File Systems

Today

- Files and access methods
- Directory structures
- Sharing and protection
- File & directory implementation

Next

- File system management & examples

Files and file systems

Most computer applications need to:

- Store large amounts of data (larger than their address space)
- that must survive process termination and
- can be access concurrently by multiple processes

→ Usual answer: Files – from user's perspective, the smallest allotment of logical secondary storage

File system – part of the OS dealing with files

- Supports the file abstraction of storage
- Naming – how do users select files?
- Protection – users are not all equal
- Reliability – information must be safe for long periods of time
- Storage mgmt. – efficient use of storage and fast access to files

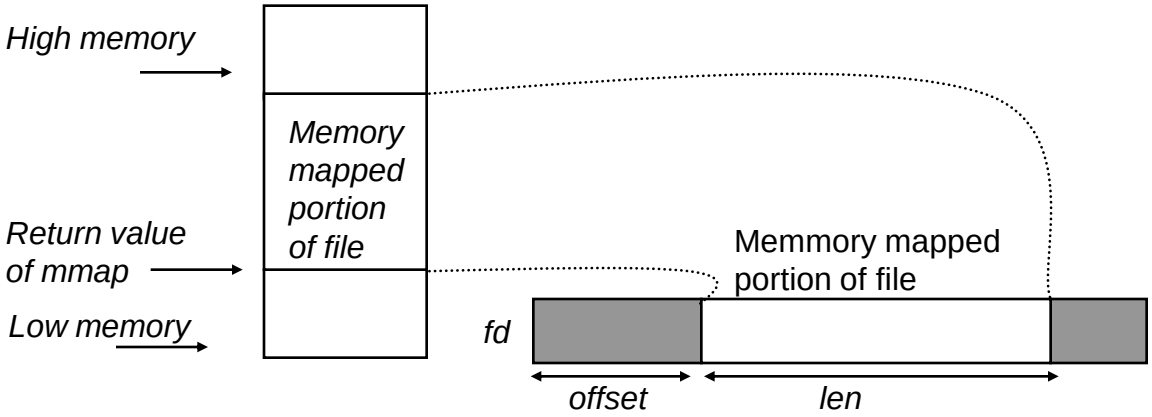
File – attributes, types and operations

- Files are collection of data with some attributes
  - Names & type, if supported, location, owner, last read/write times, …
- Different OSs support different file types
  - Regular, binary, directories, …
  - Character special (model terminals [/dev/tty], printers, etc) and block special files (model disks [/dev/hd1])
  - Extensions as hints & the use of magic numbers
    - Some typical file extensions
  - Pros and cons of strongly typed files
- Basic operations
  - Create, delete, write, read, file seek, truncate
  - Other operations can be built on this basic set (e.g. cp)

Memory-mapped files

- Accessing files & accessing memory
- Key idea – file is backing store of mapped memory
- Some problems
  - Not all files can be mapped
  - If file mapped is an output one, what's the size?
  - File mapped by one and open conventionally by another?!?
  - File size larger than virtual address space?!?

```
void  *
mmap(void *start,
     size_t length,
     int prot,
     int flags,
     int fd,
     off_t offset);
```



File structures & access methods

- Several file structures, three common ways
  - Byte sequence - Unix & Windows; user imposes meaning
  - Record sequence – think about 80-column punch cards
  - Tree – records have keys, tree is sorted by it
- Sequential Access – tape model
  - Read/write next; simplest and most common
- Random/direct access – disk model
  - Two approaches: read/write x, or position to x and read/write
  - Retain sequential access – read/write + update last position
- Other access methods
  - On top of direct access, normally using indexing
  - Multi-level indexing for big files (e.g. IBM Indexed Sequential Access Method)

