Lecture# 19: File system – data layout, naming

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Review -- 1 min

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Intro to I/O
Performance model: Log
Disk physical characteristics/desired abstractions

Physical reality	**Desired abstraction**
disks are slow	fast access to data
sector addresses (“platter 2, cylinder 42, sector 15”)	named files, directories
write 1 sector at a time	atomic writes, transactions

1.1 Case study: sector layout

What is the fastest way to lay out a sequential file on disk

answer 1:
a series of sequential sectors on a track

problem (in old systems)
read sector 1
process sector 1
read sector 2 -- whoops, sector 2 is already past
wait 1 rotation
read sector 2
…
→ N rotations to read N blocks
→ BW for sequential read is 512 bytes/rotation = 100KB/s

answer 2: (in old systems)
skip 1 sector (or 2 sectors) between sequential blocks
→ 2 rotations to read N blocks

answer 3: (modern systems)
track buffer -- on-disk cache
read entire sector into track buffer
in parallel (once sector 1 arrives…) read sector 1 (from track)
then read sector 2
…
→ 1 rotation to read N blocks

Moral: OS designer needs to understand physical properties of disk

Latency, overhead, bandwidth:
From disk -- what is overhead for a 1-sector read?
what is latency for a 1-sector read?
what is bandwidth term for a 1-sector read?
From CPU/memory system

- what is overhead for a 1-sector read
- what is latency for a 1 sector read
- what is BW term for a 1-sector read

Be careful: What is end-to-end average bandwidth for a 1-sector read (people phrase this question to mean end-to-end bytes/sec including latency and overhead)

2. Technology trends

1. Disks getting smaller for similar capacity

smaller → disk spins faster (less rotational delay, higher BW)
smaller → less distance for head to travel (faster seeks)
smaller → lighter weight (for portables)

2. disk data getting denser (more bits/square inch; allows smaller disks w/o sacrificing capacity)

Tracks closer together → faster seeks

3. Disks getting cheaper (2x/year since 1991)
4. Disks getting (a little) faster
   seek, rotation – 5-10%/year (2-3x per decade)
   bandwdith – 20-30%/year (~10x per decade)

Overall – disk density ($/byte) improving much faster than mechanical limitations (seek, rotation)

Key to improving density: get head close to surface

Heads are spring loaded, aerodynamically designed to fly as close to surface as possible (also, lightweight to allow for faster seeks)

What happens if head contacts surface? Head crash – scrapes off magnetic material (and data)

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Outline - 1 min

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Data layout
-- given a file header, find the file's blocks

mechanism v. policy

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Preview - 1 min

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File systems
- Performance -- data layout
- Performance/persistence -- naming
- Reliability -- transactions

Networks
Security

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Lecture - 20 min

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3. Data layout on disk

2 driving forces
1) technology: avoid seeks, rotation
(last time)

2) workloads:
How do users access files?

1. Sequential access – bytes read in order (give me the next X bytes, then give me the next)
2. Random access - read/write elements out of middle of array (give me bytes j-k)

How are files typically used?
1. Most files are small (e.g. .login, .c files)
2. Large files use up most of the disk space
3. Large files account for most of the bytes transferred to/from disk

Bad news: need everything to be efficient
- Need small files to be efficient since lots of them
- need large files to be efficient, b/c most of the disk space, most of the I/O due to them

4. Disk management mechanisms

How do we organize files on disk?

recall – seeks are slow,
for good bandwidth lay data out on disk sequentially

2 tasks
(1) find ith block of a file easily
(2) quickly access ith block of file

common data structures
file header – one per file; which disk sectors are associated with each file
- Head of linked list, array, root of tree → find ith block of file

What about performance
Separate mechanism from policy – once I can find where ith block of file is no matter where it is, then I have freedom to place any block anywhere → policy choice to lay data out sequentially when possible.

TO support such policies:
free space (bitmap) – 1 bit per block or sector; blocks numbered in cylinder-major order, so that adjacent numbered blocks can be accessed without seeks or rotational delay

Other aspect of performance
caching – every OS today keeps a cache of recently used disks blocks in memory to avoid having to go to disk. Common to all organizations. For now, assume no cache; add it later.

