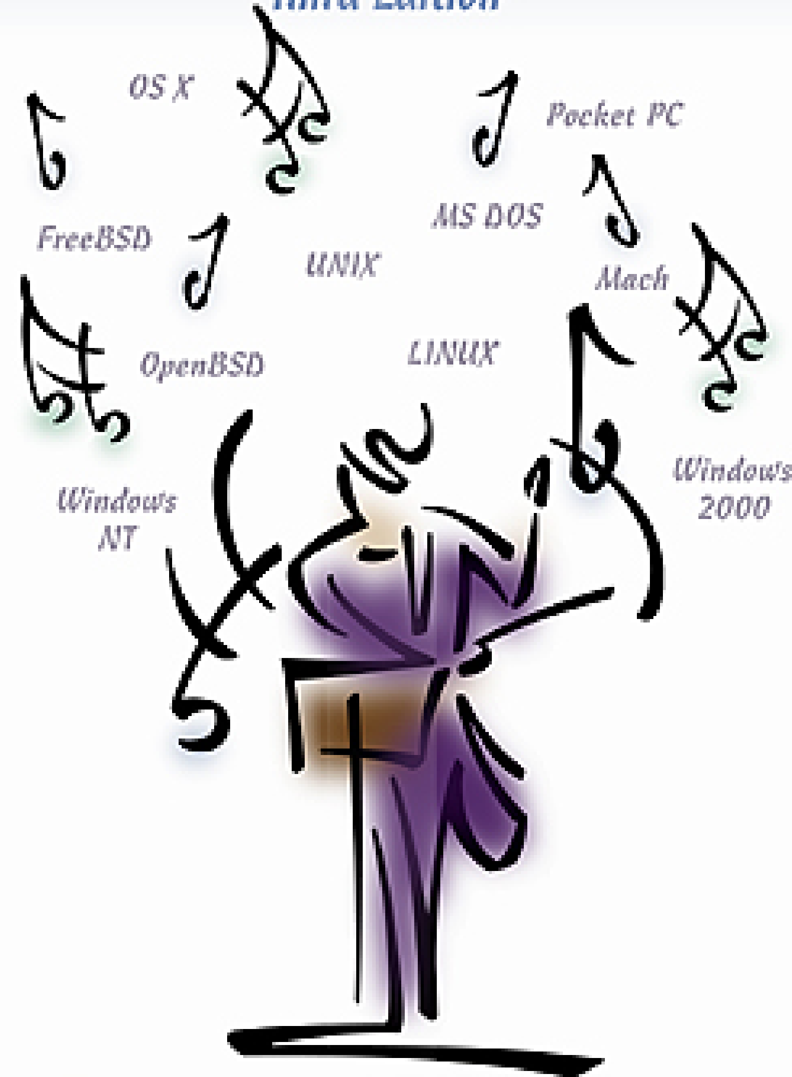
# OPERATING SYSTEMS

*Third Edition*





GARY NUTT

# File Management

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# Fig 13-2: The External View of the File Manager

Application Program

mount()
write()
close()
open()
read()
lseek()

CreateFile()
WriteFile()
CloseHandle()
ReadFile()
SetFilePointer()

File Mgr
Device Mgr
Memory Mgr
Process Mgr

UNIX

File Mgr
Device Mgr
Memory Mgr
Process Mgr

Windows

Hardware

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# Why Programmers Need Files

HTML Editor

```
<head>
…
</head>
<body>
…
</body>
```

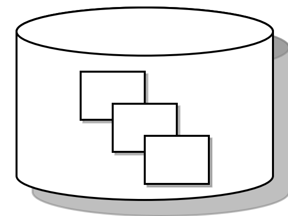
Web Browser

File Manager

foo.html

```
<head>
…
</head>
<body>
…
</body>
```

File Manager



- Persistent storage
- Shared device

- Structured information
- Can be read by any applic
  - Accessibility
  - Protocol

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# File Management

- *File* is a named, ordered collection of information
- The file manager administers the collection by:
  - Storing the information on a device
  - Mapping the block storage to a logical view
  - Allocating/deallocating storage
  - Providing file directories
- What abstraction should be presented to programmer?

