COS 318: Operating Systems

Storage and File Hierarchy

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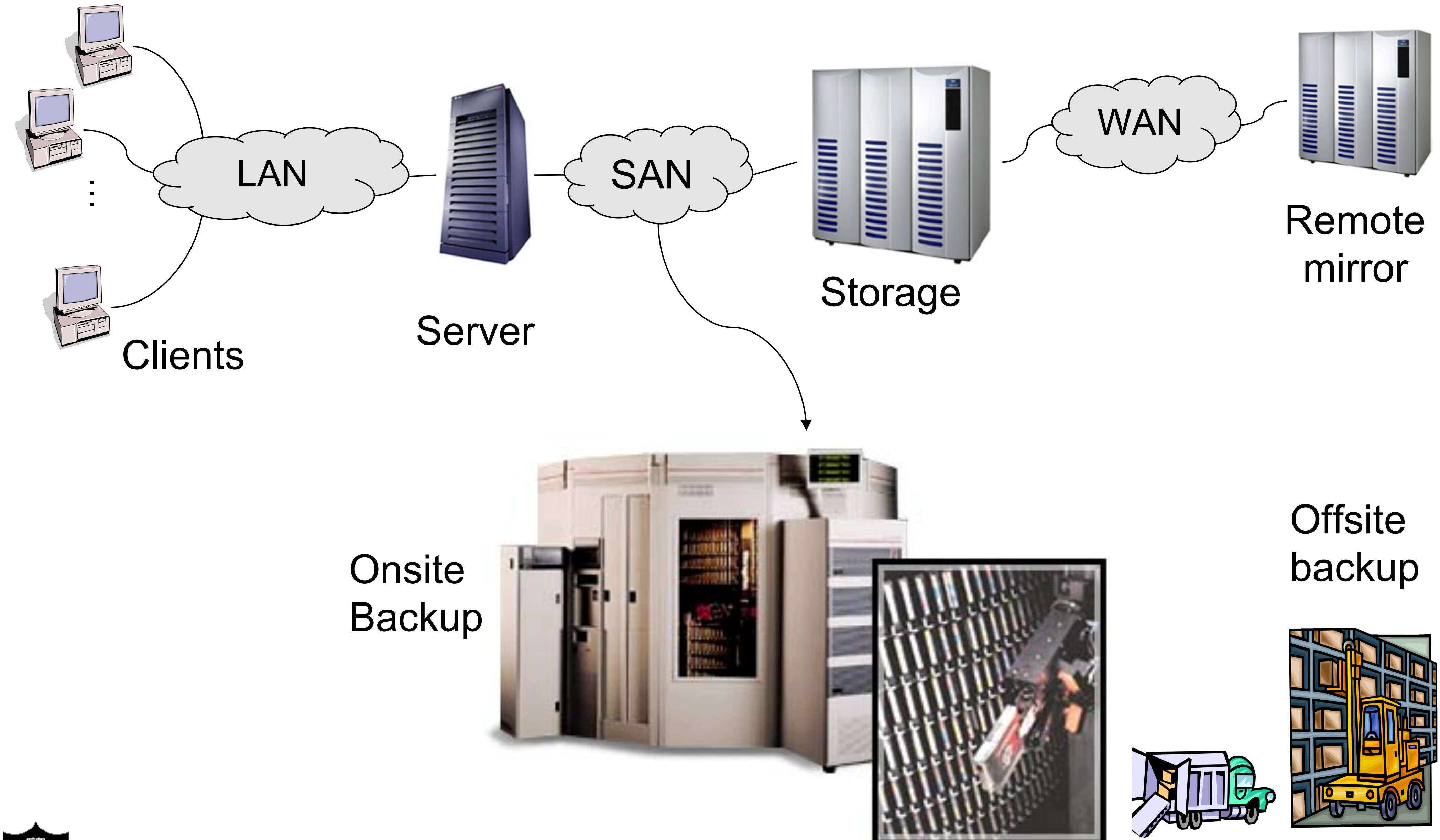
(http://www.cs.princeton.edu/courses/cos318/)

