Systems and Networking – Unit I

B.Sc. in Applied Computer Science and Artificial Intelligence

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File System's Logical View

File System API	File creation, manipulation, protection, etc.
OS Implementation	OS internal data structures and algorithms
Physical Implementation	Second storage structure, disk scheduling algorithms

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File System Implementation

How do we actually lay down data on disk?

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- **Latency:** the time to initiate a disk transfer of 1 byte to memory
  - Seek time → the time to position the head over the correct cylinder
  - Rotational time → the time for the correct sector to rotate under the head
- **Bandwidth:** once a transfer is initiated, the rate of the I/O transfer

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  - In practice, a block may be a multiple of a sector (e.g., 4 sectors)
  - Typical block size ranges from 512B to 4KiB or larger
- How it should work:
  - The OS requests for **`fileID 42`**, **`block 73`** (contiguous integer addressing)
  - The disk responds with the corresponding (**`head`**, **`cylinder`**, **`sector`**) triple

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- File location on disk:
  - Physically deploy file on disk

On-Disk Data Structures: Overview

- A boot control block (per volume)
- Contains information about how to boot up the system
- Also known as boot block in UNIX and partition boot sector in Windows
- Generally, the first sector of the volume if there is a bootable system loaded on that volume

On-Disk Data Structures: Overview

- A volume control block (per volume)
- Contains information such as the partition table, number of blocks on each filesystem, and pointers to free blocks and free FCB blocks
- Also known as the master file table in UNIX or the superblock in Windows

On-Disk Data Structures: Overview

- A directory structure (per file system)
- Contains file names and pointers to FCBs
- UNIX uses inode numbers, and NTFS uses a master file table

On-Disk Data Structures: Overview

- The File Control Block (FCB) (per file)
- Contains details about file ownership, size, permissions, dates, etc.
- UNIX stores this information in inodes, and NTFS in the master file table as a relational database structure

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- Called inode in Linux

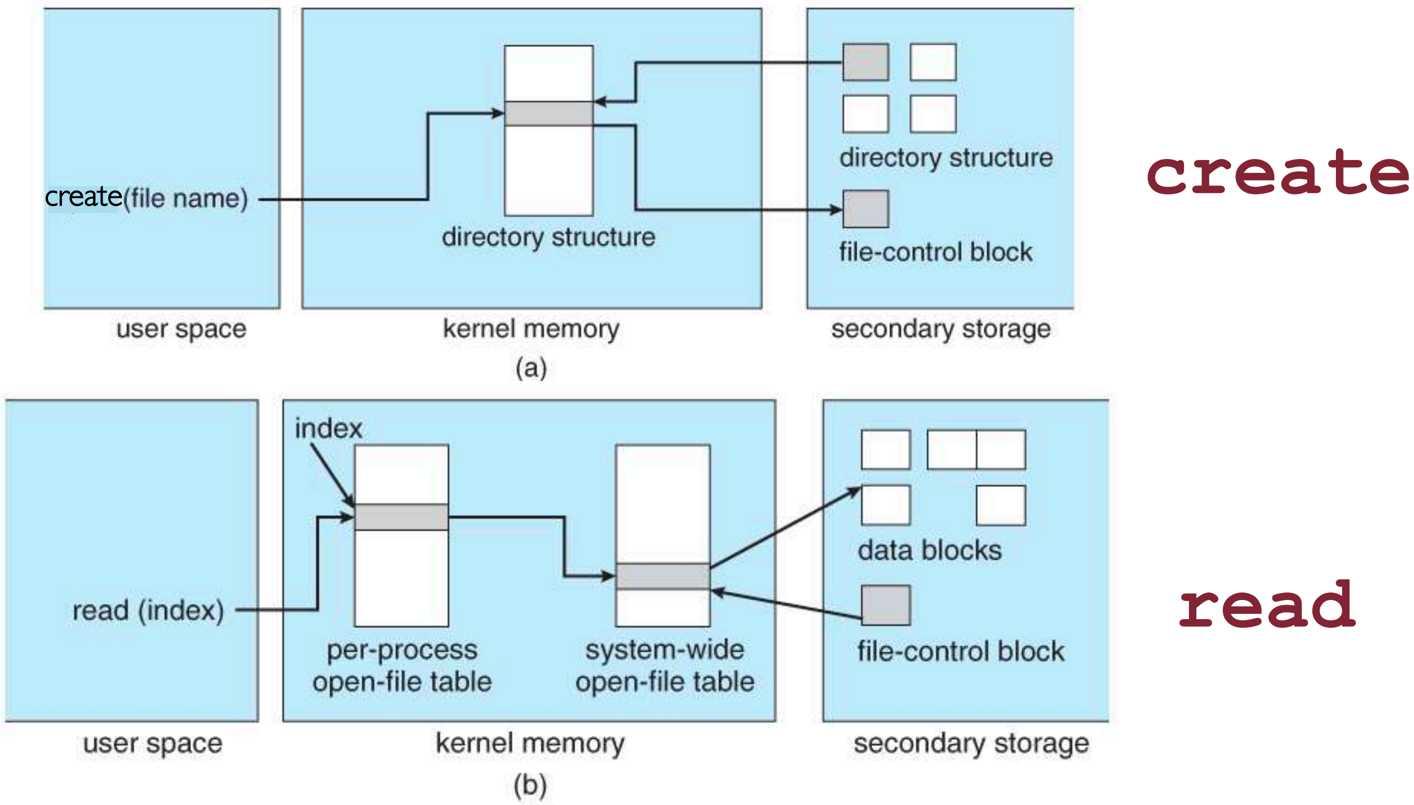
On-Disk Data Structures: File Control Block

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

In-Memory Data Structures: Overview

- In-memory mount table
- In-memory directory cache of recently accessed directory information
- The global (i.e., system-wide) open file table, containing a copy of the FCB for every currently open file in the system, plus other related information
- A local (i.e., per-process) open file table, containing a pointer to the system open file table as well as some other information

Wrapping Things Up!



