COS 318: Operating Systems

Storage and File System

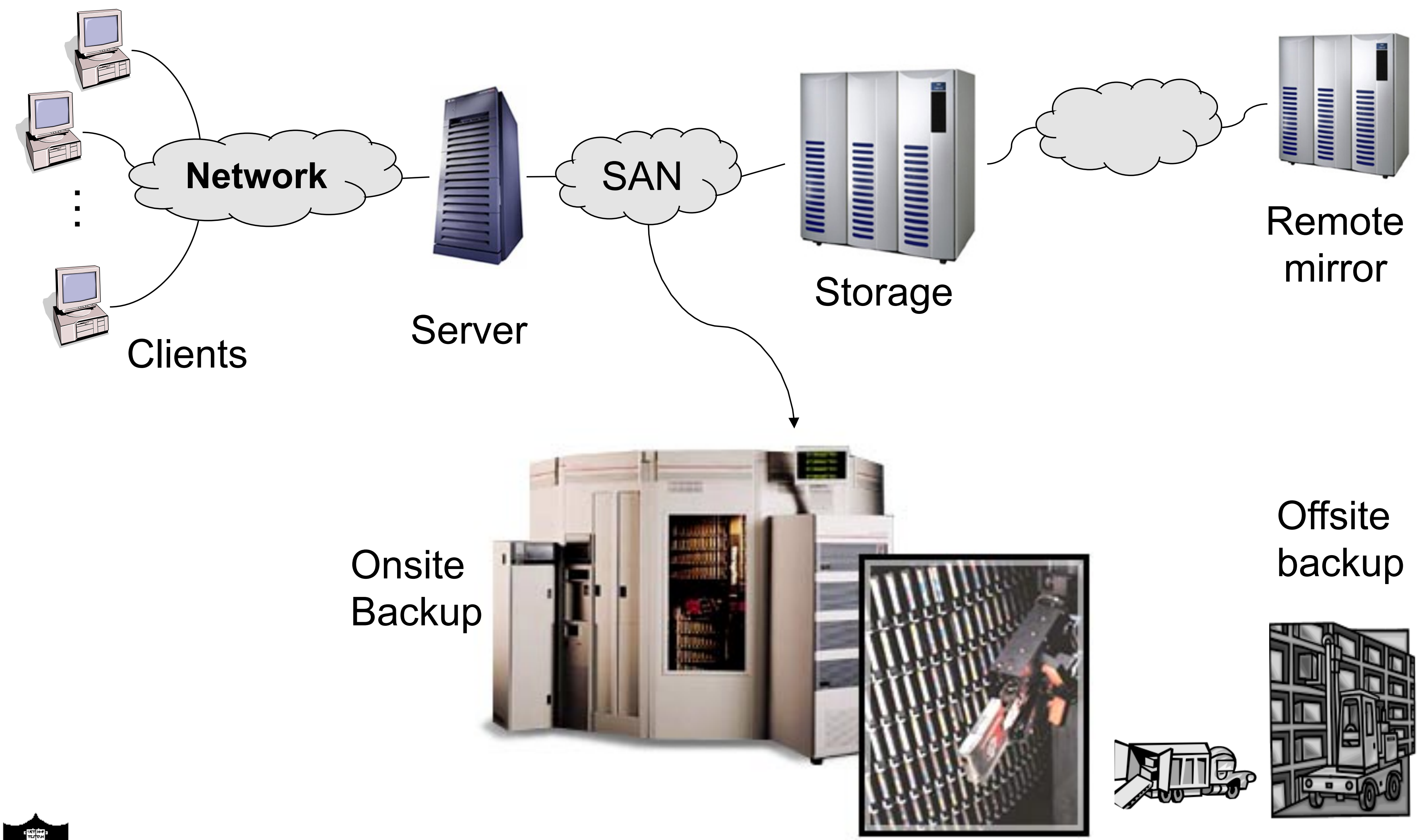
Andy Bavier
Computer Science Department
Princeton University