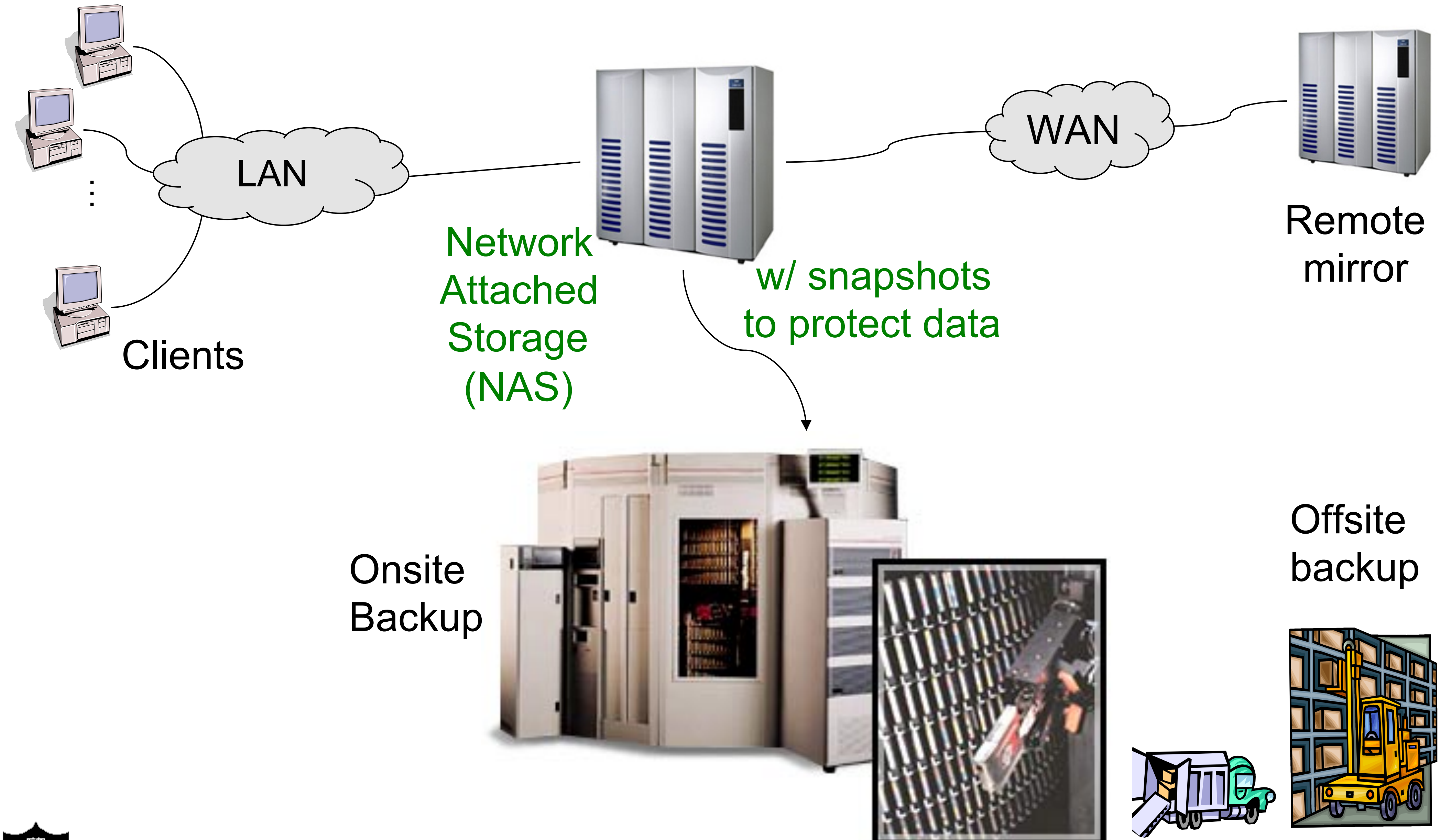
Topics

- Storage hierarchy
- File system abstraction
