CS 3204
Operating Systems

Lecture 23

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Announcements

- Project 2 Grades on Curator
- Reading assignment:
  - – Chapter 10 + 11 + 12
- Project 4 Help Sessions
  - – (1) Tonight: Thursday Nov 9: 7pm McB 126
  - – (2) Monday night: Nov 13: 7pm Norris 306

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

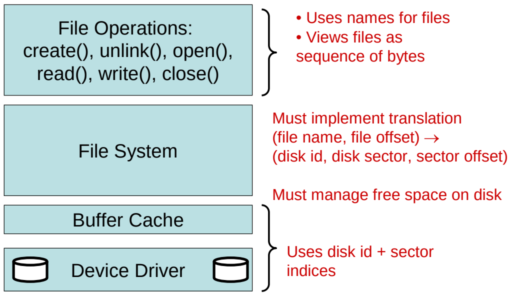
Filesystem Requirements

- 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!

Overview



File Operations: create(), unlink(), open(), read(), write(), close()

- Uses names for files
- Views files as sequence of bytes

File System

Must implement translation (file name, file offset) → (disk id, disk sector, sector offset)

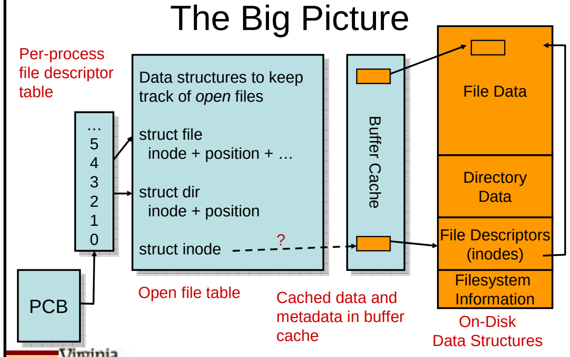
Must manage free space on disk

Buffer Cache

Device Driver

Uses disk id + sector indices

The Big Picture



Per-process file descriptor table

Data structures to keep track of *open* files

struct file
inode + position + …

struct dir
inode + position

struct inode

Open file table

Cached data and metadata in buffer cache

On-Disk Data Structures

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 inode of a 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?

Filesystem Information

Free Block Map
0100011110101010101

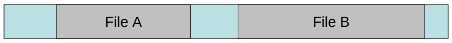
Super Block

- 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

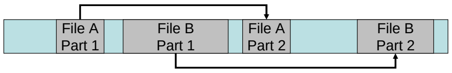
- Contiguous allocation
- Linked files
- Indexed files
- Multi-level indexed files

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

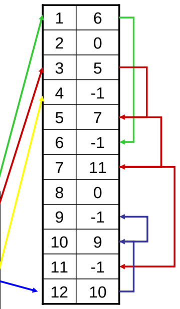


- Idea: implement linked list
  - either with variable sized blocks
  - or fixed sized blocks ("clusters")
- Solves fragmentation problem, but now
  - need lots of seeks for sequential accesses and random accesses
  - unreliable: lost first block, lose file
- Solution: keep linked list in memory
  -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

DOS FAT

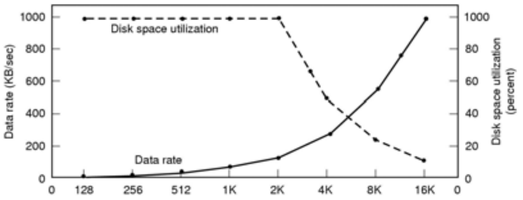
- FAT stored at beginning of disk & replicated for redundancy
- FAT cached in memory
- Size: n-bit entries, m-bit blocks → 2^(m+n) limit
  - n=12, 16, 28
  - m=9 … 15 (0.5KB-32KB)
- As disk size grows, m & n must grow
  - Growth of n means larger in-memory table

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



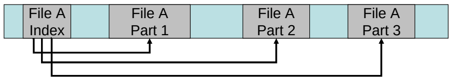
1	6
2	0
3	5
4	-1
5	7
6	-1
7	11
8	0
9	-1
10	9
11	-1
12	10

Blocksize Trade-Offs



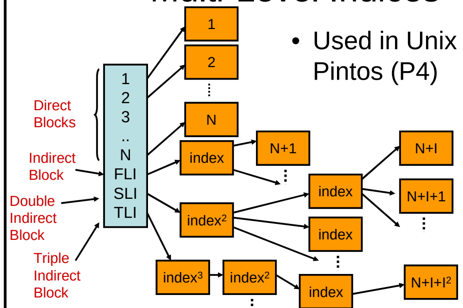
- Assume all files are 2KB in size (observed median filesz is about 2KB)
  - Larger blocks: faster reads (because seeks are amortized & more bytes per transfer)
  - More wastage (2KB file in 32KB block means 15/16th are unused)
- *Source: Tanenbaum, Modern Operating Systems*

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

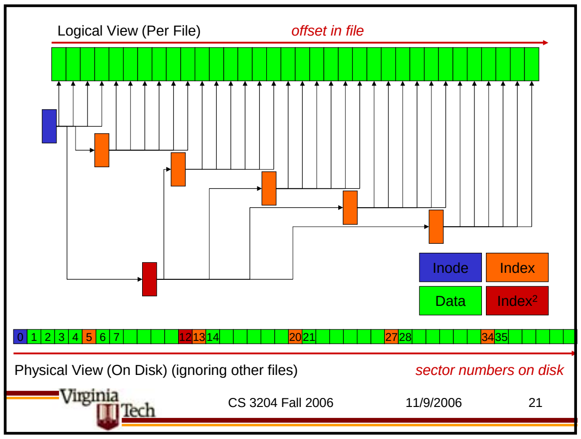
Multi-Level Indices



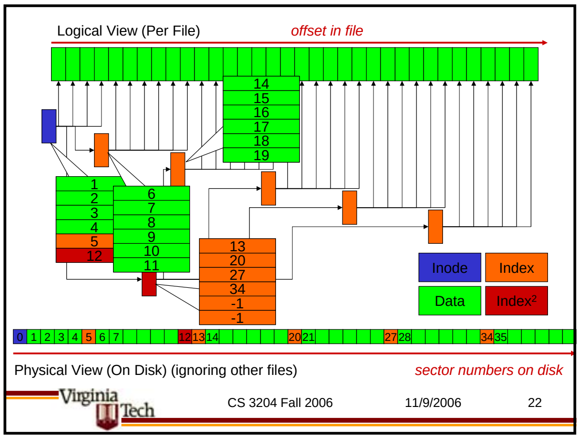
- Used in Unix & Pintos (P4)

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?)



Logical View (Per File)
offset in file
Inode
Index
Data
Index²
0
1
2
3
4
5
6
7
12
13
14
20
21
27
28
34
35
Physical View (On Disk) (ignoring other files)
sector numbers on disk



Logical View (Per File)
offset in file
14
15
16
17
18
19
1
2
3
4
5
12
6
7
8
9
10
11
13
20
27
34
-1
-1
Inode
Index
Data
Index²
0
1
2
3
4
5
6
7
12
13
14
20
21
27
28
34
35
Physical View (On Disk) (ignoring other files)
sector numbers on disk