File System Implementation (Part I)

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Motivation

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- The file system resides permanently on secondary storage.
- How to
  - structure file use
  - allocate disk space
  - recover free space
  - track the locations of data
  - interface other parts of the OS to secondary storage

File System Structure

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- File structure
  - Logical storage unit
  - Collection of related information

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  - The operations allowed on a file
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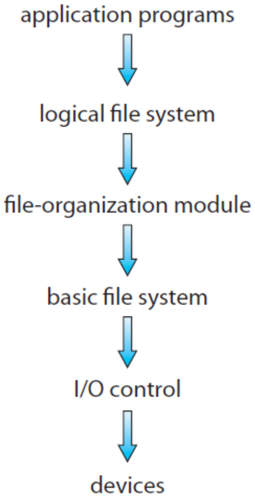
- Algorithms and data structures to map the logical file system onto the physical secondary-storage devices.

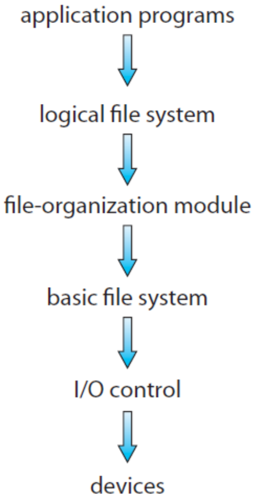
File System Layers (1/6)

- Different levels
- Each level uses the features of lower levels to create new features for use by higher levels.
- Reducing complexity and redundancy, but adds overhead and can decrease performance.



File System Layers (2/6)

- Device drivers manage I/O devices at the I/O control layer.
- Translates high-level commands to low-level hardware-specific instructions.



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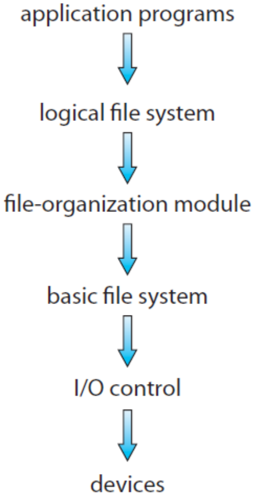
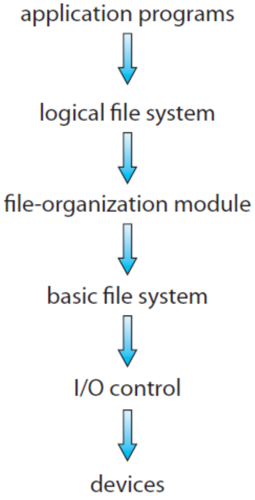


File System Layers (3/6)

- Basic file system translates given command like retrieve block 123 to device driver.
- Also manages memory buffers and caches (allocation, freeing, replacement)
  - Buffers hold data in transit
  - Caches hold frequently used data



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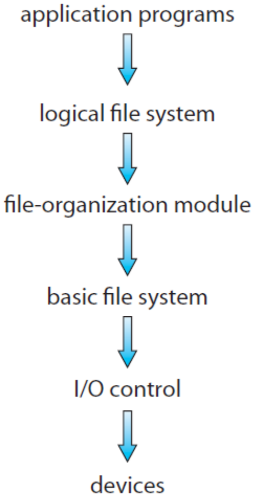

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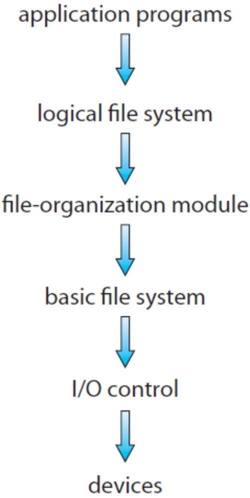

File System Layers (4/6)

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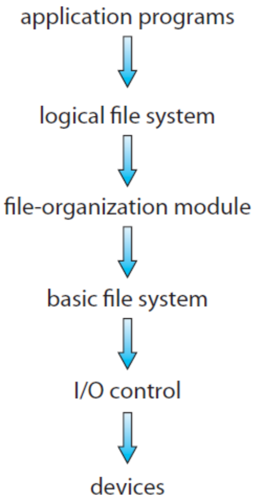
- Translates logical block number to physical block number.
- Manages free space and disk allocation.



