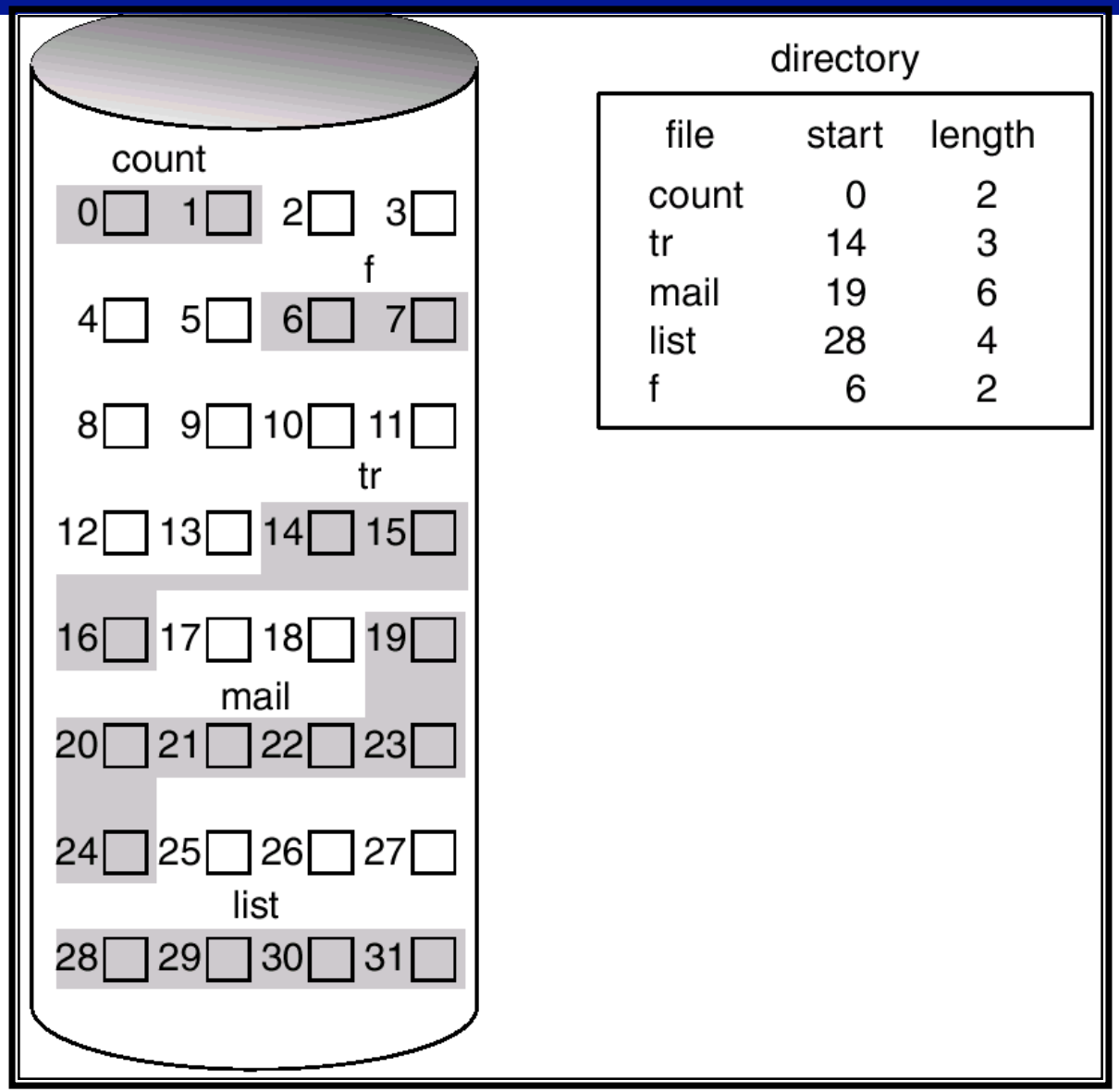
File system implementation

- Virtual File Systems - easily change underlying storage mechanisms to local or remote
- Directory Implementation: Linear list, Hash table
- Allocation: Contiguous (fragmentation), linked allocation (FAT), Indexed Allocation (single level, multilevel)
- Free space management: Bit vector, Linked list, Grouping, Counting
- Recovery and consistency checking

