CS370 Operating Systems

Colorado State University

Yashwant K Malaiya

Fall 2016 Lecture 39

File-system Implementation

Slides based on

- Text by Silberschatz, Galvin, Gagne
- Various sources

File Systems

"MS. GRIMMETT, I SORT OF LIKED THE OLD FILING SYSTEM...IN THE FILE CABINETS."

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FAQ

- Can a set of files be mounted to the top of a tree
  - What you mount is a file system on a device, which is attached to a mount point in another file system.
- Can windows mount files from linux and vice versa?
  - Samba, auto mount
- How do you access data when one drive in RAID 0 fails?
  - RAID 0: non-redundant, striping
- What is the advantage of a journaling file system? Records changes not committed. Can resolve inconsistencies due to crashes.
- How much history do journaling file systems keep?

Notes

- Poster Session Dec 9   10-noon
  - See Assignments page, Canvas
- You can get posters printed CNS Lab in
  - Anatomy/Zoology E100 (CNS Undergrads) or
  - Morgan Library (account number from Kim Judith, Accounting, 266 CSB)
  - I recommend getting it printed sometime on Dec 7.

Allocation Methods

Allocation Methods

An allocation method refers to how disk blocks are allocated for files:

- Contiguous (not common, except for DVDs etc.)
- Linked (e.g. FAT32)
- Indexed (e.g. ex4)

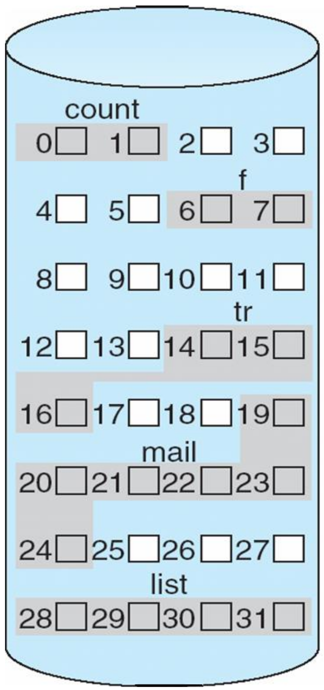
Thoughts about optimization:
- Sequential vs random access
- What is the common file size?

Allocation Methods – i.Contiguous

i. Contiguous allocation – each file occupies set of contiguous blocks

- Simple – only starting location (block #) and length (number of blocks) are required
  - Occupies n block   b, b+1, …b+n-1
- Minimal disk head movement
- Problems include finding space for file, knowing file size, external fragmentation, need for **compaction off-line** (**downtime**) or **on-line**

Contiguous Allocation



directory

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

File **tr**: 3 blocks
Starting at block 14

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Contiguous Allocation

- Mapping logical byte address LA to physical address

Assume block size =512

Q

LA/512

R

Block to be accessed = starting block number (address) + Q
Displacement into block = R

Extent-Based Systems

- Some file systems use a modified contiguous allocation scheme
- Extent-based file systems allocate disk blocks in extents
  - An **extent** is a contiguous block
    - Metadata: beginning block, number of blocks
  - Extents are allocated for file allocation
  - A file consists of one or more extents

Allocation Methods - Linked

ii. Linked allocation – each file a linked list of blocks

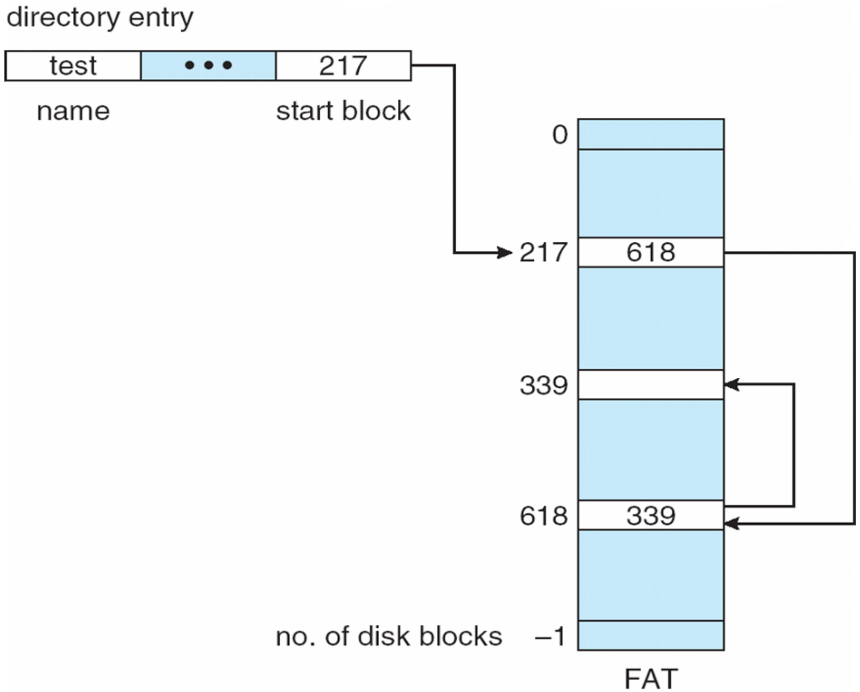
- Each block contains pointer to next block.
- File ends at null pointer
- No external fragmentation, no compaction

