ECE437/CS481

M06B: DISK SPACE MANAGEMENT

CHAPTER 12.4-12.5

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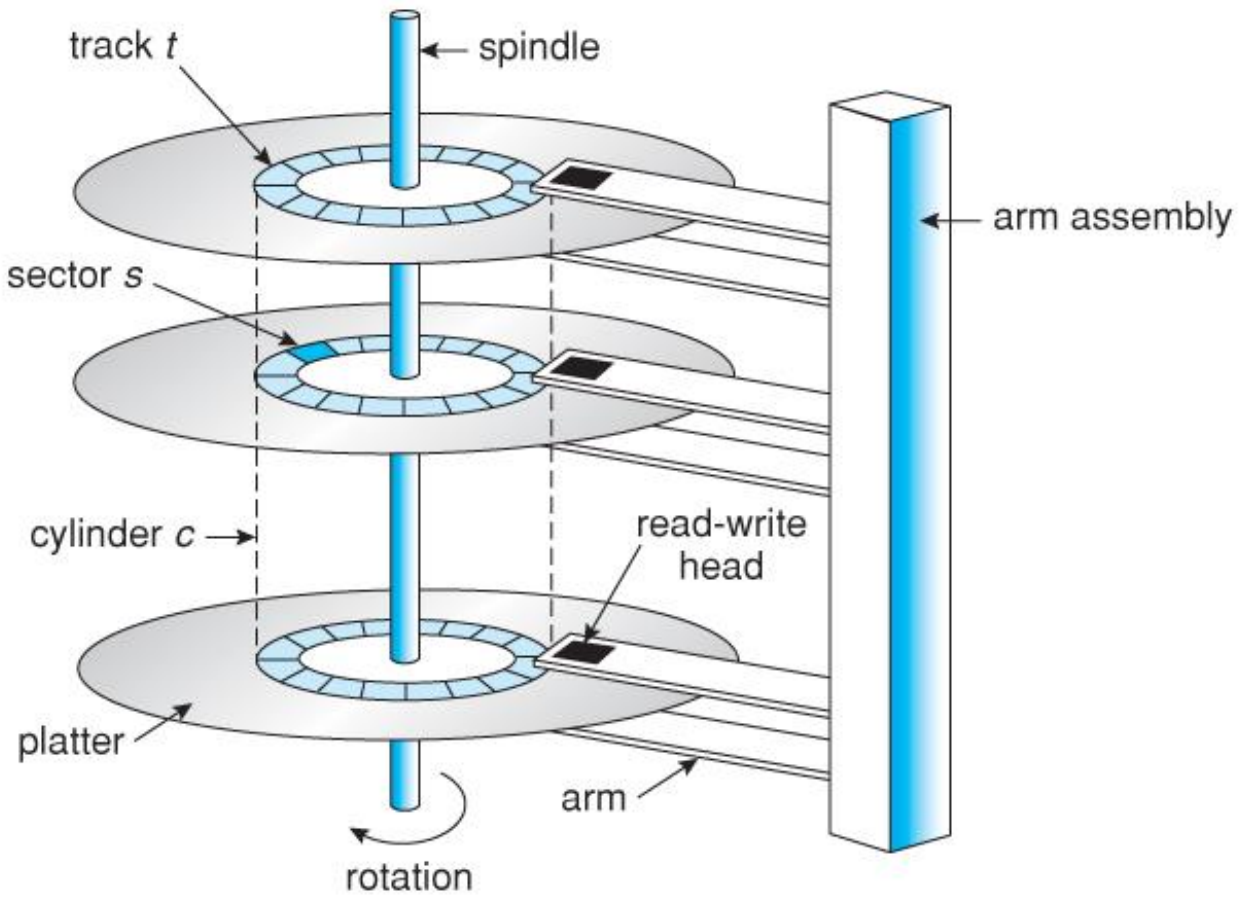
File Space Allocation

❑ Disk Structure



- **Sector**: Minimum unit (normally, 512 Byte for old hard disks; 4 KB for new hard disks) for data storage.
  - ✓ Use `cat /sys/block/sda/queue/physical_block_size` to see the size of sector for your hard disk.
- **Track**: One cycle on the platter
- **Cylinder**: The tracks with the same track number on different platters.
- Each sector is identified by a combination of cylinder number, the head number, and the sector number.

File Space Allocation

❑ Logic blocks in file systems

- The OS uses logic blocks to read and write files.
  - ❑ Size of a block = 2^n × size of a sector
  - ❑ "stat –f /" to check the size of a block
  - ❑ The way of addressing logic blocks is a simple linear addressing scheme
  - ❑ Mapping a logic block to a sector(s) is required

LBA	C	H	S
0	0	0	0
1	0	0	1
2	0	0	2
3	0	0	3
4	0	0	4
5	0	0	5
6	0	0	6
7	0	0	7
8	0	0	8
9	0	0	9
10	0	1	0
11	0	1	1
12	0	1	2
13	0	1	3
14	0	1	4
15	0	1	5
16	0	1	6
17	0	1	7
18	0	1	8
19	0	1	9
Cylinder 0			

