Disks

tsaimh (2022, CC BY-SA)
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? (1996-2016)

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Handbook and Manual pages

- Official guide can be found at
  - Adding Disks https://docs.freebsd.org/en/books/handbook/disks/#disks-adding
  - Tuning Disks https://docs.freebsd.org/en/books/handbook/config/#configtuning-disk

Outline

- Interface
- Geometry
- Add new disks
    - Installation procedure
    - Filesystem check
    - Add a disk
- RAID
    - GEOM

Disk Interfaces & Protocols

- IDE (or ATA) (since 1986)
  - Integrated Device Electronics (or Advanced Technology Attachment)
  - Renamed to PATA (Parallel ATA) after SATA is out
- SCSI (since 1986)
  - Small Computer Systems Interface
- SATA (since 2003)
  - Serial ATA
  - AHCI, Advanced Host Controller Interface
- SAS (since 2004)
  - Serial Attached SCSI
- NVMe (Non-Volatile Memory Express) (since 2011)
  - Non-Volatile Memory Host Controller Interface Specification
- USB (Universal Serial Bus)
  - Mass Storage Class (MSC)
  - Bulk Transfer

Disk Interfaces - ATA & SATA

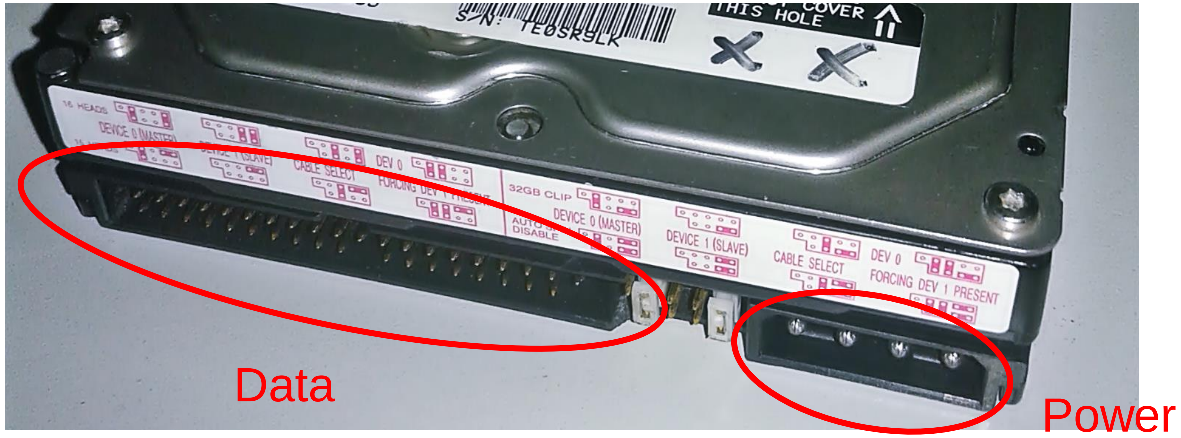
- ATA (AT Attachment)
  - ATA2
    - PIO, DMA
    - LBA (Logical Block Addressing)
  - ATA3, Ultra DMA/33/66/100/133
  - ATAPI (ATA Packet Interface)
    - CDROM, TAPE
  - Only one device can be active at a time
    - **SCSI support overlapping commands, command queuing, scatter-gather I/O**
  - Master-Slave
  - 40-pin ribbon cable

Primary Master (0) / Slave (1)
Secondary Master (2) / Slave (3)

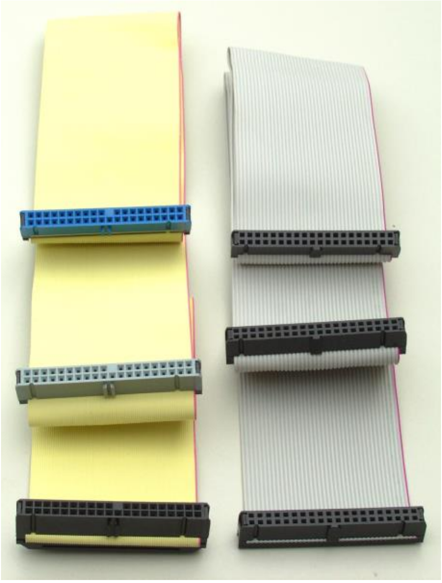
- SATA
  - Serial ATA
  - SATA-1 1.5Gbit/s, SATA-2 3Gbit/s, SATA-3 6Gbit/s
  - SATA 3.1, SATA 3.2 16Gbit/s, SATA 3.3, eSATA, mSATA