Directory structure

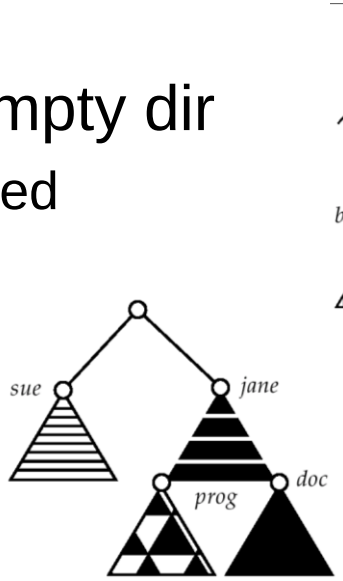
- To manage volume of info.: partitions & directories
- Directory: set of nodes with information about all files
  - Name, type, address, current & max. length, …
- Operations on directories
  - Open/close directories, create/delete/rename files from a directory, readdir, link/unlink, traverse the file system
- Directory organizations - goals
  - Efficiency – locating a file quickly.
  - Naming – convenient to users.
  - Grouping – logical grouping of files by properties (e.g. all Java progs., all games, …)

File system mounting

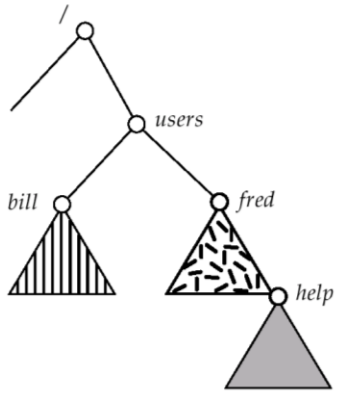
- A FS must be mounted to be available
  - What do you do if you have more than one disk? Put a self contained FS on each (*C:…)* or…
- Typically, a mount point is an empty dir
  - Existing file system (a) & unmounted partition (b)
  - After it was mounted (c)

```
# mount /dev/sda1 /users
```

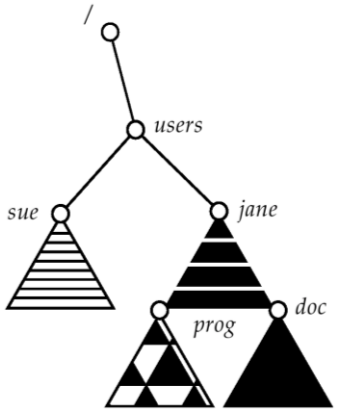
- `fstab` file in Unix



(b)



(a)

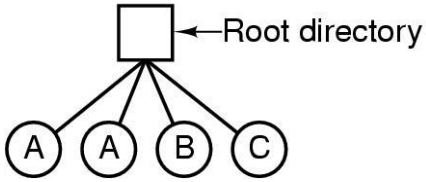


(c)

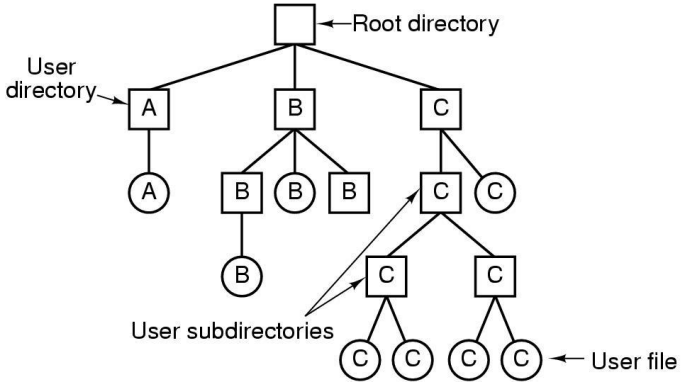
```
(10:41am) ~ % more /etc/fstab
# This file is edited by fstab-sync - see 'man fstab-sync' for details
LABEL=/           /           ext3    defaults        1 1
none              /dev/pts    devpts  gid=5,mode=620  0 0
/dev/sdb1         /export     ext3    defaults        1 2
none              /proc       proc    defaults        0 0
none              /dev/shm    tmpfs   defaults        0 0
LABEL=/usr        /usr        ext3    defaults        1 2
…
```