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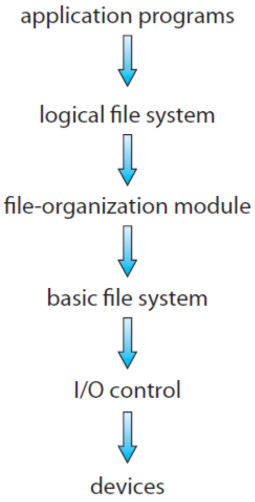

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- Logical file system manages metadata information.
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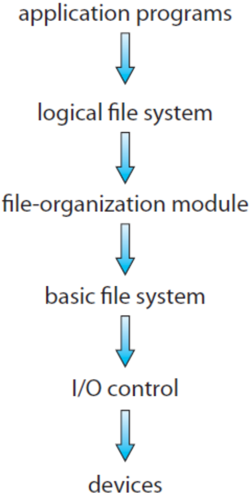

File System Layers (5/6)

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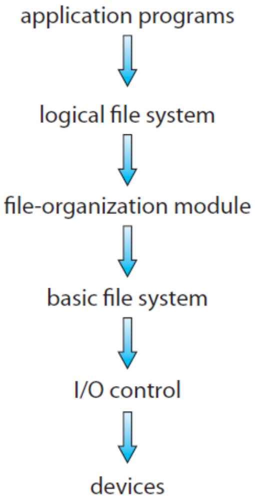
- Directory management
- Protection



File System Layers (6/6)

- Many file systems, sometimes many within an OS
- Each with its own format
  - CD-ROM: ISO 9660
  - Unix: UFS, FFS
  - Windows: FAT, FAT32, NTFS
  - Linux: more than 40 types, with extended file system (ext2, ext3, ext4)

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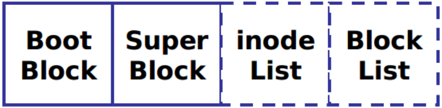
- In-memory
  - Mount table
  - Directory structure cache
  - The open-file table (system-wide and per process)
  - Buffers of the file-system blocks

On-Disk File System Structures (1/2)

- Boot control block contains information needed by system to boot OS from that volume.



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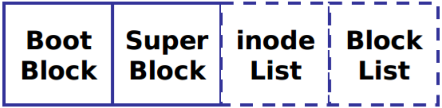

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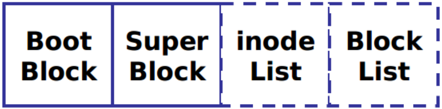

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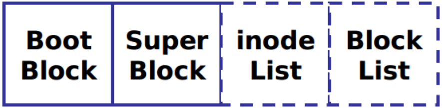
- Volume control block contains volume details.
  - Total num. of blocks, num. of free blocks, block size, free block pointers or array
  - In UFS, it is called super block, and in NTFS master file table.



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- File control block contains many details about the file.
  - In UFS, inode number, permissions, size, dates.
  - In NFTS stores into in master file table.

file permissions
file dates (create, access, write)
file owner, group, ACL
file size
file data blocks or pointers to file data blocks

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- Buffers hold file-system blocks when they are being read from disk or written to disk.

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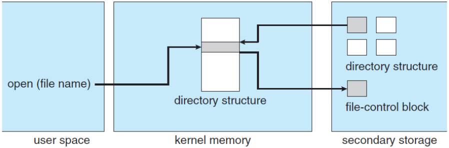
- The system, then, reads the appropriate directory into memory, updates it with the new file name and FCB, and writes it back to the disk.

Open a File

- The file must be opened.
  - The `open()` passes a file name to the logical file system.