- File system protection

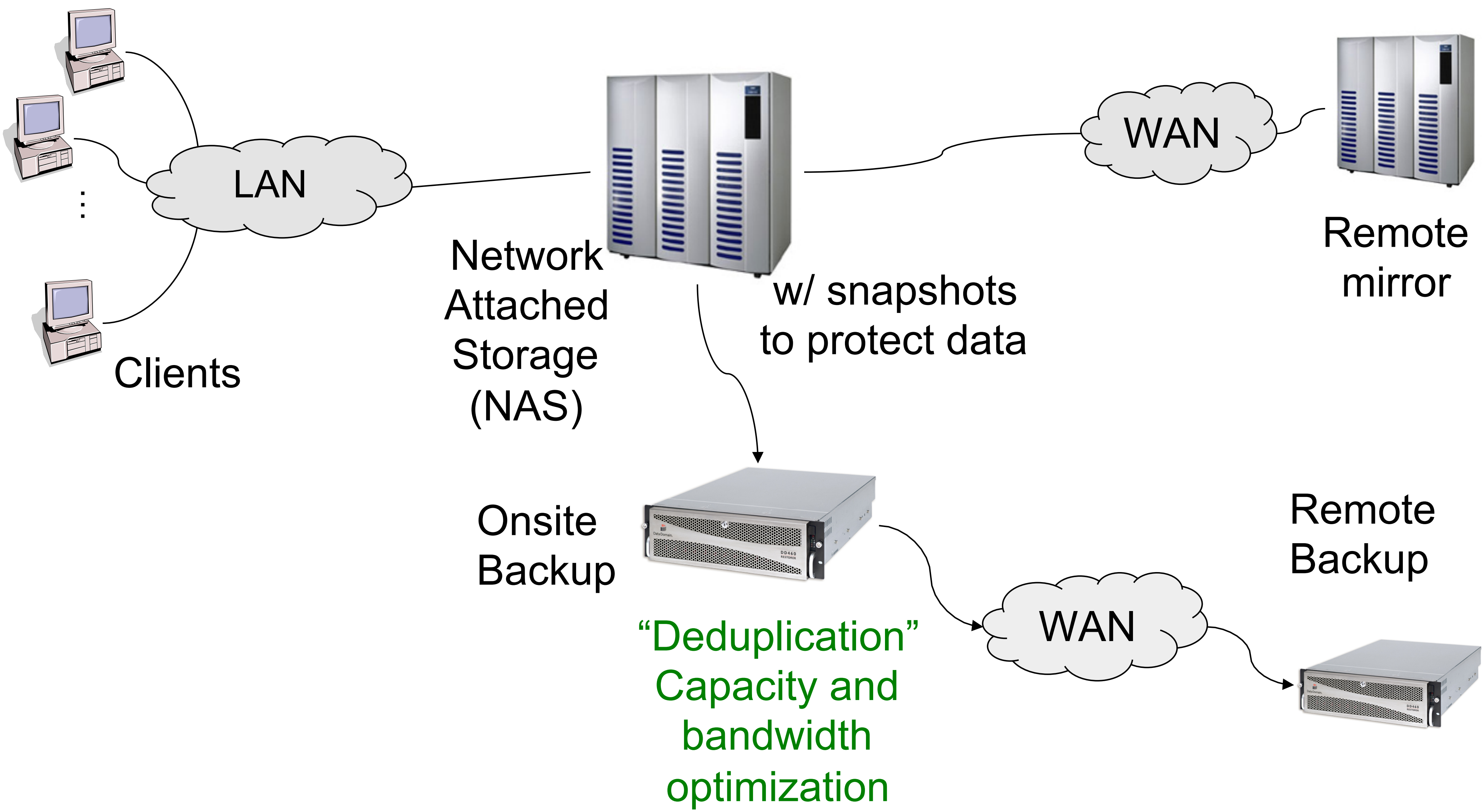
Traditional Data Center Storage Hierarchy