Single and hierarchical directory systems

- A single level directory system
  - Early PCs & supercomp. (CDC 6600), embedded systems?
  - Fast file searches, but name clashing



- Hierarchical
  - Avoid name clashing for users (MULTICS)
  - Powerful structuring tool for organization (decentralization)



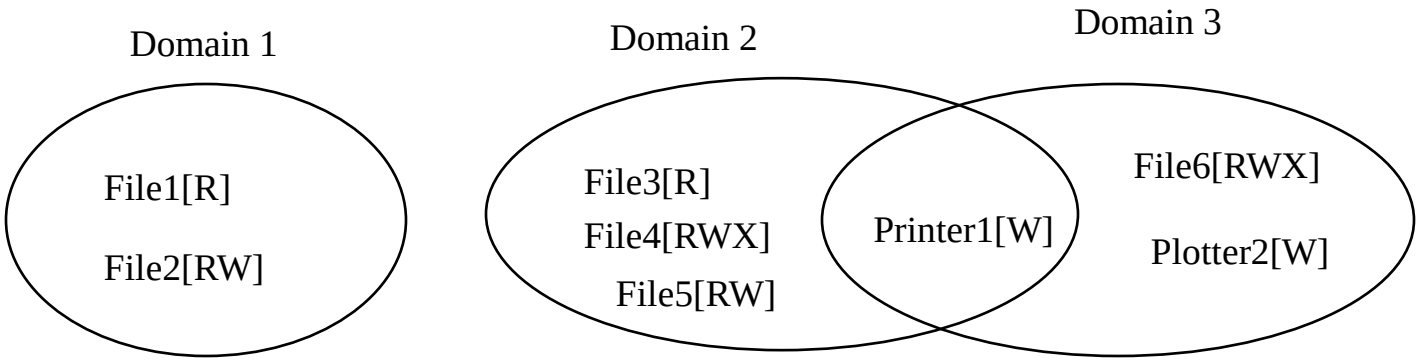
- Path names
  - Now you need a way to specify file names; two approaches:
    - Absolute `cp /home/fabianb/.aliases /home/fabianb/aliases.bak`
    - Relative path names & working directory `cp .aliases aliases.bak`
  - "." & ".."

Protection …

- FS must implement some kind of protection system
  - to control who can access a file (user)
  - to control how they can access it (e.g., read, write, or exec)
- More generally:
  - generalize files to objects (the “what”)
  - generalize users to principals (the “who”, user or program)
  - generalize read/write to actions (the “how”, or operations)
- A protection system dictates whether a given action performed by a given principal on a given object should be allowed
  - e.g., you can read or write your files, but others cannot
  - e.g., your can read /etc/motd but you cannot write to it

Protection …

- Useful to discuss protection mechanisms: domains
  - A domain – a set of *(object, rights)* pairs
  - At every instant in time, process runs in some domain
    - In Unix, this is defined by (UID, GID); exec a process with SETUID or SETGID bit on is effectively switching domains



Protection domains

- Keeping track of domains
- Conceptually, a large protection matrix

	Object							
Domain	File1	File2	File3	File4	File5	File6	Printer1	Plotter2
1	Read	Read Write						
2			Read	Read Write Execute	Read Write		Write	
3						Read Write Execute	Write	Write

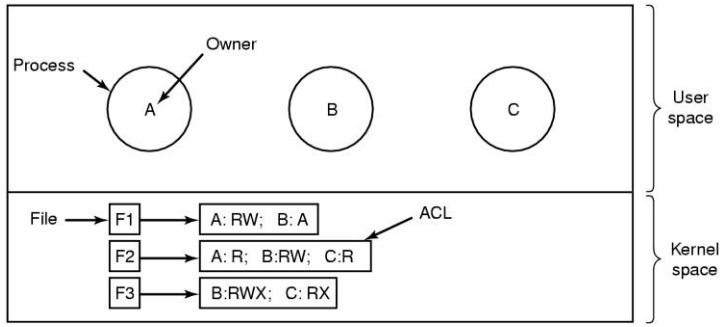
- A protection matrix with domains as objects
  - Now you can control domain switching