LBA	C	H	S
20	1	0	0
21	1	0	1
22	1	0	2
23	1	0	3
24	1	0	4
25	1	0	5
26	1	0	6
27	1	0	7
28	1	0	8
29	1	0	9
30	1	1	0
31	1	1	1
32	1	1	2
33	1	1	3
34	1	1	4
35	1	1	5
36	1	1	6
37	1	1	7
38	1	1	8
39	1	1	9
Cylinder 1			

LBA = ((C x HPC) + H) x SPT + S

- ❖ C, H and S are the cylinder number, the head number, and the sector number
- ❖ LBA is the logical block address
- ❖ HPC is the number of heads per cylinder
- ❖ SPT is the number of sectors per track

File Space Allocation

- How to allocate blocks to these files so that disk space is utilized effectively, and files can be accessed quickly?—File Space Allocation

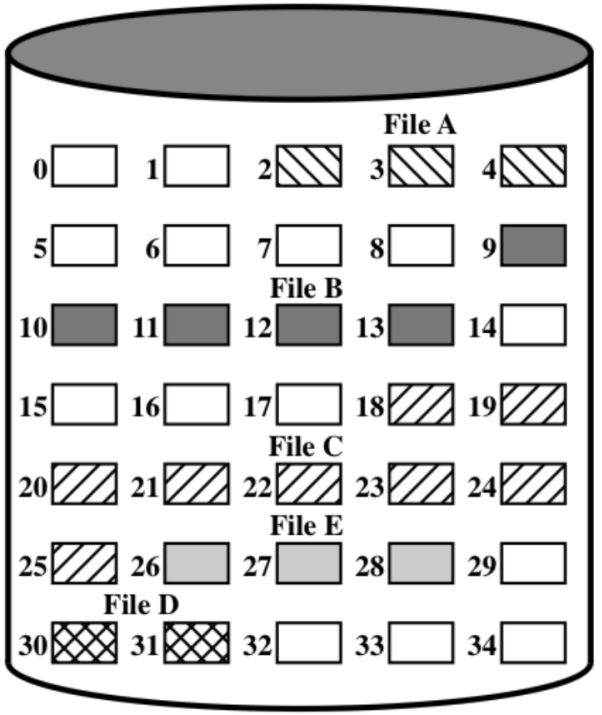
- Three major methods of allocating disk blocks:
  - Contiguous allocation
  - Linked allocation
  - Indexed allocation

File Space Allocation

❑ Continuous allocation

- Continuous blocks is allocated to a file.
- FCB only needs to store the information of the 1st block and the # of blocks allocated.
- Good performance for sequential access
- Easy to achieve direct access
  - ✓ If the system tries to access block *i* of a file that starts at block *b*, the system can immediately access block b + i

name	1st block	length
File A	2	3
File B	9	5
File C	18	8
File D	30	2
File E	26	3



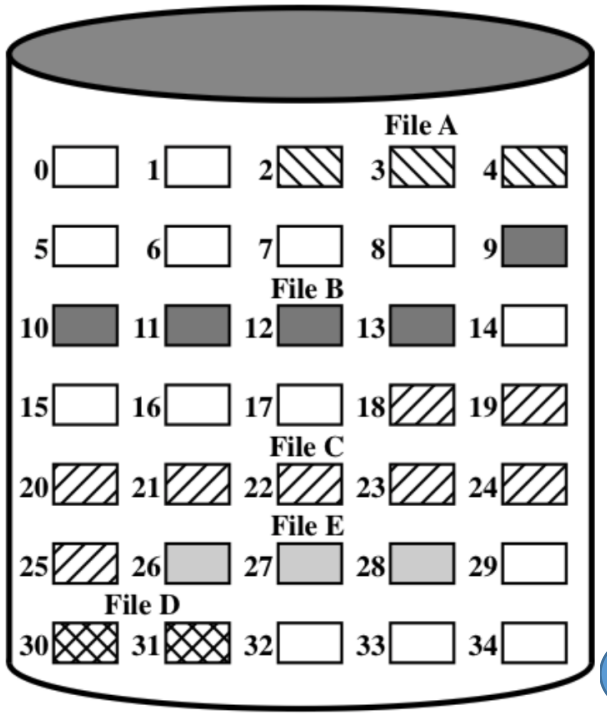
File Space Allocation

❑ Continuous allocation

- Block allocation problem: given the file size, how to pick up contiguous group of blocks to store the file.

First fit:	Best fit:
• choose the first unused contiguous group of blocks of sufficient sizes.	• choose the smallest unused contiguous group of blocks of sufficient sizes.

