Network File Systems

INF 551

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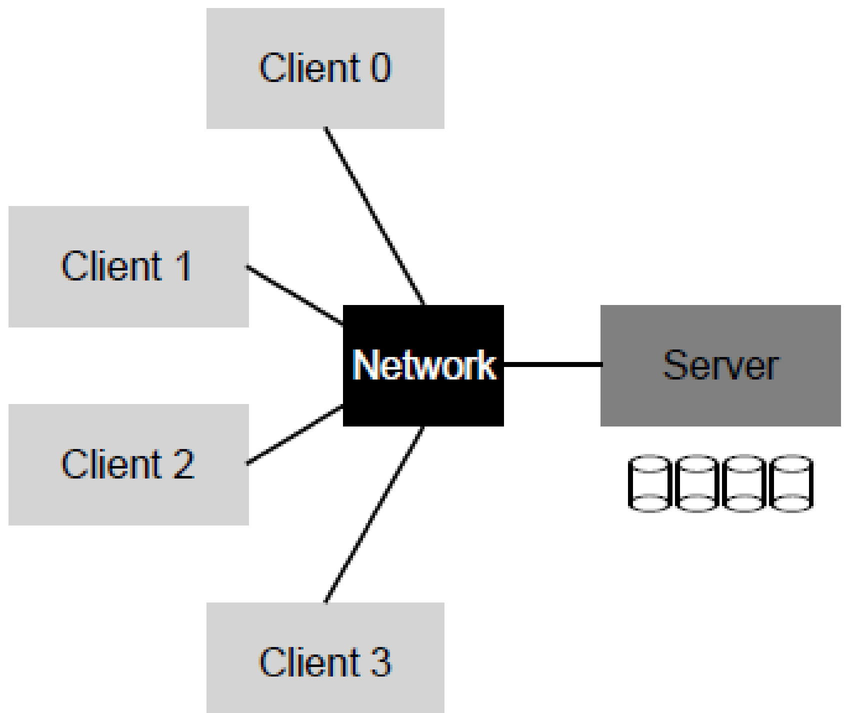
Client/server architecture



Advantages

- Easy sharing
  - Of data across clients
- Centralized administration
  - E.g., backup done on server, instead of individual clients
- Security
  - Server is located in a locked room

Disadvantages

- Network overhead

- More components to fail

A basic distributed file system (DFS)

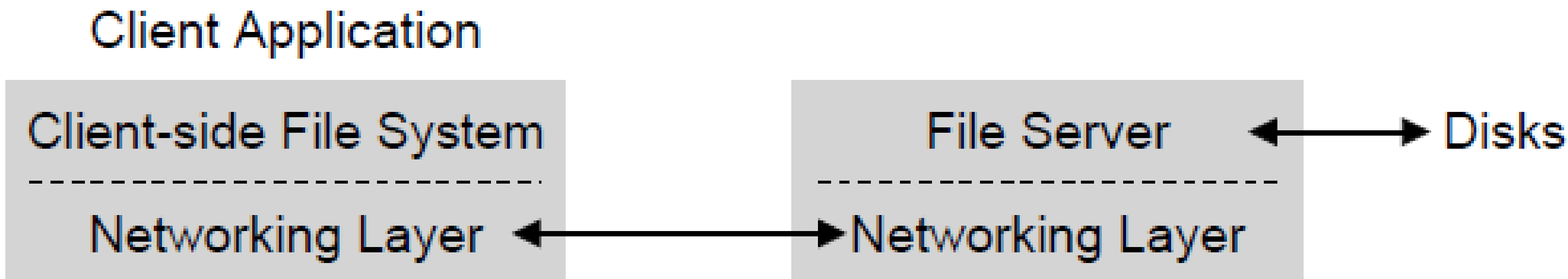
- Client/server architecture

- Applications interact with client-side file system (FS)
  - Issue system calls (i.e., calls that request services from OS kernel)
  - E.g., open(), read(), write(), etc.
  - Same interface as standalone file system