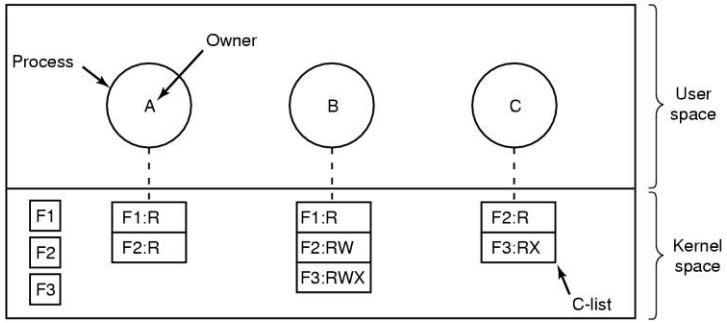
	Object										
main	File1	File2	File3	File4	File5	File6	Printer1	Plotter2	Domain1	Domain2	Domain3
1	Read	Read Write								Enter	
2			Read	Read Write Execute	Read Write		Write				
3						Read Write Execute	Write	Write			

- A global table – too large & sparse …

Implementing access matrices

- Access control list
  - Associating w/ each object a list of domain that may access it (and how)
  - Users, groups and roles
- Capabilities
  - Slice the matrix by rows
  - Associate w/ process a list of objects & rights
  - Need to protect the C-list
    - Tagged architectures (IBM AS/400)
    - Keep it in the kernel (Hydra)
    - Manage them cryptographically (Amoeba)
- *Capabilities are faster to use but do no support selective revocation*





Protection

- Unix: short version access lists & groups
  - Objects – individual files
  - Principals – owners/group/world (the domain of a process is given by its UID and GID)
  - Actions: read, write, execute (3 bits per access mode)
  - Mask provides a default (creation with 777, mask 022 → 755)
- More general access lists - setfacl & getfacl

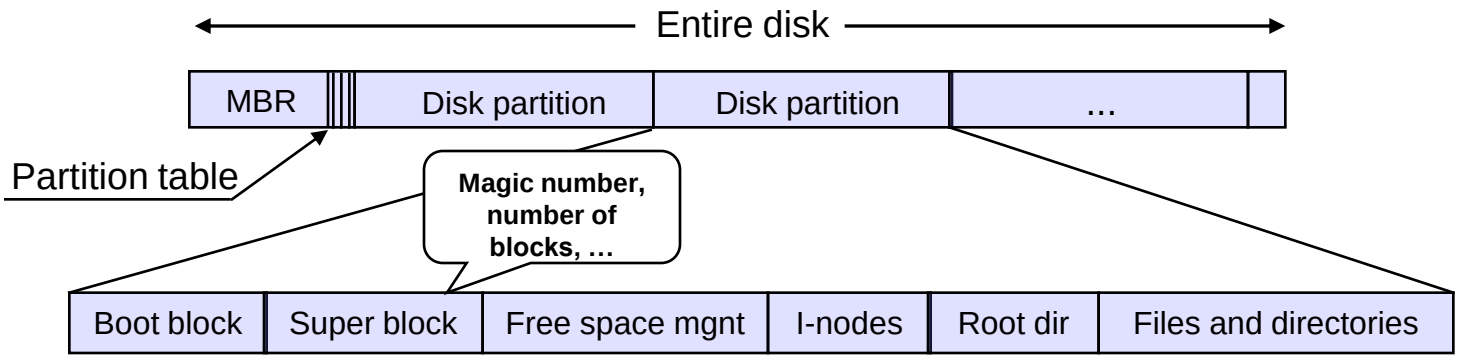
```
% getfacl -a exam.tex
 # file: exam.tex
 # owner: fabianb
 # group: other
 user::rw-
 group::r--     #effective:r--
 mask:r--
 other:r--
```

