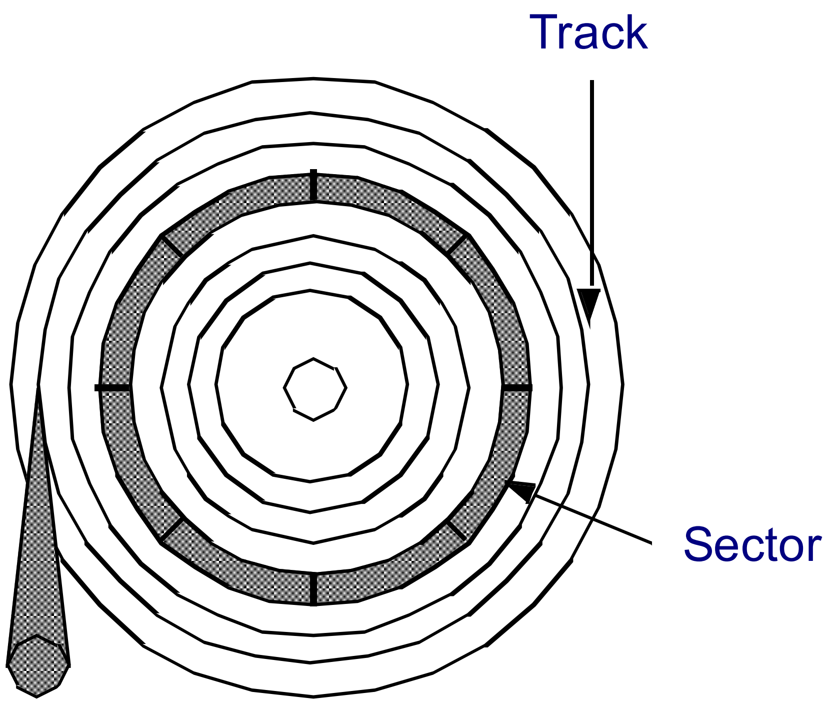
بسم الله الرحمن الرحیم

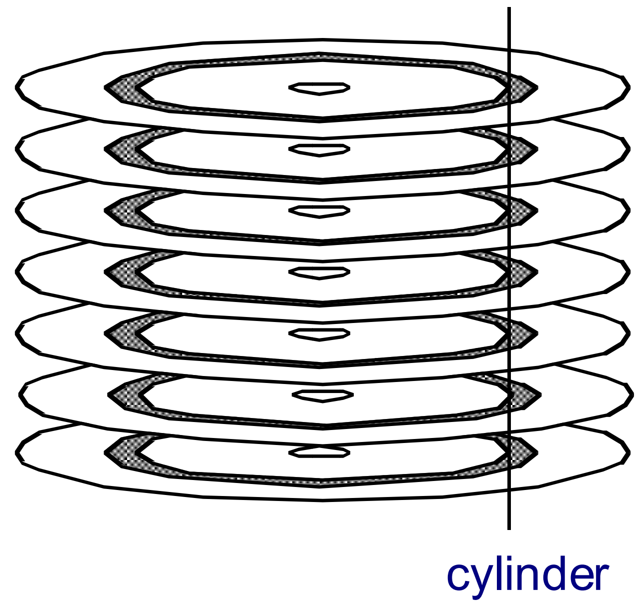
«سیستم عامل»

جلسه ۲۴: حافظه جانبی (Secondary Storage)

Disk geometry

- Disk head, surfaces, tracks, sectors …

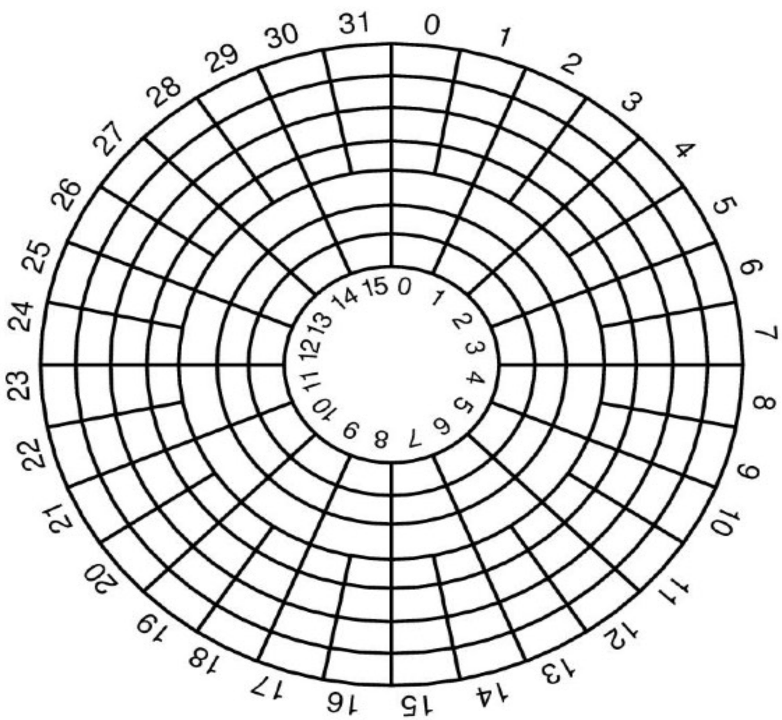




Comparison of (old) disk technology

Parameter	IBM 360-KB floppy disk	WD 18300 hard disk
Number of cylinders	40	10601
Tracks per cylinder	2	12
Sectors per track	9	281 (avg)
Sectors per disk	720	35742000
Bytes per sector	512	512
Disk capacity	360 KB	18.3 GB
Seek time (adjacent cylinders)	6 msec	0.8 msec
Seek time (average case)	77 msec	6.9 msec
Rotation time	200 msec	8.33 msec
Motor stop/start time	250 msec	20 sec
Time to transfer 1 sector	22 msec	17 μsec

Disk zones



Constant rotation speed

- Want constant bit density

Inner tracks:

- Fewer sectors per track

Outer tracks:

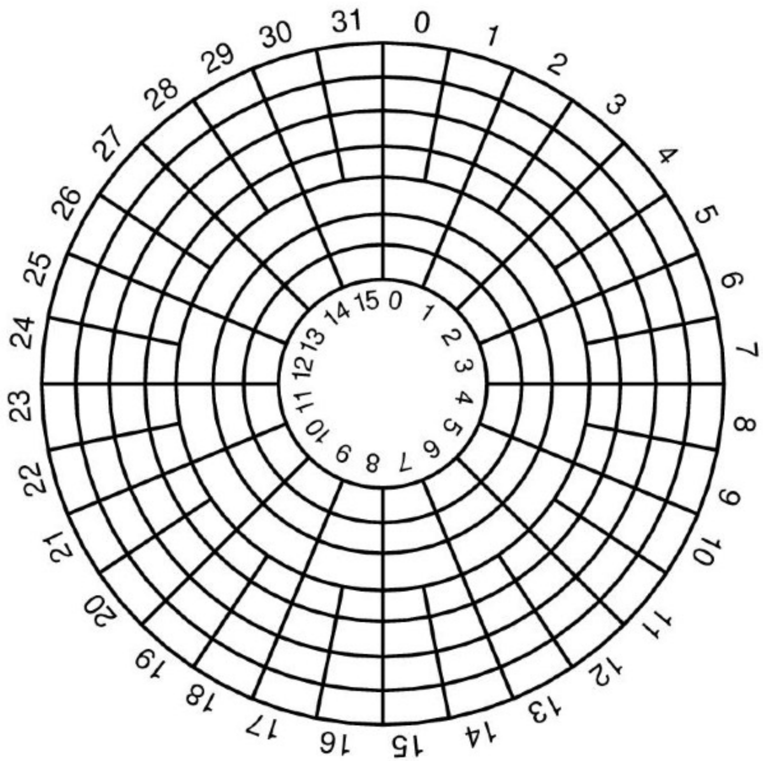
- More sectors per track

Disk geometry

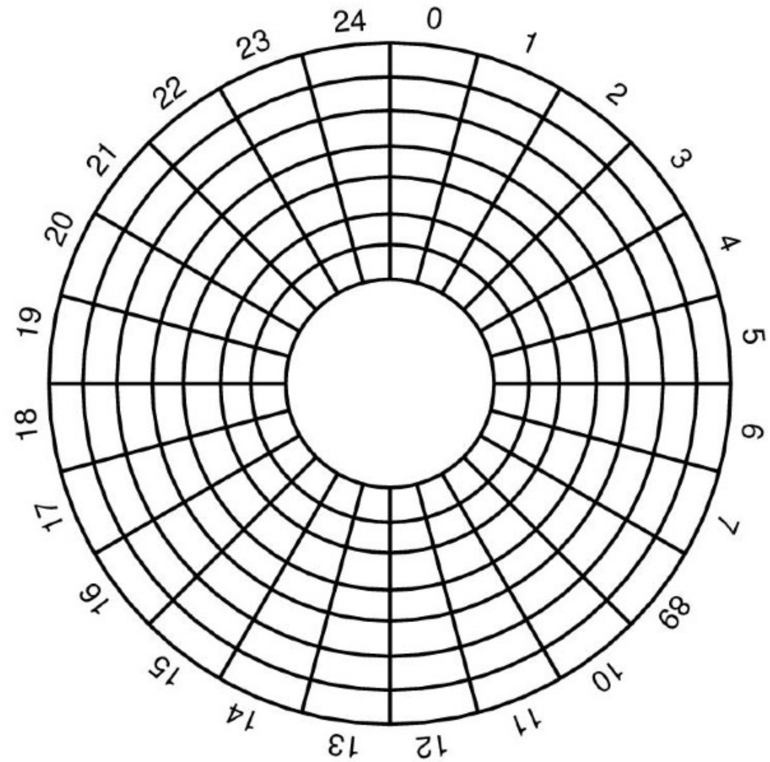
- **Physical Geometry**
  - The actual layout of sectors on the disk may be complicated
  - The disk controller does the translation
  - The CPU sees a “virtual geometry”.