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- Hashtable: usually implemented in addition to a linear structure

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- Disk I/O operations target both small and large files
- Per-file cost must be low (and large files must be handled efficiently)

Option 1: Contiguous Allocation

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- Examples: IBM/360, write-once disks, early PCs

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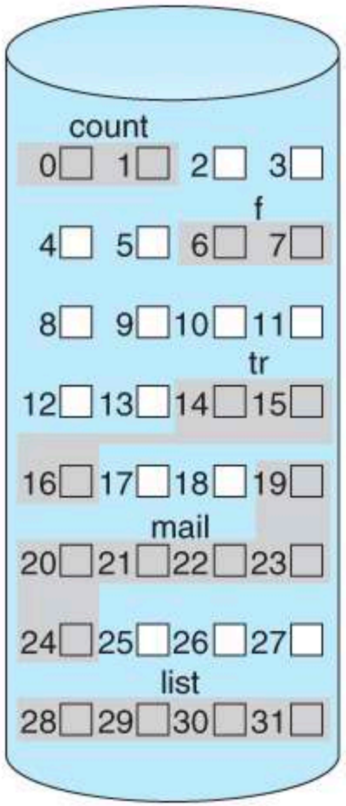

directory

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

Contiguous Allocation: PROs and CONs

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  - Best possible choice for sequential access (only 1 disk seek) and random access (1 disk seek + rotational time to get to the correct block)
- CONs:
  - Hard to change file size (may need to re-allocate it entirely to another location)
  - Fragmentation (may need to run compaction/defragmentation)

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- Examples: FAT, MS-DOS

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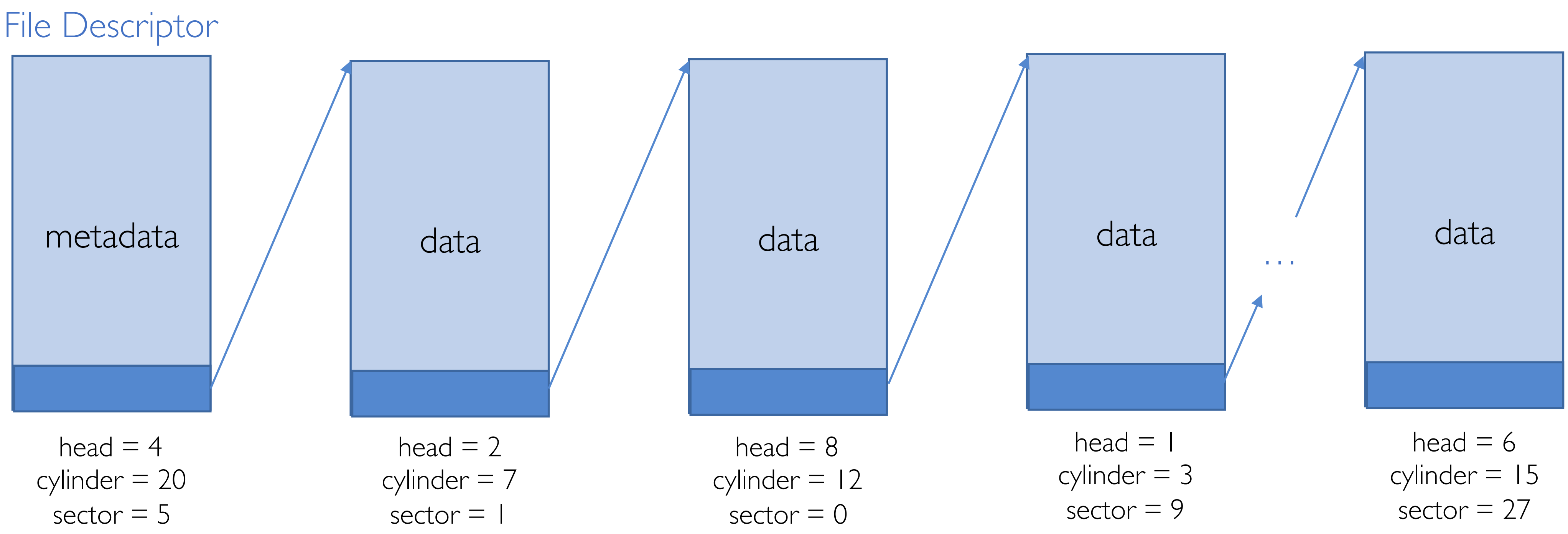

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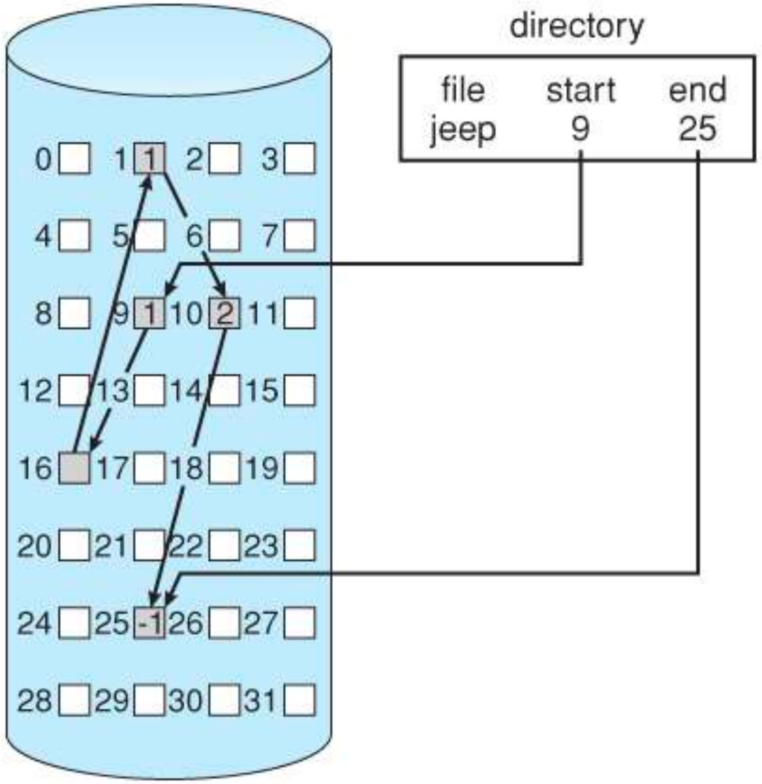

