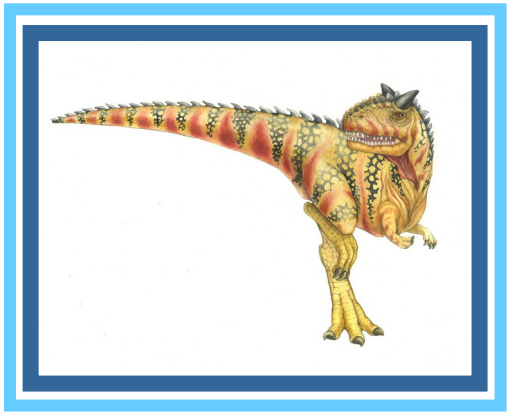
Chapter 15: File System Internals



Outline

- File Systems
- File-System Mounting
- Partitions and Mounting
- File Sharing
- Virtual File Systems
- Remote File Systems
- Consistency Semantics
- NFS

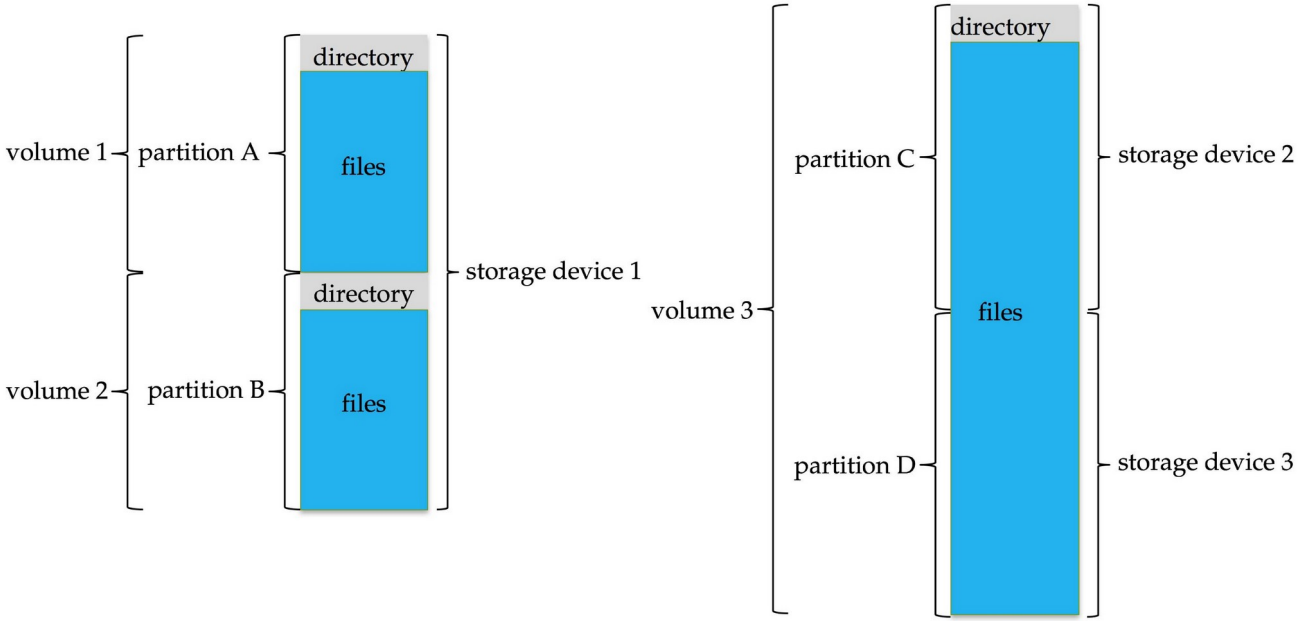
Objectives

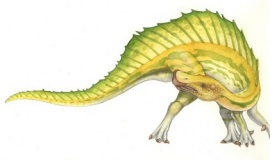
- Delve into the details of file systems and their implementation
- Explore booting and file sharing
- Describe remote file systems, using NFS as an example