Disk geometry

❑



physical geometry



virtual geometry

(192 sectors in each view)

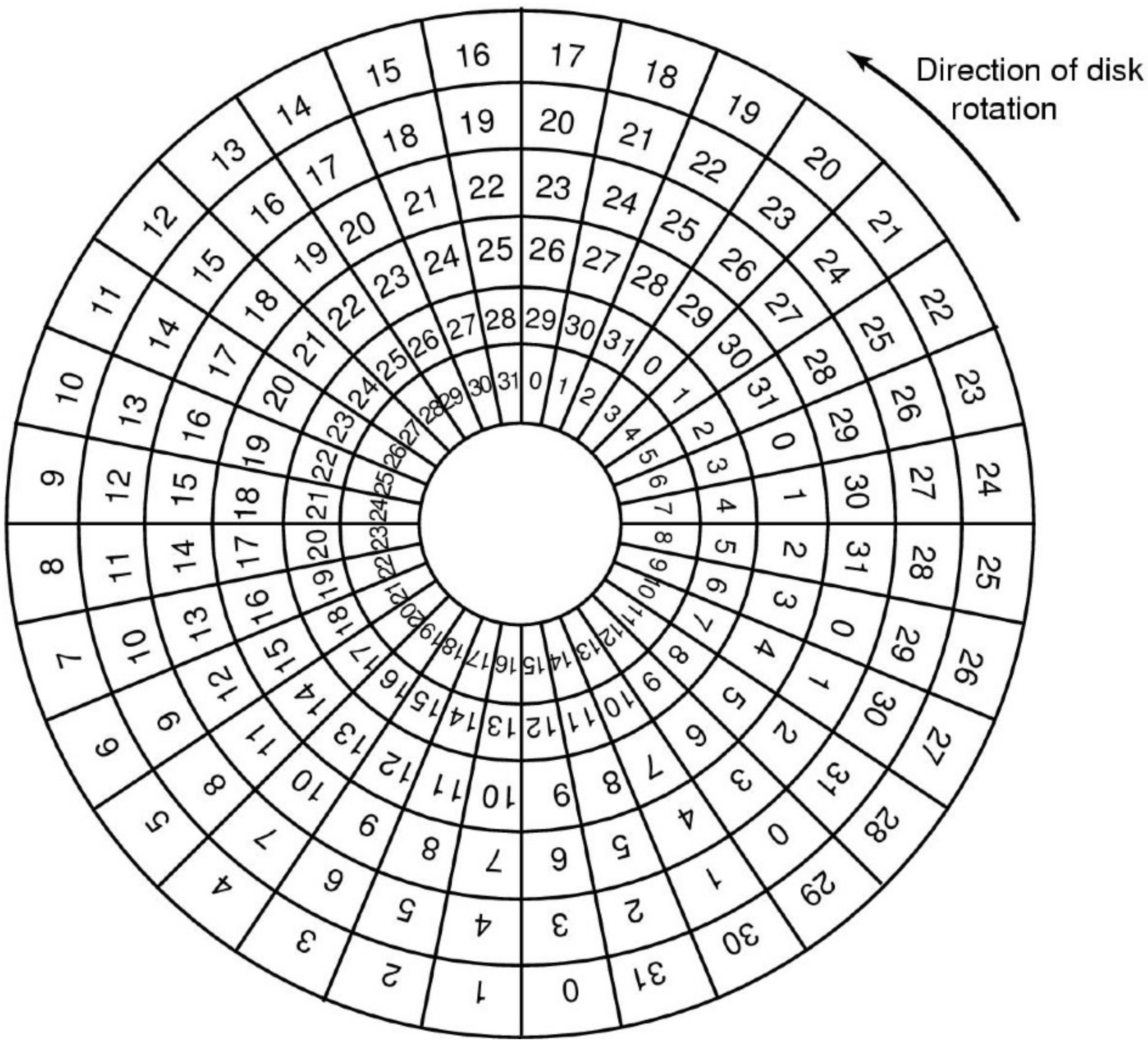
Disk formatting

- **A disk sector**

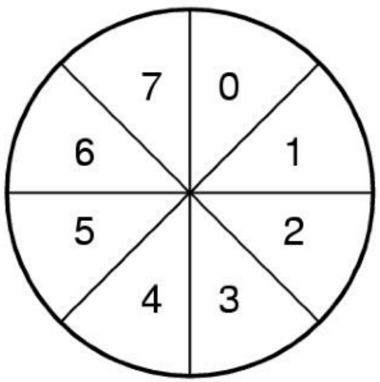
Preamble	Data	ECC

- **Typically**
  - **DATA** = 512 bytes / sector
  - ECC = 16 bytes

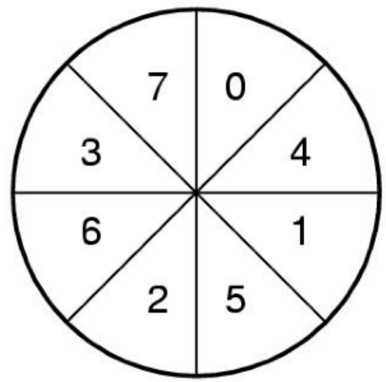
Cylinder skew



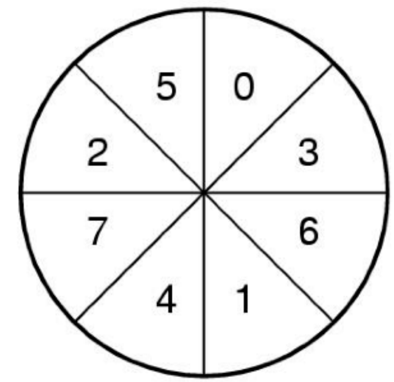
Sector interleaving



No Interleaving



Single Interleaving



Double Interleaving

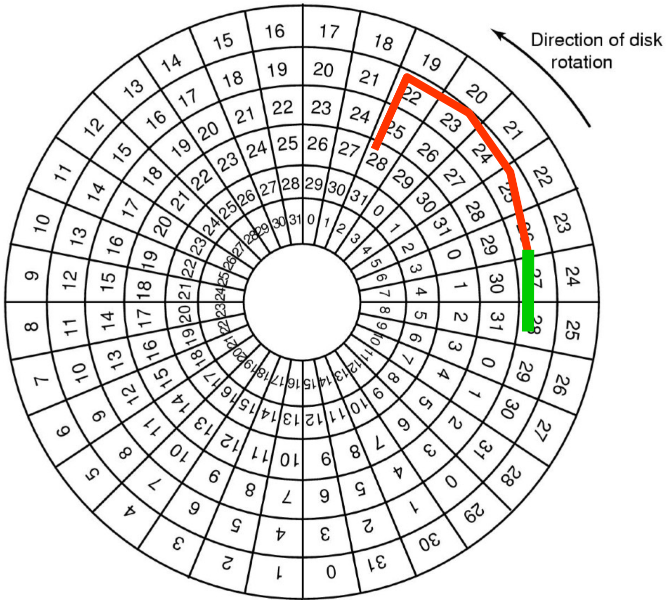
Block

- **Block** = minimum amont of read/write
  - Some sectors

Disk scheduling algorithms

- Time required to read or write a disk block determined by 3 factors
  - Seek time
  - Rotational delay
  - Actual transfer time