Intersection of specified permissions and mask field.

```
% setfacl -r -m u:sbirrer:rw-  exam.tex
% getfacl -a exam.tex
 # file: exam.tex
 # owner: fabianb
 # group: other
 user::rw-
 user:sbirrer:rw-      #effective:rw-
 group::r--            #effective:r--
 mask:rw-
 other:r--
```

File system layout

- Disk divided into 1+ partitions – one FS per partition
- Sector 0 of disk – MBR (Master Boot Record)
  - Used to boot the machine
- Followed by Partition Table (one marked as active)
  - (start, end) per partition; one of them active
- Booting: BIOS → MBR → Active partition's boot block → OS
- What else in a partition?

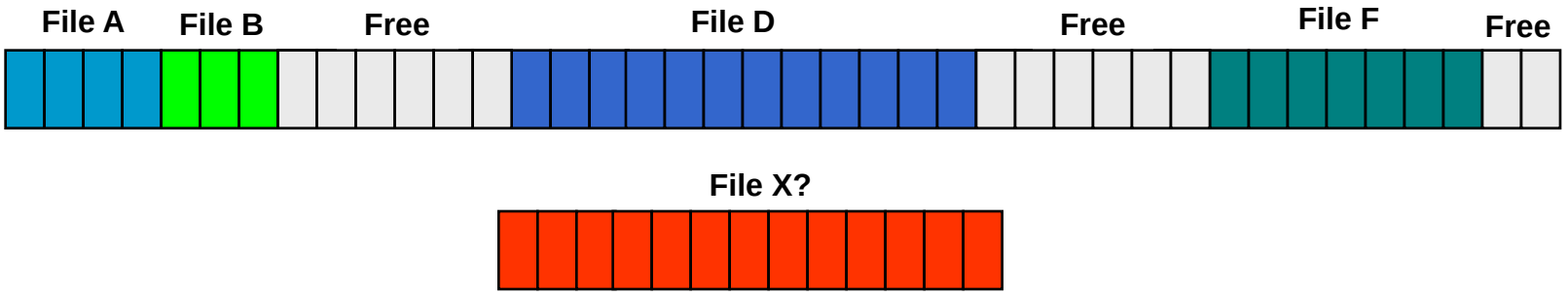


Implementing files

Keeping track of what blocks go with which file

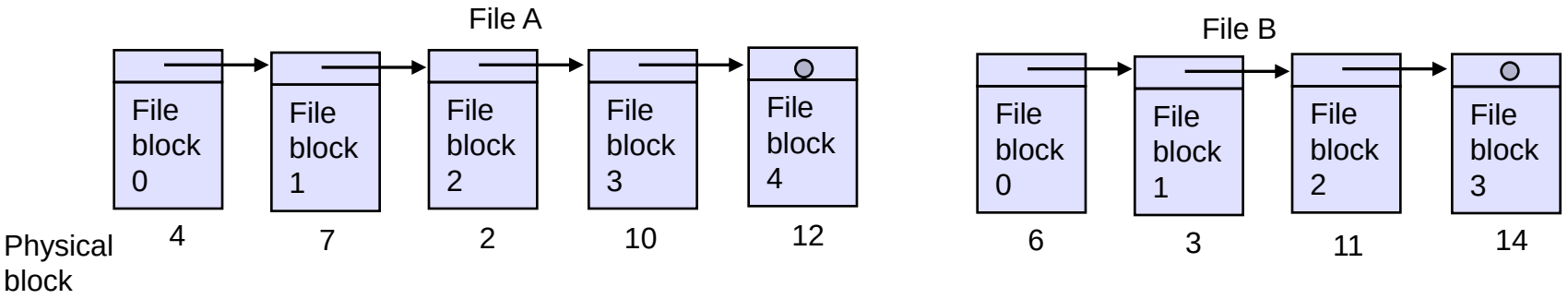
- Contiguous allocation
  - Each file is a contiguous run of disk blocks
  - e.g. IBM VM/CMS
  - Pros:
    - Simple to implement
    - Excellent read performance
  - Cons:
    - Fragmentation

Where would it make sense?