File System

- General-purpose computers can have multiple storage devices
  - Devices can be sliced into partitions, which hold volumes
  - Volumes can span multiple partitions
  - Each volume usually formatted into a file system
  - # of file systems varies, typically dozens available to choose from

  Typical storage device organization:



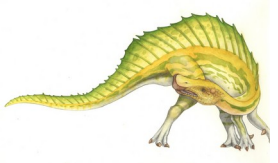


Example Mount Points and File Systems - Solaris

/	ufs
/devices	devfs
/dev	dev
/system/contract	ctfs
/proc	proc
/etc/mnttab	mntfs
/etc/svc/volatile	tmpfs
/system/object	objfs
/lib/libc.so.1	lofs
/dev/fd	fd
/var	ufs
/tmp	tmpfs
/var/run	tmpfs
/opt	ufs
/zpbge	zfs
/zpbge/backup	zfs
/export/home	zfs
/var/mail	zfs
/var/spool/mqueue	zfs
/zpbg	zfs
/zpbg/zones	zfs

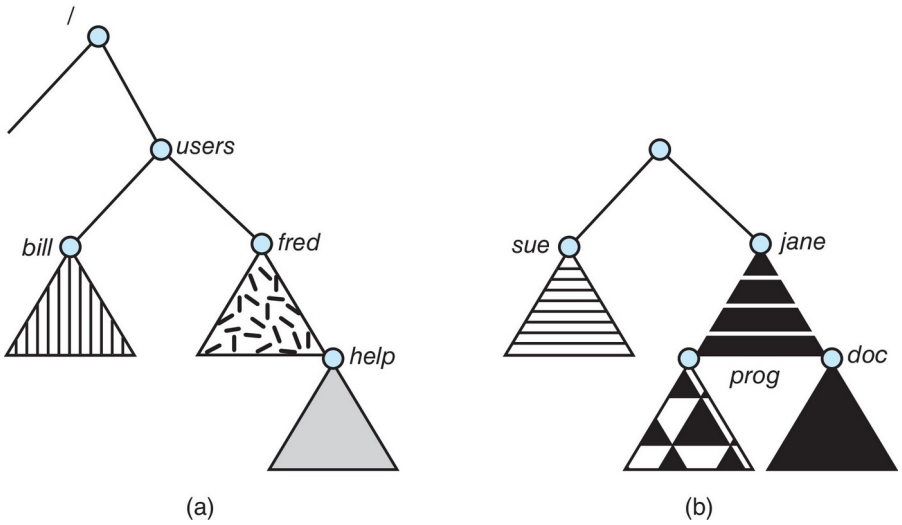
Partitions and Mounting

- Partition can be a volume containing a file system (“cooked”) or **raw** – just a sequence of blocks with no file system
- Boot block can point to boot volume or boot loader set of blocks that contain enough code to know how to load the kernel from the file system
  - Or a boot management program for multi-os booting
- **Root partition** contains the OS, other partitions can hold other OSes, other file systems, or be raw
  - Mounted at boot time
  - Other partitions can mount automatically or manually on **mount points** – location at which they can be accessed
- At mount time, file system consistency checked
  - Is all metadata correct?
    - If not, fix it, try again
    - If yes, add to mount table, allow access