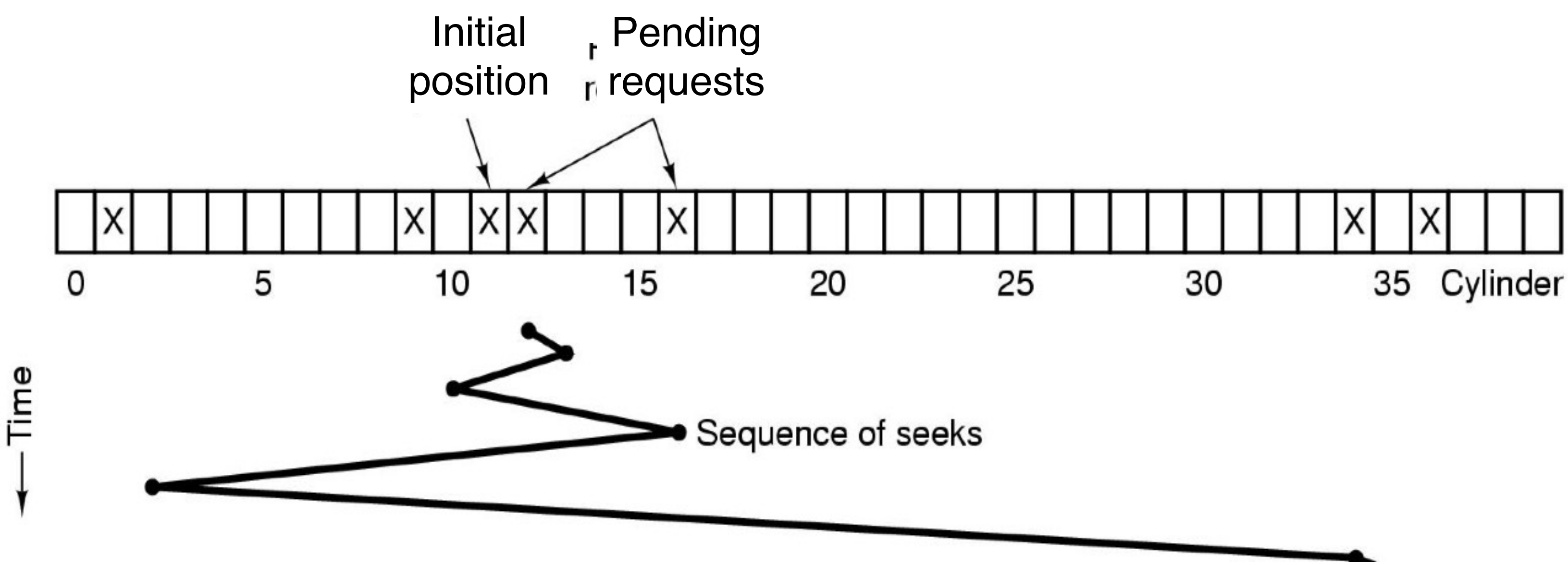
- Seek time dominates
  - Schedule disk heads to minimize it



Disk scheduling algorithms

- First-come first serve
- Shortest seek time first
- Scan → back and forth to ends of disk
- C-Scan → only one direction
- Look → back and forth to last request
- C-Look → only one direction

Shortest seek first (SSF)



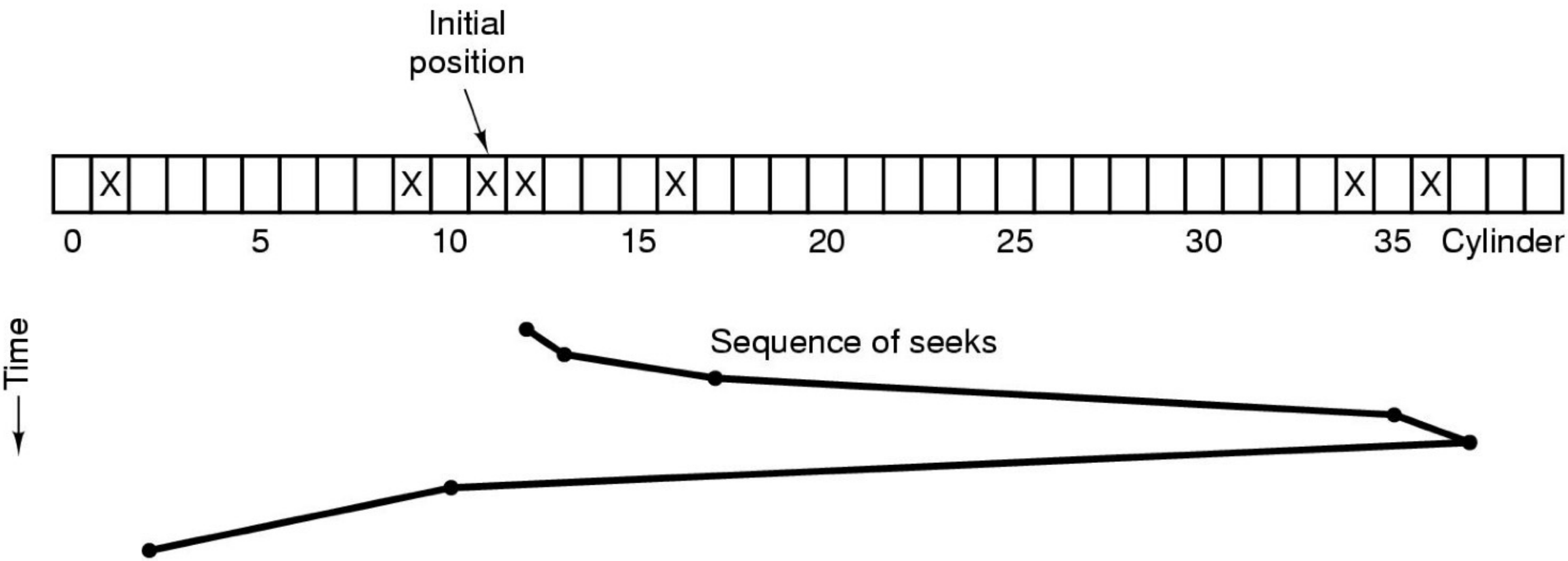
Shortest seek first (SSF)

- **Cuts arm motion in half**
- **Fatal problem:**
  - Starvation is possible!

The elevator algorithm

- **Use one bit to track which direction the arm is moving**
  - Up
  - Down
- **Keep moving in that direction**
- **Service the next pending request in that direction**
- **When there are no more requests in the current direction, reverse direction**

The elevator algorithm



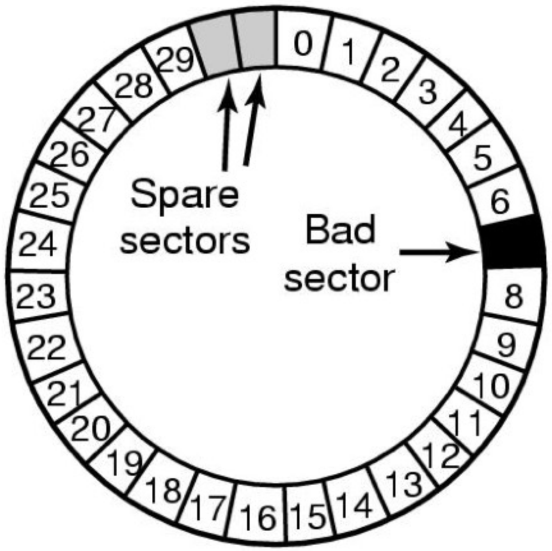
Other disk scheduling algorithms

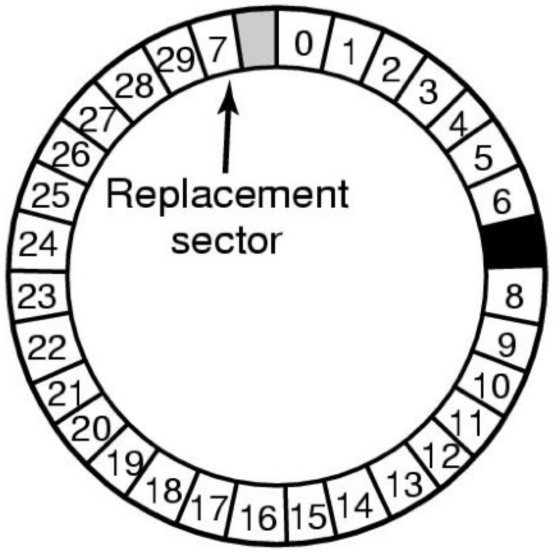
- First-come first serve
- Shortest seek time first
- Scan → back and forth to ends of disk
- C-Scan → only one direction
- Look → back and forth to last request
- C-Look → only one direction