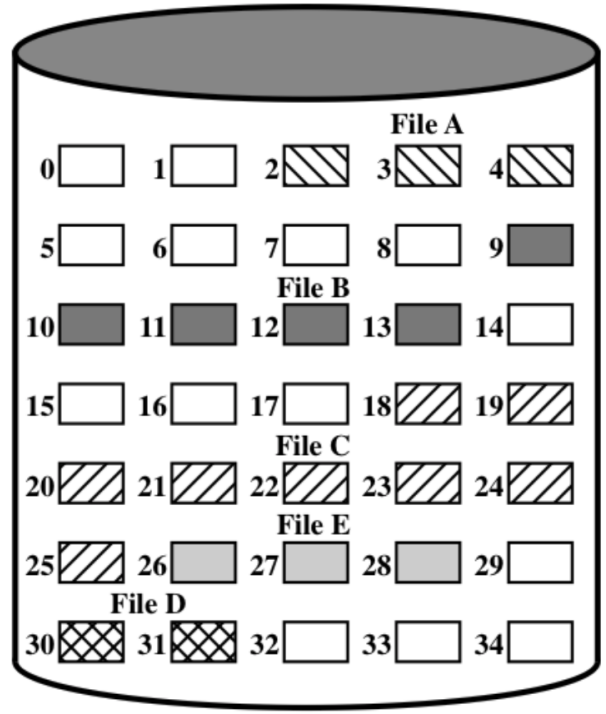
- If the system tries to allocation a file with size equal to three logic blocks, which logic blocks will be allocated to the file by applying FF and BF, respectively?



File Space Allocation

❑ Drawbacks of continuous allocation

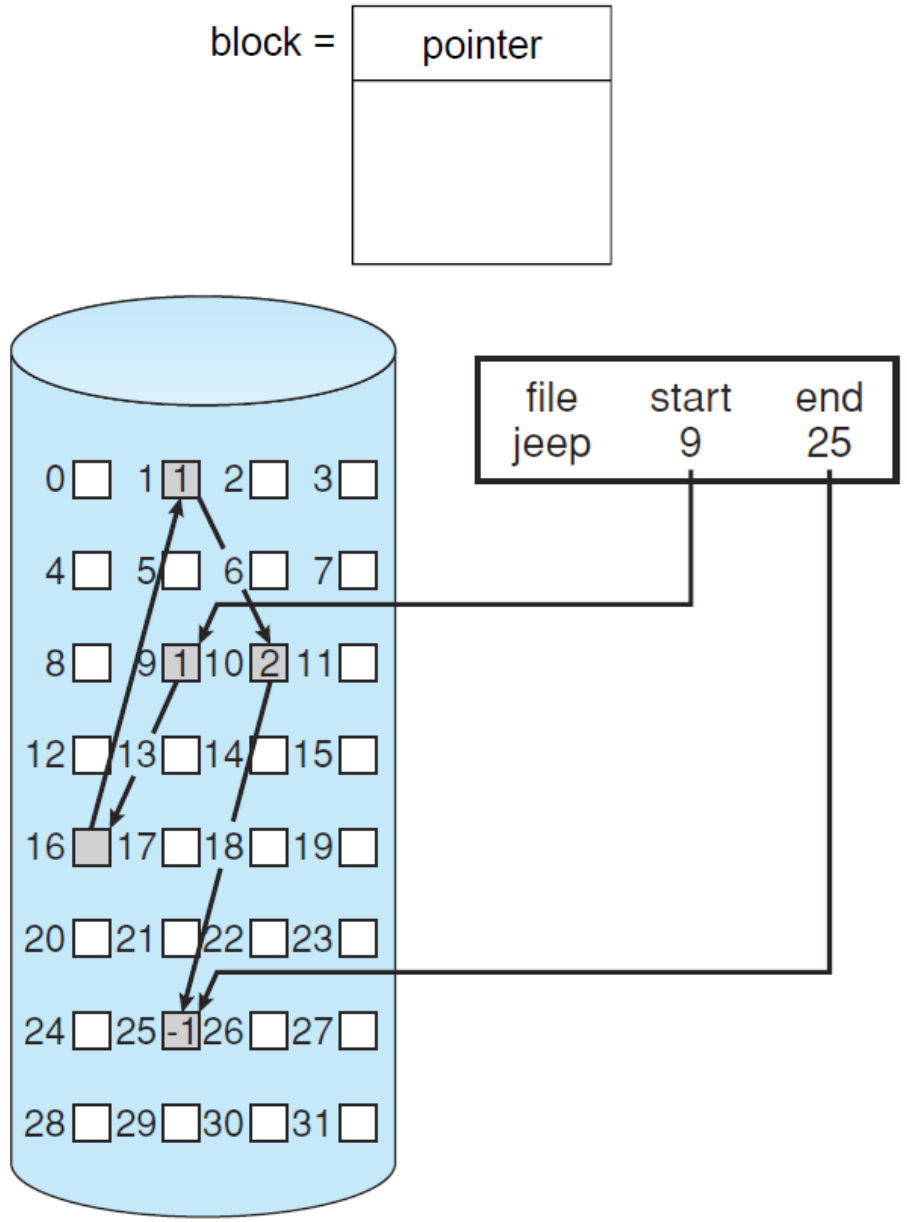
- ➢ Suffers from the problem of external fragmentation
  - ✓ External fragmentation: As files are allocated and deleted, the free disk space is broken into little pieces. Thus, none of these pieces is large enough to store files.
  - ✓ Solution: Copy an entire file system onto another disk, and then copy the file system back to the original disk by allocating contiguous space.
- ➢ May have problems in estimating the size of a file.
  - ✓ Determining how much space is needed for a file in continuous allocation.
  - ✓ In general, estimating the size of a file is difficult.
  - ✓ If the estimated size of a file is too small, the file may not be feasible to be extended (especially for the best-fit allocation strategy).