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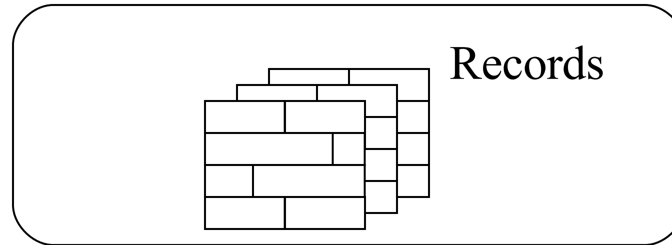
# Information Structure

Applications



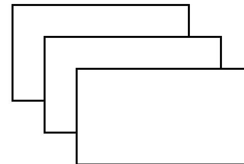

Structured Record Files

Record-Stream Translation

Byte Stream Files

Stream-Block Translation

Storage device



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# Byte Stream File Interface

```
fileID = open(fileName)
close(fileID)
read(fileID, buffer, length)
write(fileID, buffer, length)
seek(fileID, filePosition)
```

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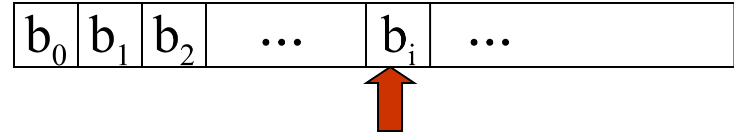
# Low Level Files

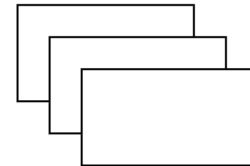
```
fid = open("fileName",…);
…
read(fid, buf, buflen);
…
close(fid);
```




```
int open(…) {…}
int close(…) {…}
int read(…) {…}
int write(…) {…}
int seek(…) {…}
```

Stream-Block Translation

Storage device response to commands



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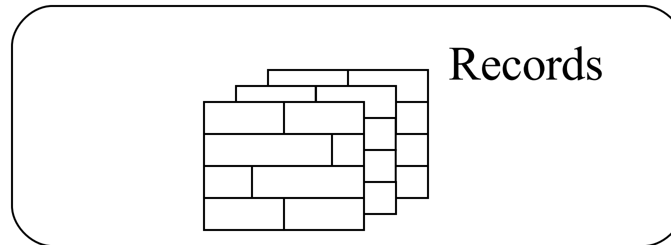
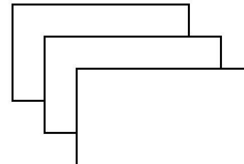
# Structured Files




Record-Block Translation



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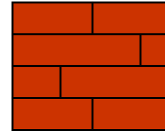
# Record-Oriented Sequential Files



Logical Record

```
fileID = open(fileName)
close(fileID)
getRecord(fileID, record)
putRecord(fileID, record)
seek(fileID, position)
```

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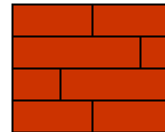
# Record-Oriented Sequential Files



Logical Record

H byte header k byte logical record

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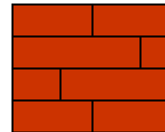
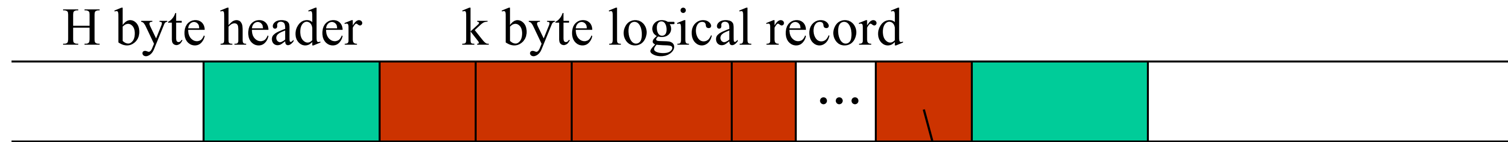
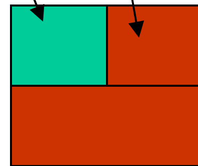
# Record-Oriented Sequential Files

