CS 3204
Operating Systems

Lecture 21

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Announcements

- Project 3 due Nov 11, 11:59pm
- Additional office hours scheduled

Filesystems

Files vs Disks

File Abstraction
- Byte oriented
- Names
- Access protection
- Consistency guarantees

Disk Abstraction
- Block oriented
- Block #s
- No protection
- No guarantees beyond block write

Filesystem Requirements

- Naming
  - Should be flexible, e.g., allow multiple names for same files
  - Support hierarchy for easy of use
- Persistence
  - Want to be sure data has been written to disk in case crash occurs
- Sharing/Protection
  - Want to restrict who has access to files
  - Want to share files with other users

FS Requirements (cont'd)

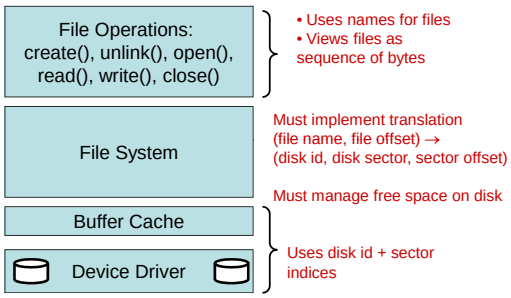
- Speed & Efficiency for different access patterns
  - Sequential access
  - Random access
  - Sequential is most common & Random next
  - Other pattern is Keyed access (not usually provided by OS)
- Minimum Space Overhead
  - Disk space needed to store metadata is lost for user data
- Twist: all metadata that is required to do translation must be stored on disk
  - Translation scheme should minimize number of additional accesses for a given access pattern
  - Harder than, say page tables where we assumed page tables themselves are not subject to paging!

Filesystems

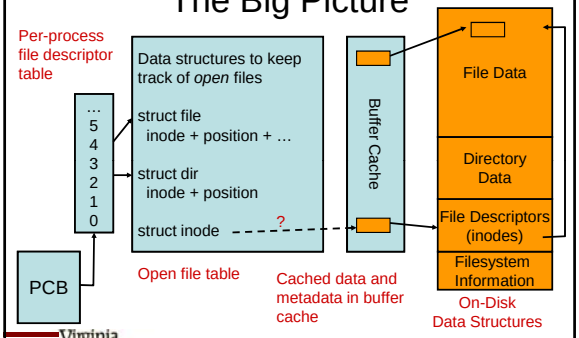
Software Architecture

(including in-memory data structures)

Overview



The Big Picture



Steps in Opening & Reading a File

- Lookup (via directory)
  - find on-disk file descriptor's block number
- Find entry in open file table (struct inode list in Pintos)
  - Create one if none, else increment ref count
- Find where file data is located
  - By reading on-disk file descriptor
- Read data & return to user

Open File Table

- inode – represents file
  - at most 1 in-memory instance per unique file
  - #number of openers & other properties
- file – represents one or more processes using an file
  - With separate offsets for byte-stream
- dir – represents an open directory file
- Generally:
  - None of data in OFT is persistent
  - Reflects how processes are currently using files
  - Lifetime of objects determined by open/close
    - Reference counting is used

File Descriptors ("inodes")

- Term "inode" can refer to 3 things:
  1. in-memory inode
     - Store information about an open file, such as how many openers, corresponds to on-disk file descriptor
  2. on-disk inode
     - Region on disk, entry in file descriptor table, that stores persistent information about a file – who owns it, where to find its data blocks, etc.
  3. on-disk inode, when cached in buffer cache
     - A bytewise copy of 2. in memory
- Q.: Should in-memory inode store a pointer to cached on-disk inode? (Answer: No.)

Filesystems

On-Disk Data Structures and Allocation Strategies

Filesystem Information

- Contains "superblock" stores information such as size of entire filesystem, etc.
  - Location of file descriptor table & free map
- Free Block Map
  - Bitmap used to find free blocks
  - Typically cached in memory
- Superblock & free map often replicated in different positions on disk

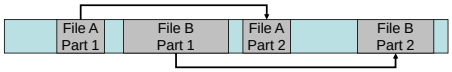
File Allocation Strategies

- Contiguous allocation
- Linked files
- Indexed files
- Multi-level indexed files

Contiguous Allocation

- Idea: allocate files in contiguous blocks
- File Descriptor = (first block, length)
- Good sequential & random access
- Problems:
  - hard to extend files – may require expensive compaction
  - external fragmentation
  - analogous to segmentation-based VM
- Pintos's baseline implementation does this

Linked Files



- Idea: implement linked list
  - either with variable sized blocks
  - or fixed sized blocks ("clusters")
- Solves fragmentation problem, but now
  - need lots of seeks for sequential accesses and random accesses
  - unreliable: lose first block, may lose file
- Solution: keep linked list in memory
  - DOS: FAT File Allocation Table