File Space Allocation

❑ Linked allocation

- Each file is a linked list of blocks which need NOT be contiguous. The blocks can be scattered anywhere on the disk.
  - ✓ A file of five blocks might start at block 9 and continue at block 16, then block 1, then block 10, and finally block 25.
- Each block contains a pointer to the next
  - ✓ These pointers are not made available to the OS.
- FCB only contains the 1st and last blocks of the file



File Space Allocation

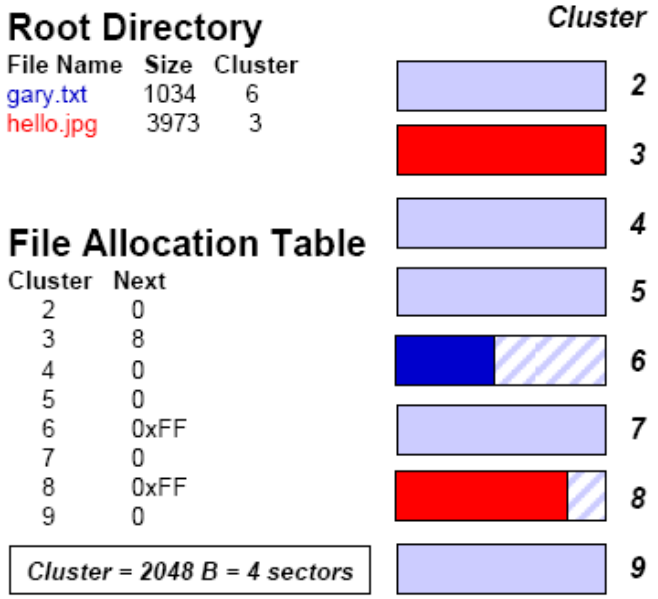
❑ Linked allocation pros and cons

- ➢ Flexible to extend blocks of a file
  - ✓ A write to the file causes to find a free block, and this new block is written to and is linked to the end of the file.
  - ✓ To read a file, we simply read blocks by following the pointers from block to block.
  - ✓ The size of a file need not be declared when the file is created. A file can continue to grow as long as free blocks are available.
- ➢ No external fragmentation
  - ✓ Any free block can be used to satisfy a request.

- ➢ Ineffectively for direct access
  - ✓ To find the i^{th} block of a file, we must start at the beginning of that file and follow the pointers until we get to the i^{th} block.
- ➢ Extra overhead for storing points in blocks
- ➢ Low reliability

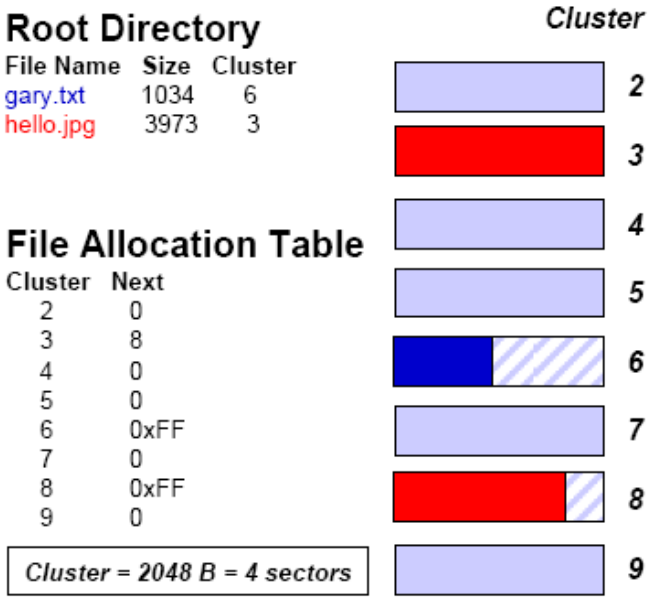
File Space Allocation

- Linked allocation: MS-DOS FAT as an example
  - FAT = File Allocation Table, a variation of linked allocation
    - ✓ one FAT per file system
    - ✓ one entry per block containing the next block in the file
  - Normally, one block= 512 bytes→ too small
  - Use cluster in FAT to replace block, where one cluster=2^x blocks (x=0,1,2,3,4,5,6,7…)
  - Size of a FAT is decided by total # of clusters on storage
    - ✓ In FAT, each entry represents a cluster
    - ✓ "0" means the cluster is free
    - ✓ "FF" means EOF



File Space Allocation

❑ Linked allocation: MS-DOS FAT as an example



- ➢ FAT-12: 12-bit addr space to index the entries in FAT
  - ✓ There are maximum 2^{12} clusters
  - ✓ If one cluster=one block= 512 B, then max volume size=512 B/cluster* 2^{12} clusters=2 MB---floppy disk, whose size is 1.44 MB
  - ✓ The size of a cluster (i.e., 2^x block) is specified in the boot record.
- ➢ FAT-16 (1987): 16-bit addr space to index the entries in FAT
  - ✓ There are maximum 2^{16} clusters
  - ✓ If one cluster=one block= 512 B, then max volume size=512 B/cluster* 2^{16} clusters=32 MB Too small
  - ✓ If one cluster=128 blocks= 64 KB, then max volume size= 64 KB/cluster * 2^{16} clusters=4 GB. Fairly enough but incurs internal fragmentation.
  - ✓ Internal fragmentation is the wasted space within each allocated block because of rounding up from the actual requested allocation to the allocation granularity.