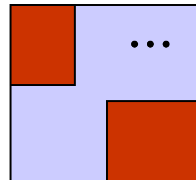


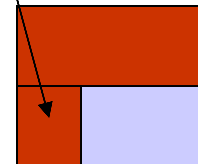
Logical Record

H byte header    k byte logical record





Physical Storage Blocks

Fragment

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# Electronic Mail Example

```
struct message {
/* The mail message */
   address to;
   address from;
   line subject;
   address cc;
   string body;
};
struct message *getRecord(void) {
    struct message *msg;
    msg = allocate(sizeof(message));
    msg->to = getAddress(...);
    msg->from = getAddress(...);
    msg->cc = getAddress(...);
    msg->subject = getLine();
    msg->body = getString();
    return(msg);
}
```

```
putRecord(struct message *msg) {
    putAddress(msg->to);
    putAddress(msg->from);
    putAddress(msg->cc);
    putLine(msg->subject);
    putString(msg->body);
}
```

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# Indexed Sequential File

- Suppose we want to directly access records
- Add an *index* to the file

```
fileID = open(fileName)
close(fileID)
getRecord(fileID, index)
index = putRecord(fileID, record)
deleteRecord(fileID, index)
```

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# Indexed Sequential File (cont)

Application structure

| Account # | Index |
|---|---|
| 012345 | |
| 123456 | i |
| 294376 | k |
| ... | |
| 529366 | j |
| ... | |
| 965987 | |

index = i

index = k

index = j

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# More Abstract Files

- Inverted files
  - *System index* for each datum in the file
- Databases
  - More elaborate indexing mechanism
  - DDL & DML
- Multimedia storage
  - Records contain radically different types
  - Access methods must be general

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# Implementing Low Level Files

- Secondary storage device contains:
  - Volume directory (sometimes a root directory for a file system)
  - External file descriptor for each file
  - The file contents
- Manages blocks
  - Assigns blocks to files (descriptor keeps track)
  - Keeps track of available blocks
- Maps to/from byte stream

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# Disk Organization



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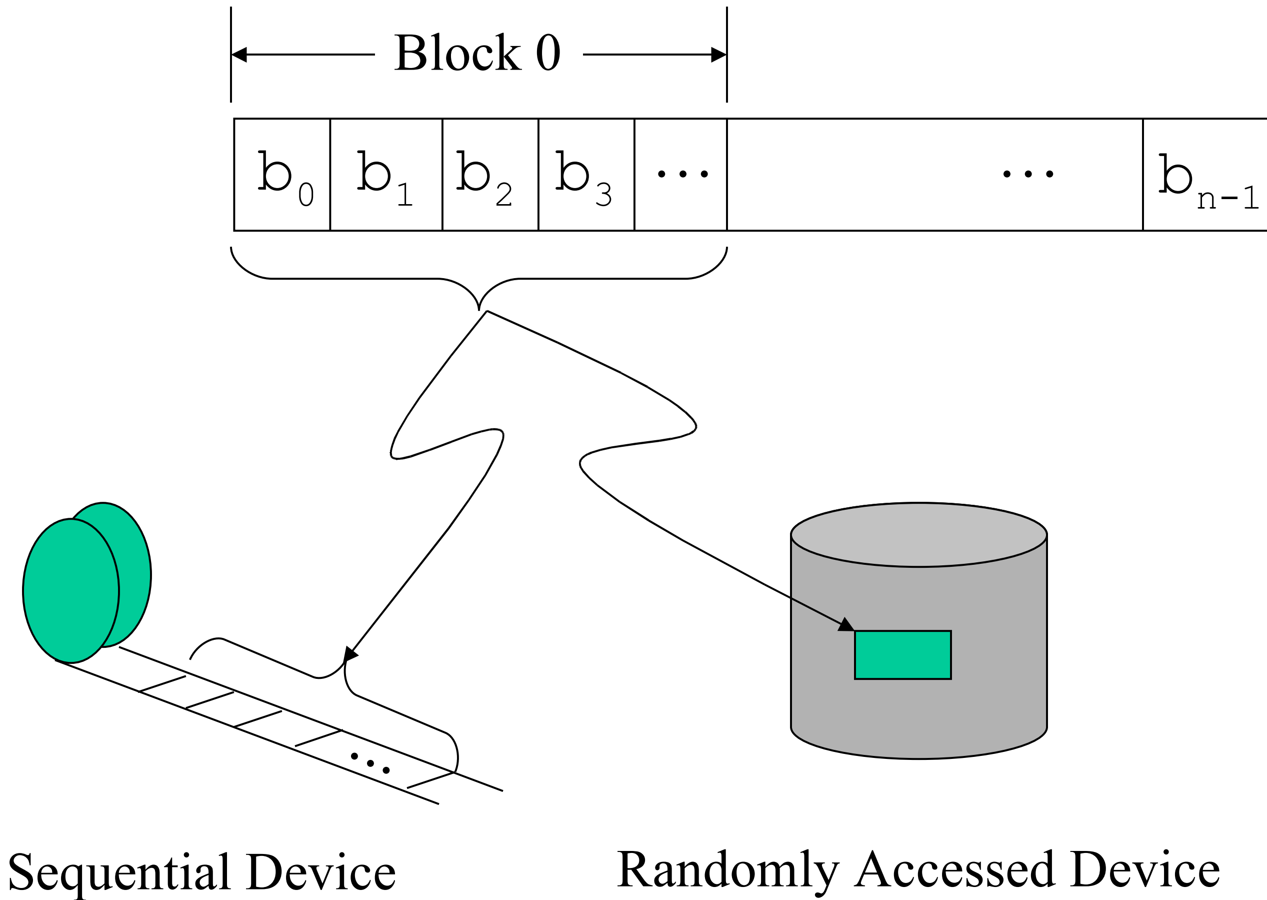
# Low-level File System Architecture