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- CONs:
  - Inefficient sequential access: need to traverse the whole linked list (may need *n* seeks + *n* rotational delays for *n*-block files)
  - Inefficient random access: basically, as above (of course the exact cost depends on the specific block referenced)

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- Example: Nachos

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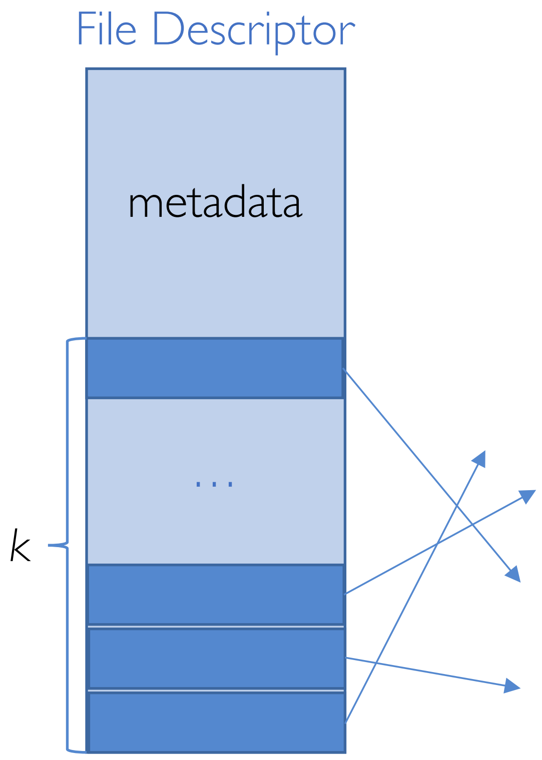

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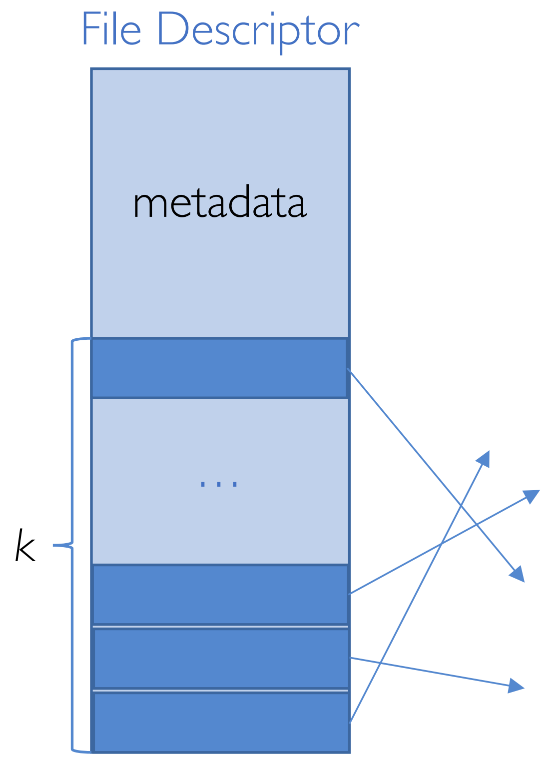

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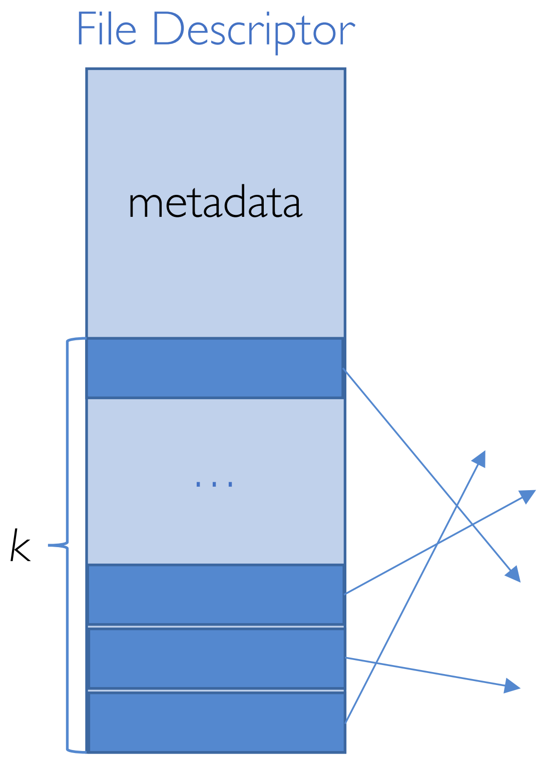

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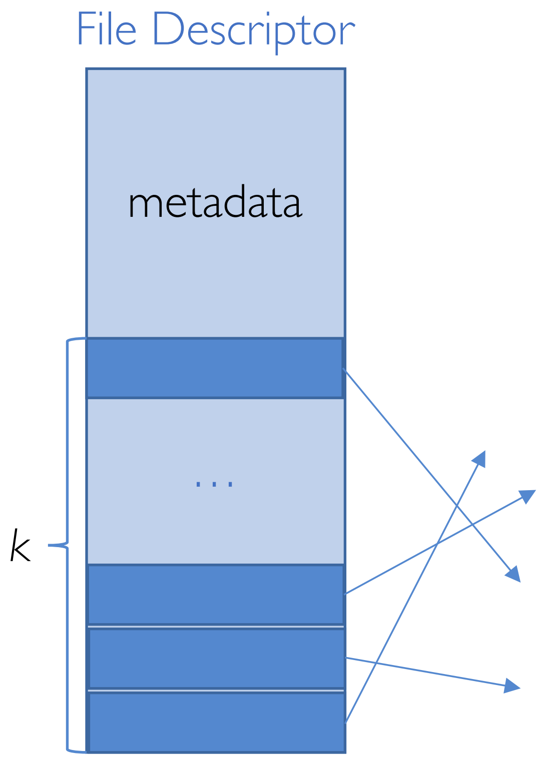