DOS FAT

- FAT stored at beginning of disk & replicated for redundancy
- FAT cached in memory
- Size: n-bit entries, m-bit blocks → 2^(m+n) limit
  - n=12, 16, 28
  - m=9 … 15 (0.5KB-32KB)
- As disk size grows, m & n must grow
  - Growth of n means larger in-memory table

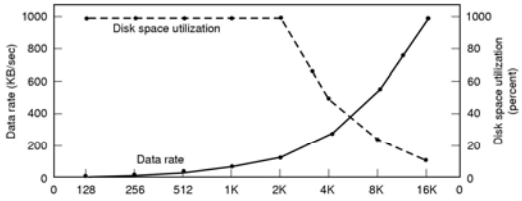
Filename	Length	First Block
"a"	2	1
"b"	4	3
"c"	3	12
"d"	1	4

1	6
2	0
3	5
4	-1
5	7
6	-1
7	11
8	0
9	-1
10	9
11	-1
12	10

DOS FAT Scalability Limits

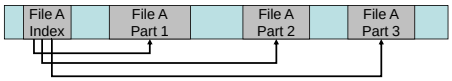
- FAT-12 uses 12 bit entries, max of 4096 clusters
  - FAT-16: 65536 clusters, FAT-32 uses 28bits, so theoretical max of 2^28 (1 Gi) clusters
- Floppy disk, say 1.4MB; FAT-12, 1K clusters, need 1,400 entries, 2 bytes each -> 2.8KB
- Modern disk, say ~500 GB (~2^41 bytes)
  - At 4 KB cluster size, would need 2^29 entries. Each entry at 4 bytes, would need 2^31 bytes, or 2GB, RAM just to hold the FAT.
  - At 32 KB cluster size, would need only 1/8, but still 256MB RAM to hold FAT; simple operations, such as determining how much space is free on disk, require reading entire FAT

Blocksize Trade-Offs



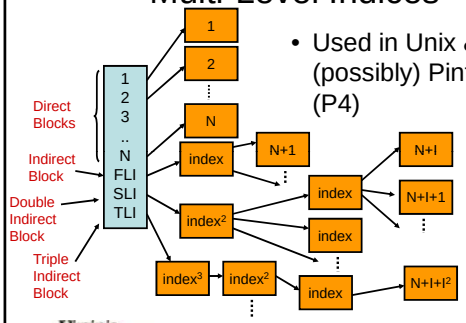
- Chart above assumes all files are 2KB in size (observed median file size is about 2KB)
  - Larger blocks: faster reads (because seeks are amortized & more bytes per transfer)
  - More wastage (2KB file in 32KB block means 15/16th are unused)
- *Source: Tanenbaum, Modern Operating Systems*

Indexed Allocation

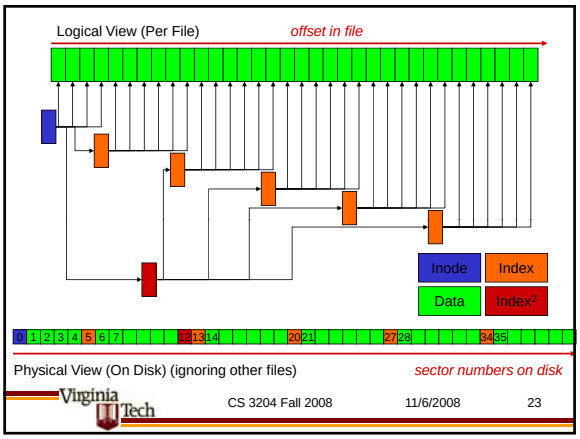


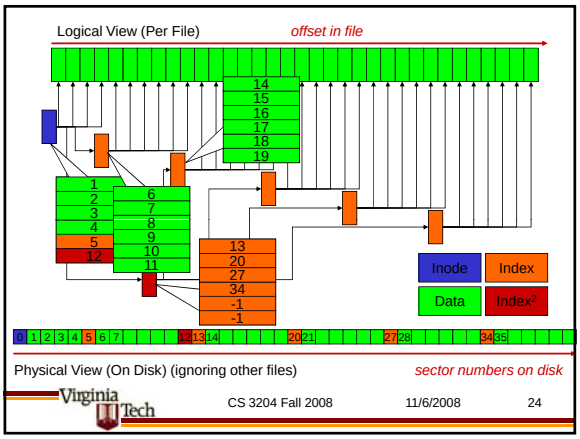
- Single-index: specify maximum filesize, create index array, then note blocks in index
  - Random access ok – one translation step
  - Sequential access requires more seeks – depending on contiguous allocation
- Drawback: hard to grow beyond maximum

Multi-Level Indices



- Used in Unix & (possibly) Pintos (P4)





Multi-Level Indices

- If filesz < N * BLKSIZE, can store all information in direct block array
  - Biased in favor of small files (ok because most files are small…)
- Assume index block stores I entries
  - If filesz < (I + N) * BLKSIZE, 1 indirect block suffices
- Q.: What's the maximum size before we need triple-indirect block?
- Q.: What's the per-file overhead (best case, worst case?)