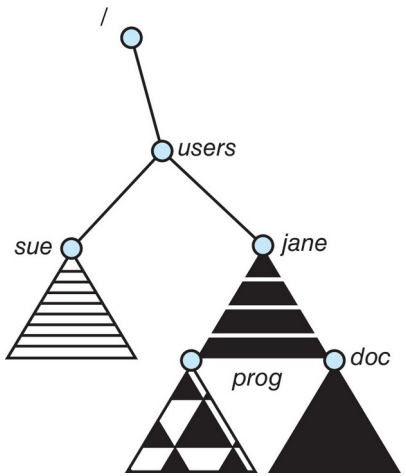


File Systems and Mounting

(a) Unix-like file system directory tree
(b) Unmounted file system



After mounting (b) into the existing directory tree



File Sharing

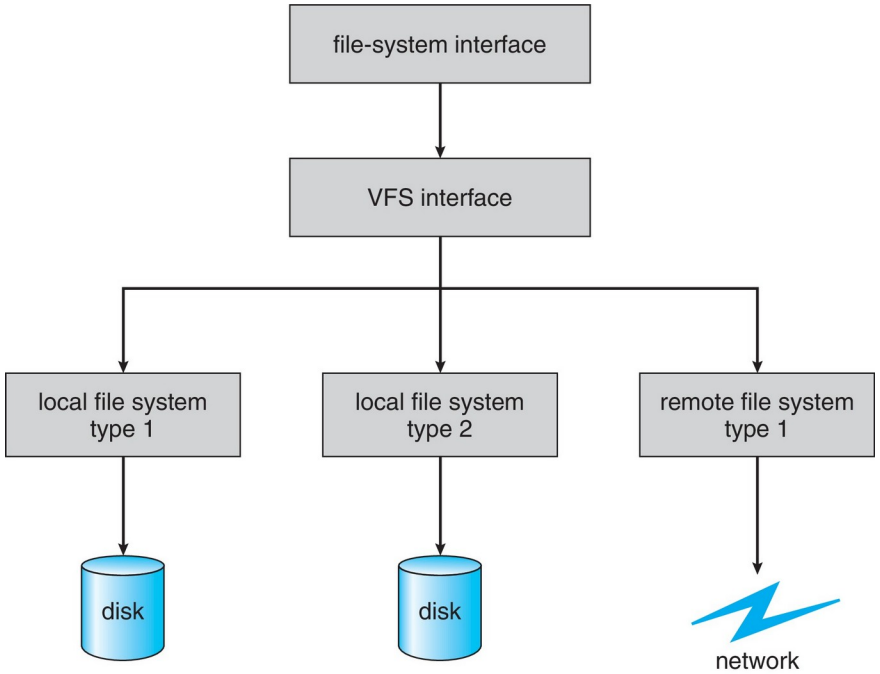
- Allows multiple users / systems access to the same files
- Permissions / protection must be implement and accurate
  - Most systems provide concepts of owner, group member
  - Must have a way to apply these between systems

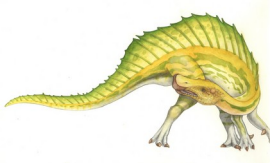
Virtual File Systems

- **Virtual File Systems** (**VFS**) on Unix provide an object-oriented way of implementing file systems
- VFS allows the same system call interface (the API) to be used for different types of file systems
  - Separates file-system generic operations from implementation details
  - Implementation can be one of many file systems types, or network file system
    - Implements **vnodes** which hold inodes or network file details
  - Then dispatches operation to appropriate file system implementation routines

Virtual File Systems (Cont.)

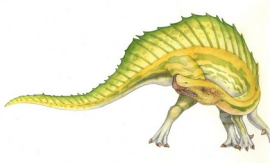
- The API is to the VFS interface, rather than any specific type of file system





Virtual File System Implementation

- For example, Linux has four object types:
  - **inode, file, superblock, dentry**
- VFS defines set of operations on the objects that must be implemented
  - Every object has a pointer to a function table
    - Function table has addresses of routines to implement that function on that object
    - For example:
    - • **`int open(. . .)`**—Open a file
    - • **`int close(. . .)`**—Close an already-open file
    - • **`ssize t read(. . .)`**—Read from a file
    - • **`ssize t write(. . .)`**—Write to a file
    - • **`int mmap(. . .)`**—Memory-map a file



Remote File Systems

- Sharing of files across a network
- First method involved manually sharing each file – programs like `ftp`
- Second method uses a **distributed file system** (**DFS**)
  - Remote directories visible from local machine
- Third method – **World Wide Web**
  - A bit of a revision to first method
  - Use browser to locate file/files and download /upload
  - **Anonymous** access doesn't require authentication