File Space Allocation

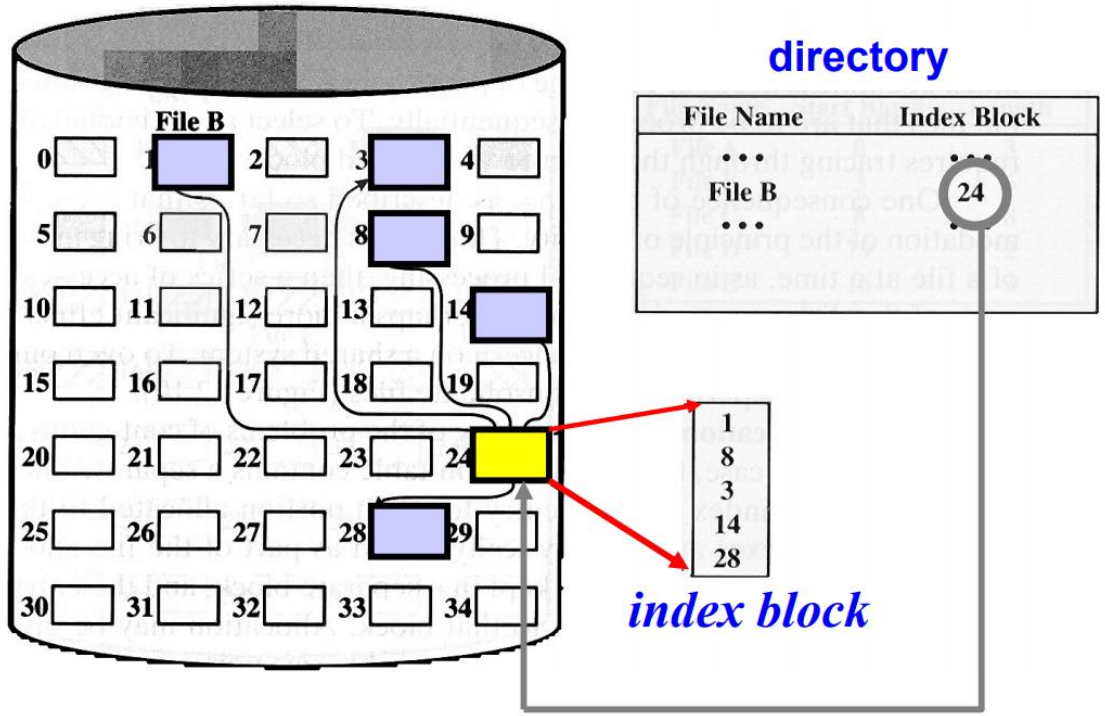
- Linked allocation: MS-DOS FAT as an example
  - FAT-32 (1996, Windows 95): 32-bit addr space to index the entries in FAT
    - ✓ There are maximum 2^{32} clusters
    - ✓ If one cluster=one block= 512 B, then max volume size=512 B/cluster* 2^{32} clusters=2 TB
    - ✓ If one cluster=8 blocks= 4 KB, then max volume size=4 KB/cluster* 2^{32} clusters=16 TB

      The setup is used as the default setting by NTFS
  - FAT requires storing the entire table in memory for efficient access --- A huge table!

File Space Allocation

❑ Indexed allocation

- ➢ Bring all pointers together in an index block
- ➢ The i^{th} entry in the index block points to the i^{th} block of the file.
- ➢ FCB contains a pointer to its index block.