http://www.cs.princeton.edu/courses/archive/fall10/cos318/

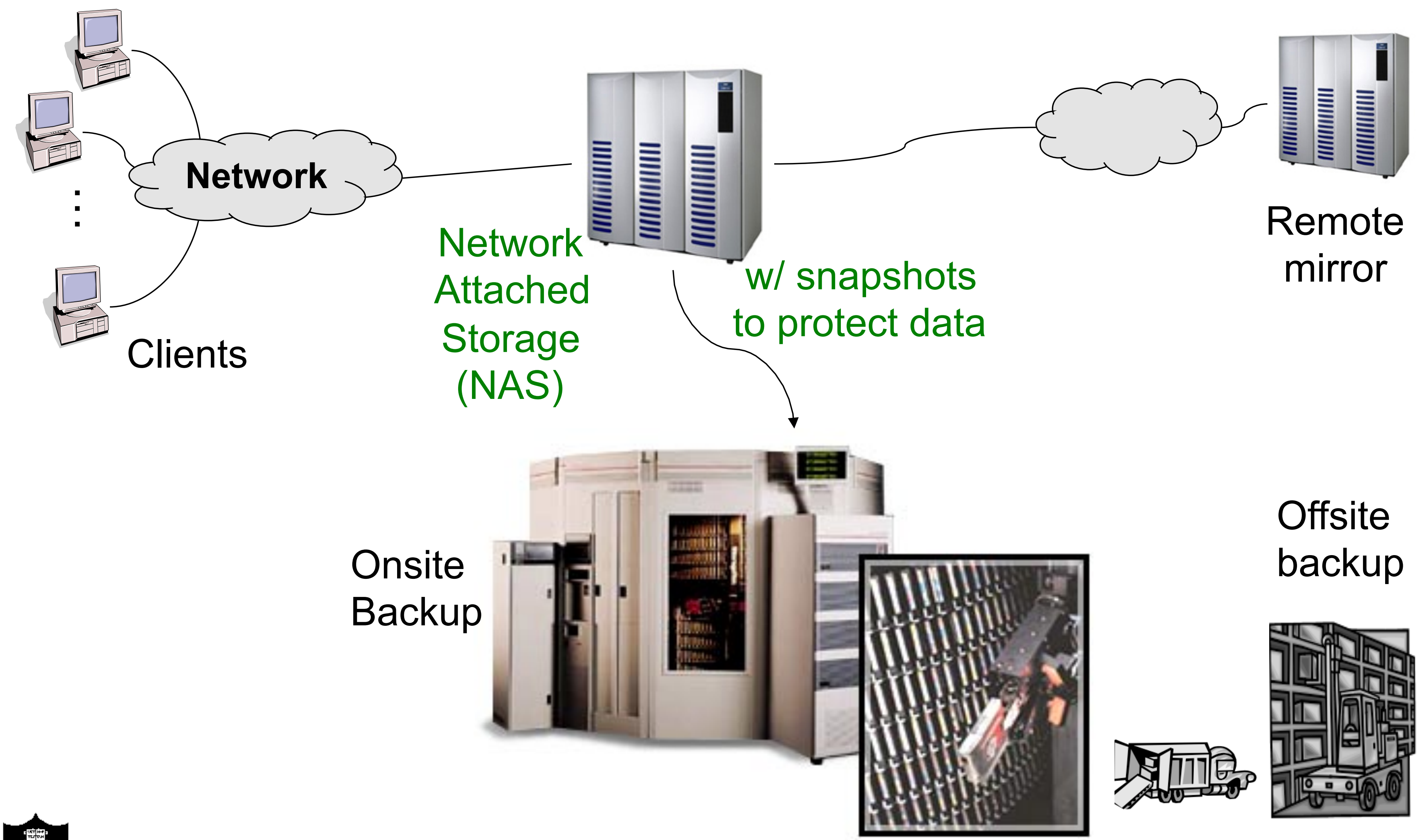
Topics

- Storage hierarchy
- File system abstraction
- File system operations
- File system protection