Client-Server Model

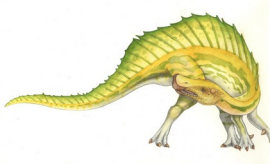
- Sharing between a server (providing access to a file system via a network protocol) and a client (using the protocol to access the remote file system)
- Identifying each other via network ID can be spoofed, encryption can be performance expensive
- NFS an example
  - User auth info on clients and servers must match (UserIDs for example)
  - Remote file system mounted, file operations sent on behalf of user across network to server
  - Server checks permissions, file handle returned
  - Handle used for reads and writes until file closed

Distributed Information Systems

- Aka **distributed naming services**, provide unified access to info needed for remote computing
- **Domain name system** (**DNS**) provides host-name-to-network-address translations for the Internet
- Others like **network information service** (**NIS**) provide user-name, password, userID, group information
- Microsoft's **common Internet file system** (**CIFS**) network info used with user auth to create network logins that server uses to allow to deny access
  - **Active directory** distributed naming service
  - **Kerberos-derived** network authentication protocol
- Industry moving toward **lightweight directory-access protocol** (**LDAP**) as secure distributed naming mechanism

Consistency Semantics

- Important criteria for evaluating file sharing-file systems
- Specify how multiple users are to access shared file simultaneously
  - When modifications of data will be observed by other users
  - Directly related to process synchronization algorithms, but atomicity across a network has high overhead (see Andrew File System)
- The series of accesses between file open and closed called **file session**
- UNIX semantics
  - Writes to open file immediately visible to others with file open
  - One mode of sharing allows users to share pointer to current I/O location in file
  - Single physical image, accessed exclusively, contention causes process delays
- Session semantics (Andrew file system (OpenAFS))
  - Writes to open file not visible during session, only at close
  - Can be several copies, each changed independently

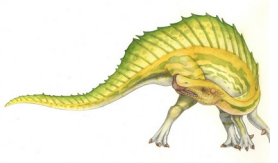


The Sun Network File System (NFS)

- An implementation and a specification of a software system for accessing remote files across LANs (or WANs)
- The implementation originally part of SunOS operating system, now industry standard / very common
- Can use unreliable datagram protocol (UDP/IP) or TCP/IP, over Ethernet or other network

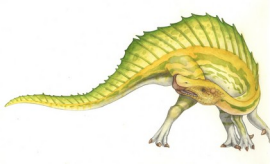
NFS (Cont.)

- Interconnected workstations viewed as a set of independent machines with independent file systems, which allows sharing among these file systems in a transparent manner
  - A remote directory is mounted over a local file system directory
    - The mounted directory looks like an integral subtree of the local file system, replacing the subtree descending from the local directory
  - Specification of the remote directory for the mount operation is nontransparent; the host name of the remote directory has to be provided
    - Files in the remote directory can then be accessed in a transparent manner
  - Subject to access-rights accreditation, potentially any file system (or directory within a file system), can be mounted remotely on top of any local directory