Transparent remote access

- Same operations but access remote files
  - Details of accessing are made transparent to clients
- Read()
  - Client-side FS sends a message to server-side file system (file server): read block xyz
  - File server reads the block from cache/disk
  - Server sends a message back to client with data

DFS architecture



Sun's NFS (network file system)

- Example of DFS

- Open protocol
  - Specifies only the format of messages btw client and server
  - Permits different implementations
  - Enhances interoperability among different vendors

- NFSv2
  - Basis for later versions
  - Focus: simple and fast server crash recovery

Key: statelessness

- Server does not keep track of states of clients
  - Which files are currently open at which clients
  - Current position/offset of file
  - Which clients have read/cached which blocks

- Requests from clients must make sure:
  - the server can deliver all the information needed to complete the requests
  - & do not rely on previous requests

Stateless file handle

- Contains 3 parts (note it is richer than fd)

1. Volume (file system) identifier
   - Which volume? (e.g. partition C or D if NTFS)
2. Inode number
   - Which file in the volume?
3. Generation number
   - Needed since inode number may be reused at the server (e.g., after file has been deleted by other clients)

Client-side file open table

File handle

Server	File descriptor	File system (volume)	File name	Inumber	Generation #	Position offset	Status	…
Server1	3	vol1	"/foo"	32382	1	4096	open	
Server1	4	vol2	"/foo/more"	48482	1	0	close	…

Client uses file handle to communication with server

Obtain file handle via lookup

- Lookup
  - Input: parent directory file handle + name of file/directory to look up
  - Output: file handle of lookup file/directory

- E.g., lookup(root file handle, "foo.txt")
  - obtain handle of "/foo.txt"

- File handle for the root directory may be obtained via the mount protocol

File system table in Linux

- Each line represents a file system to be mounted when machine starts
  - UUID is the ID of file system
- Each FS gets mounted to a different part of directory tree

Root directory

```
# /etc/fstab: static file system information.
#
# Use 'blkid' to print the universally unique identifier for a
# device; this may be used with UUID= as a more robust way to name devices
# that works even if disks are added and removed. See fstab(5).
#
# <file system> <mount point>   <type>  <options>       <dump>  <pass>
# / was on /dev/sda1 during installation
UUID=10487898-7c57-4f29-8348-eac99c3d3b41 /               ext4    errors=remount-ro 0       1
UUID=029ee386-153d-40c1-a314-5c430b13ea01 /mnt/newpart  ext4 errors=remount-ro 0       1
# swap was on /dev/sda5 during installation
UUID=959409f7-aee2-4010-a6dc-3bc0f80b9f15 none            swap    sw              0       0
~
~
```

Remote procedure call (RPC)

- Remote server publishes a set of procedures
  - E.g., f(args)

- In making RPC calls,
  - Client notifies remote server of executing f & sends over arguments args for f
  - Server executes f(args) => results
  - Server sends back results

RPC in NFS

- NFS server publishes a set of RPCs
  - E.g., NFSPROC_LOOKUP for lookup file handle
  - Others include: read, write, create, remove, etc.

```
NFSPROC_LOOKUP
  expects: directory file handle, name of file/directory to look up
  returns: file handle
```

Lookup with long path

- Multiple lookup requests needed for long path
  - One component of path at a time
- Avoid additional parsing of separators
  - plus different OS's may have different separators
  - e.g., "/" (Linux) or "\" (Windows)

Example

- Look up "/foo/more/bar.txt"
  - First, use / file handle to obtain foo's handle
  - Next, use foo's handle to obtain more's handle
  - Finally, use more's handle to obtain bar.txt handle

CRUD

- All CRUD operations use file handle
  - Instead of file descriptors as in local file system

Read

Explicit offset

- NFSPROC_READ(file handle, offset, count)
  - Return: data + file attributes
  - File attributes include modification time, useful for client-size cache validation

- Compared to local FS
  - n = read(fd, buffer, size)
  - n is the number of bytes actually read

- Offset is implicit here (current location)
- Buffer is provided

Write

- NFSPROC_WRITE(file handle, offset, count, data)
  – Return: file attributes
  – Note again explicit offset is specified in the call