Errors on disks

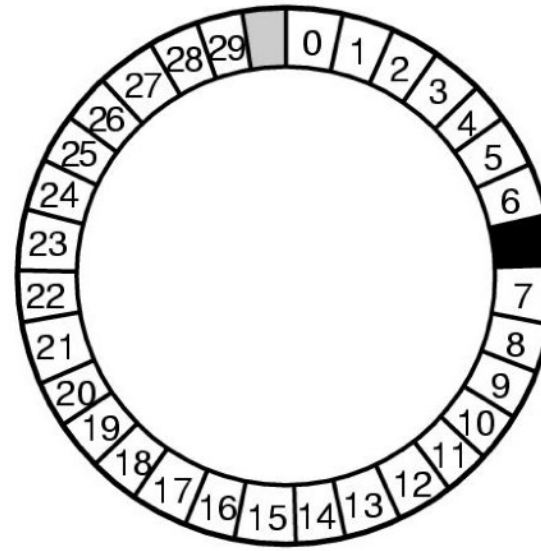
- **Transient errors v. hard errors**
- **Manufacturing defects are unavoidable**
  - Some will be masked with the ECC (error correcting code) in each sector
- **Dealing with bad sectors**
  - Allocate several spare sectors per track
- **At the factory, some sectors are remapped to spares**
  - Errors may also occur during the disk lifetime
- **The sector must be remapped to a spare**
  - By the OS
  - By the device controller

Using spare sectors





Substituting a new sector



Shifting sectors

Handling bad sectors in the OS

- **Add all bad sectors to a special file**
  - The file is hidden; not in the file system
  - Users will never see the bad sectors
    - **There is never an attempt to access the file**

- **Backups**
  - Some backup programs copy entire <u>tracks</u> at a time
    - **Efficient**
  - Problem:
    - **May try to copy every sector**
    - **Must be aware of bad sectors**

Stable storage

- **The model of possible errors:**
  - Disk writes a block and reads it back for confirmation
  - If there is an error during a write...
    - **It will probably be detected upon reading the block**
  - Disk blocks can go bad spontaneously
    - **But subsequent reads will detect the error**
  - CPU can fail (just stops)
    - **Disk writes in progress are detectable errors**
  - Highly unlikely to loose the same block on two disks (on the same day)

Stable storage

- **Use two disks for redundancy**
- **Each write is done twice**
  - Each disk has N blocks.
  - Each disk contains exactly the same data.
- **To read the data ...**
  - you can read from either disk
- **To perform a write ...**
  - you must update the same block on both disks
- **If one disk goes bad ...**
  - You can recover from the other disk

Stable storage

- Stable write
  - Write block on disk # 1
  - Read back to verify
  - If problems…
    - **Try again several times to get the block written**
    - **Then declare the sector bad and remap the sector**
    - **Repeat until the write to disk #1 succeeds**
  - Write same data to corresponding block on disk #2
    - **Read back to verify**
    - **Retry until it also succeeds**

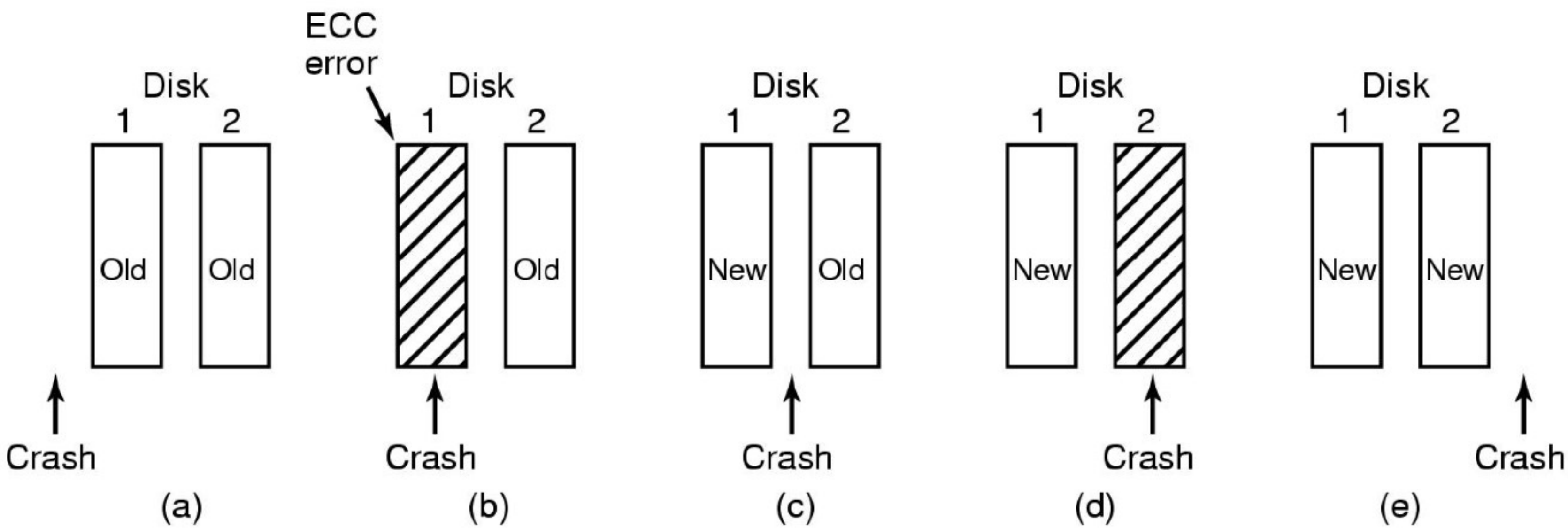
Stable storage

- Stable Read
  - Read the block from disk # 1
  - If problems...
    - **Try again several times to get the block**
  - If the block can not be read from disk #1...
    - **Read the corresponding block from disk #2**
  - Our Assumption:
    - **The same block will not simultaneously go bad on both disks**

Stable storage

- Crash Recovery
- Scan both disks
- Compare corresponding blocks
- For each pair of blocks...
  - If both are good and have same data...
    - Do nothing; go on to next pair of blocks
  - If one is bad (failed ECC)...
    - Copy the block from the good disk
  - If both are good, but contain different data...
    - (CPU must have crashed during a "Stable Write")
    - Copy the data from disk #1 to disk #2

Crashes during a stable write

- 

Stable storage

- **Disk blocks can spontaneously decay**
- **Given enough time...**
  - The same block on both disks may go bad
    - **Data could be lost!**
  - Must scan both disks to watch for bad blocks (e.g., every day)

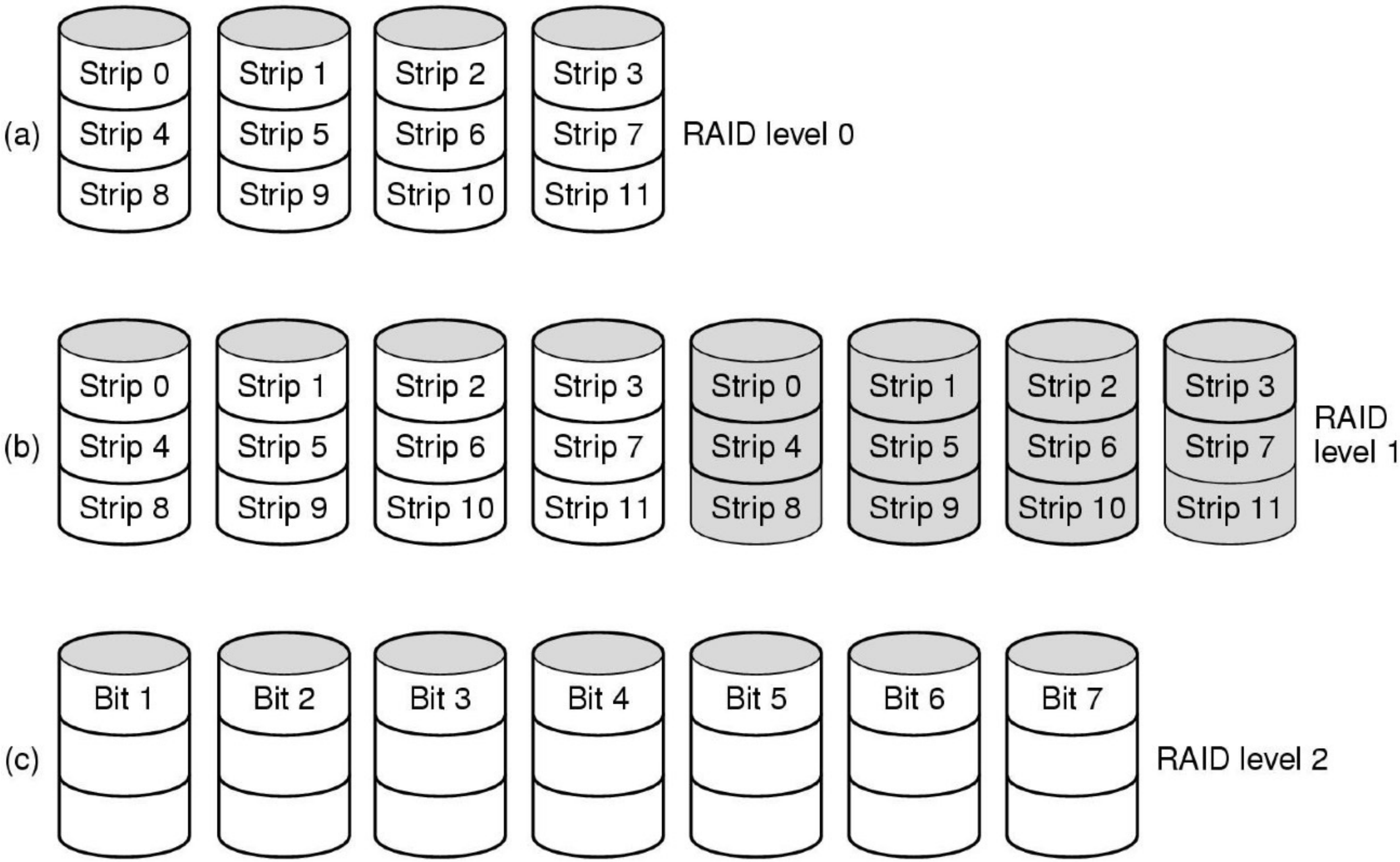
- **Many variants to improve performance**
  - Goal: avoid scanning entire disk after a crash.
  - Goal: improve performance
    - **Every stable write requires: 2 writes & 2 reads**
    - **Can do better...**