4.1 contiguous allocation

User says in advance how big file will be

Search bit map (using best fit/first fit) to locate space for file

File header contains:

- first sector in file
- file size (# sectors)

Pros & cons:
+ fast sequential access
+ easy random access
DA: external fragmentation
DA: hard to grow files

4.2 Linked files

Each block, pointer to next on disk (Xerox Alto)

(DRAW PICTURE)

file header – points to first block on disk

Pros&cons
+ can grow files dynamically
+ free list managed same as file
DA: sequential access horrible: seek between each block
DA: random access is horrible
DA: unreliable (lose block, lose rest of file)

4.3 FAT (MS-DOS, Windows9x, OS2)

Store liked list in separate table ("File allocation table")

A table entry for each block on disk
Each table entry in a file has pointer to next table entry in file (with special "eof" value to mark end)

Use "0" value to mean "free" (why not just put free elements on linked free list?)

compare to linked allocation
Sequential access
OK if FAT is cached
How much memory to cache entire FAT?
10GB disk/1KB sector = 10M entries ~~40MB!
→ FAT allocates larger "clusters"
→ policy -- try to allocate different parts of file near each other (reduces disk seeks and improves FAT cachability)

Random access
Reliability
Can replicate FAT if you want…

4.4 Indexed files (VMS)

User declares max file size

file header holds array of pointers big enough to point to file size number of blocks

<PICTURE>

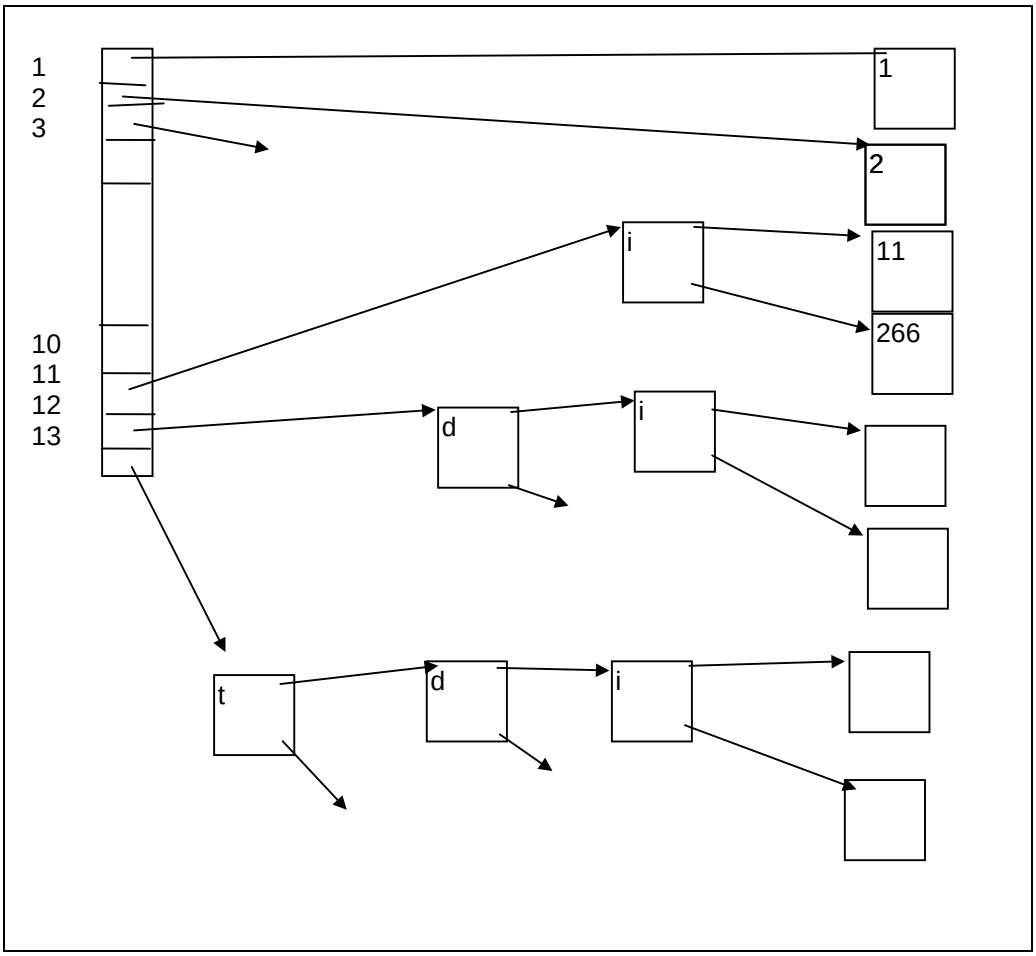
+ can easily grow up to space allocated for descriptor
+ random access is fast
DA: clumsy to grow file bigger than table size
DA: still lots of seeks