- Compared to local FS
  – n = write(fd, buffer, size)
  – Offset is again implicit (current position)

Create and remove files

- NFSPROC_CREATE(directory file handle, name of file in the directory, attributes)
  - Return file handle (note difference from reading material, see more at: https://tools.ietf.org/html/rfc1094)
- NFSPROC_REMOVE(directory file handle, name of file to be removed)
  - Return nothing

Working with directories

- NFSPROC_MKDIR & NFSPROC_RMDIR
  - Similar to create & remove files
  - but create & remove a directory instead

- NFSPROC_READDIR
  - Similar to read file, but here read directory content

Get/set attributes of files

- GetAttr
  - Obtain file attributes, e.g., last modified time
  - Important for client-side caching

```
NFSPROC_GETATTR
  expects: file handle
  returns: attributes
NFSPROC_SETATTR
  expects: file handle, attributes
  returns: nothing
```

Example: opening a file for read

1. Obtain file handle + client-side book-keeping

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	

Example: reading the file

2. Start to read

- Obtain file handle & offset from client-side open table

4KB

```
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
```

Example: reading a file

3. Continue to read

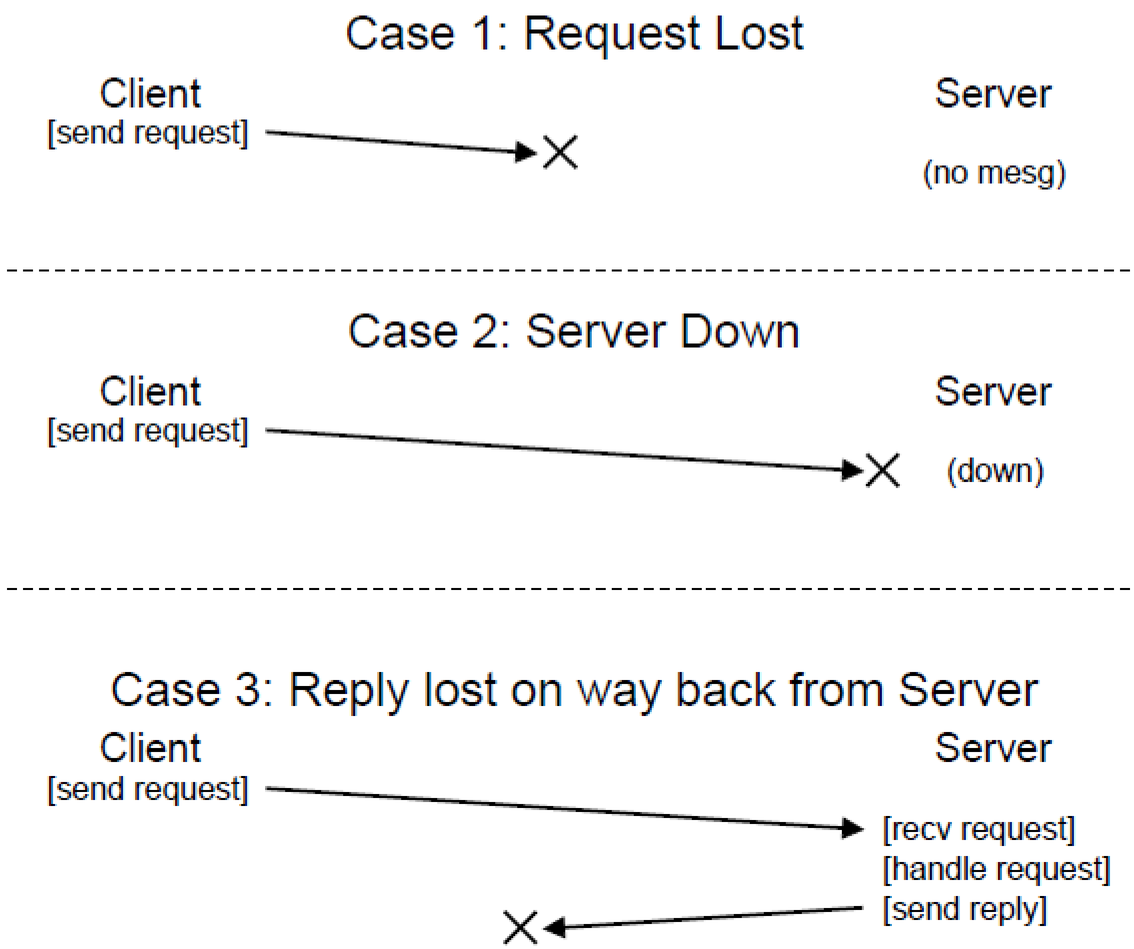
4. Done and clean up

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)

Deal with failures



Idempotent operations

- Does not matter how many times you execute
  - Effect is the same as single execution
- All these common operations are idempotent
  - Lookup
  - Read
  - ReadDir
  - Write: since it specifies the exact offset

Power of idempotent operations

- Simplify handling of failure

- Client sets timer, when time-out but no reply
  - Simply retry the same request

Non-idempotent operations

- These operations are not idempotent:
  - Create (file)
  - Remove (file)
  - Mkdir (create directory)
  - RmDir

- Error message will return from server
  - E.g., when create is executed more than once

Improving performance

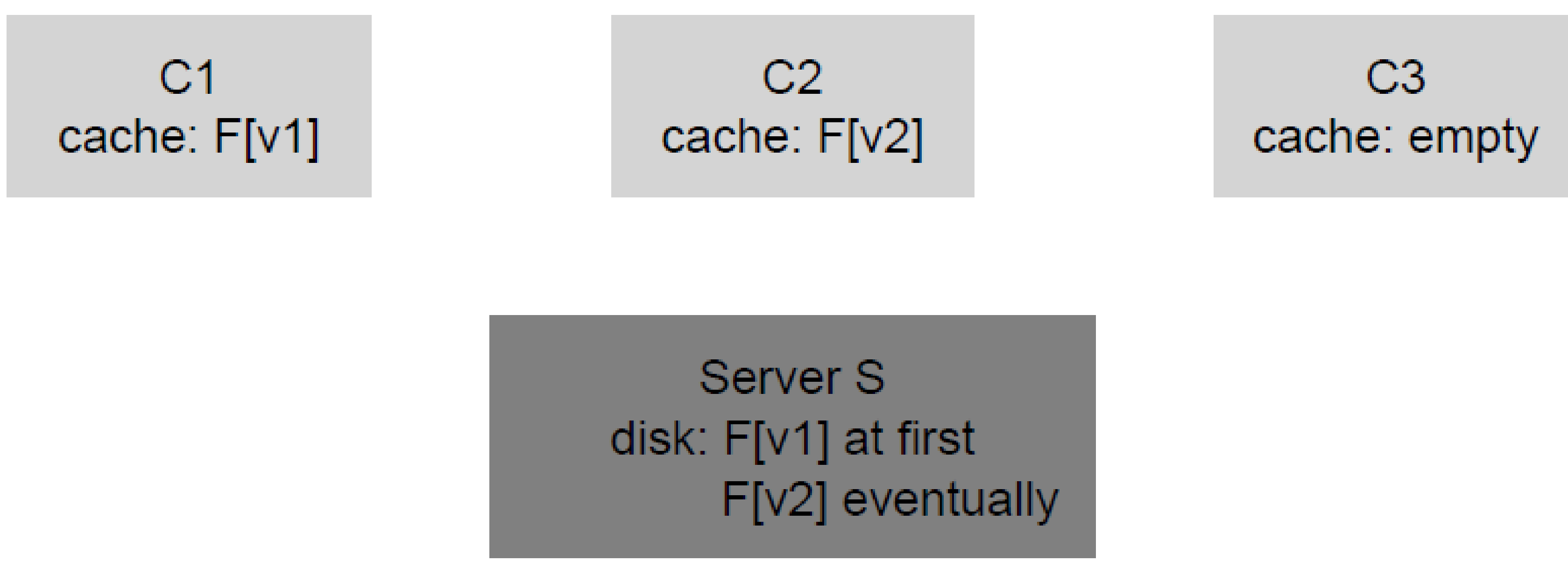
- Client side
  - Read caching
  - Write buffering