RAID

- **Redundant Array of Independent Disks**
- **Redundant Array of Inexpensive Disks**

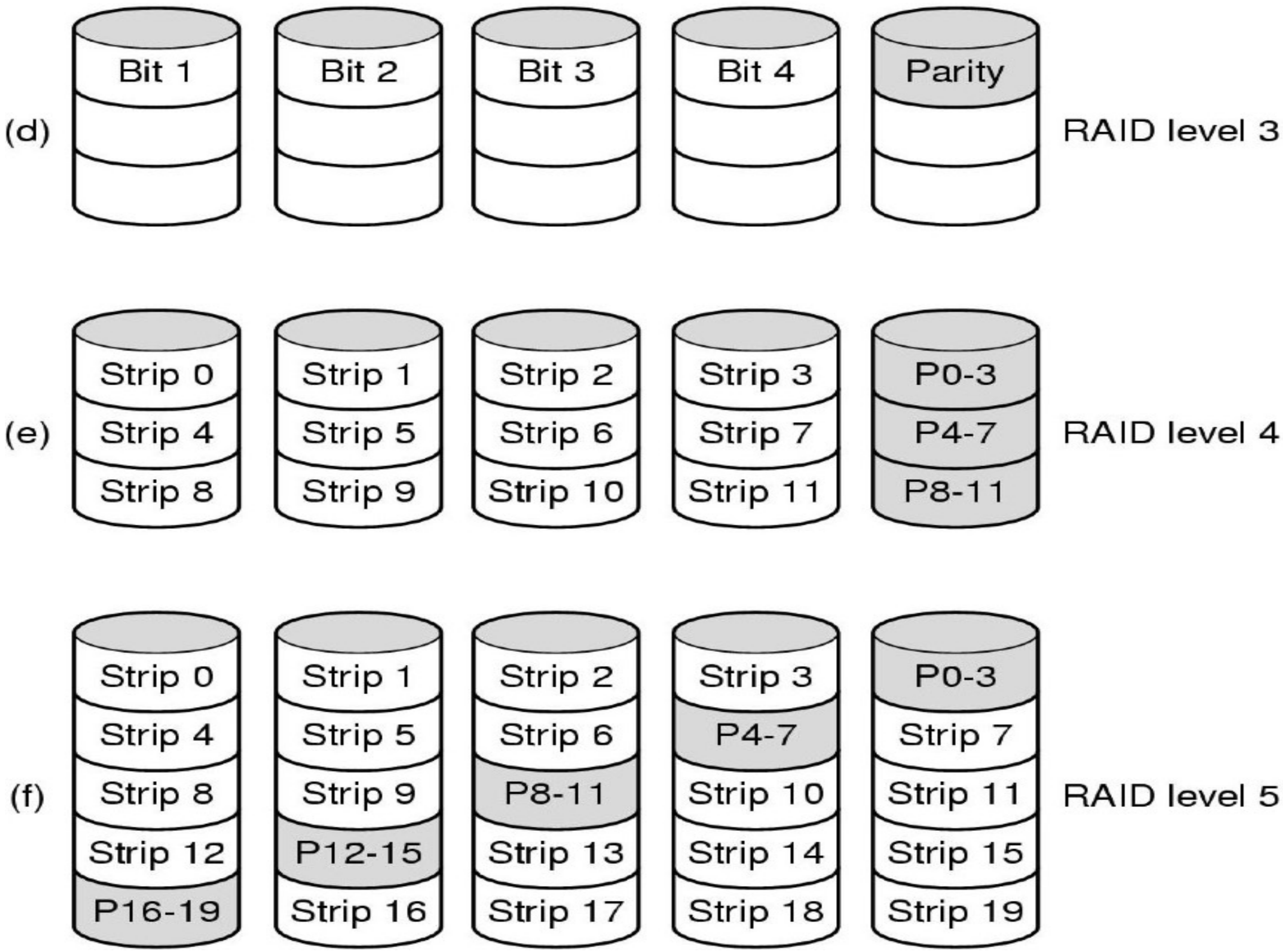
- **Goals:**
  - Increased reliability
  - Increased performance

RAID



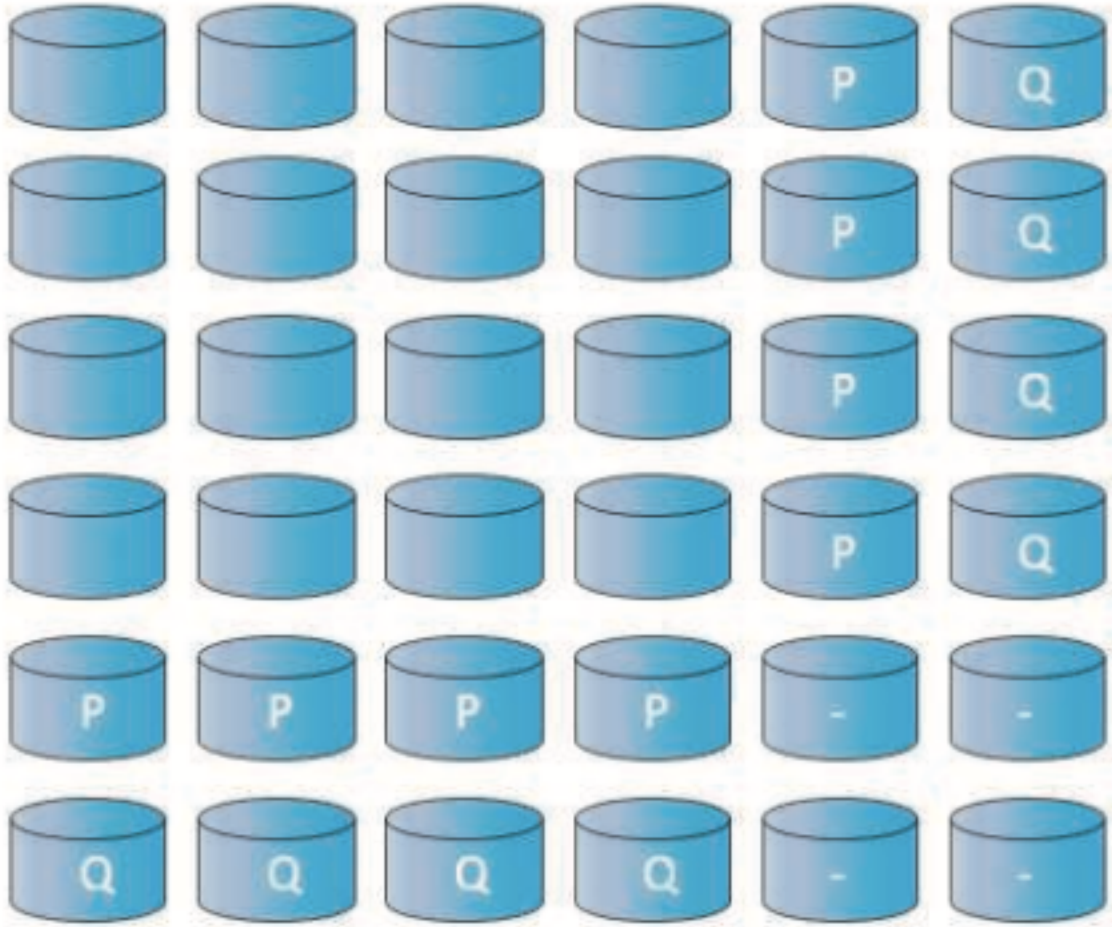
Strip 0
Strip 1
Strip 2
Strip 3
Strip 4
Strip 5
Strip 6
Strip 7
Strip 8
Strip 9
Strip 10
Strip 11
(a)
RAID level 0
Strip 0
Strip 1
Strip 2
Strip 3
Strip 0
Strip 1
Strip 2
Strip 3
Strip 4
Strip 5
Strip 6
Strip 7
Strip 4
Strip 5
Strip 6
Strip 7
Strip 8
Strip 9
Strip 10
Strip 11
Strip 8
Strip 9
Strip 10
Strip 11
(b)
RAID level 1
Bit 1
Bit 2
Bit 3
Bit 4
Bit 5
Bit 6
Bit 7
(c)
RAID level 2