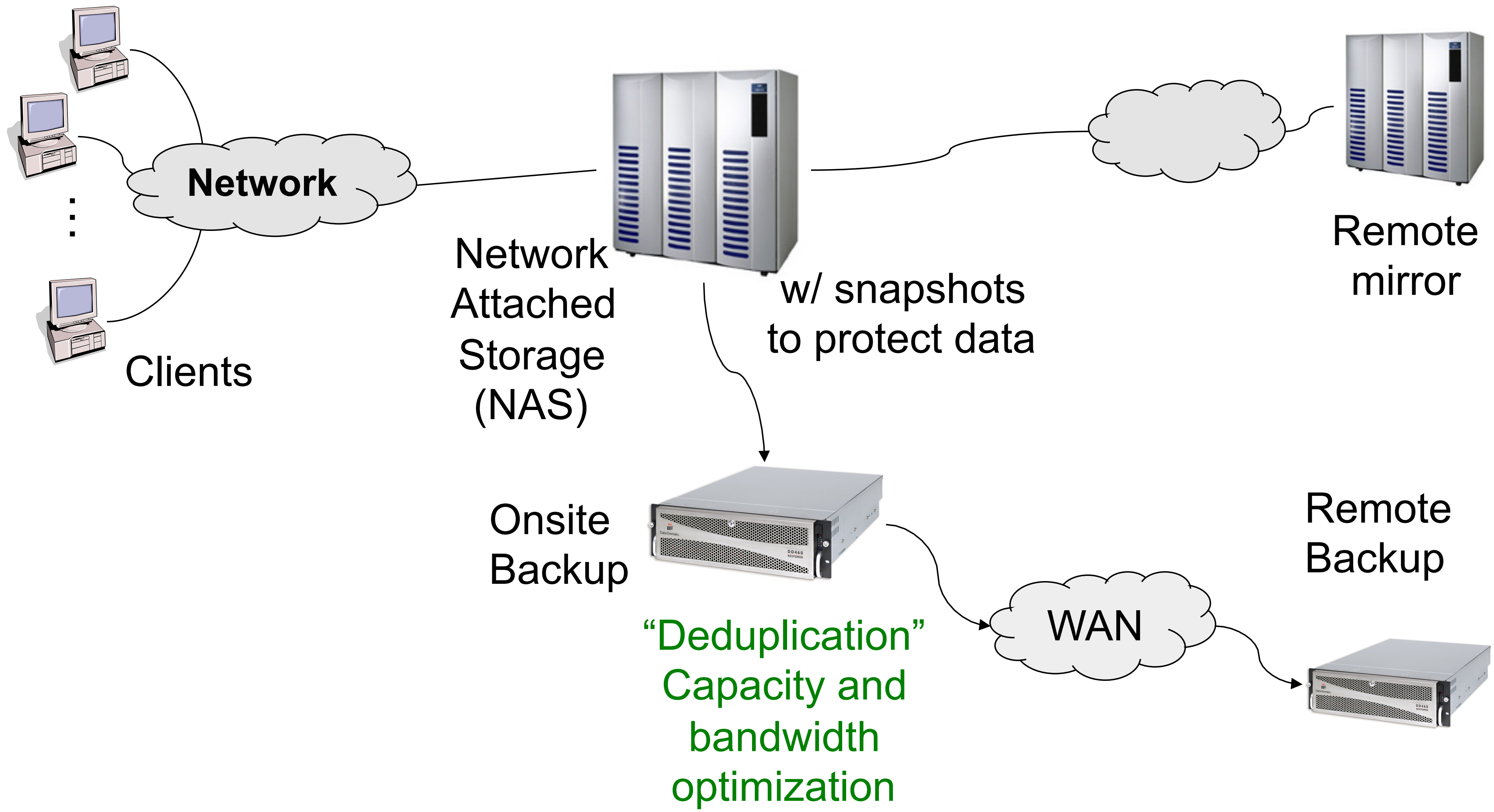
Traditional Data Center Storage Hierarchy



Evolved Data Center Storage Hierarchy

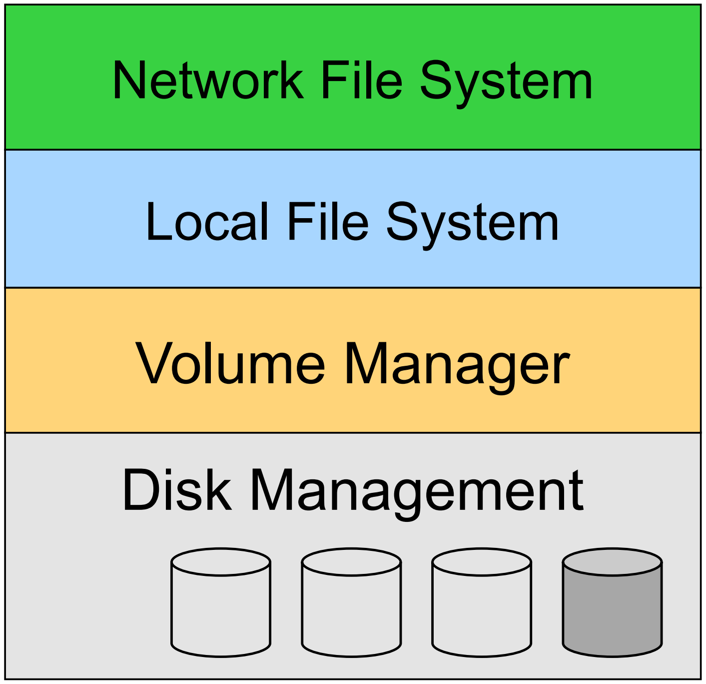


Modern Data Center Storage Hierarchy



File System Layers and Abstractions

- Network file system maps a network file system protocol to local file systems
  - NFS, CIFS, DAFS, etc
- Local file system implements a file system on blocks in volumes
  - Local disks or network of disks
- Volume manager maps logical volume to physical disks
  - Provide logical unit
  - RAID and reconstruction
- Disk management manages physical disks
  - Sometimes part of volume manager
  - Drivers, scheduling, etc