- Similar to standalone file system

- Unique change: cache consistency problem
  - Due to multiple caches in several clients

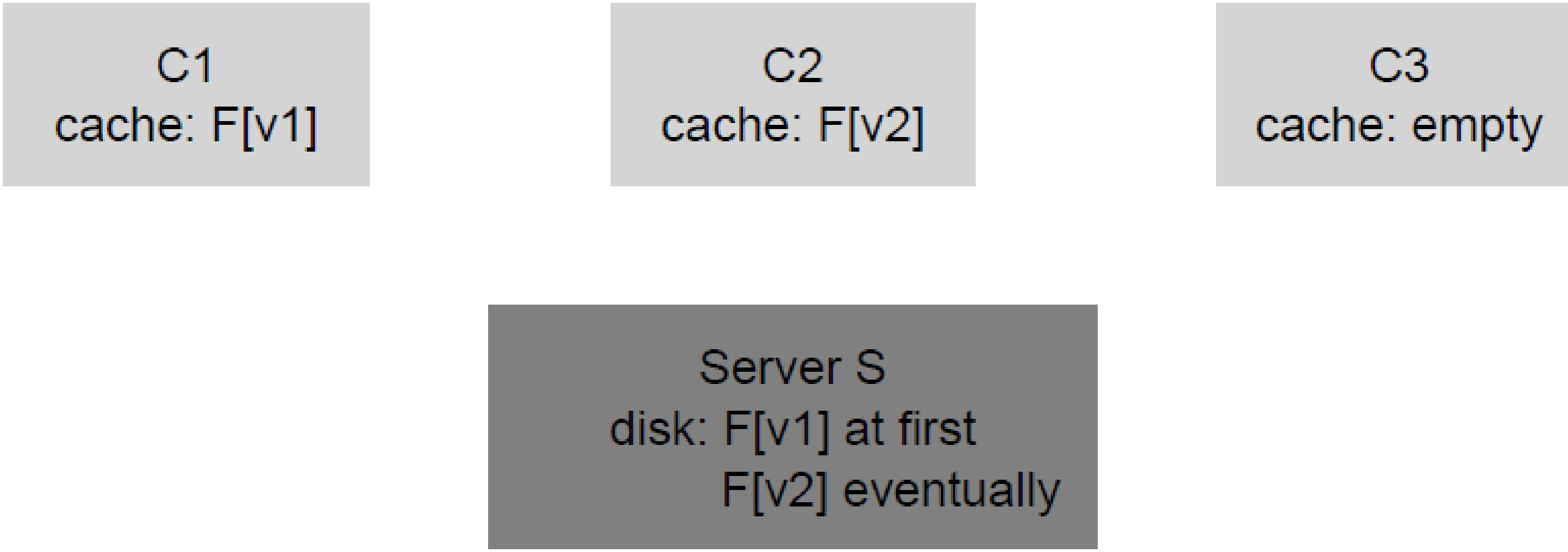
Cache consistency problems

- C2 updates file F to version 2: F[v2], but does not commit it to server when it closes the file
- Problems: update visibility & stale cache