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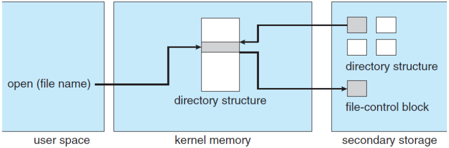

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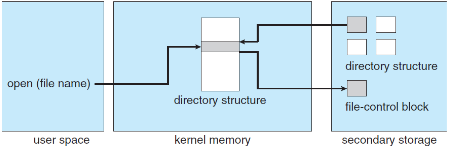

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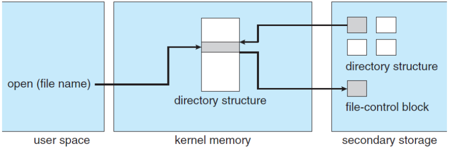

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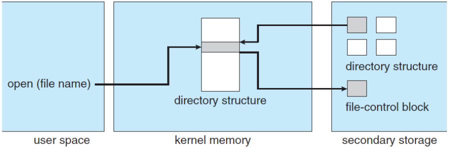
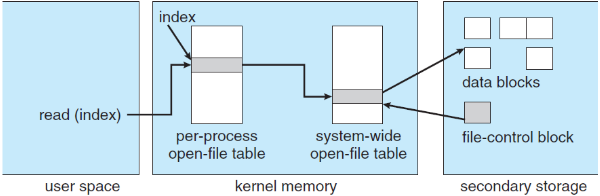
- This table stores the FCB as well as the number of processes that have the file open.



Read From a File

- The `open()` returns a pointer to the appropriate entry in the per-process file-system table.
- All file operations are then performed via this pointer.
- This pointer is called file descriptor in Unix and file handle in Windows.



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- When all users that have opened the file close it, any updated meta-data is copied back to the disk-based directory structure, and the system-wide open-file table entry is removed.

Partitions and Mounting (1/2)

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  - Raw partition: just a sequence of blocks with no file system.
- Boot block points to boot volume or boot loader.
  - Boot loader: knows enough about the file-system structure to be able to find and load the kernel and start it executing.
  - Dual-boot that allows to install multiple OS on a single system.

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Partitions and Mounting (2/2)

- Root partition contains the OS
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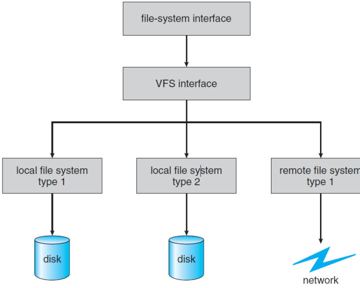
  - Other partitions can mount automatically or manually
- At mount time, file system consistency checked.
  - Is all metadata correct? if not, fix it, try again, if yes, add to mount table, allow access

Virtual File Systems

Virtual File Systems (1/2)

- Virtual File Systems (VFS) on Unix provide an object-oriented way of implementing file systems.



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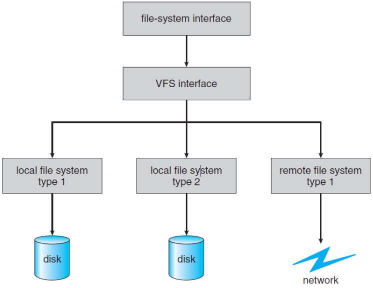

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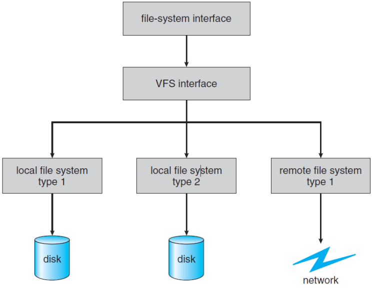
- The API is to the VFS interface, rather than any specific type of file system.