Implementing files

- Linked list
  - Files as a linked list of blocks
  - Pros:
    - Every block gets used
    - Simple directory entry per file (address of first block)
  - Cons:
    - Random access is a pain
    - List info in block → block data size not a power of 2
    - Reliability (file kept together by pointers scattered throughout the disk)



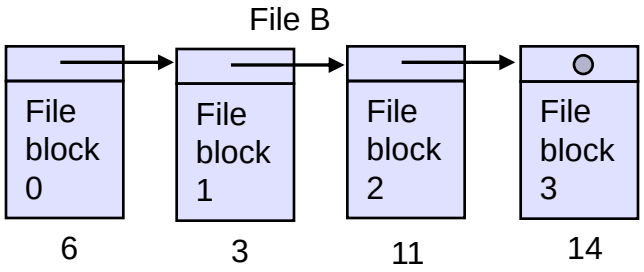
Implementing files

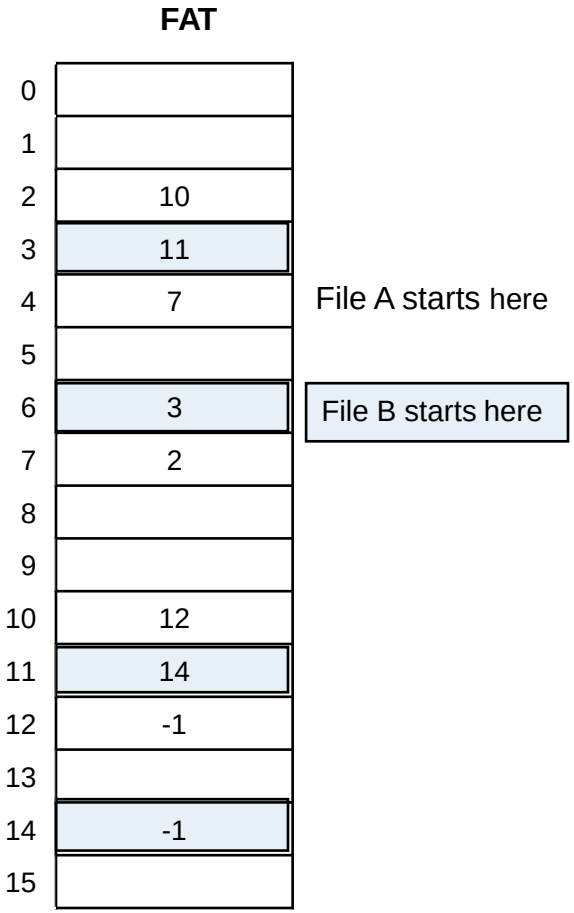
- Linked list with a table in memory
  - Files as a linked list of blocks
  - Pointers kept in FAT (File Allocation Table)
  - Pros:
    - Whole block free for data
    - Random access is easy
  - Cons:
    - Overhead on seeks or
    - Keep the entire table in memory