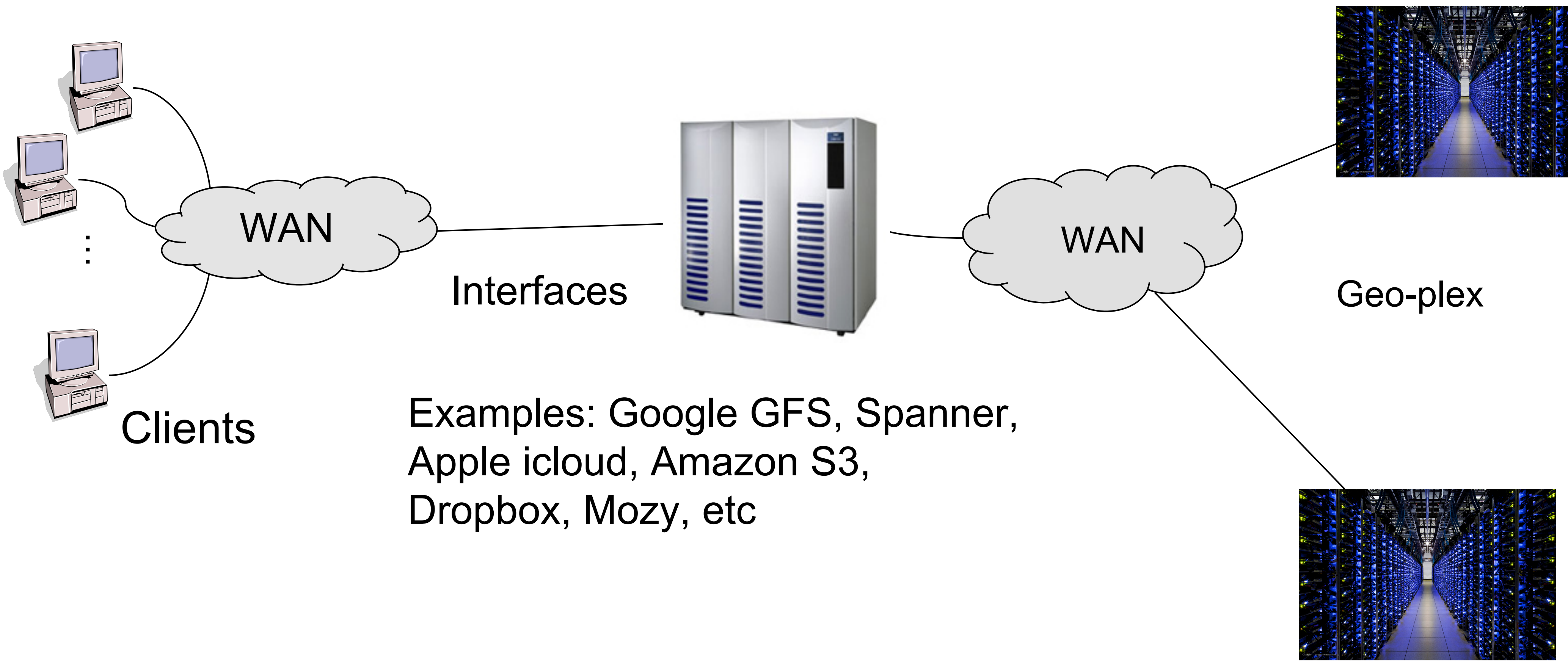
Evolved Data Center Storage Hierarchy



Alternative with no Tape



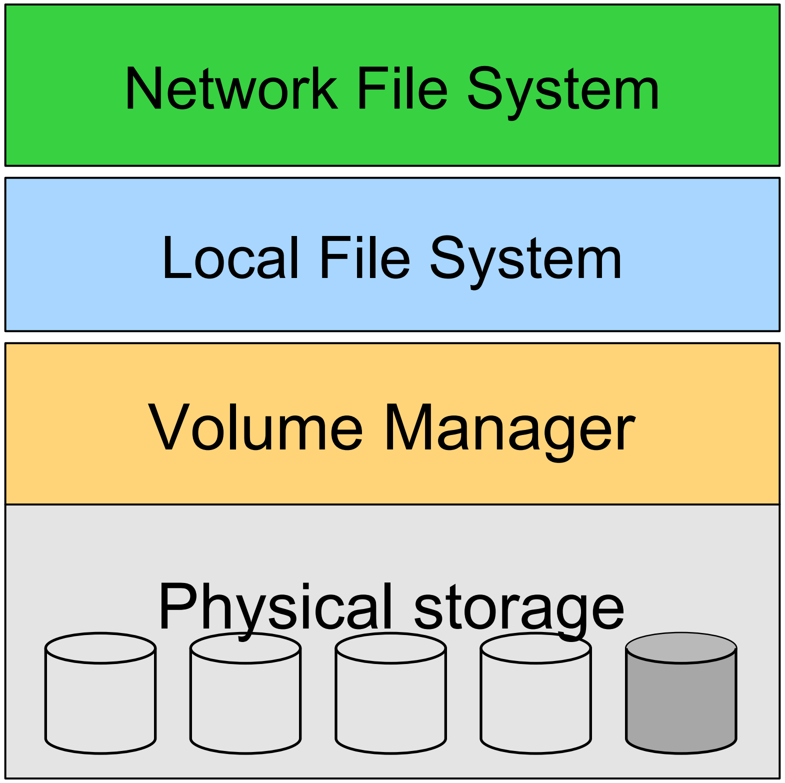
“Public Cloud” Storage Hierarchy



Examples: Google GFS, Spanner, Apple icloud, Amazon S3, Dropbox, Mozy, etc

Revisit File System Abstractions

- Network file system
  - Map to local file systems
  - Exposes file system API
  - NFS, CIFS, etc
- Local file system
  - Implement file system abstraction on block storage
  - Exposes file system API
- Volume manager
  - Logical volume of block storage
  - Map to physical storage
  - RAID and reconstruction
  - Exposes block API
- Physical storage
  - Previous lectures



Volume Manager

- Group multiple storage partitions into a logical volume
  - Grow or shrink without affecting existing data
  - Virtualization of capacity and performance