Free space management system called when new block needed

- Locating a block can take many I/Os and disk seeks.
- Improve efficiency by clustering blocks into groups but increases internal fragmentation
- Reliability can be a problem, since every block in a file is linked

Allocation Methods – Linked (Cont.)

- FAT (File Allocation Table) variation
  - Beginning of volume has table, indexed by block number
  - Much like a linked list, but faster on disk and cacheable
  - New block allocation simple



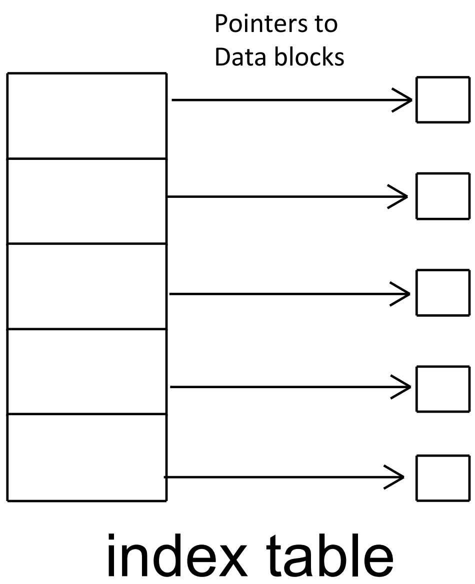
Each FAT entry corresponds to the corresponding block of Storage.

Free block entries are also linked.

