
- Server doesn't need to keep track of “file offset” for each client's open files
  - *Clients do this themselves*
- Server doesn't have to do anything to recover from a crash!
  - *Clients simply retry NFS operations until the server comes back up*

Disadvantages:

- Server doesn't keep track of concurrent access to same file
- Multiple clients might be modifying a file at the same time
  - *NFS does not provide any consistency guarantees!!!*
- However, there is a separate *locking protocol* – discussed later

NFS Protocol Overview

mount() returns filehandle for root of filesystem

- Actually a separate protocol from NFS...

lookup(dir-handle, filename) returns filehandle, attribs

- Returns unique file handle for a given file
- File handle used in subsequent read/write/etc. calls

create(dir-handle, filename, attributes) returns filehandle

remove(dir-handle, filename) returns status

getattr(filehandle) returns attribs

- Returns attributes of the file, e.g., permissions, owner, group ID, size, access time, last-modified time

setattr(filehandle, attribs) returns attribs

read(filehandle, offset, size) returns attribs, data

write(filehandle, offset, count, data) returns attribs

Example

What happens if we do “/bin/cat testfile” ?

```
140.247.60.36.031e 140.247.50.252.0801 U C3 cd9d450a  3
    lookup   fh 0013eef90000001b00000000 name "testfile" euid 813b egid 186c
    con = 146 len = 174

140.247.50.252.0801 140.247.60.36.031e U R3 cd9d450a  3
    lookup   OK fh 0013eef90000002a00000000 ftype 1 mode 180 nlink 1 uid 813b gid 186c
    size 1aca used 2000 rdev 0 rdev2 0 fsid 13eef9 fileid eef9002a
    atime 1082215906.000000 mtime 1082215906.000580 ctime 1082215906.000580 status=0
    pl = 192 con = 70 len = 262

140.247.60.36.031e 140.247.50.252.0801 U C3 ce9d450a  6
    read     fh 0013eef90000002a00000000 off 0 count 2000 euid 813b egid 186c

140.247.50.252.0801 140.247.60.36.031e U R3 ce9d450a  6
    read     OK ftype 1 mode 180 nlink 1 uid 813b gid 186c size 1aca
    used 2000 rdev 0 rdev2 0 fsid 13eef9 fileid eef9002a
    atime 1082215906.000000 mtime 1082215906.000580 ctime 1082215906.000580 count aca
```

Example -2

- What happens if we issue
  - fd = open("/usr/joe/6360/list.txt")
- It would result it several Lookup calls to server
  - lookup(rootfh, "usr") returns (fh0, attr)
  - lookup(fh0, "joe") returns (fh1, attr)
  - lookup(fh1, "6360") returns (fh2, attr)
  - lookup(fh2, "list.txt") returns (fh, attr)
- Why is this needed ?
  - Any of components of /usr/joe/6360/list.txt could be a mount point
  - Mount points are client dependent and mount information is kept above the lookup() level

NFS Caching

NFS clients are responsible for caching recently-accessed data

- Remember: the server is stateless!

The NFS protocol does not *require* that clients cache data ...

- But, it provides support allowing a range of client-side caching techniques

This is accomplished through the getattr() call

- Returns size, permissions, and last-modified time of file
- This can tell a client whether a file has changed since it last read it
  - *Read/write calls also return attributes so client can tell if object was modified since the last getattr() call*

How often does the client use getattr()?

- Whenever the file is accessed?
  - *Could lead to a lot of getattr calls!*
- Only if the file has not been accessed for some time?
  - *e.g., If the file has not been accessed in 30 sec?*
- Different OS's implement this differently!

NFS Locking

NFS does not prevent multiple clients from modifying a file simultaneously

- Clearly, this can be a Bad Thing for some applications...

Solution: Network Lock Manager (NLM) protocol

- Works alongside NFS to provide file locking
- NFS itself does not know anything about locks
  - *Clients have to use NLM "voluntarily" to avoid stomping on each other*
- NLM has to be *stateful*
  - *Why?*

NLM Protocol

NLM server has to keep track of locks held by clients

If the NLM server crashes...

- **All locks are released!**
- BUT ... clients can reestablish locks during a "grace period" after the server recovers
  - *No new locks are granted during the grace period*
  - *Server has to remember which locks were previously held by clients*