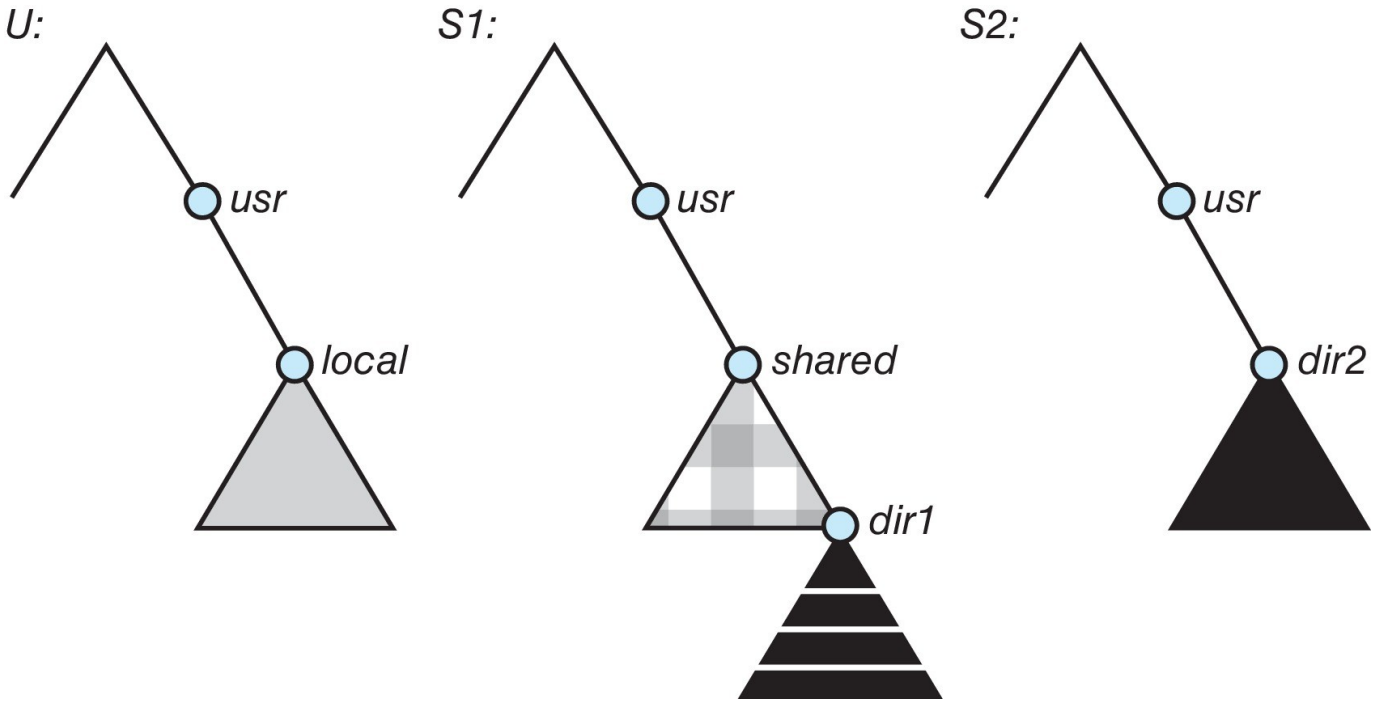


NFS (Cont.)

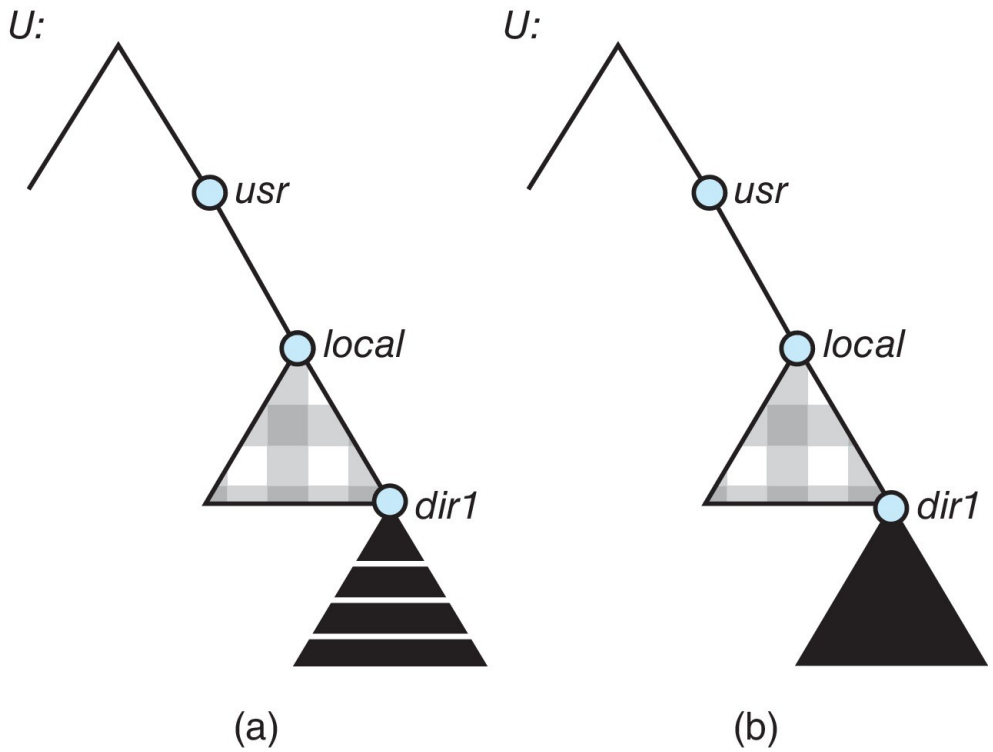
- NFS is designed to operate in a heterogeneous environment of different machines, operating systems, and network architectures; the NFS specifications independent of these media
- This independence is achieved through the use of RPC primitives built on top of an External Data Representation (XDR) protocol used between two implementation-independent interfaces
- The NFS specification distinguishes between the services provided by a mount mechanism and the actual remote-file-access services