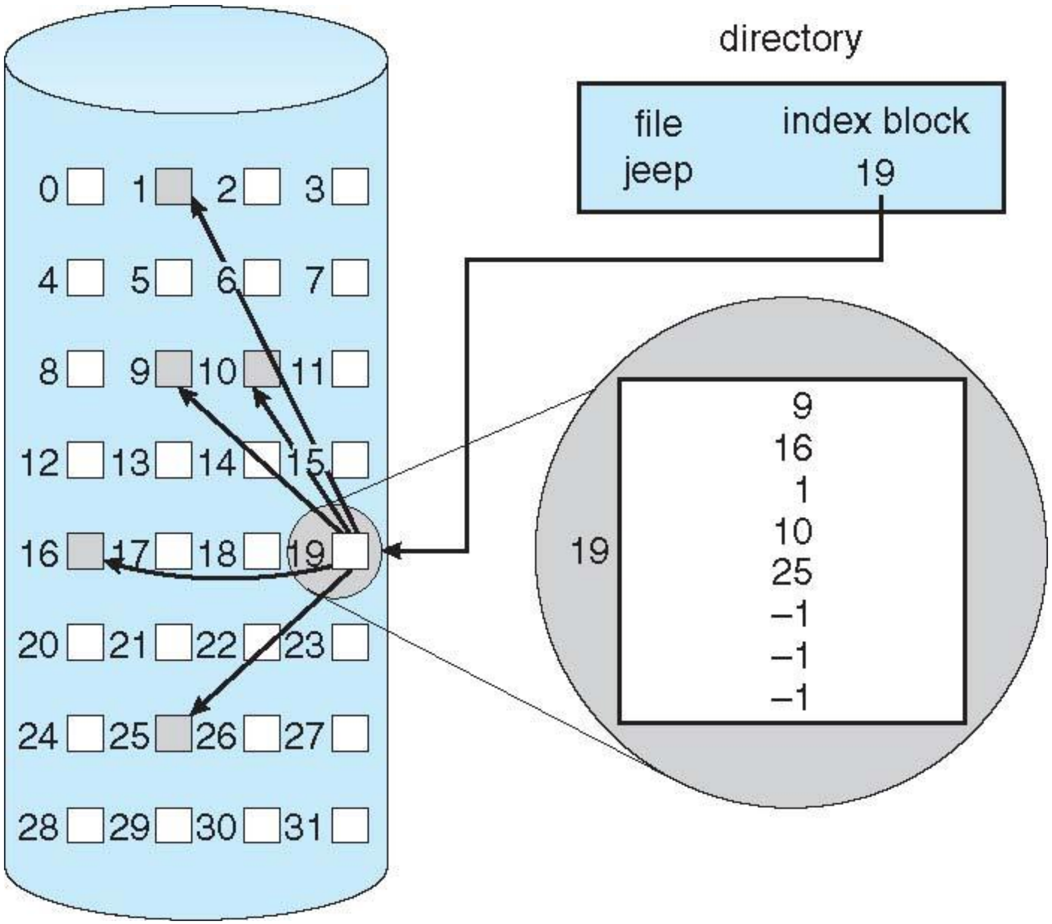
Allocation Methods - Indexed

- **Indexed allocation**
  - Each file has its own **index block**(s) of pointers to its data blocks

- Logical view



Example of Indexed Allocation



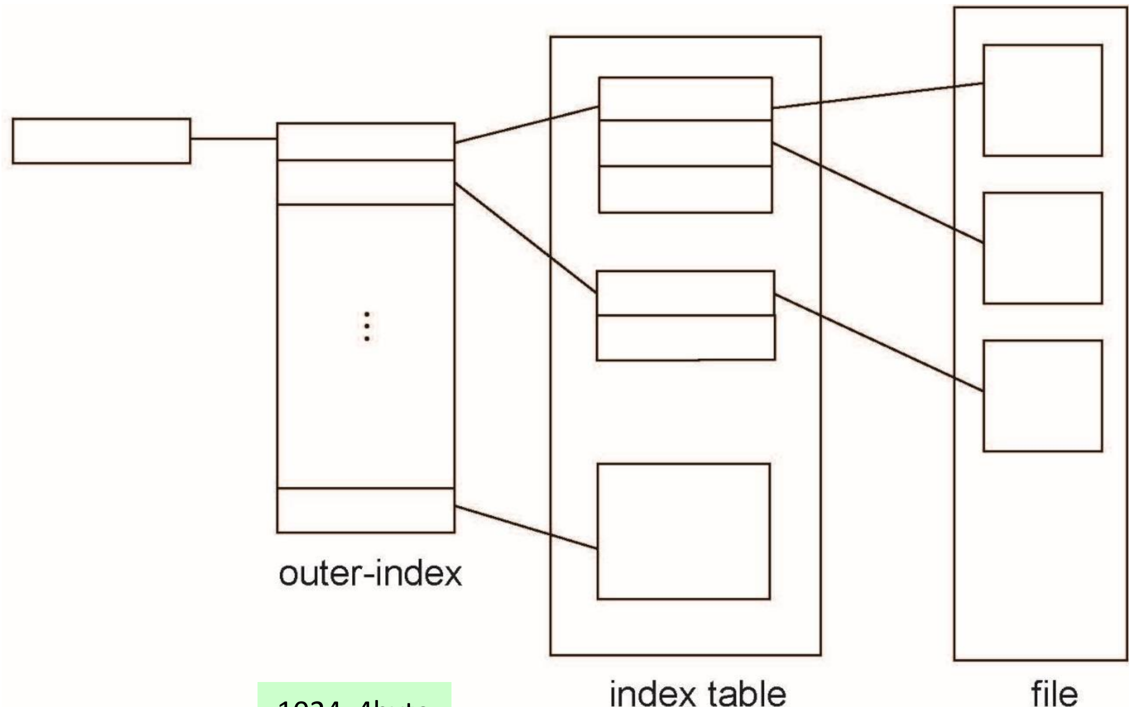
Indexed Allocation (Cont.)

- Need index table
- Random access
- Dynamic access without external fragmentation, but have overhead of index block even for a small file
- Assuming pointer size is 1 byte, block is 512 bytes
- 1 block for index table can be used for a file of maximum size of 512x512 = 256K bytes
- Larger files? Multi-block index table?