    20GB disk & 1KB block size →

    20 million entries in table →

    4 bytes per entry ~ 80MB of memory

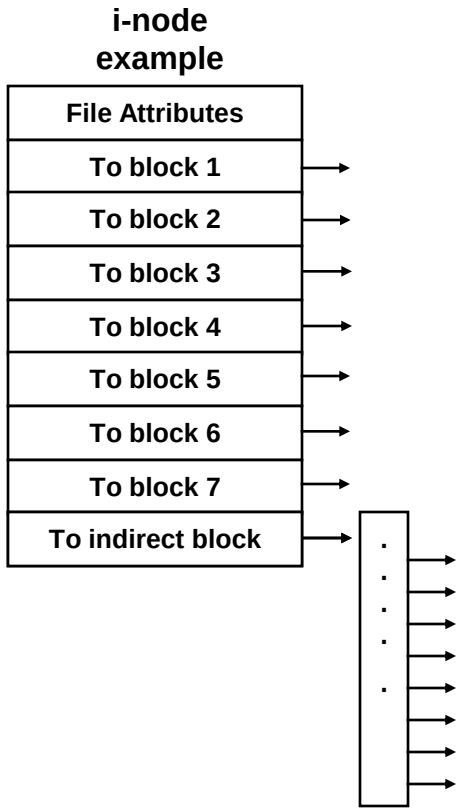




Implementing files

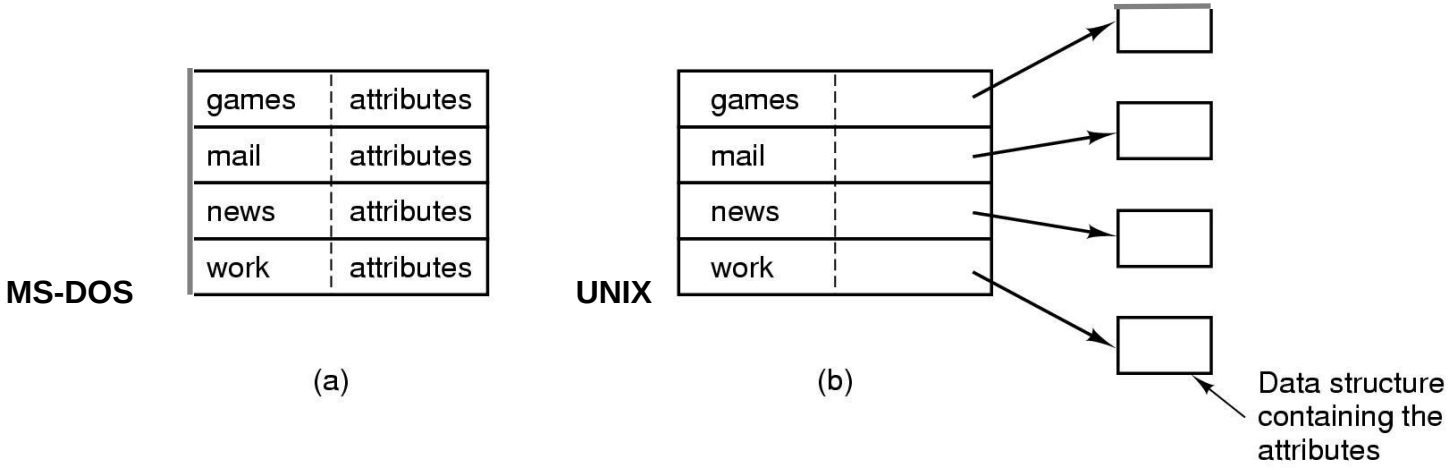
- I-nodes - index-nodes
  - Files as linked lists of blocks, all pointers in one location: i-node
  - Each file has its own i-node
  - Pros:
    - Support direct access
    - No external fragmentation
    - Only a file i-node needed in memory (proportional to # of open files instead of to disk size)
  - Cons:
    - Wasted space (how many entries?)
  - More entries – what if you need more than 7 blocks?