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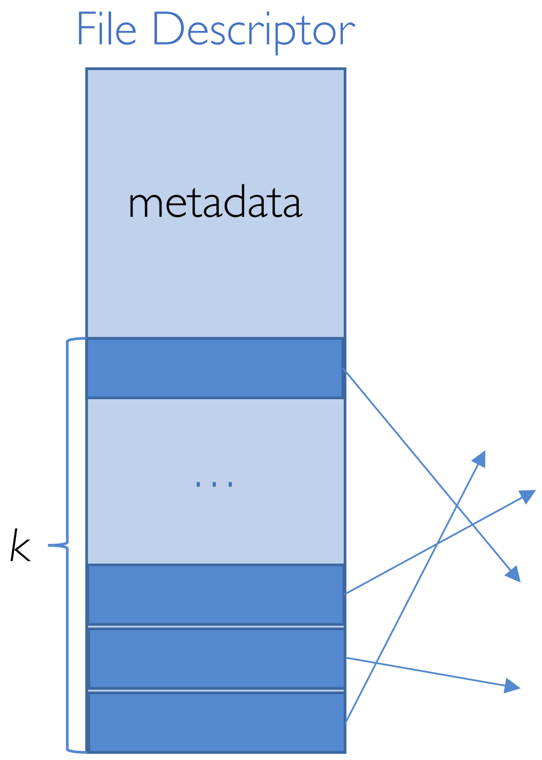

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Of course, only pointers to blocks are allocated on the file descriptor, not the blocks themselves!

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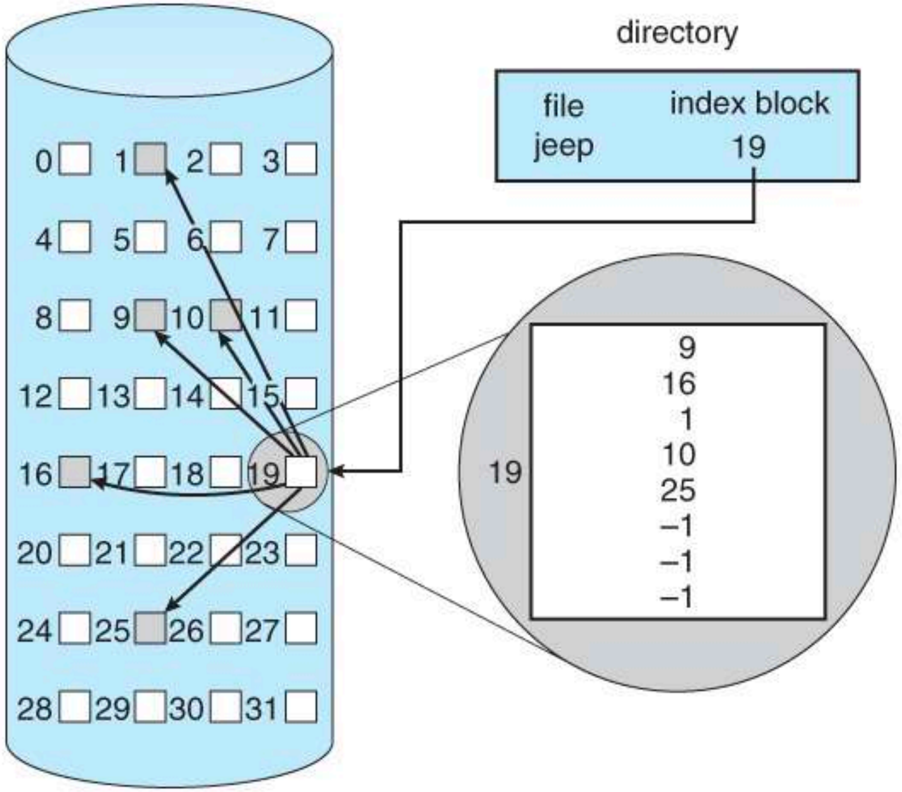

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- PROs:
  - No fragmentation
  - Efficient random access: just follow the correct pointer (1 seek + 1 rotation)
- CONs:
  - Waste some space on the file descriptor
  - Max file size to be set upfront (things change very quickly!)
  - Inefficient sequential access: as for the linked files approach, it may need n seeks + n rotational delays for n-block files

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- Example: UNIX BSD 4.3

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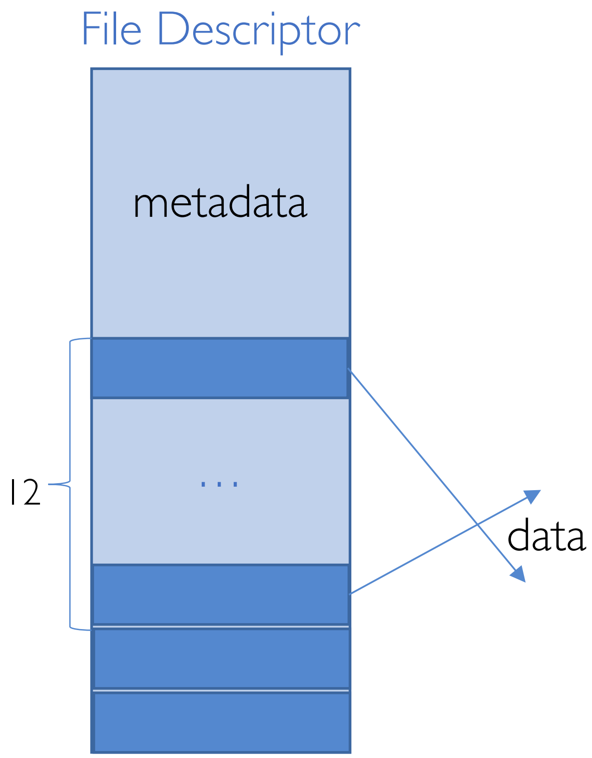