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# File Descriptors

- External name
- Current state
- Sharable
- Owner
- User
- Locks
- Protection settings
- Length
- Time of creation
- Time of last modification
- Time of last access
- Reference count
- Storage device details

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# An `open()` Operation

- Locate the on-device (external) file descriptor
- Extract info needed to read/write file
- Authenticate that process can access the file
- Create an internal file descriptor in primary memory
- Create an entry in a “per process” open file status table
- Allocate resources, e.g., buffers, to support file usage

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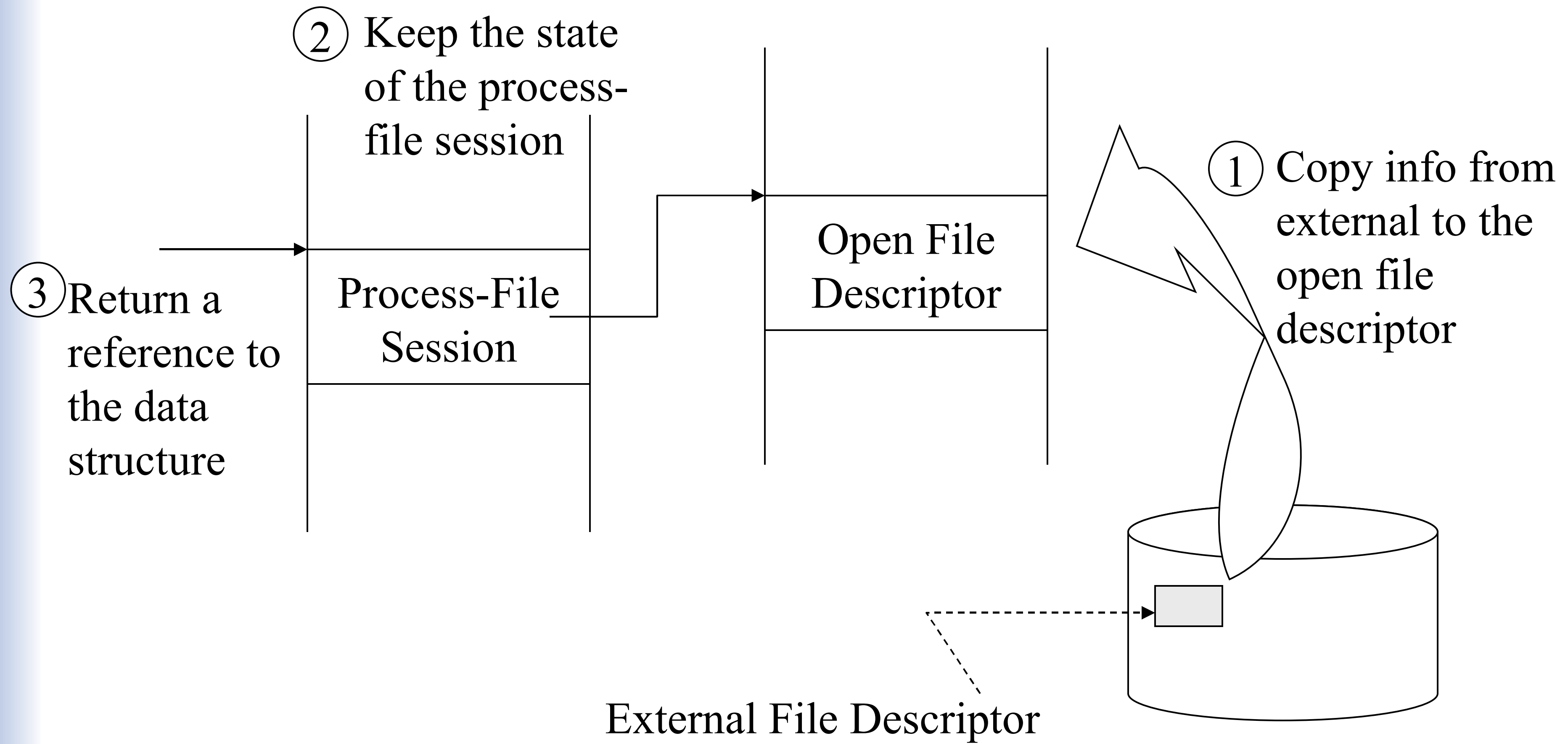
# File Manager Data Structures

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# Opening a UNIX File

```
fid = open("fileA", flags);
…
read(fid, buffer, len);
```

| | |
|---|---|