Indexed Allocation – Two level

- **Two-level index: Ex:** 4K blocks could store 1,024 four-byte pointers in outer index -> 1024x1024 data blocks and file size of up to 4GB

$2^{10} = 1024$



1024 4byte pointers

1024 tables, 1024 pointers each

4KB each

Most files are ..

- Most file are small, but the few very large files* occupy a large fraction of the space
- Optimize for small files, but allow for large files also

* Y. K. Malaiya and J. Denton " Module Size Distribution and Defect Density," Proc. IEEE International Symposium on Software Reliability Engineering, Oct. 2000, pp. 62-71

Inode idea

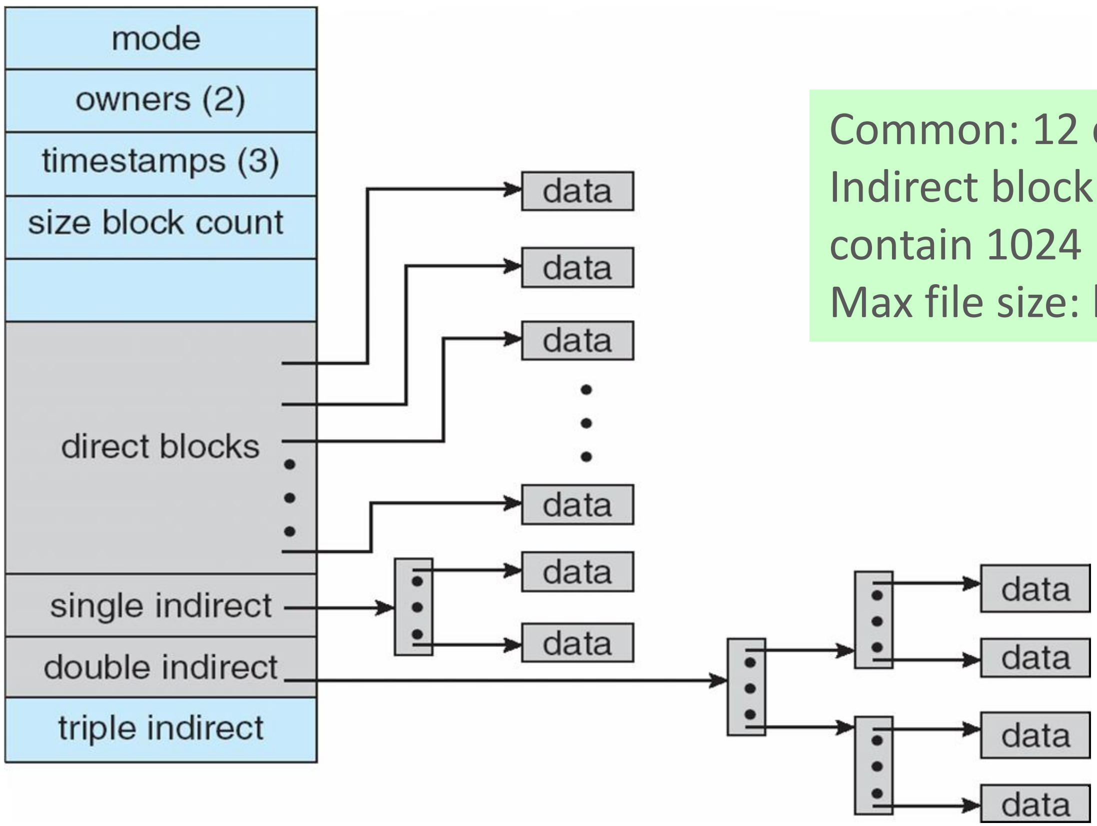
Inode: hold file metadata including pointers to actual data

- Small file stored in the inode itself. Typical inode size 128 bytes
- Medium size: direct pointers to data
- If the file is large: Indirect pointer
  - To a block of pointers that point to additional data blocks
- If the file is larger: Double indirect pointer
  - Pointer to a block of indirect pointers
- If the file is huge: Triple indirect pointer
  - Pointer to a block of double-indirect pointers