RAID

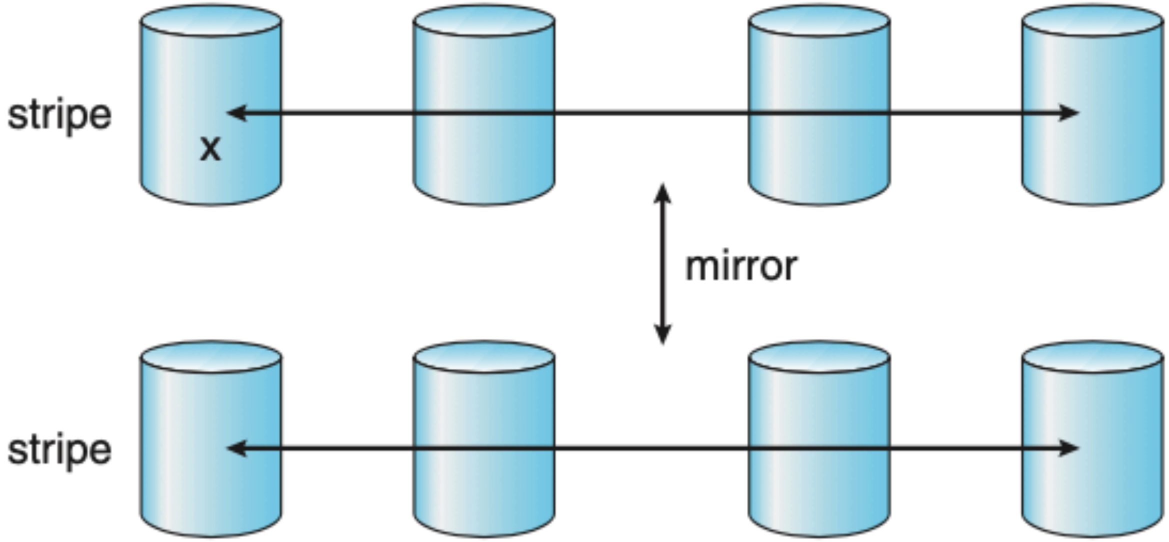

(d)
Bit 1
Bit 2
Bit 3
Bit 4
Parity
RAID level 3
(e)
Strip 0
Strip 1
Strip 2
Strip 3
P0-3
Strip 4
Strip 5
Strip 6
Strip 7
P4-7
Strip 8
Strip 9
Strip 10
Strip 11
P8-11
RAID level 4
(f)
Strip 0
Strip 1
Strip 2
Strip 3
P0-3
Strip 4
Strip 5
Strip 6
P4-7
Strip 7
Strip 8
Strip 9
P8-11
Strip 10
Strip 11
Strip 12
P12-15
Strip 13
Strip 14
Strip 15
P16-19
Strip 16
Strip 17
Strip 18
Strip 19
RAID level 5

(d) RAID 5: block-interleaved distributed parity.

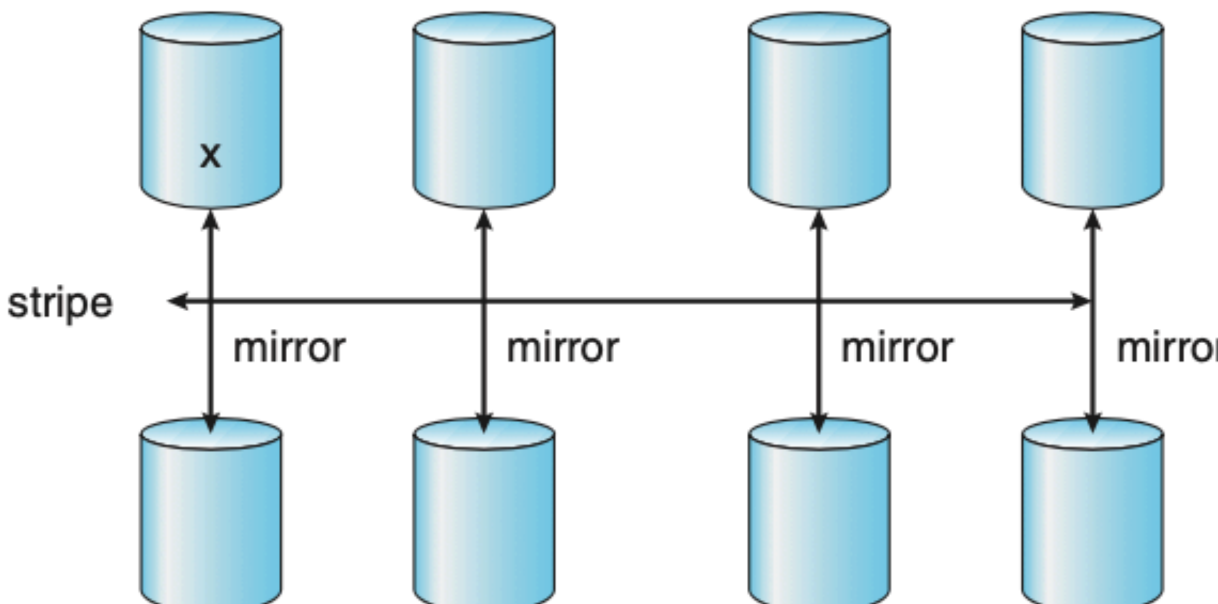
(e) RAID 6: P + Q redundancy.



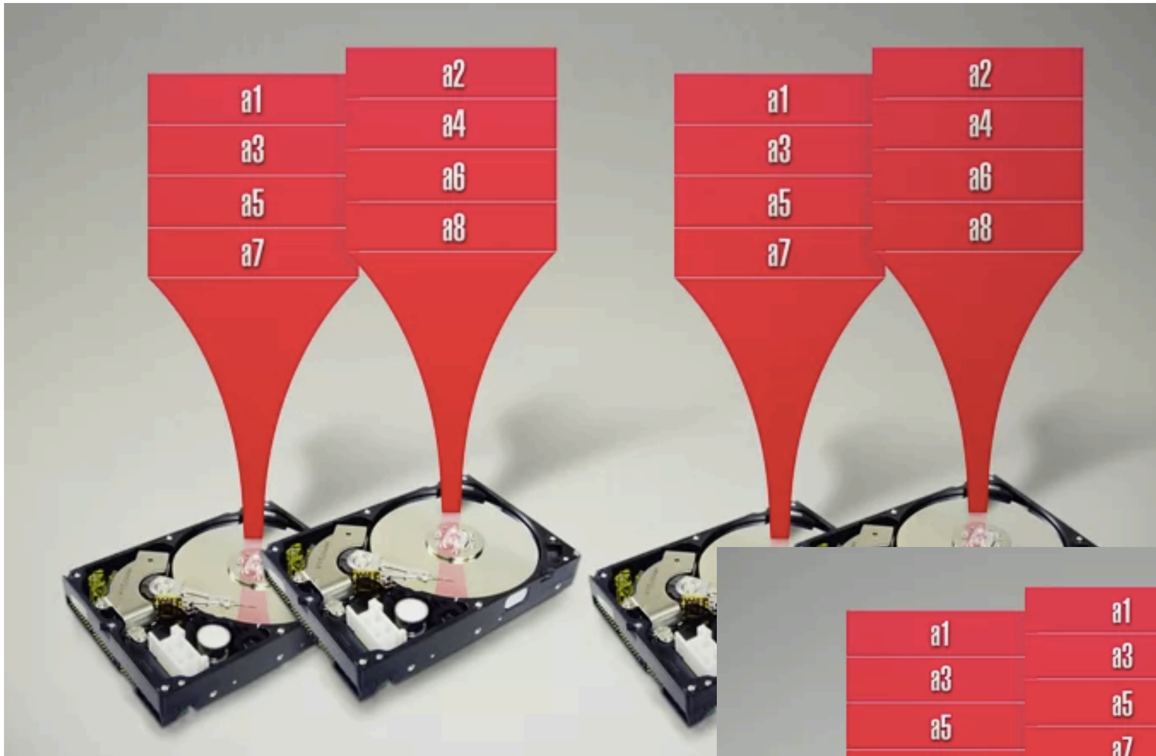
(f) Multidimensional RAID 6.