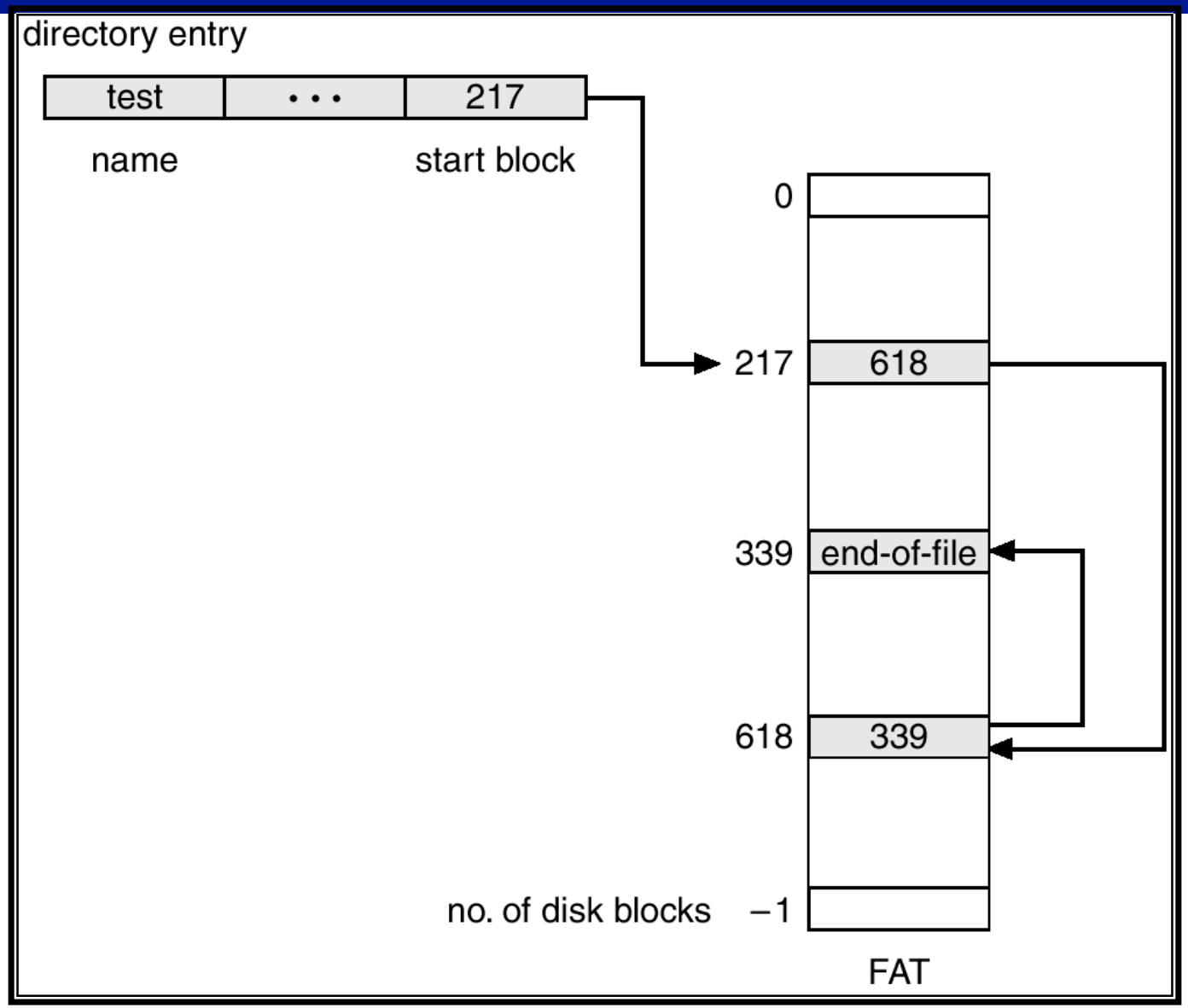
Contiguous allocation



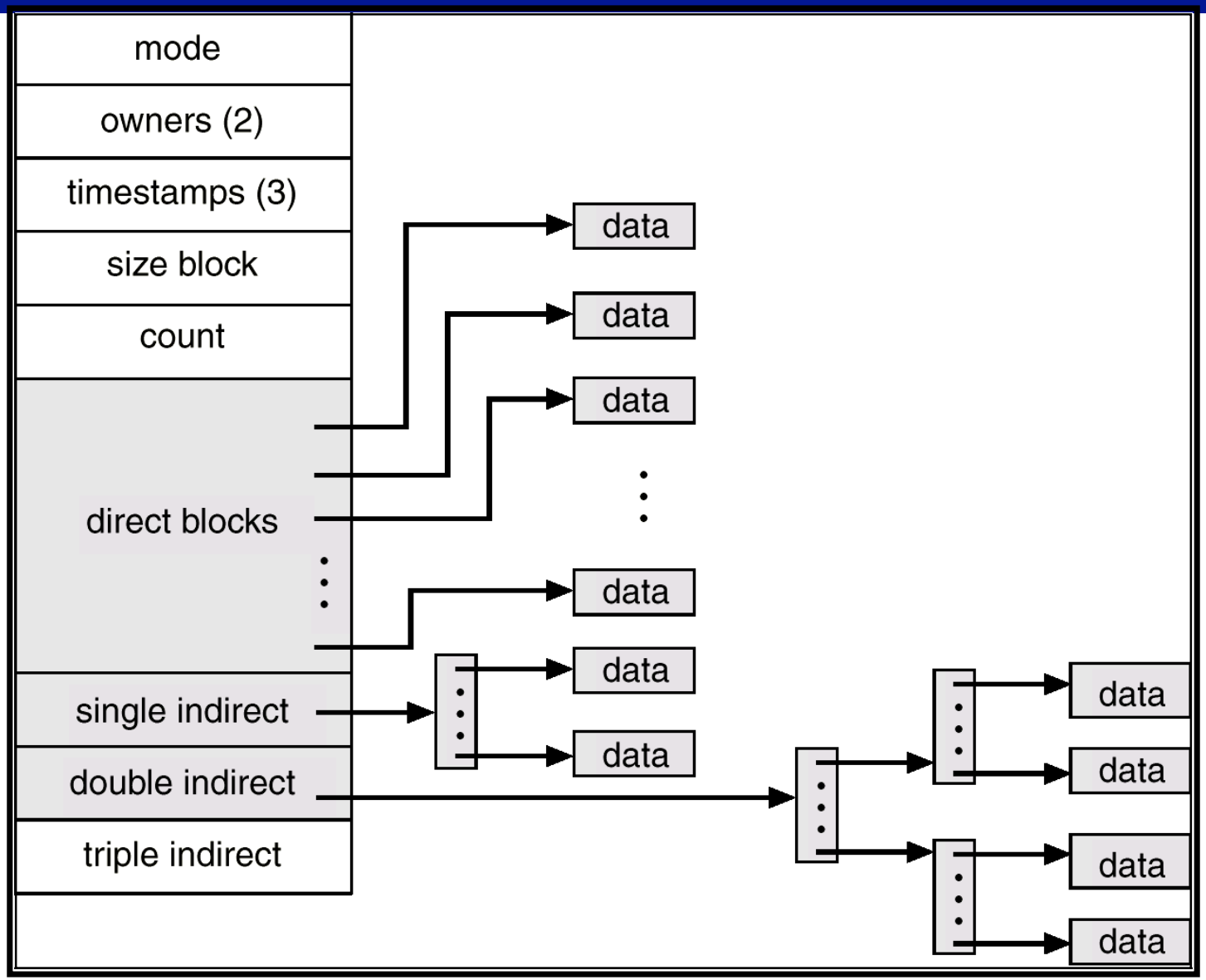
directory

file	start	length
count	0	2
tr	14	3
mail	19	6
list	28	4
f	6	2

File allocation table (FAT)



Unix - Indexed allocation



Backups

- Backup and restore: Towers of Hanoi style levels
  - Full+Incremental backups
  - Level 0 - full
  - level n takes all changes since last, lower numbered level
  - E.g. 0, 5, 6, 3, 5, 6
  - Full, 5-0, 6-5, 3-0, 5-3, 6-5
- Log structured file system
  - Provide transactional guarantees for critical meta-data
- Pathname translation:
  - Multilevel directories in order from the root
  - Caching to improve performance
  - /usr/local/bin/ls would be /, /usr, /usr/local, /usr/local/bin ..