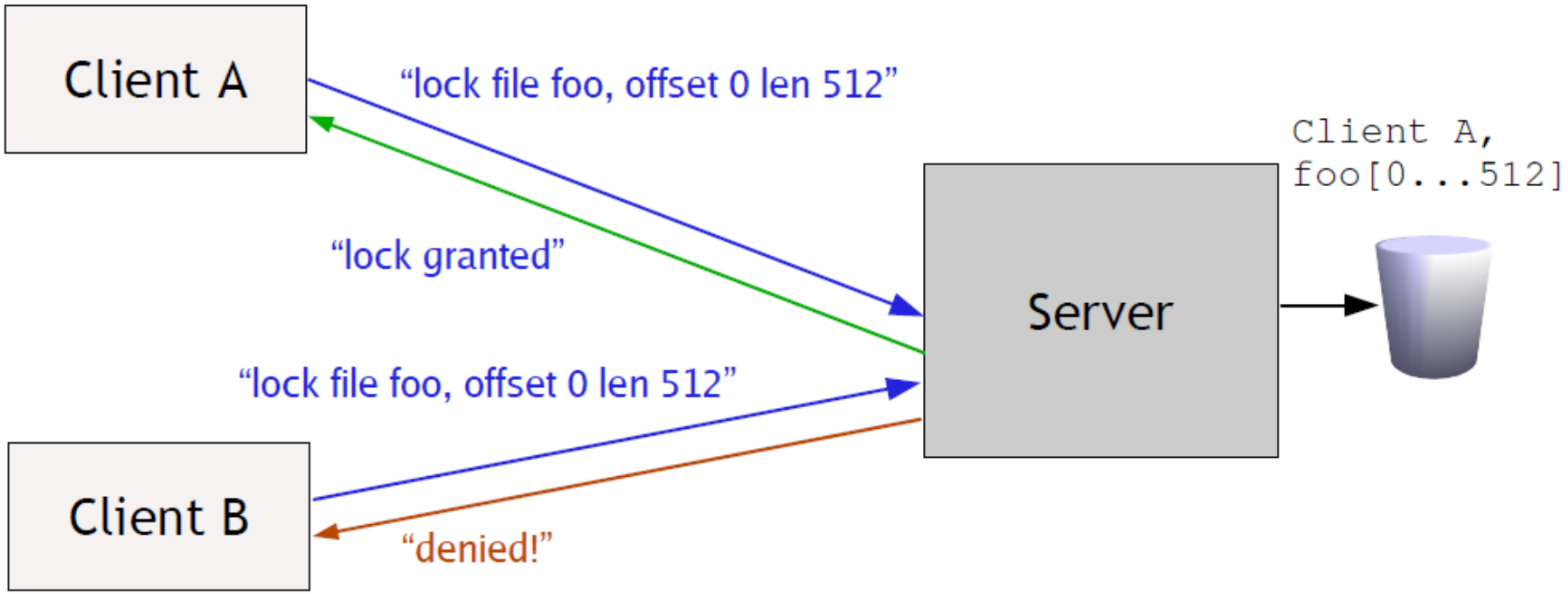
If an NLM client crashes...

- The server is notified when the client recovers and releases all of its locks
  - *What happens if a client crashes and does not come back up for a while?*

Servers and clients must be notified when they crash and recover

- This is done with the simple "Network Status Monitor" (NSM) protocol
- Essentially, send a notification to the other host when you reboot

NLM Example


Client A
"lock file foo, offset 0 len 512"
"lock granted"
Server
Client A,
foo[0...512]
"lock file foo, offset 0 len 512"
Client B
"denied!"