- Reliable block storage
  - Include RAID, tolerating device failures
  - Provide error detections at block level
- Remote abstraction
  - Block storage in the cloud
  - Remote volumes for disaster recovery
  - Remote mirrors can be split or merged for backups
- How to implement?
  - OS kernel: Windows, OSX, Linux, etc.
  - Storage subsystem: EMC, Hitachi, HP, IBM, NetApp

File versus Block Abstractions

File abstraction

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

- Emulate block storage interface

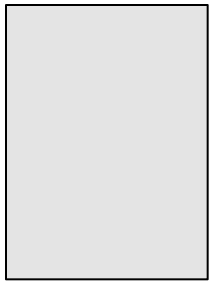
Disk/Volume abstraction

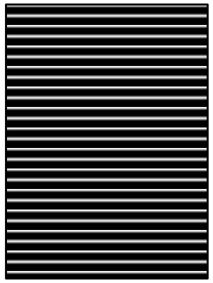
- Block oriented
- Block numbers
- No protection among users of the system
- Data might be corrupted if machine crashes

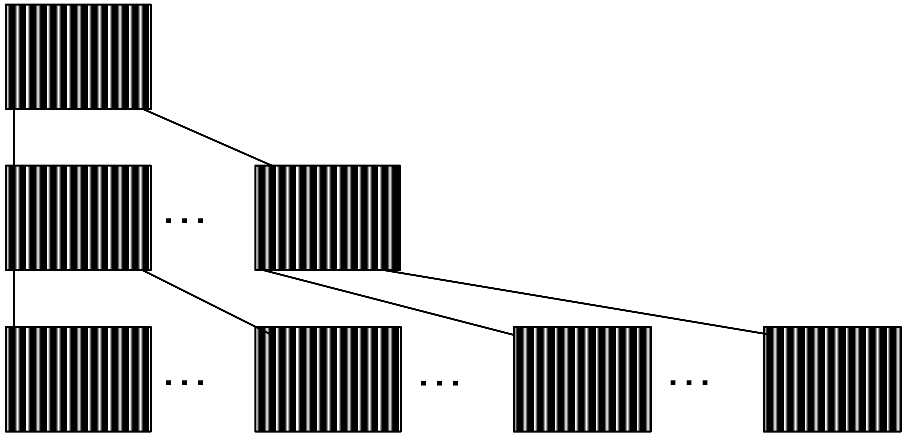
- Support file systems, database systems, etc.