LFS

- **Log structured** (or journaling) file systems record each update to the file system as a **transaction**.
- All transactions are written to a **log**. A transaction is considered **committed** once it is written to the log. However, the file system may not yet be updated.
- The transactions in the log are asynchronously written to the file system. When the file system is modified, the transaction is removed from the log.
- If the file system crashes, all remaining transactions in the log must still be performed.

SAN vs NAS

- Storage area network (SAN)
  - Provides a block storage abstraction and clients can build file systems on top of it
  - High speed fibre interconnects
  - More expensive
- Network Attached storage (NAS)
  - Exports a file system view (NFS, CIFS)
  - Ethernet interconnect

Network File System (NFS)

- Network protocol built over UDP/TCP
- NFS is a stateless protocol - server does not maintain information about files
  - Does not know clients that are accessing a file
  - No implicit state
  - Recovery is easy, clients reissue the commands
  - Execute mostly once semantics
  - No write caching on server, writes are synchronous
  - Newer versions allow time stamped block caching
    - TTL for client caching

Andrew File System (AFS)

- Global name space
- Security through Kerberos
- Whole file caching
  - Utilize client disk cache
- Call back invalidation
  - On conflict, AFS server will issue a callback
  - Server should remember invalidation tokens across crash
  - Network partitions?
- Last writer wins semantics

Trace driven analysis of the UNIX file system

- Rather old, but seminal. Influenced much of file system design for a long time

- Studies like these are extremely important to understand how typical users are using a file system so that you can tune for performance

- The key is to trace the “typical user population”.
  - Academics do not have access to commercial work loads
  - Chicken and Egg syndrome: Users perform certain tasks because current systems perform poorly.
    - E.g. users may backup their work into a separate file every so often because of poor consistency guarantees.
    - UNIX vi editor saves files by deleting old file, creating a new file with the same name, writing all the data and then closing. If the system crashes after creating and write, before close, data is left in buffers which are lost, leading to a 0 byte file. It happened a lot and so programs create backup files often.

Important conclusions

- Most files are small; whole file transfer and open for short intervals. Most files are short lived. Caching really works.
- UNIX used files as intermediate data transfer mechanisms:
  - E.g. compiler
    - Preprocessor reads .c file -> .i file
    - CC1 reads .i -> .asm file and deletes .i file
    - Assembler reads .asm -> .o file and deletes .asm file
    - Linker reads .o -> executable and deletes .o file
- One solution: Make /tmp an in-memory file system

```
df /tmp
Filesystem           1k-blocks      Used Available Use% Mounted on
swap                   1274544      1776   1272768   1% /tmp
```

Most files are read sequentially

- UNIX provides no support for structured files
- Applications that provide structured access (data bases) use raw file interface and by-pass operating systems
- Solution:
  - Read-ahead to improve performance

Most file accesses are to the same directory

- UNIX has a hierarchical file system structure
- Typical academic users compile, word process from one directory and so all accesses are to a single directory
- File systems such as Coda, AFS have notions of volumes, cells that capture this
- Does this apply to Windows?

Most files are small

- On a departmental machine with 8 MB of main memory, what else do you expect
- Is it true now with our Netscape, xemacs, IE, Power point etc?
- Relatively, it may still be true. On a 60 GB hard disk, 1 MB file may be “small”

Berkeley FFS

- tunefs -p /

  tunefs: ACLs: (-a) disabled
  tunefs: MAC multilabel: (-l) disabled
  tunefs: soft updates: (-n) disabled
  tunefs: maximum blocks per file in a cylinder group: (-e) 2048
  tunefs: average file size: (-f) 16384
  tunefs: average number of files in a directory: (-s) 64
  tunefs: minimum percentage of free space: (-m) 8%
  tunefs: optimization preference: (-o) time

- Another seminal paper describing a file system that is heavily optimized and used in FreeBSD, Mac OSX (default is HFS)
- Optimize page placement, and block sized to reflect newer usage patterns

LFS

- Files are only written to logs, there is no traditional file system backing up the LFS
- Write performance is much improved, especially for small files