File Space Allocation

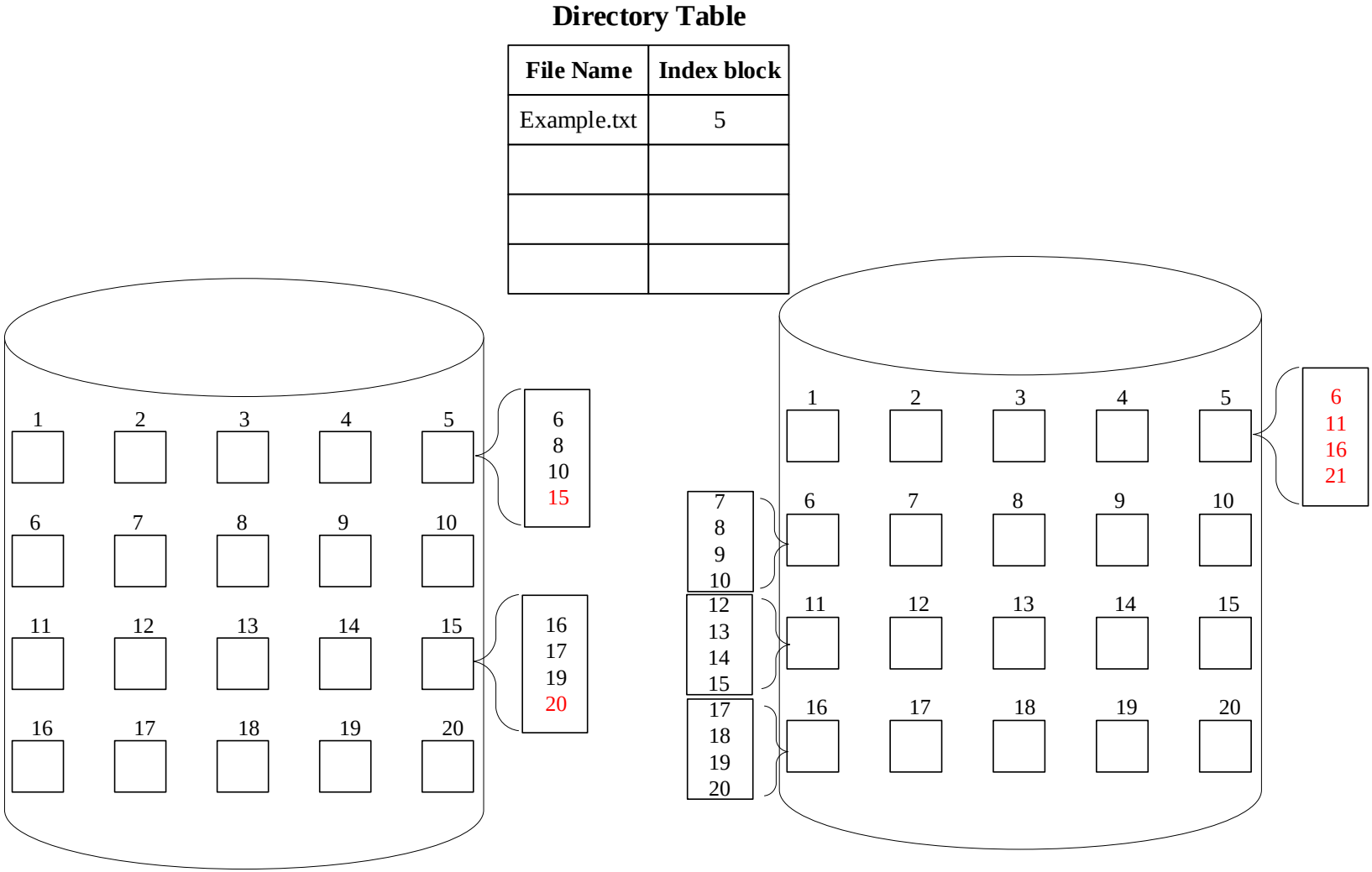
- Indexed allocation pros and cons
  - Flexible to extend, insert, and delete blocks
  - Index allocation supports both sequential and direct access without external fragmentation.
  - Suffer from wasted space
    - ✓ The overhead of the index block may be greater than the pointer overhead of linked allocation.
  - An index block could be too small to hold enough pointers for a large file

File Space Allocation

❑ Indexed allocation (Multiple index blocks in UNIX-based file system)