File Structures

- Byte sequence
  - Read or write N 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
  - Record
  - Tree
  - An Unix executable file
    - header: magic number, sizes, entry point, flags
    - text
    - data
    - relocation bits
    - symbol table
- Devices
- Everything else in the system

File Operations

- Operations for "sequence of bytes" files
  - Create: create a file (mapping from a name to a file)
  - Delete: delete a file
  - Open: authentication
  - Close: done with 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 operations on directories: later
- Implementation challenges
  - Keep disk accesses low
  - Keep space overhead low

Access Patterns

- Sequential (the common pattern)
  - File data processed sequentially
  - Example: Editor writes out a file
- Random access
  - Access a block in file directly
  - Example: Read a message in an inbox file
- 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 it all in one cycle

File metadata

- Manage the mappings of files
- Map byte offset to disk block address
- Check access permission and illegal addressing
- Implemented in software, may cause I/Os

File System vs. Virtual Memory

- Similarity
  - Location transparency
  - Size "obliviousness"
  - Protection
- File system is easier than VM in some ways
  - File system mappings can be slow
  - Files are dense and mostly sequential, while page tables deal with sparse address spaces and random accesses
- File system is more difficult than VM in some ways
  - Each layer of translation causes potential I/Os
  - Memory space for caching is never enough
  - File size range vary: many < 10k, some > GB
  - Implementation must be reliable

Protection: Policy vs. Mechanism

- Policy is about what
- Mechanism is about how
- A protection system is the mechanism to enforce a security policy
  - Same set of choices, no matter what policies
- A security policy defines acceptable and unacceptable behaviors. Examples:
    - A given user can only allocate 4GB of disk storage
    - No one but root can write to the password file
    - A user is not allowed to read others' mail files

Protection Mechanisms

- Authentication
  - Identity check
    - Unix: password
    - Credit card: last 4 digits of credit card # + SSN + zipcode
    - Airport: driver’s license or passport
- 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

Authentication

- Usually done with passwords
  - Relatively weak, because you must remember them
- Passwords are stored in an encrypted form
  - Use a “secure hash” (one way only)
- Issues
  - Passwords should be obscure, to prevent “dictionary attacks”
  - Each user has many passwords
- Alternatives?

Protection Domain

- Once identity known, provides rules
  - E.g. what is Bob allowed to do?
- Protection matrix: domains vs. resources

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

By Columns: Access Control Lists (ACLs)

- Each object has a list of
  <user, privilege> pairs
- ACL is simple, implemented in most systems
  - Owner, group, world
- Implementation considerations
  - Stores ACLs in each file
  - Use login authentication to identify
  - Kernel implements ACLs
- Any issues?

By Rows: Capabilities

- For each user, there is a capability list
  - A lists of <object, privilege> pairs
- Capabilities provide both naming and protection
  - Can only “see” an object if you have a capability
- Implementation considerations
  - Architecture support
  - Capabilities stored in the kernel
  - Capabilities stored in the user space in encrypted format
- Issues?

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 there is a bug, the entire system could 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; }”
- Listener
  - Passively watch network traffic

No Perfect Protection System

- Cannot prevent bad things, can only make it difficult to do them
- There are always ways to defeat protection
  - burglary, bribery, blackmail, bludgeoning, etc.
- Every system has holes

Summary

- Storage hierarchy can be complex
  - Reliability, security, performance and cost
  - Many things are hidden
- Key storage layers above hardware
  - Volume or block storage
  - Local file system
  - Network file system
- Protection
  - ACL is the default in file systems
  - More protection is needed in the cloud