Three Independent File Systems

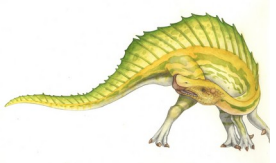


Mounting in NFS



Mounts

Cascading mounts

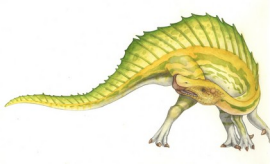


NFS Mount Protocol

- Establishes initial logical connection between server and client
- Mount operation includes name of remote directory to be mounted and name of server machine storing it
  - Mount request is mapped to corresponding RPC and forwarded to mount server running on server machine
  - Export list – specifies local file systems that server exports for mounting, along with names of machines that are permitted to mount them
- Following a mount request that conforms to its export list, the server returns a file handle—a key for further accesses
- File handle – a file-system identifier, and an inode number to identify the mounted directory within the exported file system
- The mount operation changes only the user's view and does not affect the server side

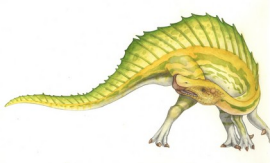
NFS Protocol

- Provides a set of remote procedure calls for remote file operations. The procedures support the following operations:
  - searching for a file within a directory
  - reading a set of directory entries
  - manipulating links and directories
  - accessing file attributes
  - reading and writing files
- NFS servers are **stateless**; each request has to provide a full set of arguments (NFS V4 is newer, less used – very different, stateful)
- Modified data must be committed to the server's disk before results are returned to the client (lose advantages of caching)
- The NFS protocol does not provide concurrency-control mechanisms