Combined Scheme: UNIX inodes

Assume 4K bytes per block, 32-bit addresses

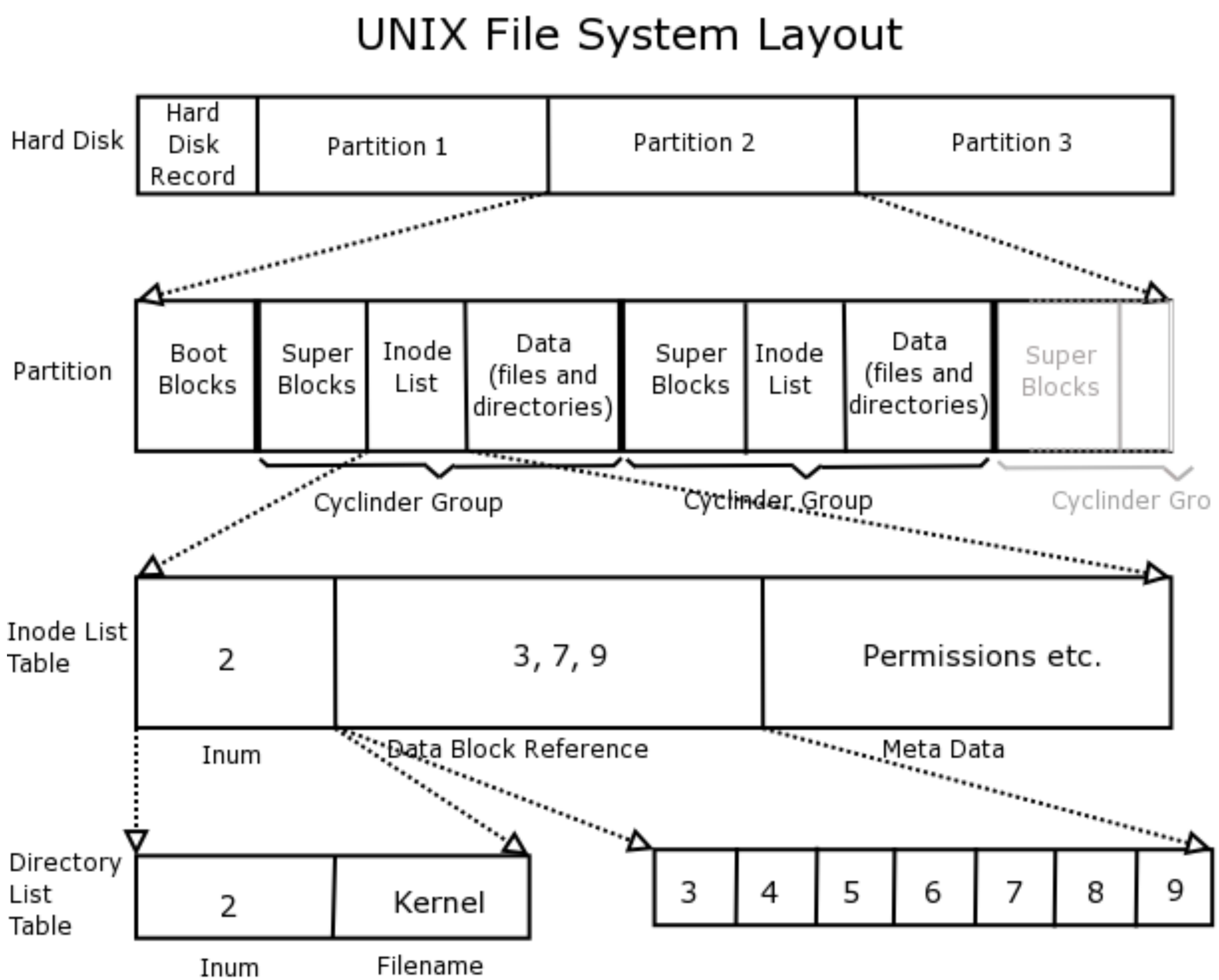
Volume block:
Table with file names
Points to this inode
(file control block)



Common: 12 direct+3.
Indirect block could
contain 1024 pointers.
Max file size: k.k.k.4k+

More index blocks than can be addressed with 32-bit file pointer

On-disk layout of a typical UNIX file system



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Performance

- Best method depends on file access type
  - Contiguous great for sequential and random
- Linked good for sequential, not random
- Indexed more complex
  - Single block access could require 0-3 index block reads then data block read
  - Clustering can help improve throughput, reduce CPU overhead

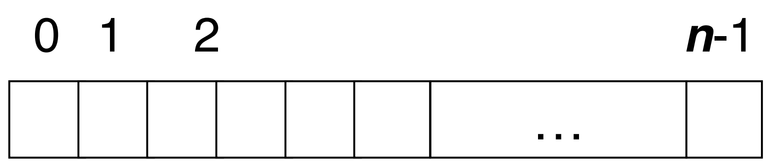
Cluster: set of contiguous sectors

Performance (Cont.)