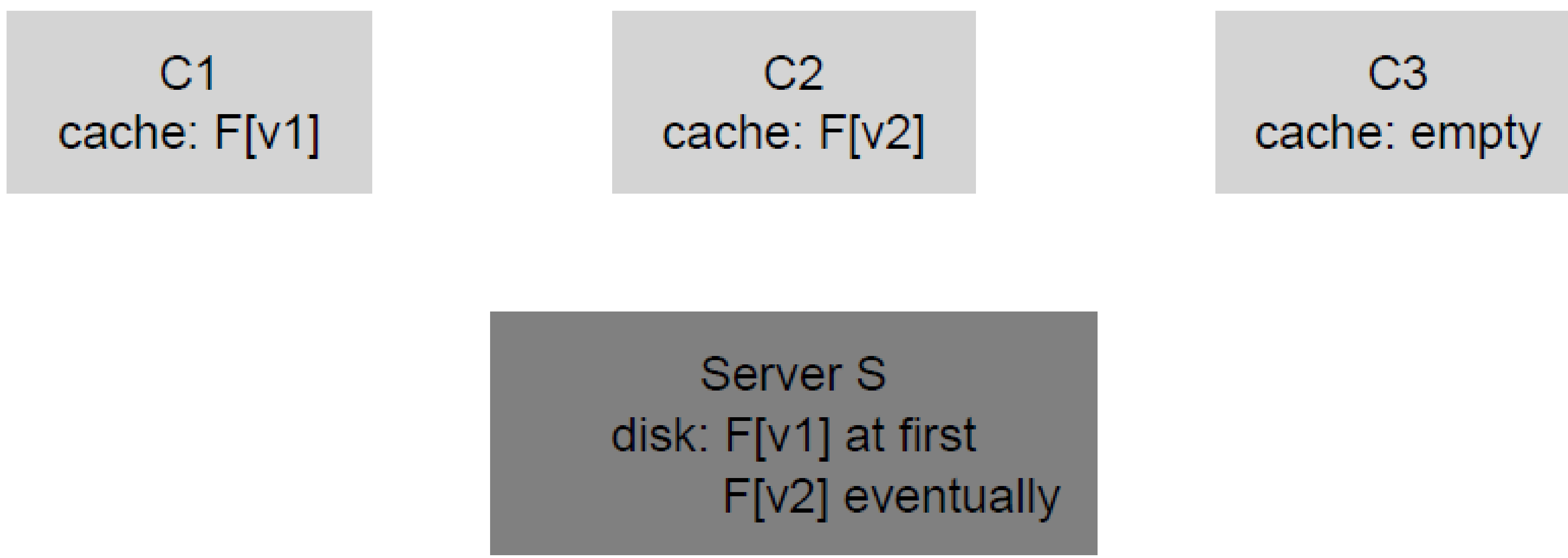
Update visibility problem

- C3 reads F from server, got old content



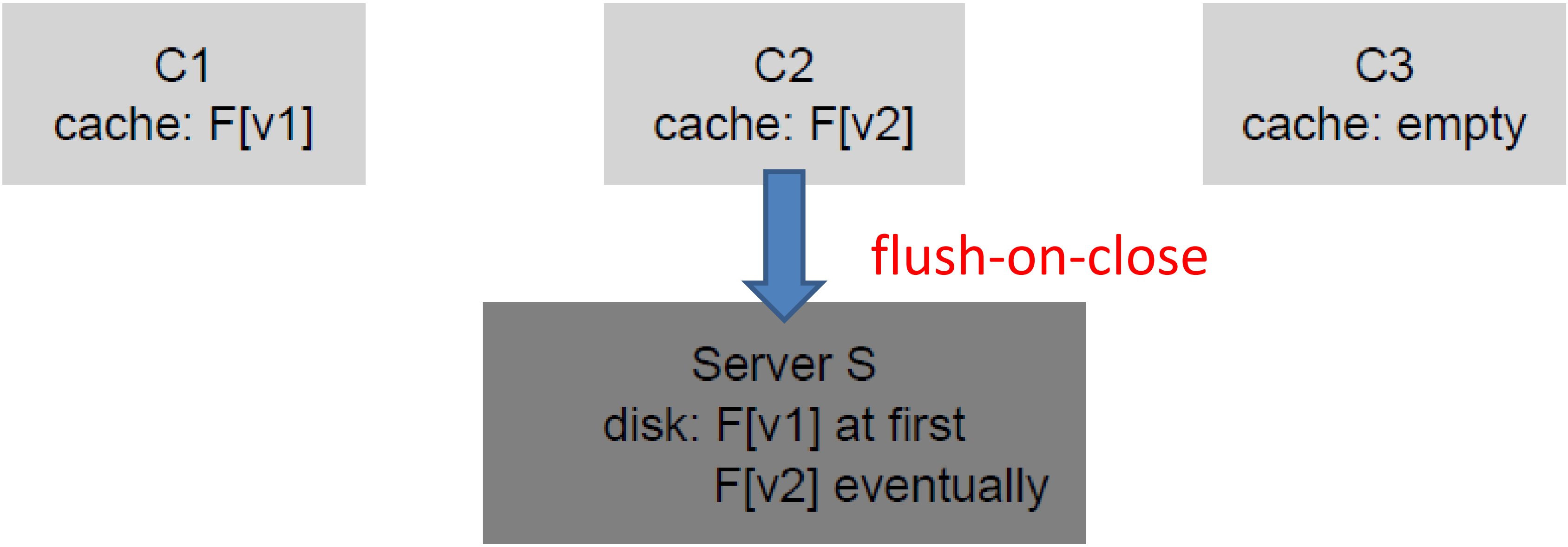
Stale cache problem

- F[v2] finally flushed to server, but now caches C1 (& C3) are stale



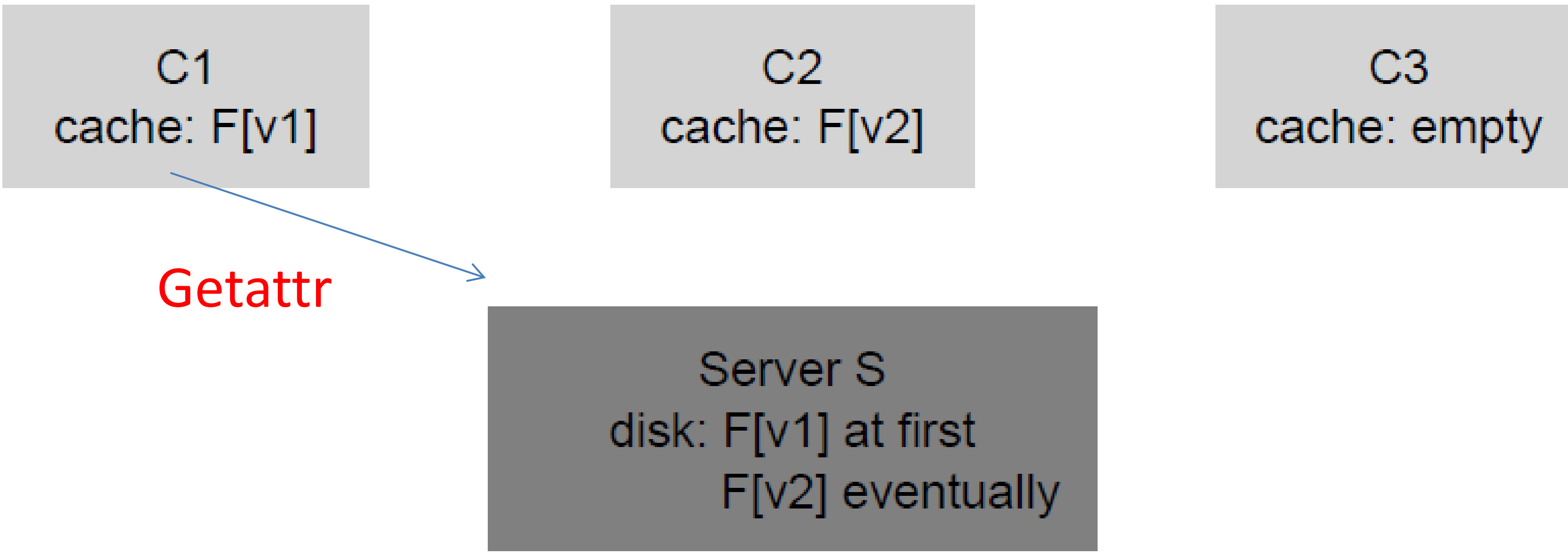
Solution: flush-on-close

- Client flushes all updates to server when file is closed
- Solve the update visibility problem



Solution: cache validation

- Client checks if cache is current by issuing GETATTR to server before opening/accessing the file



References

- NFS: Network File System Protocol Specification
  - https://tools.ietf.org/html/rfc1094