Save entry to point to address of block of addresses



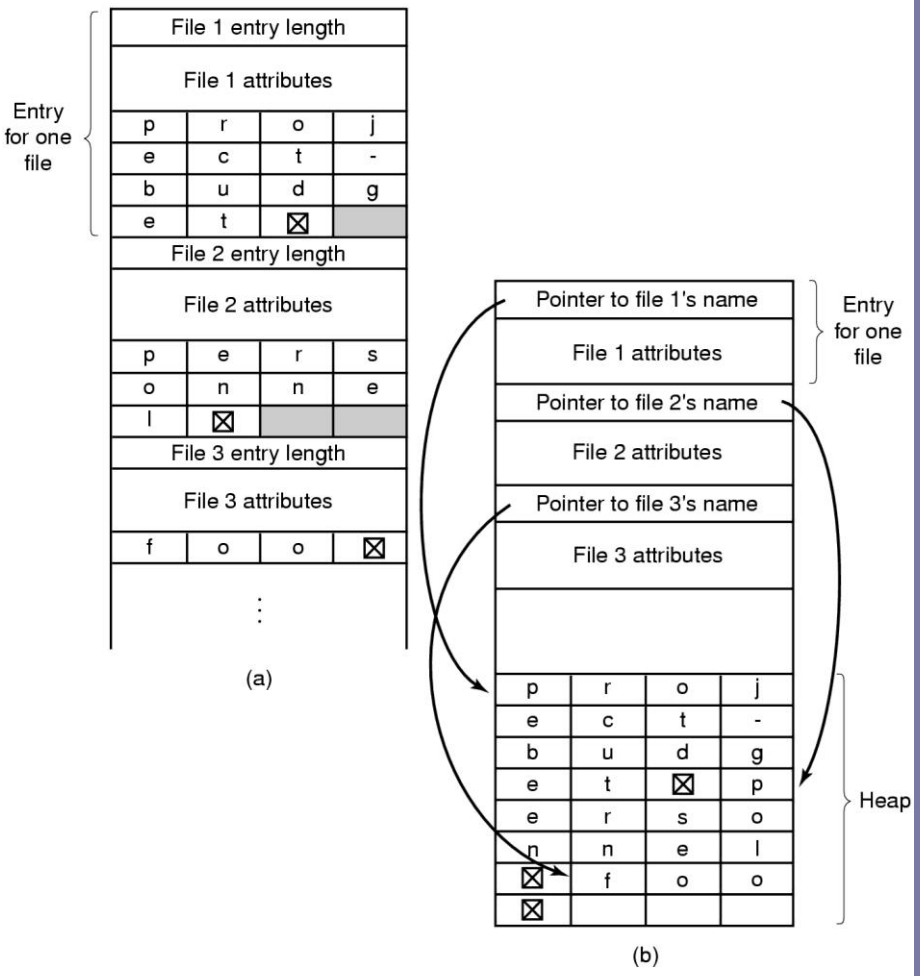
Implementing directories

- Directory system function: map ASCII name onto what's needed to locate the data
- Related: where do we store files' attributes?
  - A simple directory: fixed size entries, attributes in entry (a)
  - With i-nodes, use the i-node for attributes as well (b)
- As a side note, you find a file based on the path name; this mixes what your data is with where it is – *what's wrong with this picture?*



Implementing directories

- So far we've assumed short file names (8 or 14 char)
- Handling long file names in directory
  - In-line (a)
    - Fragmentation
    - Entry can span multiple pages (page fault reading a file name)
  - In a heap (b)
    - Easy to +/- files
- Searching large directories
  - Hash
  - Cash



Path name translation

- To open a file such as “/a/b/c” for editing

  fd = open (“/a/b/c”, O_RDWR);
- What does it take?
  - Open directory “/” (well known)
  - Search directory, for “a”, get location of “a”
  - Open directory “a”, search directory, for “b”, get location of “b”
  - Open directory “b”, search for “c”, get location for “c”
  - Open “c”
- FS spend a lot of time at this
  - This is why we use open first
  - OS can then cache prefix lookups to enhance performance
  - “/”, “/a”, “/a/b”, …

Shared files

- Links and directories implementation
  - Leave file's list of disk blocks out of directory entry (i-node)
    - Each entry in the directory points to the i-node
  - Use symbolic links
    - Link is a file w/ the path to shared file
    - Good for linking files from another machine
- Problem with first solution
  - Accounting
    - C creates file, B links to file, C removes it
    - B is the only user of a file owned by C!
- Problem with symbolic links
  - Performance (extra disk accesses)

Next Time

- Details on file system implementations and some examples …