| 0 | stdin |
| 1 | stdout |
| 2 | stderr |
| 3 | ... |
| | |

Open File Table

File structure

On-Device File Descriptor

inode

Internal File Descriptor

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# Block Management

- The job of selecting & assigning storage blocks to the file
- For a fixed sized file of k blocks
  - File of length m requires $N = \quad m/k \quad$ blocks
  - Byte $b_i$ is stored in block $\quad i/k$
- Three basic strategies:
  - Contiguous allocation
  - Linked lists
  - Indexed allocation

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# Contiguous Allocation

- Maps the N blocks into N contiguous blocks on the secondary storage device
- Difficult to support dynamic file sizes

File descriptor

| | |
|---|---|
| Head position | 237 |
| … | |
| First block | 785 |
| Number of blocks | 25 |

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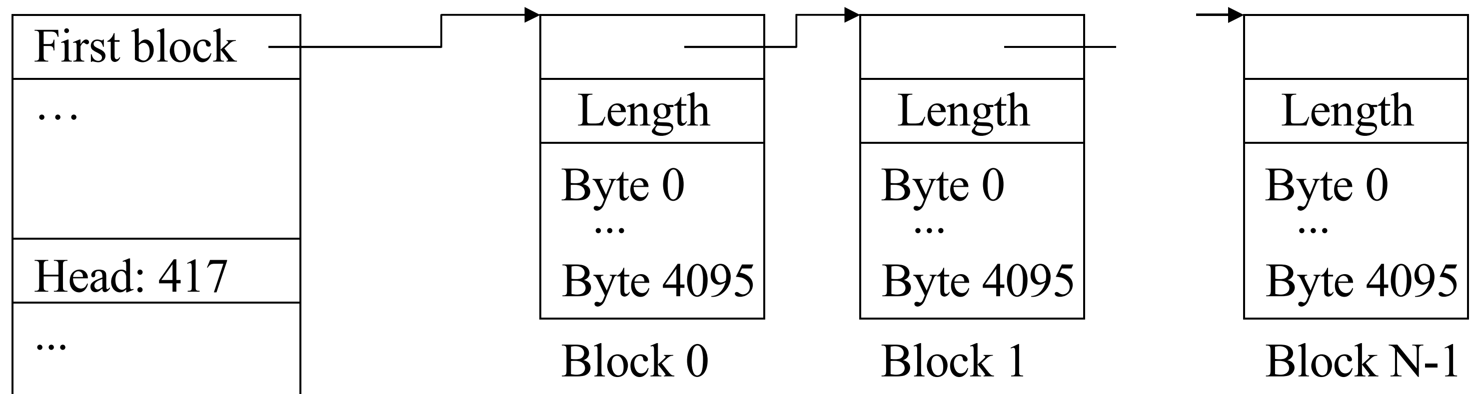
# Linked Lists