➢ Solution

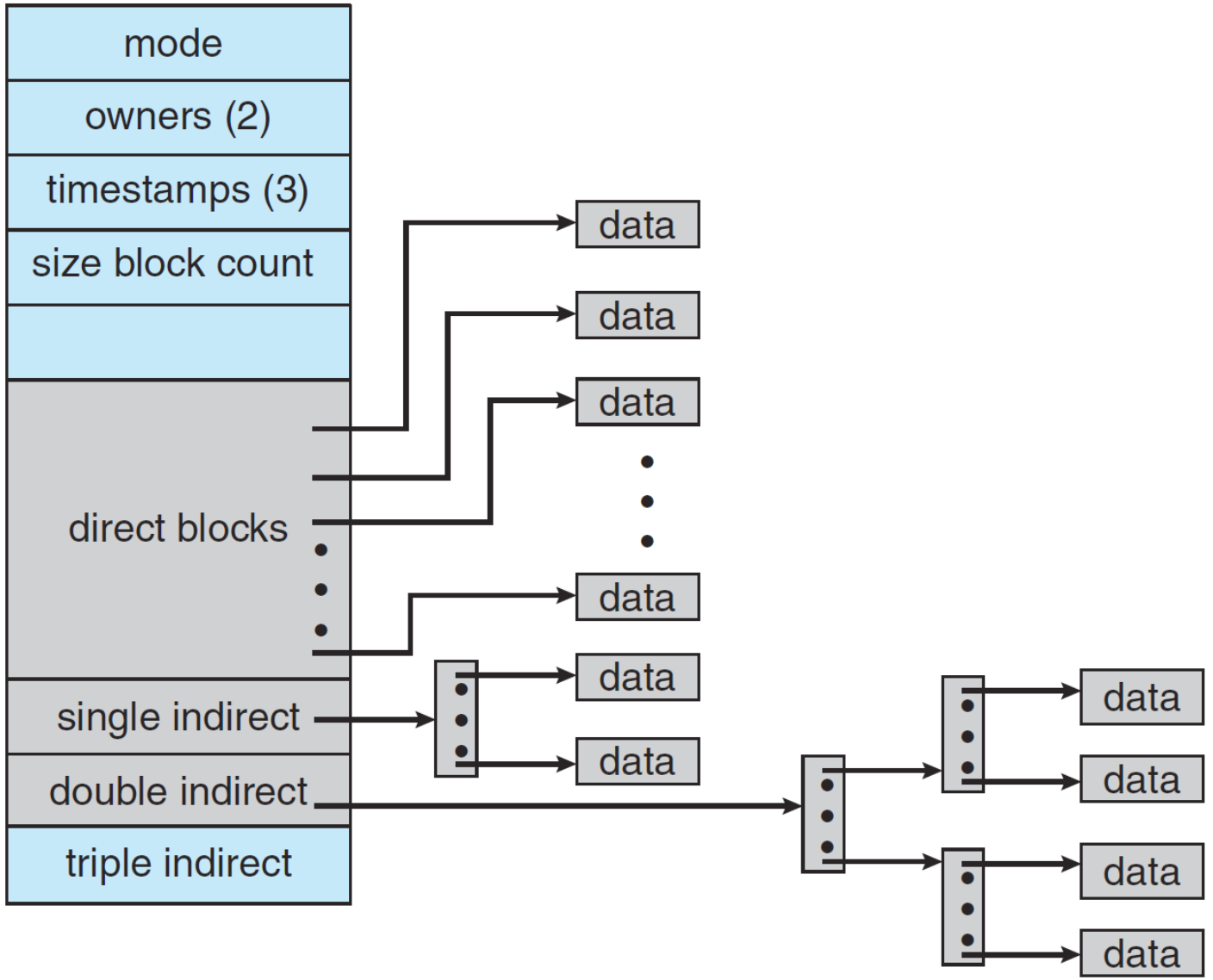
1) Have multiple index blocks and chain them into a linked-list.
2) Have multiple index blocks but make them a tree just like the indexed access method.



File Space Allocation

- Indexed allocation (Multiple index blocks in UNIX-based file system)
  - Solution

    3) Mixed solution



Free Space Management

- How do we keep track free blocks on a disk?

- A free block list is maintained. When a new block is requested, we search this list to find one.

- The following are commonly used techniques:
  - ✓ Bit Vector
  - ✓ Linked List
  - ✓ Grouping
  - ✓ Linked List + Address + Count

Free Space Management

Bit Vector

- Each block is represented by a bit in a vector. Thus, if there are n disk blocks, the vector has n bits.
- If a block is free, its corresponding bit is 0.
- When a block is needed, the vector is searched.
- If the disk capacity is small, the whole bit vector can be stored in the main memory. For a large disk, this bit vector will consume too much memory.
- We could group a few blocks into a cluster and allocate clusters. This can reduce the size of the vector, but may cause internal fragmentation.

$$bit[i] = \begin{cases} 0 \Rightarrow block[i] \text{ free} \\ 1 \Rightarrow block[i] \text{ occupied} \end{cases}$$

Free Space Management

Bit Vector

- Block size=512 B=2^9 Bytes
- Disk size=1 TB=2^{40} Bytes
- What is the size of the bit vector?

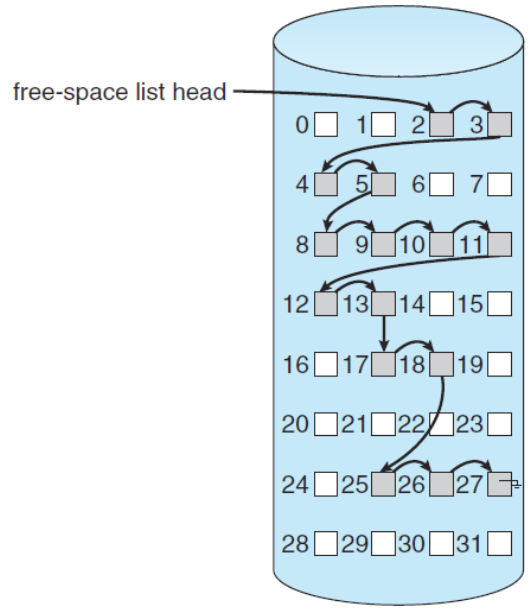
- Solution:

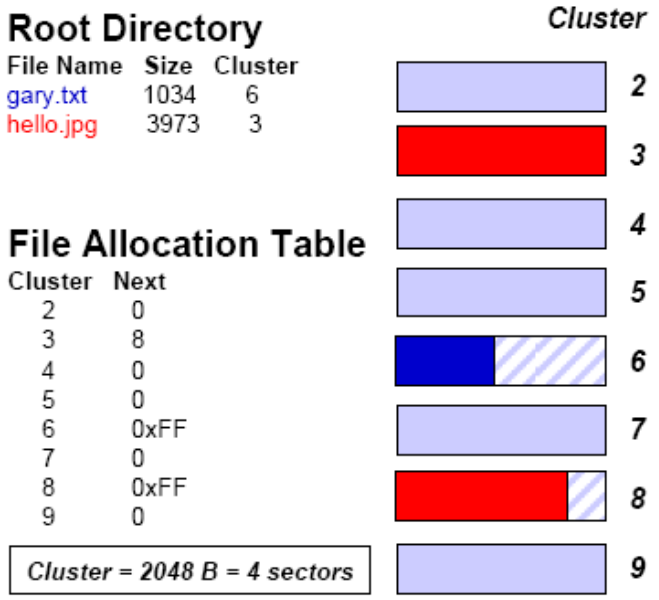
  - ✓ Total number of blocks=2^{40}/ 2^9 =2^{31}
  - ✓ 2^{31} bits (=256 MB) are used to represent 2^{31} blocks.
  - ✓ That is, the size of the bit vector is 256 MB, which is normally stored in the memory.
  - ✓ If we group 4 blocks into a cluster, size of the bit vector= 64 MB.

Free Space Management

Linked List

- Like the linked allocation method, free blocks can be chained into a linked list.
- When a free block is needed, the first one in the chain is allocated.
- However, this method has the same disadvantages of the linked allocation method.
- We may use a FAT for the disk and chain the free block pointers together. Note that the FAT may be very large and consume memory space.

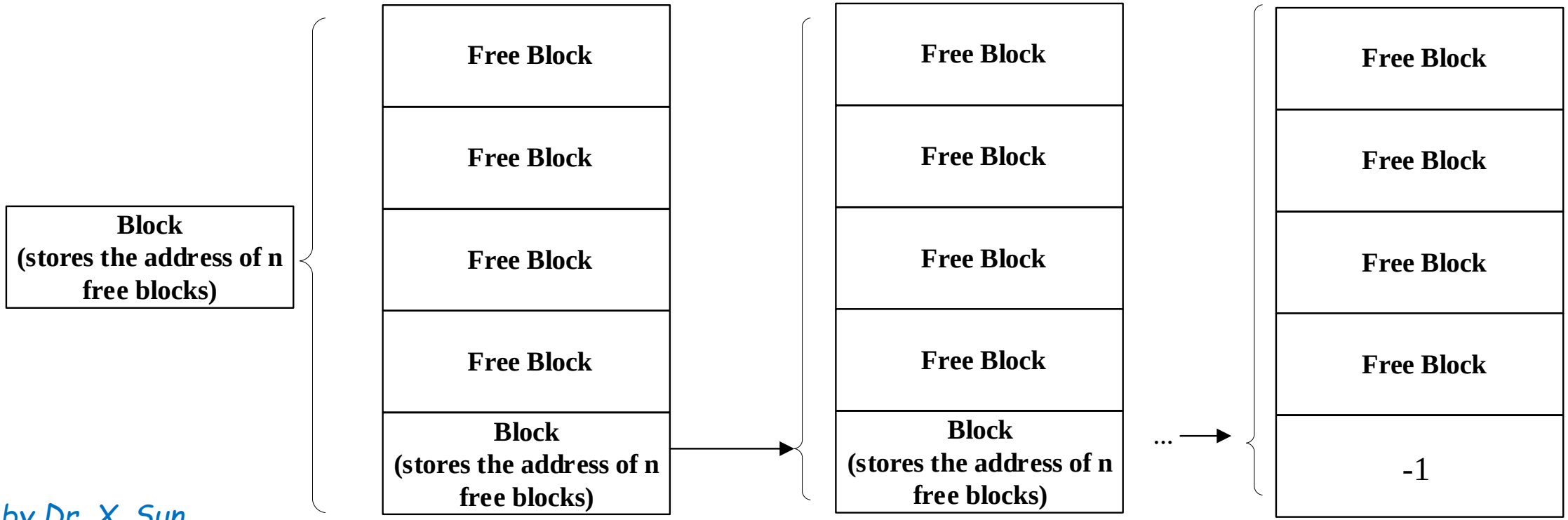




Free Space Management

Grouping

- The first free block stores the address of n free blocks.
- Out of these n blocks, the first n-1 blocks are actually free, and the last block contains the address of next free n blocks.
- In this way, we can quickly locate free blocks.



Free Space Management

Grouping

- Block size=4 KB=2^{12} Bytes
- Disk size=1 TB=2^{40} Bytes
- Assume that 32 bits are used to represent a block number
- How many blocks are needed to store the addresses of free blocks in the worst-case scenario?

- Solution:

  - ✓ Each block can store $2^{12}/4=2^{10}$ block numbers.
  - ✓ In the worst-case scenario, total number of free blocks= $2^{40} / 2^{12} = 2^{28}$
  - ✓ Number of needed blocks= $2^{28} /2^{10}= 2^{18}$, which needs 2^{18} *4 KB=1 GB.

Free Space Management

❑ Link List + Address + Counting

- Blocks are often allocated and freed in groups.
- We can store the address of the first free block and the number of the following n free blocks.