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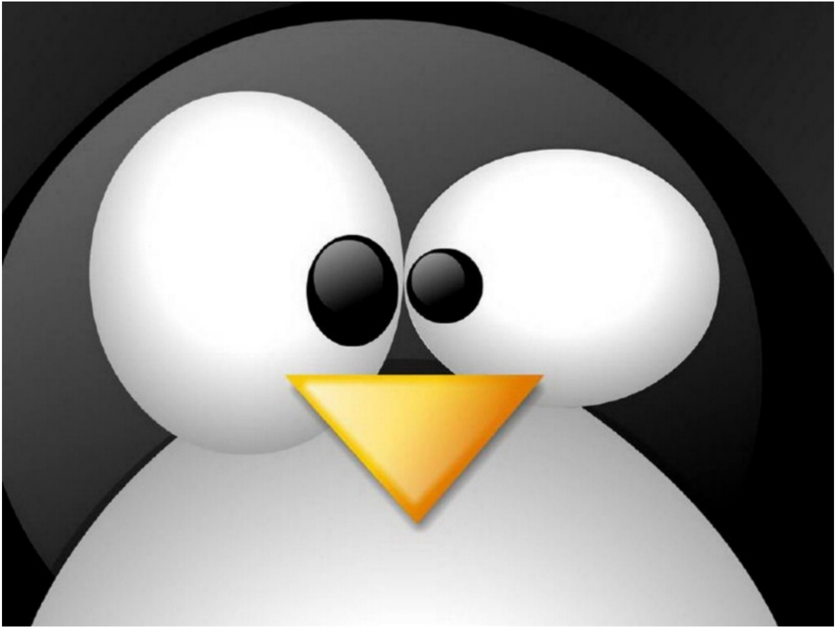
  - The kernel maintains one vnode structure for each active node.



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  - Function table has addresses of routines to implement that function on that object.
  - For example:
    `int open(...)`: open a file
    `int close(...)`: close an already-open file
    `ssize_t read(...)`: read from a file
    `ssize_t write(...)`: write to a file
    `int mmap(...)`: memory-map a file

Directory Implementation

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- Hash table

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- Could keep ordered alphabetically via linked list or use B+ tree: binary search, but heavy

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- Chained-overflow method.
    - Each hash entry can be a linked list instead of an individual value.

Allocation Methods

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- Methods:
  - Contiguous allocation
  - Linked allocation
  - Indexed allocation

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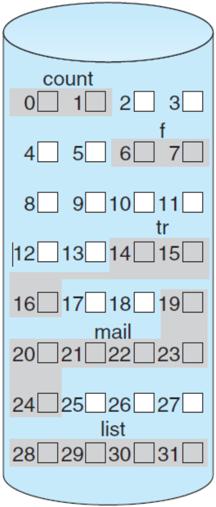
- Allocation strategies like contiguous memory allocation:
  - First fit
  - Best fit
  - Worst fit

Contiguous Allocation (2/2)



directory

file	start	length
count	0	2
tr	14	3
mail	19	6
list	28	4
f	6	2

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- ? Knowing file size

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- An extent is a contiguous block of disks.
  - Extents are allocated for file allocation.
  - A file consists of one or more extents.

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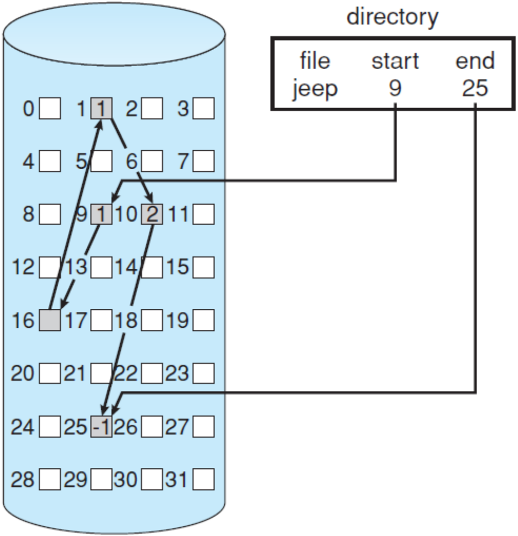
- Linked allocation: each file is a linked list of blocks.
  - Each block contains pointer to next block.
  - File ends at null pointer.
- No external fragmentation, no compaction.
- Free space management system called when new block needed.