- Each block contains a header with
  - Number of bytes in the block
  - Pointer to next block
- Blocks need not be contiguous
- Files can expand and contract
- Seeks can be slow

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# Indexed Allocation

- Extract headers and put them in an index
- Simplify seeks
- May link indices together (for large files)



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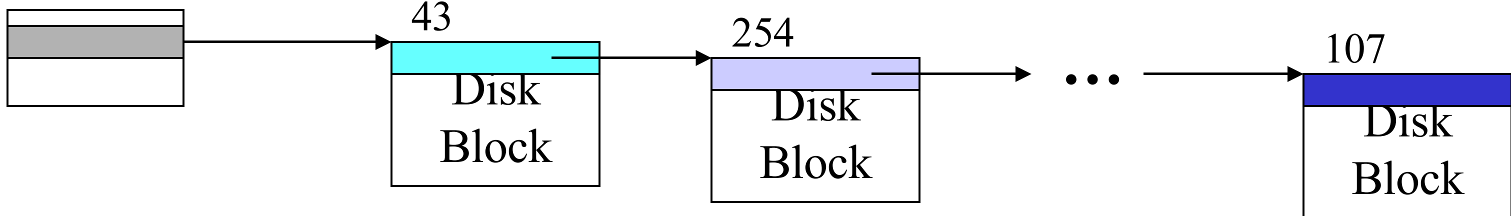
# DOS FAT Files



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# UNIX Files

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# Unallocated Blocks

- How should unallocated blocks be managed?
- Need a data structure to keep track of them
  - Linked list
    - Very large
    - Hard to manage spatial locality
  - Block status map ("disk map")
    - Bit per block
    - Easy to identify nearby free blocks
    - Useful for disk recovery

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# Marshalling the Byte Stream

- Must read at least one buffer ahead on input
- Must write at least one buffer behind on output
- Seek flushing the current buffer and finding the correct one to load into memory
- Inserting/deleting bytes in the interior of the stream

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# Full Block Buffering

- Storage devices use block I/O
- Files place an explicit order on the bytes
- Therefore, it is possible to predict what is likely to be read after $byte_i$
- When file is opened, manager **reads** as many blocks **ahead** as feasible
- After a block is logically written, it is queued for **writing behind**, whenever the disk is available
- Buffer pool – usually variably sized, depending on virtual memory needs
  - Interaction with the device manager and memory manager

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# Directories

- A set of logically associated files and sub directories
- File manager provides set of controls:
  - `enumerate`
  - `copy`
  - `rename`
  - `delete`
  - `traverse`
  - etc.

# Directory Structures

- How should files be organized within directory?
  - Flat name space
    - All files appear in a single directory
  - Hierarchical name space
    - Directory contains files and subdirectories
    - Each file/directory appears as an entry in exactly one other directory -- a *tree*
    - Popular variant: All directories form a tree, but a file can have multiple parents.