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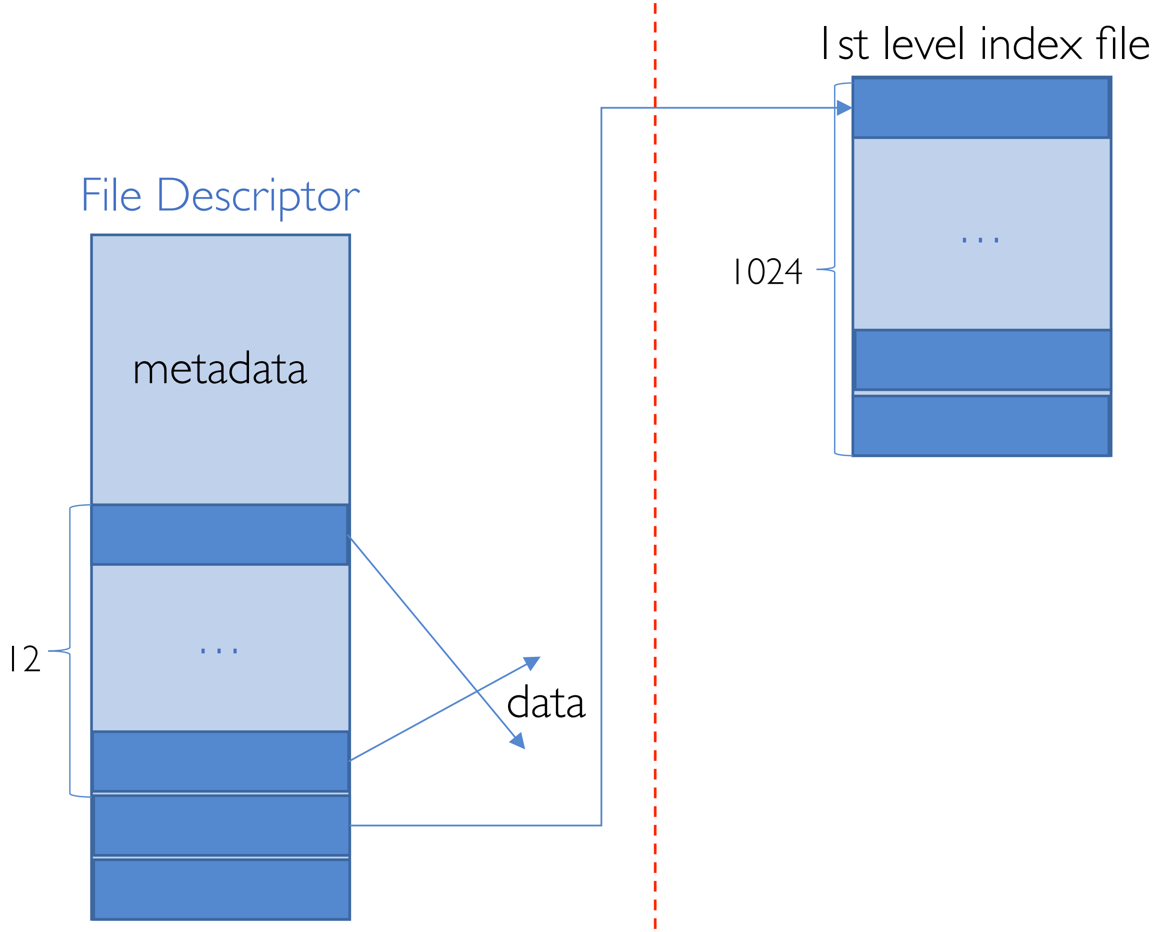

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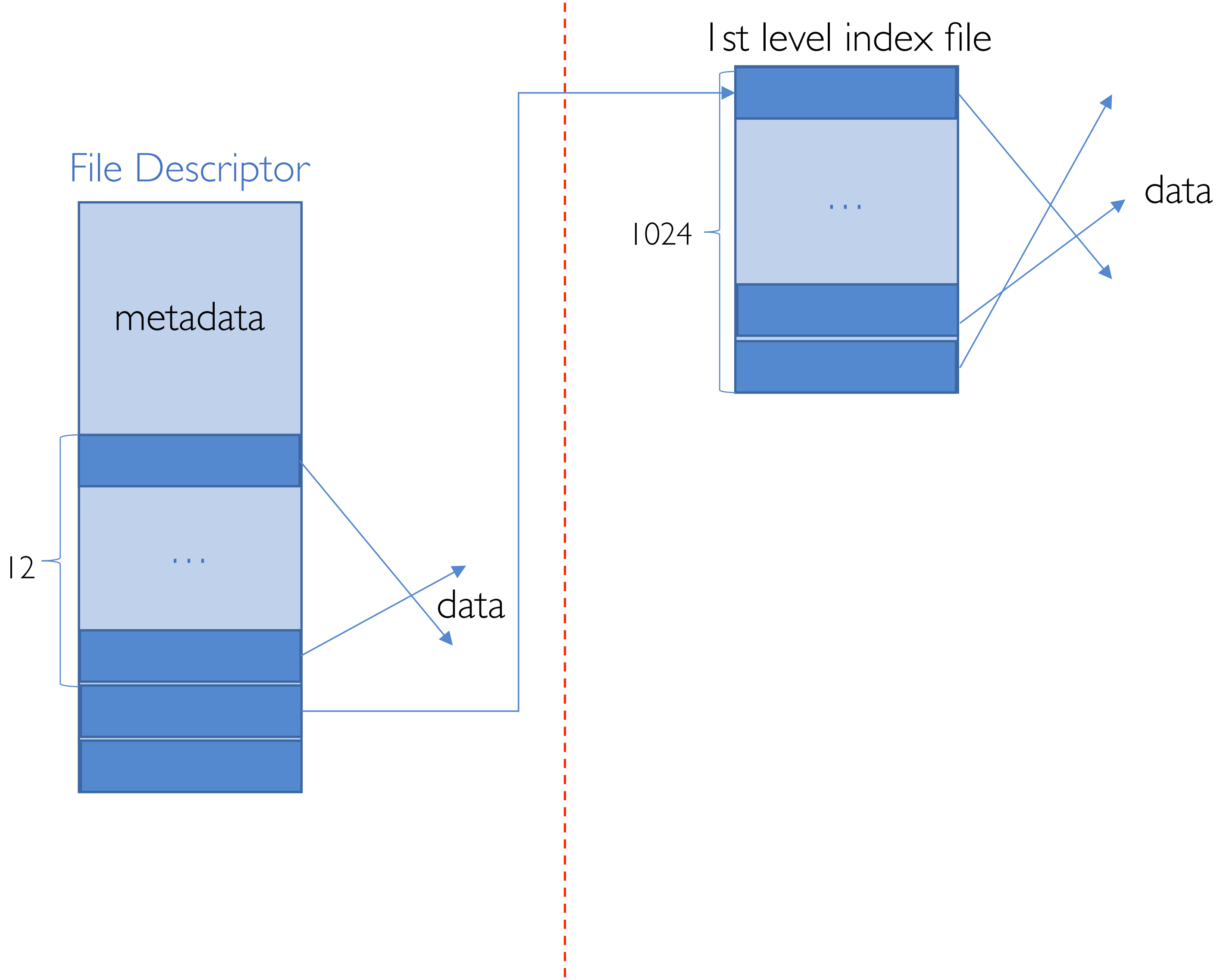