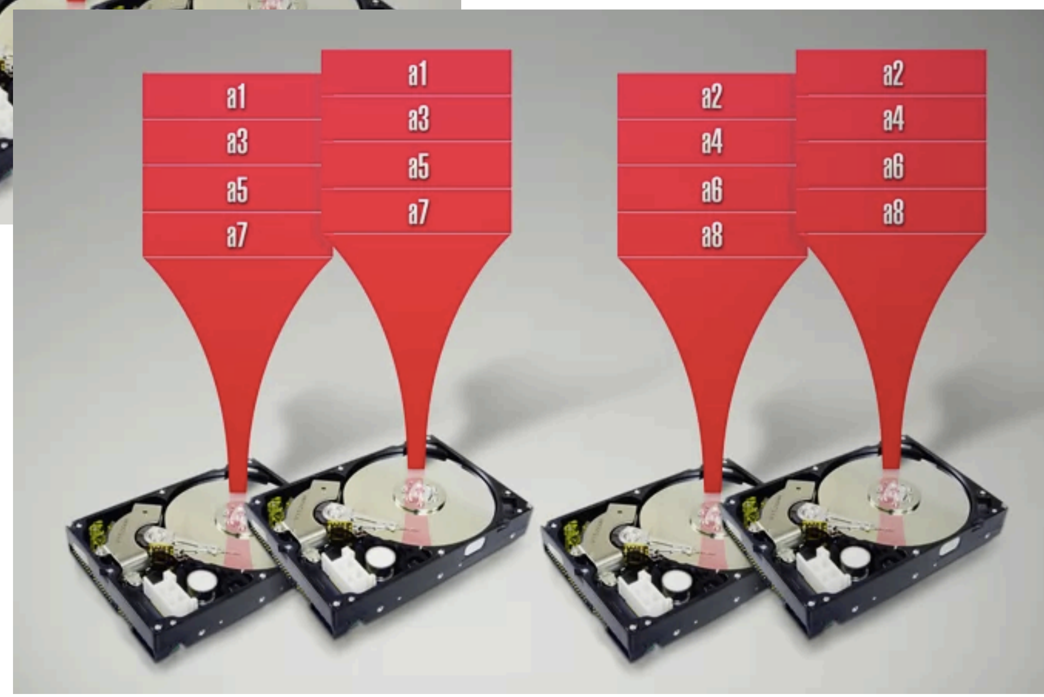
a) RAID 0 + 1 with a single disk failure.



b) RAID 1 + 0 with a single disk failure.



Raid 0+1



Raid 1+0

Disk space management

- **The OS must choose a disk "block" size...**
  - The amount of data written to/from a disk
  - Must be some multiple of the disk's sector size

- **How big should a disk block be?**
  - = Page Size?
  - = Sector Size?
  - = Track size?

Disk space management

- **How big should a disk block be?**
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- **Large block sizes:**
  - Internal fragmentation
  - Last block has (on average) 1/2 wasted space
  - Lots of very small files; waste is greater.

Disk space management

- **Must choose a disk block size...**
  - = Page Size?
  - = Sector Size?
  - = Track size?
- **Large block sizes:**
  - Internal fragmentation
  - Last block has (on average) 1/2 wasted space
  - Lots of very small files; waste is greater.
- **Small block sizes:**
  - More seeks; file access will be slower.

Block size tradeoff

- **Smaller block size?**
  - Better disk utilization
  - Poor performance

- **Larger block size?**
  - Lower disk space utilization
  - Better performance

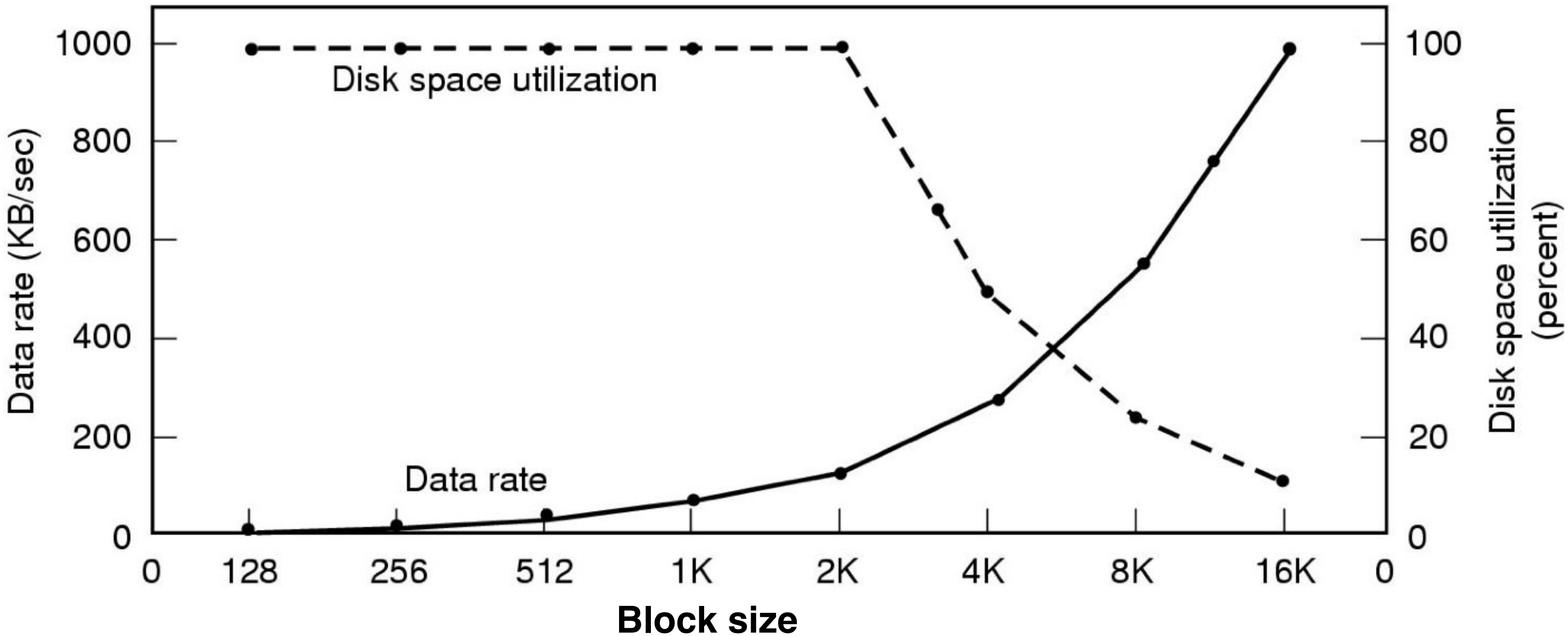
Example

- A Unix System
  - 1000 users, 1M files
  - Median file size = 1,680 bytes
  - Mean file size = 10,845 bytes
  - Many small files, a few really large files

Example

- A Unix System
  - 1000 users, 1M files
  - Median file size = 1,680 bytes
  - Mean file size = 10,845 bytes
  - Many small files, a few really large files
- **Let's assume all files are 2 KB...**
  - What happens with different block sizes?
  - (The tradeoff will depend on details of disk performance.)