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# Directory Implementation

- Device Directory
  - A device can contain a collection of files
  - Easier to manage if there is a root for every file on the device -- the device root directory
- File Directory
  - Typical implementations have directories implemented as a file with a special format
  - Entries in a file directory are handles for other files (which can be files or subdirectories)

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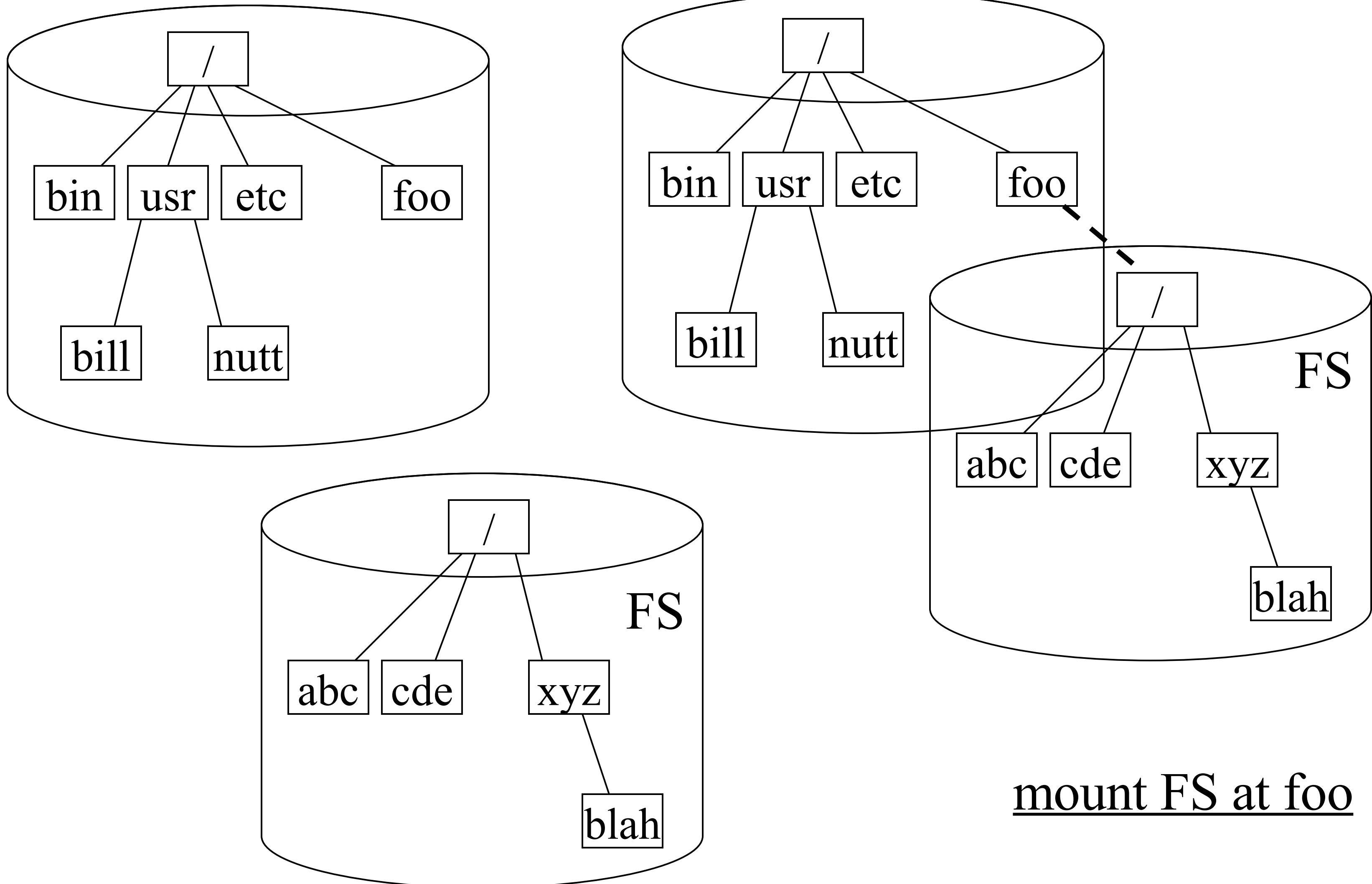
# UNIX `mount` Command

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# VFS-based File Manager

Exports OS-specific API

File System Independent Part of File Manager

Virtual File System Switch

MS-DOS Part of File Manager

ISO 9660 Part of File Manager

…

ext2 Part of File Manager

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