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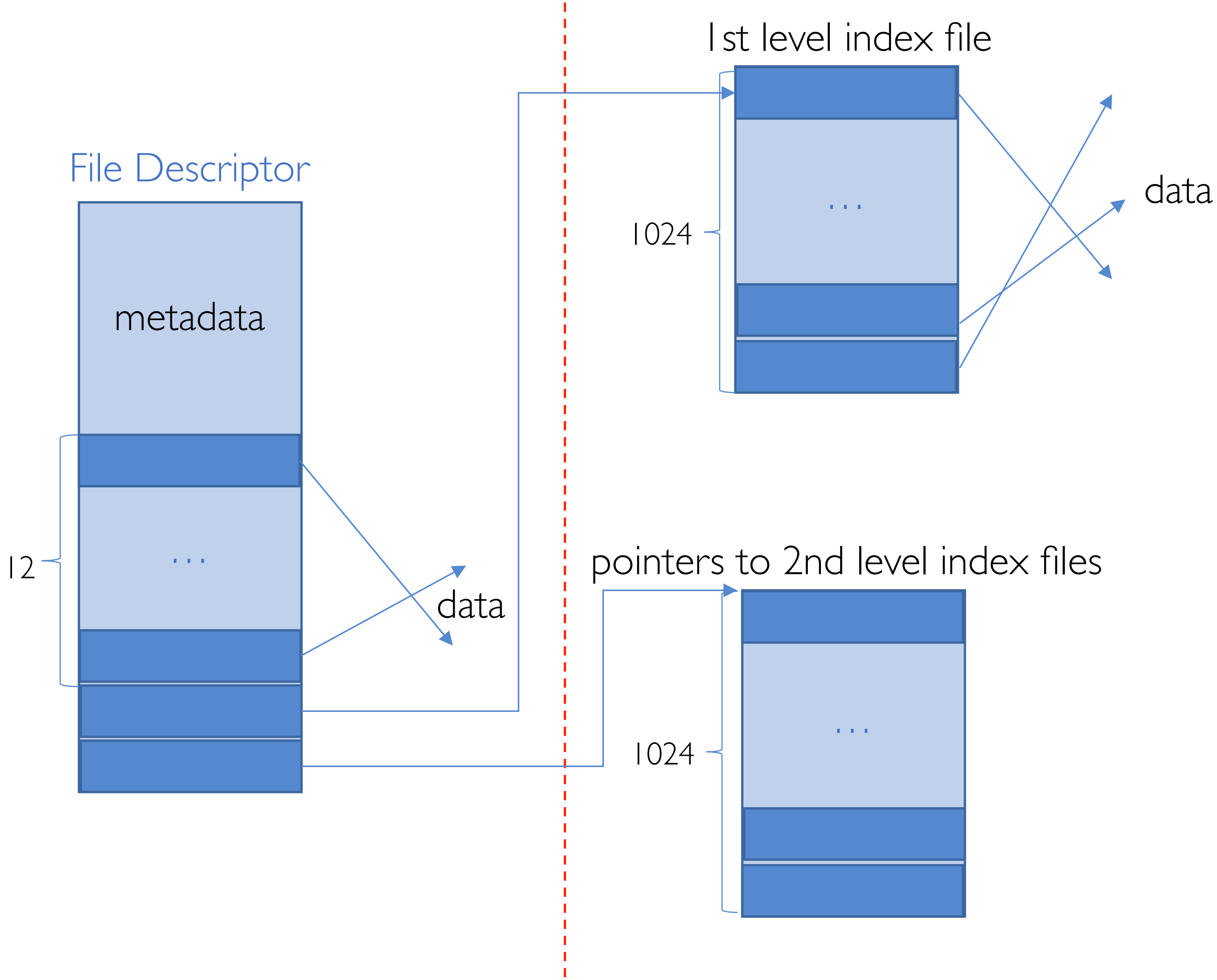