- Adding instructions to the execution path to save one disk I/O is reasonable
  - Intel Core i7 Extreme Edition 990x (2011) at 3.46Ghz = 159,000 MIPS
    - http://en.wikipedia.org/wiki/Instructions_per_second
  - Typical disk drive at 250 I/Os per second
    - 159,000 MIPS / 250 = 630 million instructions during one disk I/O
  - Fast SSD drives provide 60,000 IOPS
    - 159,000 MIPS / 60,000 = 2.65 millions instructions during one disk I/O

Free-Space Management

- File system maintains **free-space list** to track available blocks/clusters
  - (Using term "block" for simplicity)
- **Approaches: i. Bit vector ii. Linked list iii. Grouping iv. Counting**
- **Bit vector** or **bit map** (***n*** blocks)



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

Block number calculation for first free block

(number of bits per word) *(number of 0-value words) + offset of first 1 bit

00000000
00000000
00111110
..

CPUs may instructions to return offset within word of first "1" bit

Free-Space Management (Cont.)

- Bit map requires extra space
  - Example:

    block size = 4KB = 2^{12} bytes

    disk size = 2^{40} bytes (1 terabyte)

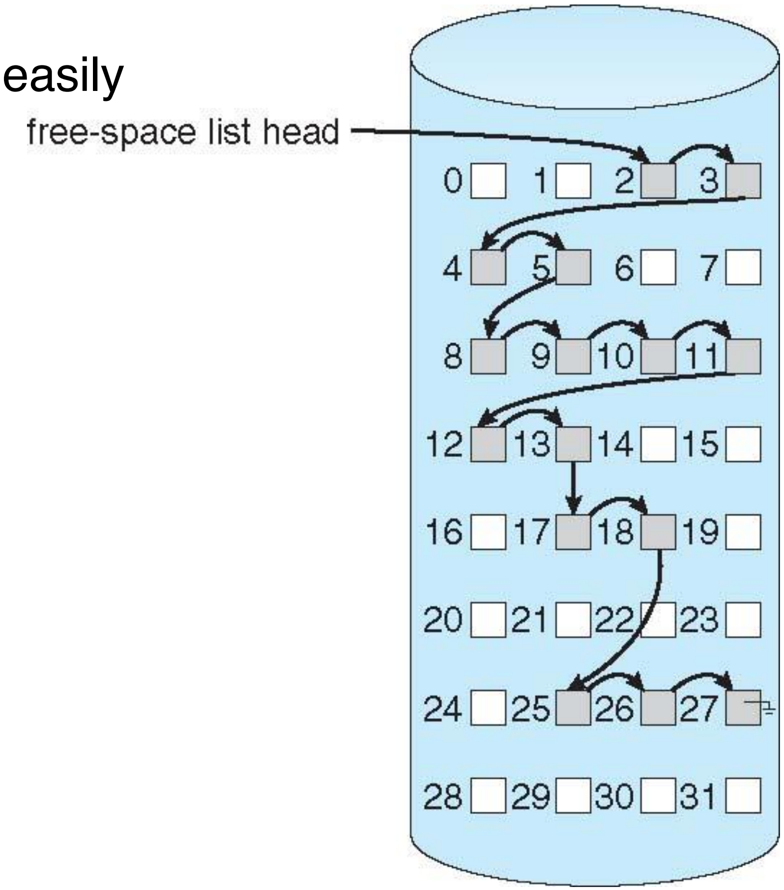
    blocks: $\boldsymbol{n} = 2^{40}/2^{12} = 2^{28}$ bits (or 32MB) for map

    if clusters of 4 blocks -> 8MB of memory

- Easy to get contiguous files if desired

Linked Free Space List on Disk

- ii. Linked list (free list)
  - Cannot get contiguous space easily
  - No waste of space



Superblock Can hold pointer to head of linked list

Free-Space Management (Cont.)

- iii. Grouping
  - Modify **linked list** to store address of next *n-1* free blocks in first free block, plus a pointer to next block that contains free-block-pointers
- iv. Counting
  - Because space is frequently contiguously used and freed, with contiguous-allocation allocation, extents, or clustering
    - Keep address of first free block and count of following free blocks
    - Free space list then has entries containing **addresses and counts**