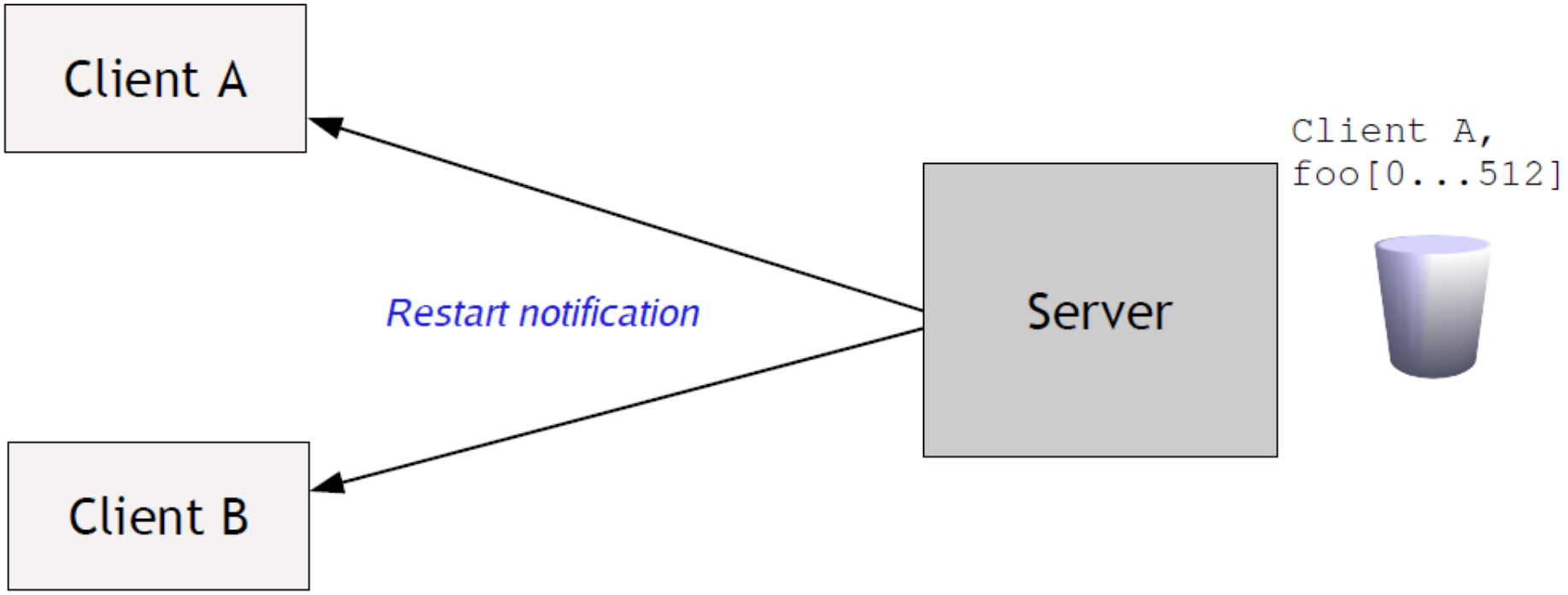
NLM Example

Client A

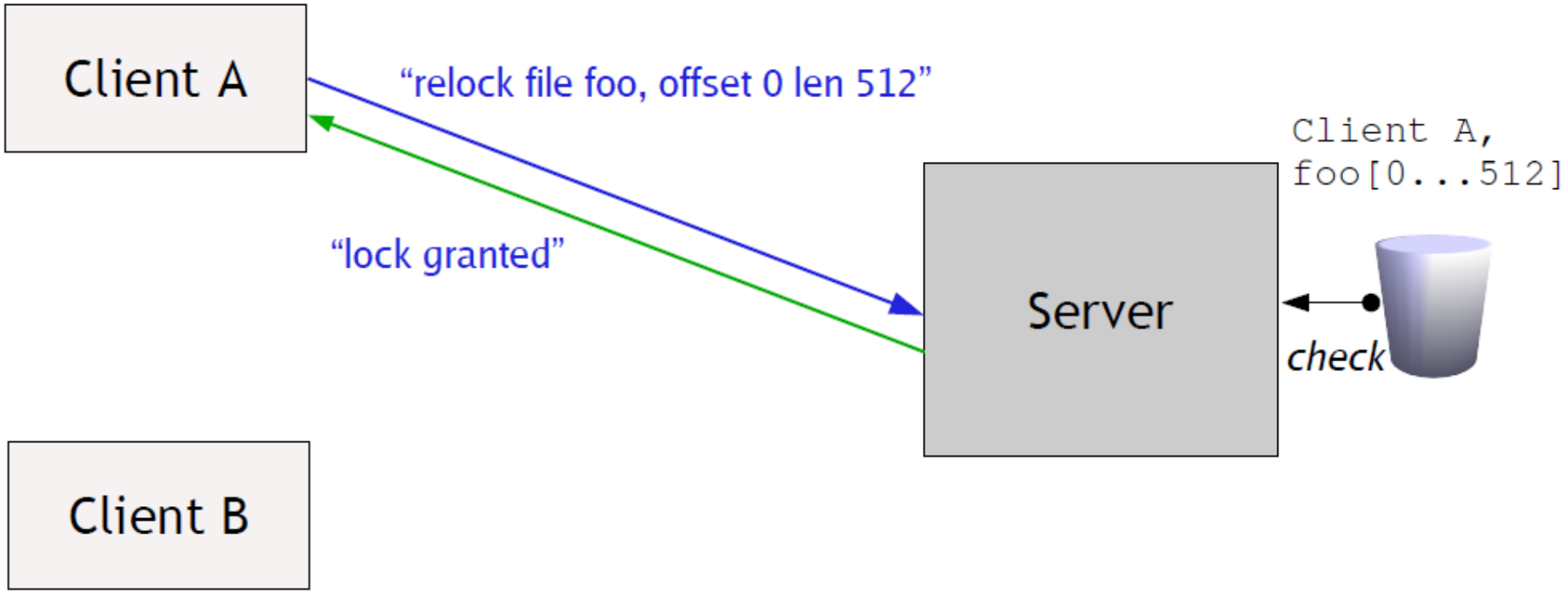
Client B

Client A,
foo[0...512]

NLM Example


Client A
Client B
Restart notification
Server
Client A,
foo[0...512]

NLM Example


Client A
"relock file foo, offset 0 len 512"
"lock granted"
Client A,
foo[0...512]
Server
check
Client B

Three Major Layers of NFS Architecture

- UNIX file-system interface (based on the **open, read, write**, and **close** calls, and **file descriptors**)

- *Virtual File System* (VFS) layer – distinguishes local files from remote ones, and local files are further distinguished according to their file-system types
  - The VFS activates file-system-specific operations to handle local requests according to their file-system types
  - Calls the NFS protocol procedures for remote requests

- NFS service layer – bottom layer of the architecture
  - Implements the NFS protocol

Schematic View of NFS Architecture