4.5 Multilevel index (Unix 4.1)

Key idea: efficient for small files, but still allow big files

file header 13 poiners (fixed sized table; *not all pointers equivalent)*

- first 10 – point to data blocks
- 11th – pointer to indirect block - pointer to a block of pointers
  - gives us 256 blocks + 10 from file header = ¼ MB
- what if you allocate a 267th block? Pointer to doubly indirect block – a block of pointers to indirect blocks (in turn block of pointers to data blocks); gives about 64K blocks → 64MB
- triply-indirect block – block of pointers to doubly indirect blocks (which are…)



1) Bad news: still an upper limit on file size (16 GB)
2) pointers get filled in dynamically: need to allocate indirect blocks only when file grows > 10 blocks; if small file, no indirection needed
3) How many disk accesses to reach block #23? Which are they?
   Block 5?
   Block 340?

UNIX pros&cons
+ simple (more or less)
+ files can easily expand (up to a point)
+ small files particularly cheap and easy
DA: very large files spend lots of time reading indirect blocks
   (but caching makes sequential I/O work well)
DA: lots of seeks

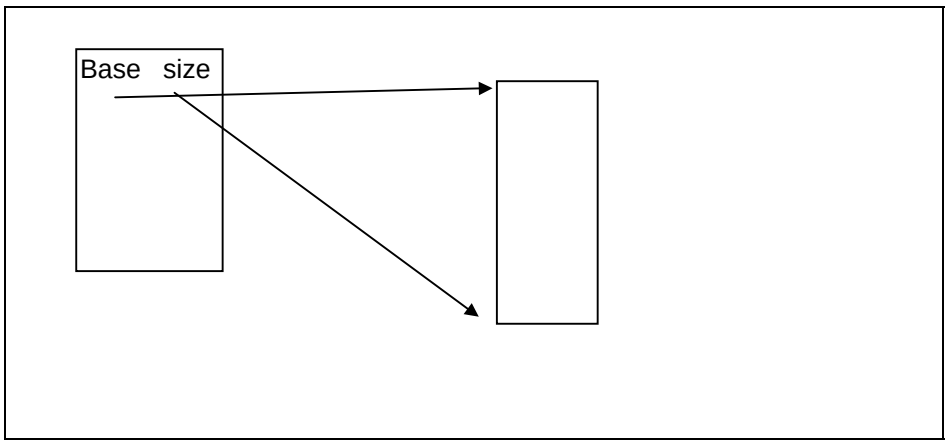
4.6 DEMOS

OS for Cray1 (mid to late 70's) – File system approach corresponds to segmentation

Cray1 had 12ns cycle time, so CPU:disk speed ratio about the same as today (a few million instructions = 1 seek)

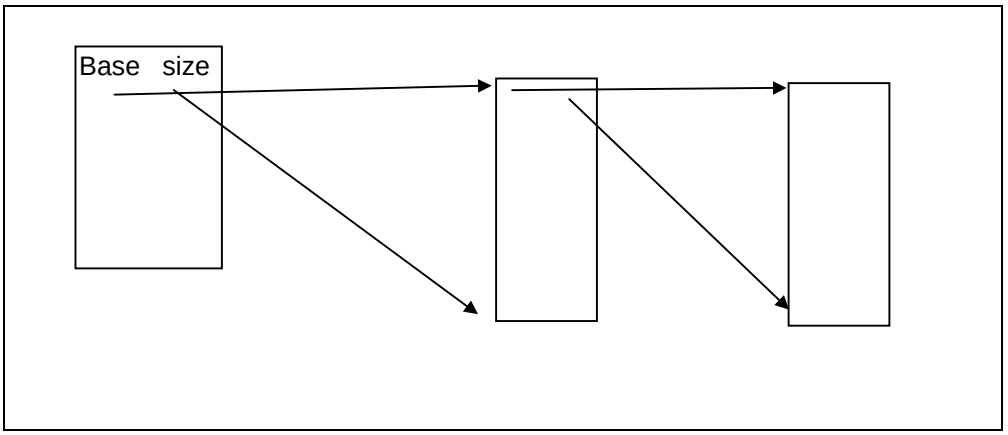
Idea: reduce disk seeks by using contigous allocation in normal case, but allow flexibility to have non-contiguous allocation