Volume Manager

- What and why?
  - Group multiple disk partitions into a logical disk volume
    - No need to deal with physical disk, sector numbers
    - To read a block: read(vol#, block#, buf, n);
  - Volume can include RAID, tolerating disk failures
    - No need to know about parity disk in RAID-5, for example
    - No need to know about reconstruction
  - Volume can provide error detections at disk block level
    - Some products use a checksum block for 8 blocks of data
  - Volume can grow or shrink without affecting existing data
  - Volume can have remote volumes for disaster recovery
  - Remote mirrors can be split or merged for backups
- How to implement?
  - OS kernel: Veritas (for SUN and NT), Linux
  - Disk subsystem: EMC, Hitachi, IBM

Block Storage vs. Files

Disk abstraction

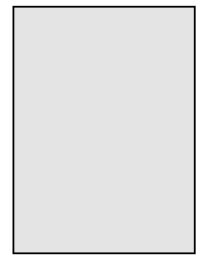
- Block oriented
- Block numbers
- No protection among users of the system
- Data might be corrupted if machine crashes

File abstraction

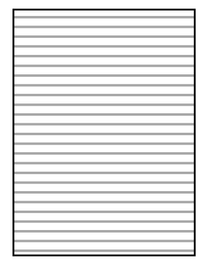
- Byte oriented
- Named files
- Users protected from each other
- Robust to machine failures

File Structure Alternatives

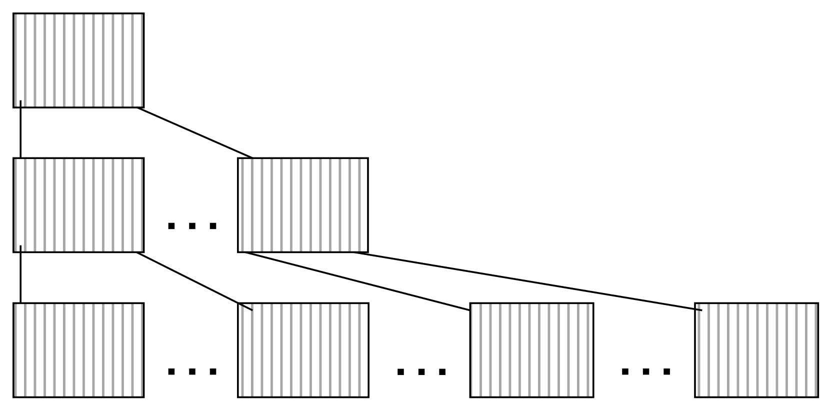
- Byte sequence
  - Read or write a number of bytes
  - Unstructured or linear



- Record sequence
  - Fixed or variable length
  - Read or write a number of records



- Tree
  - Records with keys
  - Read, insert, delete a record (typically using B-tree)



File Types

- ASCII
- Binary data
  - Records, trees
  - Documents, music, video, etc.
  - An Unix executable file
    - header: magic number, sizes, entry point, flags
    - text
    - data
    - relocation bits
    - symbol table
- Devices

File Operations

- Operations for “sequence of bytes” files
  - Create: create a mapping from a name to bytes
  - Delete: delete the mapping
  - Open: authentication
  - Close: finish accessing a file
  - Seek: jump to a particular location in a file
  - Read: read some bytes from a file
  - Write: write some bytes to a file
  - A few more on directories: talk about this later
- Implementation goal
  - Operations should have as few disk accesses as possible and have minimal space overhead

Access Patterns

- Sequential (the common pattern)
  - File data processed sequentially
  - Examples
    - Editor writes out a new file
    - Compiler reads a file
- Random access
  - Address a block in file directly without passing through predecessors
  - Examples:
    - Data set for demand paging
    - Read a message in an inbox file
    - Databases
- Keyed access
  - Search for a record with particular values
  - Usually not provided by today's file systems
  - Examples
    - Database search and indexing

VM Page Table vs. File System Metadata

Page table

- Manage the mappings of an address space
- Map virtual page # to physical page #
- Check access permission and illegal addressing
- TLB does all in one cycle