Linked Allocation (2/2)



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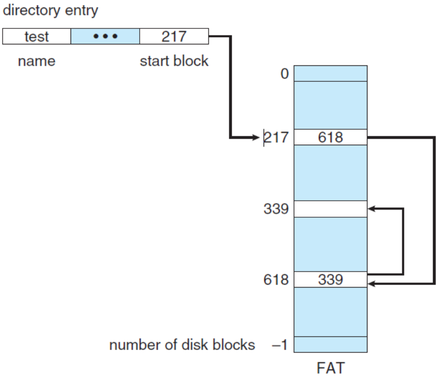
- Reliability can be a problem.
- The space required for the pointers.
  - Efficiency can be improved by clustering blocks into groups but increases internal fragmentation.

File-Allocation Table (FAT)

- Beginning of volume has a table, indexed by block number.
- Much like a linked list, but faster on disk and cacheable.



Indexed Allocation

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Indexed Allocation (1/2)

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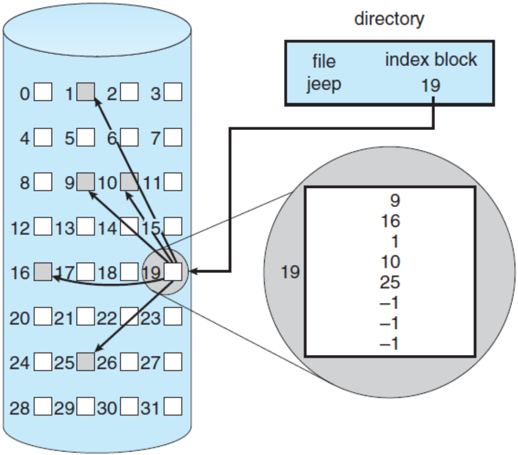
- Need index table
- Random access
- Dynamic access without external fragmentation, but have overhead of index block

Indexed Allocation (2/2)



Indexed Allocation Problems

- Wasted space: overhead of the index blocks.

- For example, even with a file of only one or two blocks, we need an an entire index block.

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- Mechanisms for this purpose include the following:
  - Linked scheme
  - Multi-level index
  - Combined scheme

Linked Scheme

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- For example, an index block might contain a small header giving the name of the file and a set of the first 100 disk-block addresses.

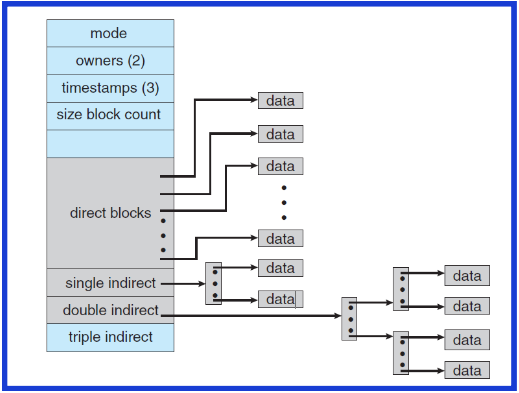
- The next address is null or is a pointer to another index block.

Multi-Level Index

- Two-level index
- A first-level index block to point to a set of second-level index blocks, which in turn point to the file blocks.
- Could be continued to a third or fourth level.

Combined Scheme

- Combine scheme: used in Unix/Linux FS
- The first 12 pointers point to direct blocks
  - The data for small files do not need a separate index block.
- The next 3 pointers point to indirect blocks.
  - Single indirect
  - Double indirect
  - Triple indirect



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- Best method depends on file access type.
- Contiguous is great for sequential and random.
- Linked is good for sequential, not random.
- Indexed is more complex
  - Single block access could require 2 index block reads then data block read
  - Clustering can help improve throughput, reduce CPU overhead

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- Allocation methods: contiguous allocation, linked allocation, and indexed allocation

Questions?

Acknowledgements

Some slides were derived from Avi Silberschatz slides.