file header table of base&size (10 "block group" pointers)



Each "block group" a contiguous region of blocks

Are 10 block groups pointers enough? No. If need more than 10 block groups, set flag in file header BIGFILE
→ each table entry now points to an indirect block group – a block group of pointers to block groups



Can get huge files this way: suppose 100 blocks in a block group (can be bigger or smaller) → 10GB file size

QUESTION: How do you allocate a block group?
A: use bit map to find block of 0's

Pros&cons
+ easy to find free block group
+ free areas merge automatically
DA when disk fills up
a) no long runs of free blocks (fragmentation)
b) high CPUoverhead to find free block

In practice disks are always full!

Solution: don't let disks get full – keep pointers in reserve
normally, don't even try to allocate if free count == 0
change this to
don't allocate if free count < reserve

Why do this?
Tradeoff – pay for more disk space, get contiguous allocation

How much reserve do you need?
In practice, 10% seems like enough

4.7 UNIX BSD 4.2

(Most current unices)

Policy v. mechanism

Same mechanisms as BSD 4.1 (same file header, triply indirect blocks)
except incorporate some ideas from DEMOS:

- uses bitmap allocation in place of free list
- attempt to allocate files contiguously
- 10% reserve disk space

- skip sector positioning

Problem: when you create a file, don't know how big it will become (in UNIX most writes are by appending to file) So how much contiguous space do you allocate for a file when it is created?

In Demos, power of 2 growth: once it grows past 1MB, allocte 2MB, etc

IN BSD 4.2, just find some range of free blocks, put each new file at front of a different range. When need to expand a file, you first try successive blocks in bitmap

sequential files
processing overhead can cause problems
read 1 block, process, read next block…
While processing, disk was turning. If have to wait for entire rotation, bad performance. GO from reading @ disk BW to readig 1 sector per rotation

Two solutions:

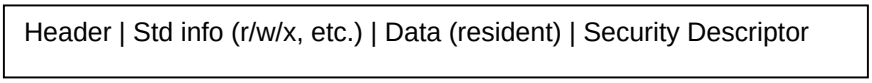
- skip sector positioning (BSD 4.2)
- read ahead/disk track buffers – read next block right after first, even if application hasn't asked for it yet. This could be done either by OS (read ahead) or disk itself (track buffers)

4.8 NTFS

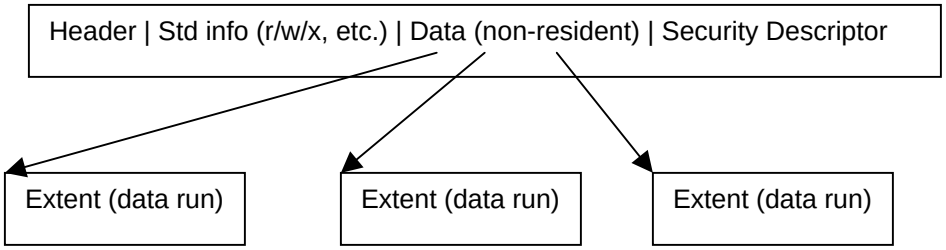
Master file table – table of MFT entries (MFT entry = file header, typically 1-4 KB)

Data can be "resident" in header (for small file), or header can have pointers to data extents for larger file (array of <**file offset, disk offset, length**>), or header can have pointer to another MFT entry that holds nothing but pointers to extents (for large files), or header can have pointer to several MFT entries that hold nothing but pointers to extents (for really huge fragmented files)