File metadata

- Manage the mappings of files
- Map byte offset to disk block address
- Check access permission and illegal addressing
- All implement in software and may cause disk accesses

File System vs. Virtual Memory

- Similarity
  - Location transparency
  - Oblivious to size
  - Protection
- File system is easier than VM
  - CPU time to do file system mappings is not a big deal
  - Files are dense and mostly sequential
  - Page tables deal with sparse address spaces and random accesses
- File system is harder than VM
  - Each layer of translation causes potential disk accesses
  - Memory space for caching is never enough
  - Range very extreme: many < 10k, some > GB
  - Implementation must be very reliable

Protection Policy vs. Mechanism

- Policy is about what and mechanism is about how
- A protection system is the mechanism to enforce a security policy
  - Roughly the same set of choices, no matter what policy
- A security policy delineates what acceptable behavior and unacceptable behavior
  - Example security policies:
    - Each user can only allocate 40MB of disk
    - No one but root can write to the password file
    - You cannot read my mail

Protection Mechanisms

- Authentication
  - Make sure we know who we are talking to
    - Unix: password
    - Credit card companies: social security # + mom's name
    - Bar's: driver's license
  - Theme?
- Authorization
  - Determine if x is allowed to do y
  - Need a simple database
- Access enforcement
  - Enforce authorization decision
  - Must make sure there are no loopholes
  - This is difficult

Authentication

- Usually done with passwords
  - This is usually a relatively weak form of authentication, since it's something that people have to remember
  - Empirically is typically based on girlfriend/boyfriend name
- Passwords should not be stored in a directly-readable form
  - Use some sort of one-way-transformation (a "secure hash") and store that
  - If you look in /etc/passwords will see a bunch of gibberish associated with each name. That is the password
- Problem: to prevent guessing ("dictionary attacks") passwords should be long and obscure
  - Unfortunately easily forgotten and usually written down
- What are the alternatives?

Protection Domain

- Once identity known, what is Bob allowed to do?
  - More generally: must be able to determine what each “principle” is allowed to do with what
- Can be represented as an “protection matrix” with one row per domain, one column per resource
- What are the pros and cons of this approach?

	File A	Printer B	File C
Domain 1	R	W	RW
Domain 2	RW	W	…
Domain 3	R	…	RW

Access Control Lists (ACLs)

- By column: For each object, indicate which users are allowed to perform which operations
  - In most general form, each object has a list of <user,privilege> pairs
- Access control lists are simple, and are used in almost all file systems
  - Owner, group, world
- Implementation
  - Stores ACLs in each file
  - Use login authentication to identify
  - Kernel implements ACLs
- What are the issues?

Capabilities

- By rows: For each user, indicate which files may be accessed and in what ways
  - Store a lists of <object, privilege> pairs which each user.
    - Called a *Capability List*
- Capabilities frequently do both naming and protection
  - Can only “see” an object if you have a capability for it.
  - Default is no access
- Implementation
  - Capability lists
    - Architecture support
    - Stored in the kernel
    - Stored in the user space but in encrypted format
  - Checking is easy: no enumeration
- Issues with capabilities?

Access Enforcement

- Use a trusted party to
  - Enforce access controls
  - Protect authorization information
- Kernel is the trusted party
  - This part of the system can do anything it wants
  - If it has a bug, the entire system can be destroyed
  - Want it to be as small & simple as possible
- Security is only as strong as the weakest link in the protection system

Some Easy Attacks

- Abuse of valid privilege
  - On Unix, super-user can do anything. Read your mail, send mail in your name, etc.
  - If you delete the code for COS318 project 5, your partner is not happy
- Spoiler/Denial of service (DoS)
  - Use up all resources and make system crash
  - Run shell script to: “while(1) { mkdir foo; cd foo; }”
  - Run C program: “while(1) { fork(); malloc(1000)[40] = 1; }”
- Listener
  - Passively watch network traffic. Will see anyone’s password as they type it into telnet. Or just watch for file traffic: Will be transmitted in plaintext.

No Perfect Protection System

- Protection can only increase the effort needed to do something bad
  - It cannot prevent bad things from happening
- Even assuming a technically perfect system, there are always ways to defeat
  - burglary, bribery, blackmail, bludgeoning, etc.
- Every system has holes
  - It just depends on what they look like

Summary

- Storage hierarchy is complex
  - Reliability, security, performance and cost
  - Many things are hidden, but the world is becoming tapeless
- Primary
  - Network file system
  - Local file system
  - Volume manager
- Protection
  - We basically live with access control list
  - More protection is needed in the future