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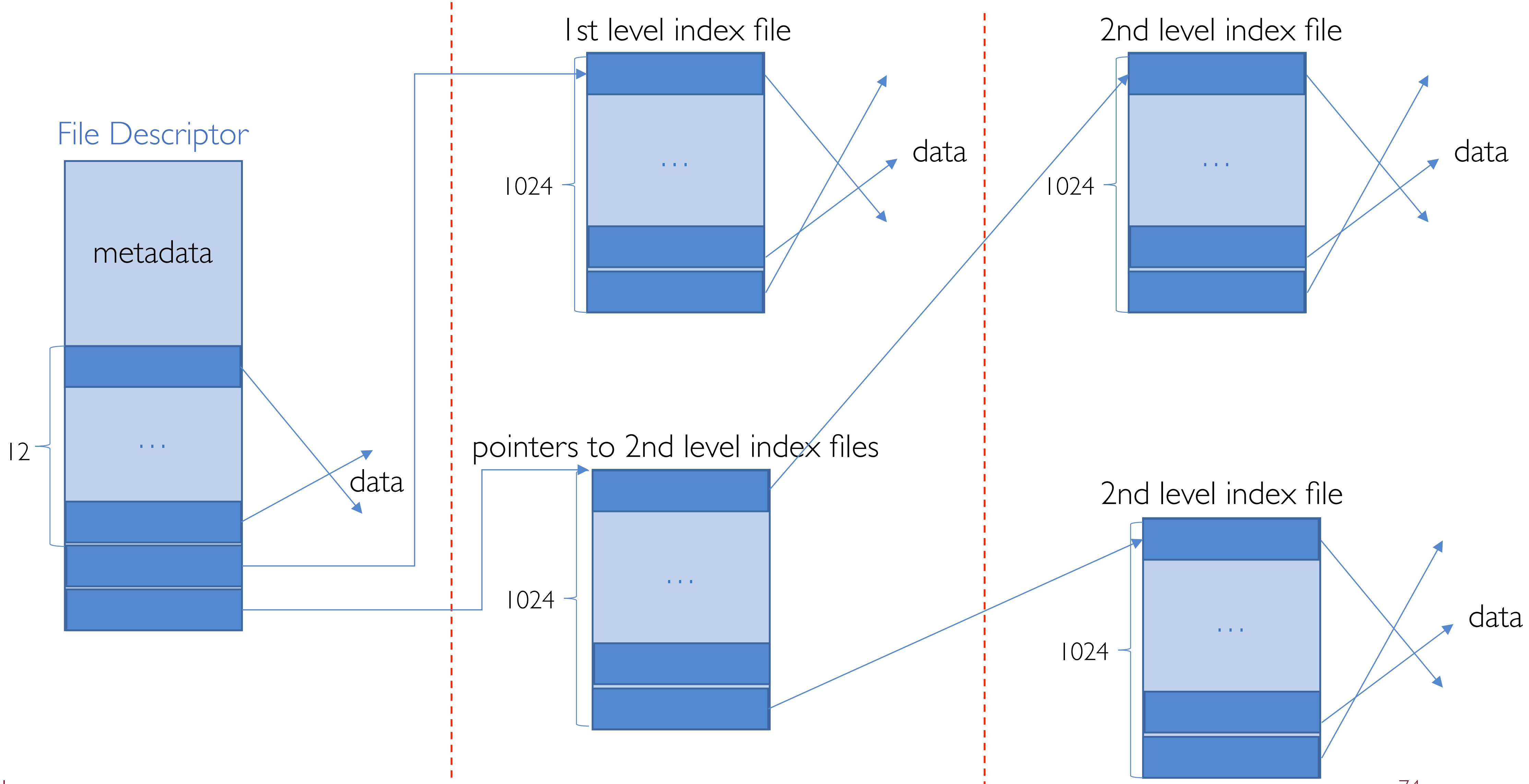

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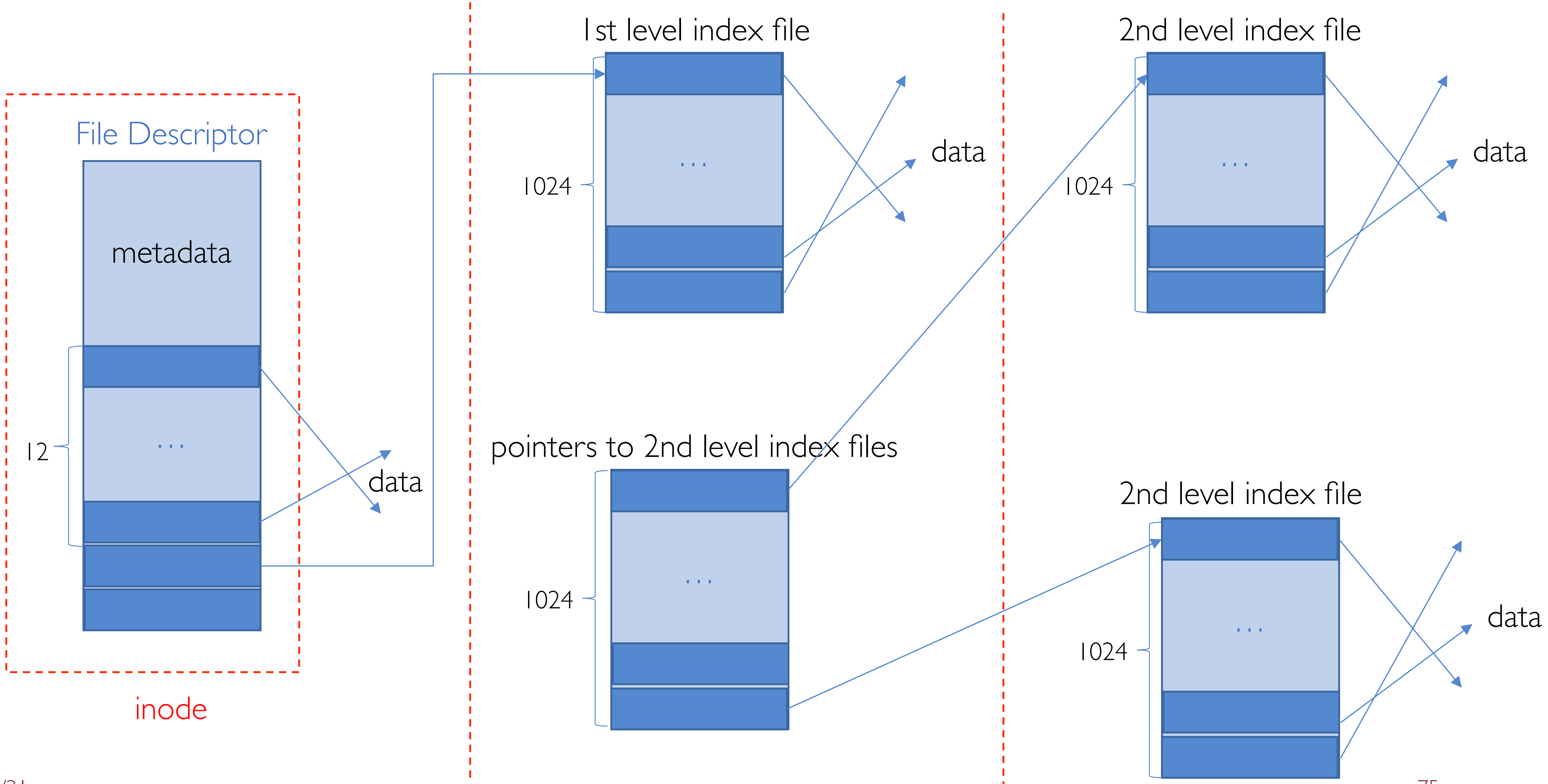