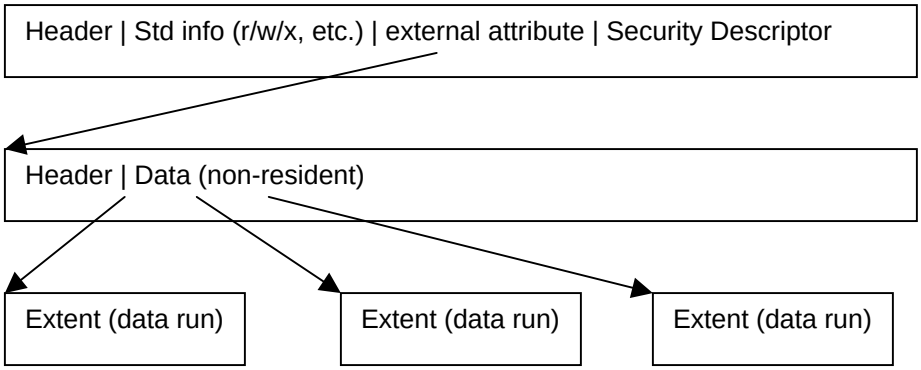
Small file:



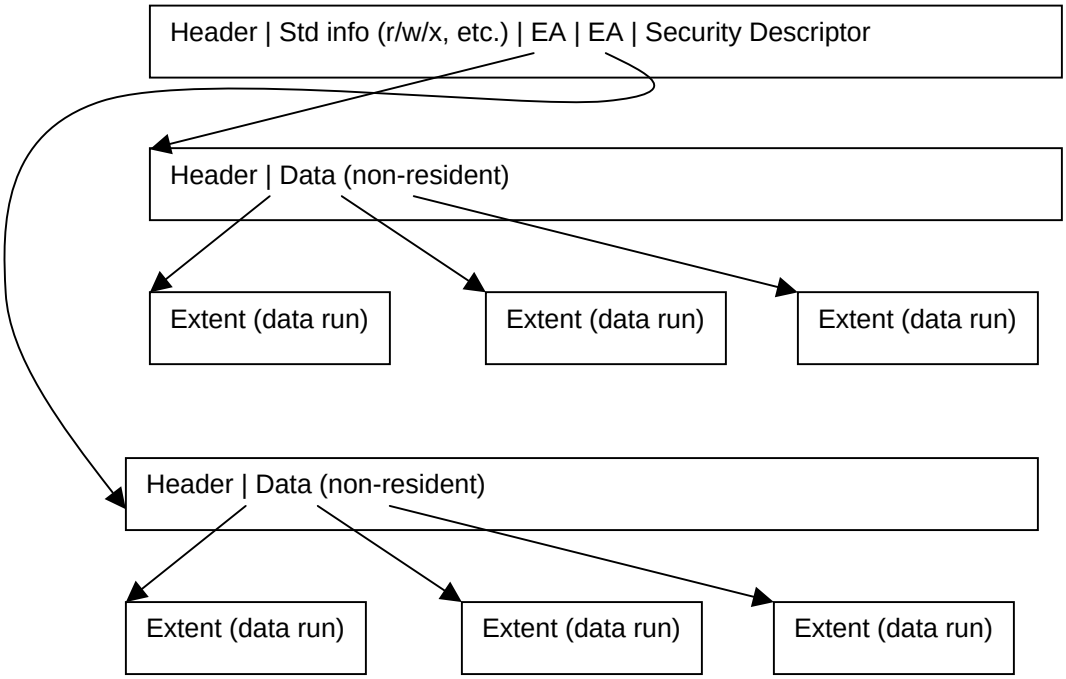
Large file:



Huge file:



Extremely huge file:



5. Policy v. mechanism

Separating mechanism from policy can be useful

What properties should a file index mechanism have in order to support the widest range of policies?

Which of the protocols listed above (contiguous, linked, FAT, index, multi-level index, demos) have sufficient mechanism to allow flexible policy?

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Admin - 3 min

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Drafts of projects 2-3 available

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Lecture - 23 min

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Summary - 1 min

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