Block size tradeoff



Assumption: All files are 2K bytes

Given: Physical disk properties

Seek time=10 msec

Transfer rate=15 Mbytes/sec

Rotational Delay=8.33 msec * 1/2

Managing free blocks

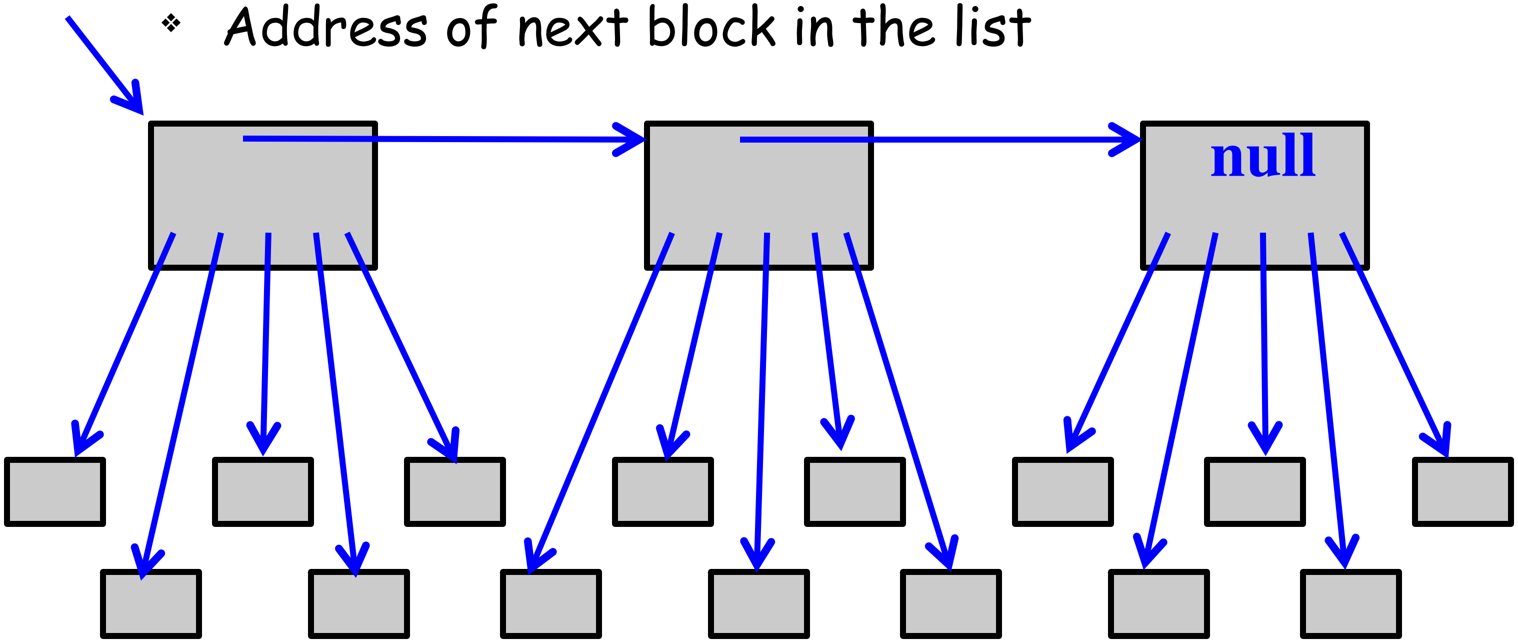
- **Approach #1:**
  - Keep a bitmap
  - 1 bit per disk block
-
- **Approach #2**
  - Keep a free list

Managing free blocks

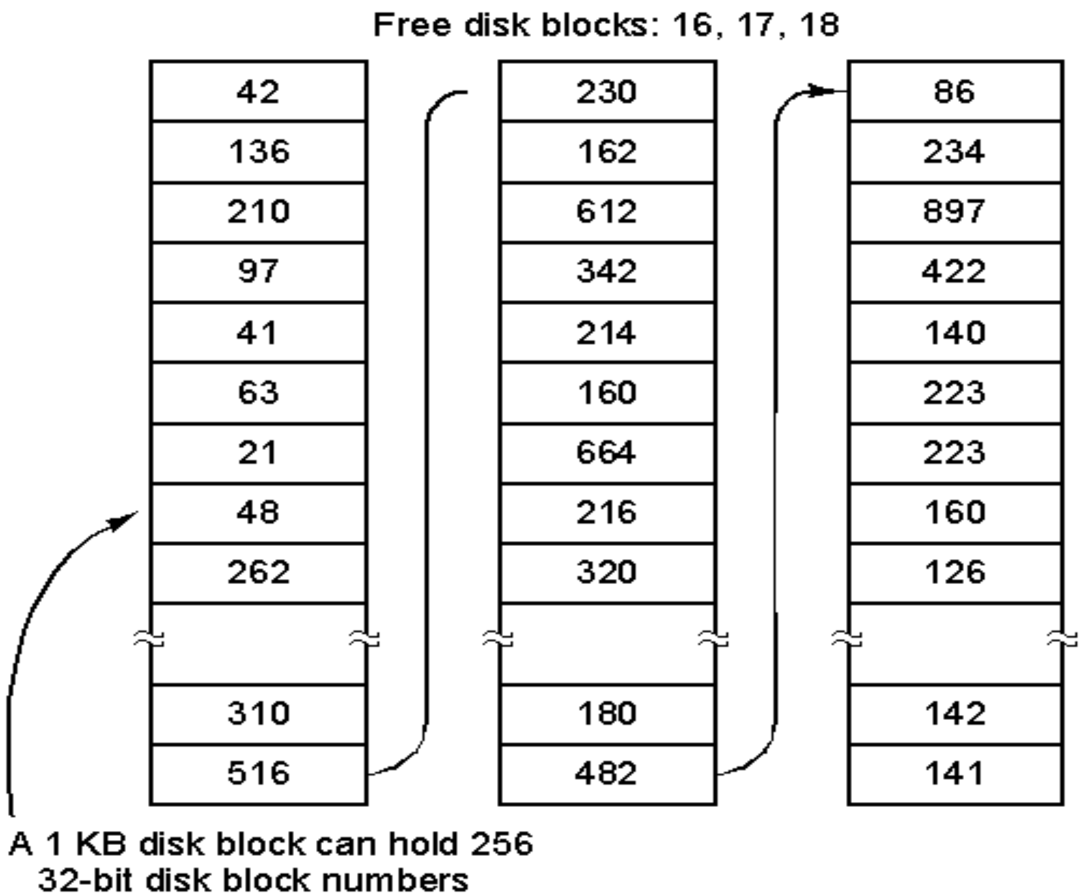
- Approach #1:
  - Keep a bitmap
  - 1 bit per disk block
    - Example:
      - 1 KB block size
      - 16 GB Disk ⇒ 16M blocks = 2^{24} blocks
    - Bitmap size = 2^{24} bits ⇒ 2K blocks
      - 1/8192 space lost to bitmap
-
- Approach #2
  - Keep a free list

Free list of disk blocks

- **Linked List of Free Blocks**
- **Each block on disk holds**
  - A bunch of addresses of free blocks
  - Address of next block in the list



Free list of disk blocks



Assumptions:

- Block size = 1K
- Each block addr = 4bytes
- Each block holds
  - 255 ptrs to free blocks
  - 1 ptr to the next block

This approach takes more space than bitmap...

But "free" blocks are used, so no real loss!

Free list of disk blocks

- **Two kinds of blocks:**
  - Free Blocks
  - Block containing pointers to free blocks

- **Always keep one block of pointers in memory.**
- **This block may be partially full.**

- **Need a free block?**
  - This block gives access to 255 free blocks.
  - Need more?
    - **Look at the block's "next" pointer**
    - **Use the pointer block itself**
    - **Read in the next block of pointers into memory**

Free list of disk blocks

- **To return a block (X) to the free list...**
  - If the block of pointers (in memory) is not full:
    - **Add X to it**

Free list of disk blocks

- **To return a block (X) to the free list…**
  - If the block of pointers (in memory) is not full:
    - **Add X to it**
  - If the block of pointers (in memory) is full:
    - **Write it to out to the disk**
    - **Start a new block in memory**
    - **Use block X itself for a pointer block**
      - **All empty pointers**
      - **Except the next pointer**

Free list of disk blocks

- **Scenario:**
  - Assume the block of pointers in memory is almost empty.
  - A few free blocks are needed.

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-

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  - Next, a few blocks are freed.
  - The block fills up
    - **This triggers a disk write of the block of pointers.**
- **Problem:**
  - Numerous small allocates and frees, when block of pointers is right at boundary
  - Lots of disk I/O associated with free block mgmt!

Free list of disk blocks

- **Solution (in text):**
  - Try to keep the block in memory about 1/2 full
  - When the block in memory fills up...
    - **Break it into 2 blocks (each 1/2 full)**
    - **Write one out to disk**

- **Similar Algorithm:**
  - Keep 2 blocks of pointers in memory at all times.
  - When both fill up
    - **Write out one.**
  - When both become empty
  - Read in one new block of pointers.

Comparison: free list vs bitmap

- **Desirable:**
  - Keep all the blocks in one file close together.

Comparison: free list vs bitmap

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  - Keep all the blocks in one file close together.
- **Free Lists:**
  - Free blocks are all over the disk.
  - Allocation comes from (almost) random location.

Comparison: free list v. bitmap

- <u>Desirable:</u>
  - Keep all the blocks in one file close together.
- <u>Free Lists:</u>
  - Free blocks are all over the disk.
  - Allocation comes from (almost) random location.
- <u>Bitmap:</u>
  - Much easier to find a free block "close to" a given position
  - Bitmap implementation:
    - **Keep 2 MByte bitmap in memory**
    - **Keep only one block of bitmap in memory at a time**