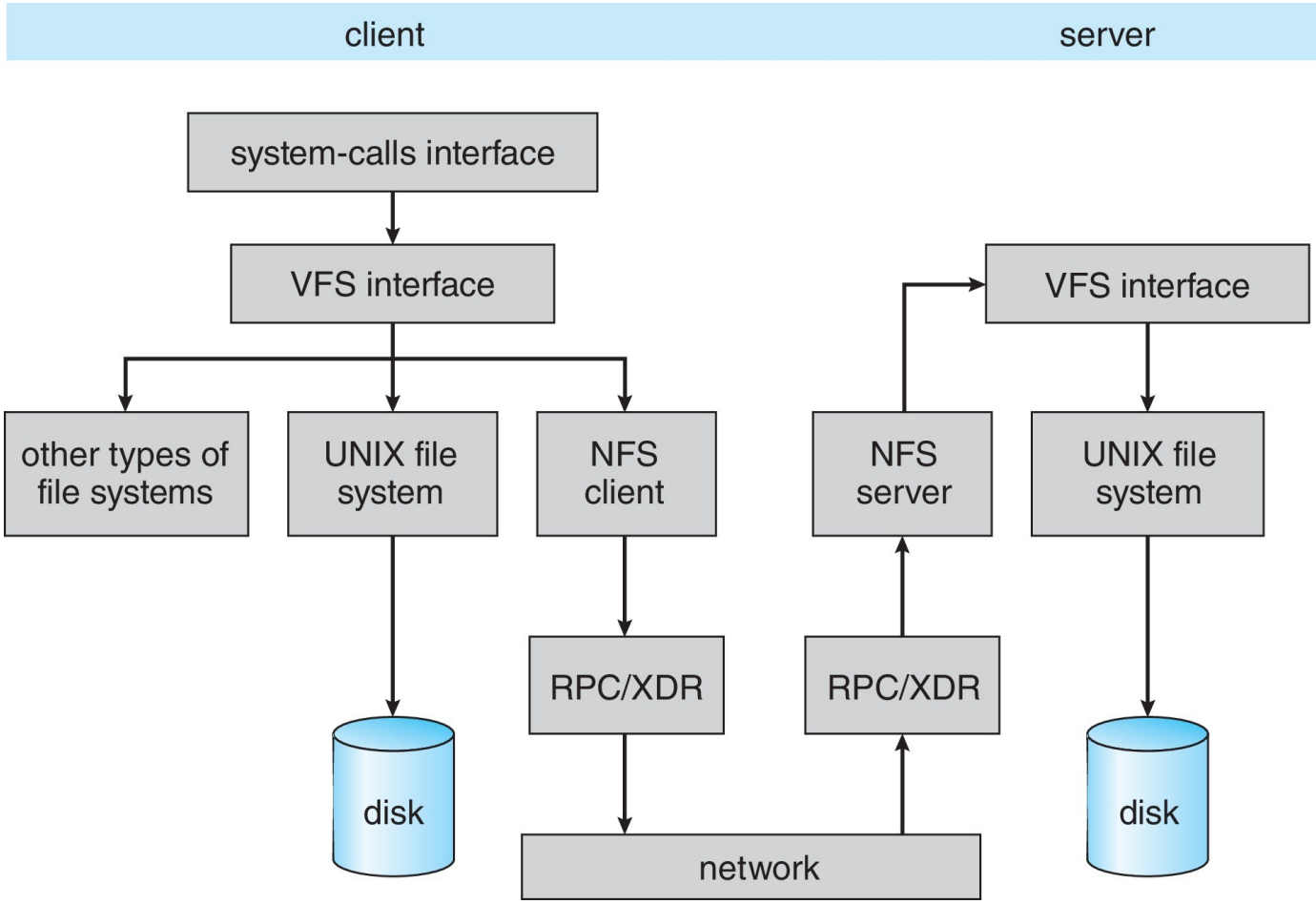


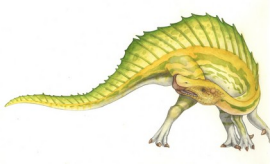
Three Major Layers of NFS Architecture

- 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



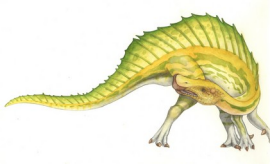
Schematic View of NFS Architecture





NFS Path-Name Translation

- Performed by breaking the path into component names and performing a separate NFS lookup call for every pair of component name and directory vnode
- To make lookup faster, a directory name lookup cache on the client's side holds the vnodes for remote directory names



NFS Remote Operations

- Nearly one-to-one correspondence between regular UNIX system calls and the NFS protocol RPCs (except opening and closing files)
- NFS adheres to the remote-service paradigm, but employs buffering and caching techniques for the sake of performance
- File-blocks cache – when a file is opened, the kernel checks with the remote server whether to fetch or revalidate the cached attributes
  - Cached file blocks are used only if the corresponding cached attributes are up to date
- File-attribute cache – the attribute cache is updated whenever new attributes arrive from the server
- Clients do not free delayed-write blocks until the server confirms that the data have been written to disk

End of Chapter 15