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In general, $\sim k^m$ if k = n. of block pointers and m = n. of levels

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- CONs:
  - Still inefficient sequential/random access yet better than linked files
  - Lots of seeks because of non-contiguous allocation

Free Space Management: Bitmap

- Need a free-space list to keep track of which disk blocks are free (just as we need for main memory)
- Need to be able to find free space quickly and release space quickly
- The bitmap has one bit for each block on the disk
- If the bit is 1 the block is free, otherwise (0) the block is allocated

Free Space Management: Bitmap

- Use a 32-bit bitmap (i.e., a typical CPU-word size)
- Can quickly determine if any block in the next 32 is free, by comparing the word to 0
- If the bitmap is 0, all the blocks are in use
- Otherwise, use bit operations to find an empty block
- Marking a block as freed is simple since the block number can be used to index into the bitmap to set a single bit

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How many entries does a 2 TB disk with 512-byte sectors need?

~4,000,000,000 bitmap entries = 500,000,000 bytes = 500MB

Free Space Management: Linked List

- If most of the disk is in use, it will be expensive to find free blocks with a bitmap
- An alternative implementation is to link together the free blocks
- The head of the list is cached in kernel memory
- Each block contains a pointer to the next free block
- Allocating/Deallocating blocks by modifying pointers of this list

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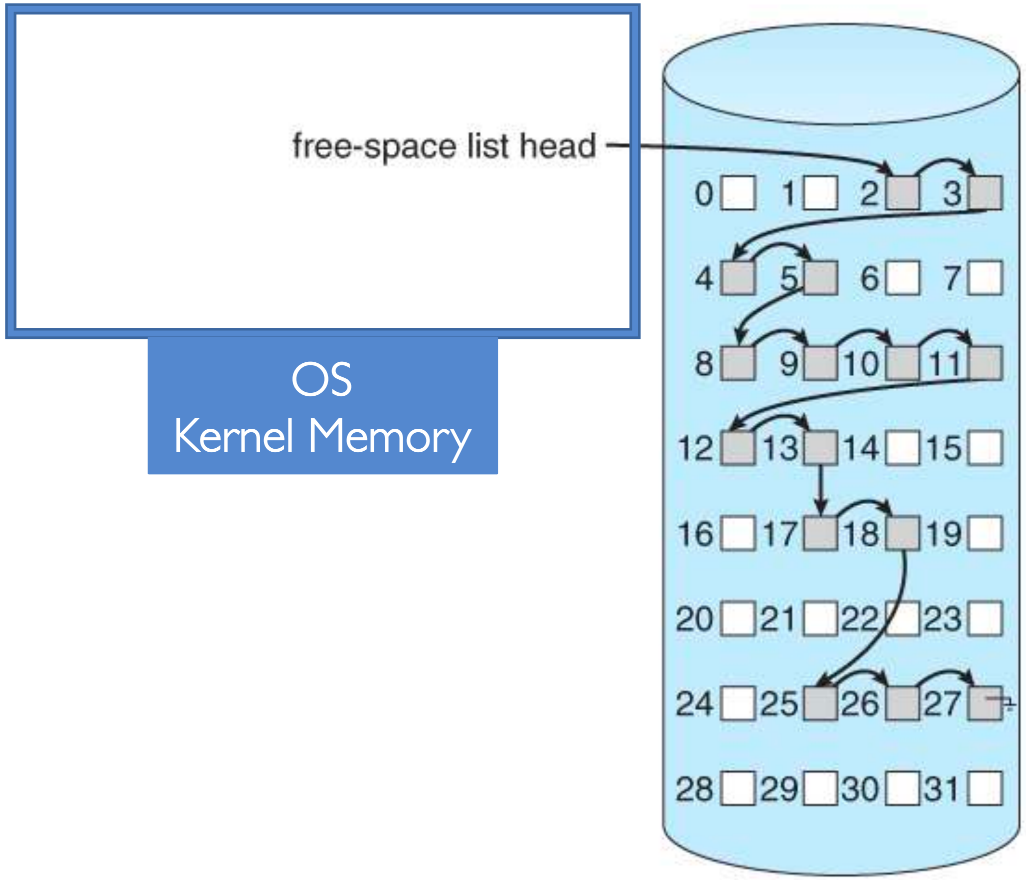

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- Contiguous allocation is simple, but suffers from external fragmentation, the need for compaction, and the need to move files as they grow
- Indexed allocation is very similar to page tables
  - A table maps from logical file blocks to physical disk blocks
- Free space can be managed using a bitmap or a linked list