Disk Interfaces - ATA & SATA Interfaces

- ATA interface and its cable

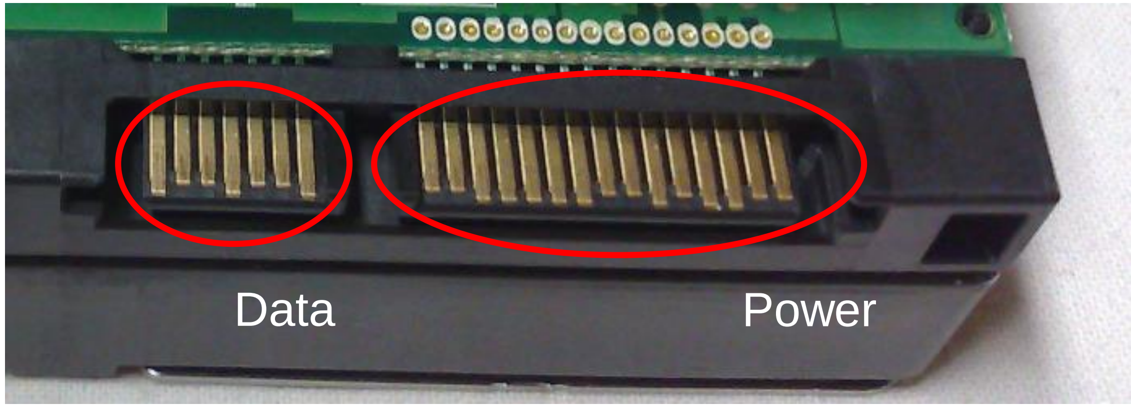


Credit: JulianVilla26



Credit: User Smial on de.wikipedia

- SATA interface and its cable



Credit: Dsimic

Disk Interfaces - USB

- IDE/SATA to USB converters

Disk Geometry (1)

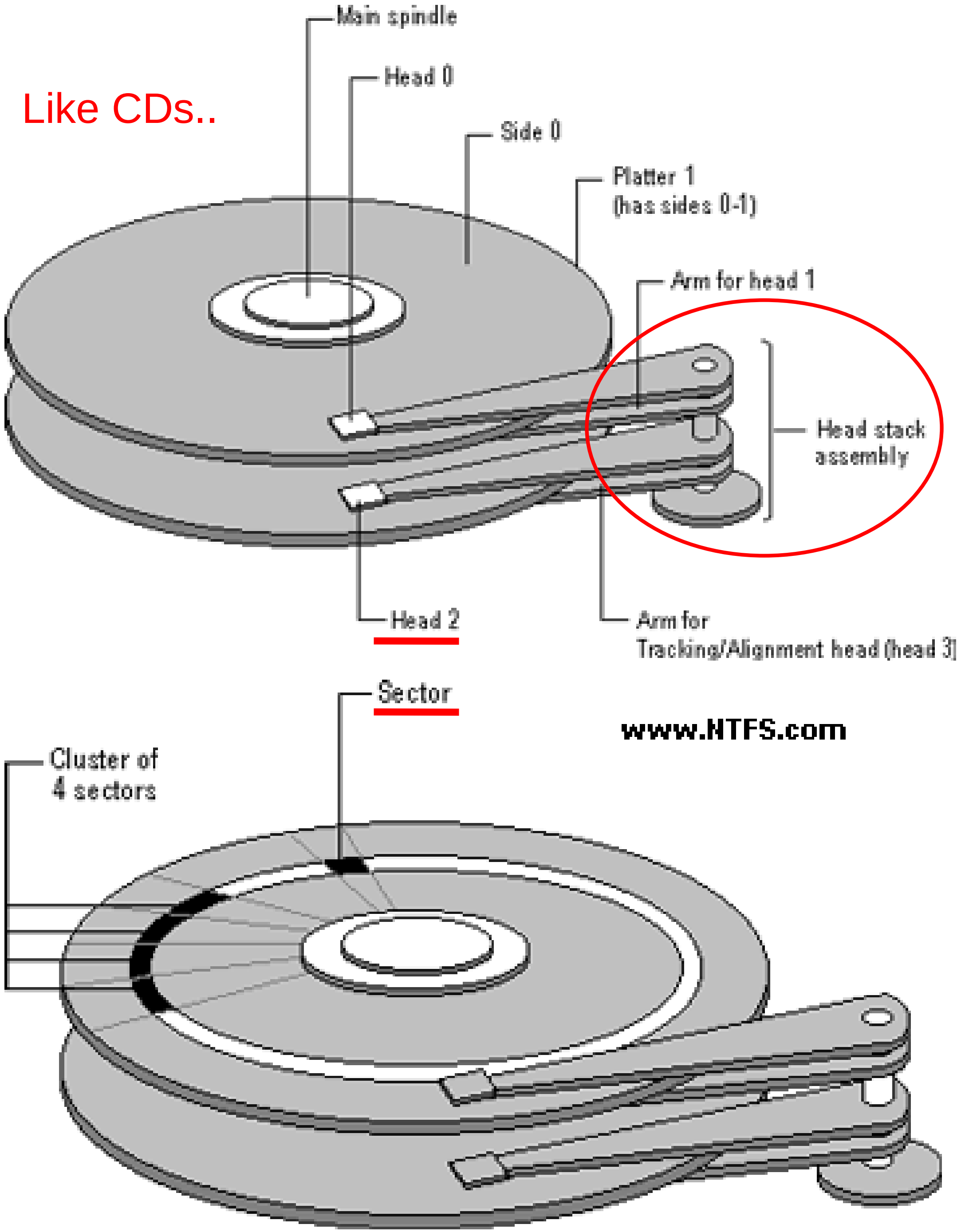
- Sector
  - ○ Individual data block
- Track
  - ○ circle
- Cylinder
  - ○ circle on all platters
- Position
  - ○ CHS:

    Cylinder,

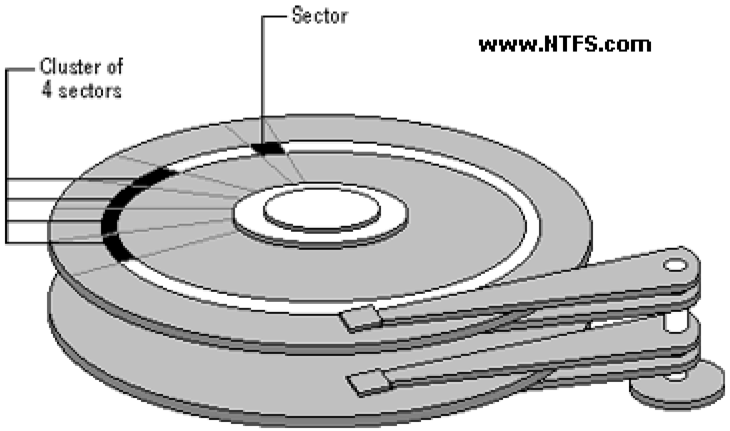
    Head (0, 1, …)

    Sector

Like CDs..



Disk Geometry (2)



- 40G HD
  - 4866 cylinders, 255 heads
  - 63 sectors per track, 512 bytes per sector
  - 512 * 63 * 4866 * 255 = 40,024,212,480 bytes

G M K

  - 1KB = 1024 bytes
  - 1MB = 1024 KB = 1,048,576 bytes
  - 1GB = 1024 MB = 1,073,741,824 bytes
  - 40,024,212,480 / 1,073,741,824 ≒ 37.275 GB

Why?

10^3 vs. 2^10…

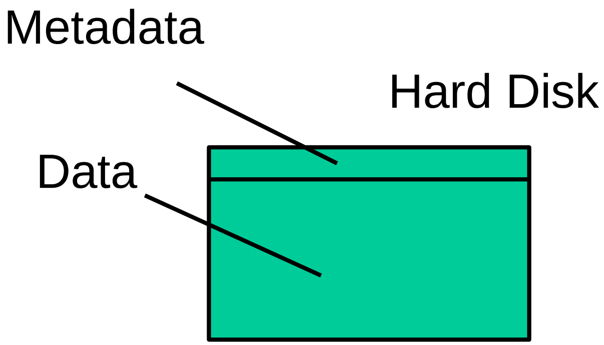
CHS & LBA

- CHS: Cylinder-Head-Sector
    - Not useful for block device other than spinning disk
- LBA: Logical Block Addressing
    - First block -> LBA0, Second block -> LBA1, …
- Conversion
    - HPC: Heads per Cylinder
    - SPT: Sectors per Track
    - $LBA = (C \times HPC + H) \times SPT + (S - 1)$
    - $C = LBA \div (HPC \times SPT)$
    - $H = (LBA \div SPT) \bmod HPC$
    - $S = (LBA \bmod SPT) + 1$

Disk Installation Procedure (in FreeBSD…)

Disk Installation Procedure (1)

- The procedure involves the following steps:
  - Connecting the disk to the computer
    - IDE: master/slave
    - SATA
    - SCSI: ID, terminator
    - Power, hot-plug or not
  - Creating device files
    - Auto created by devfs(5)
  - Formatting the disk
    - Low-level format
      - Manufacturer diagnostic utility
      - **Kill all** address information and timing marks on platters
      - Repair bad sectors -> mark the bad sectors and don't use them!



Format (metadata + data)
vs. fast format (metadata only)

Disk Installation Procedure (2)

- Partitioning (and Labeling) the disk
    - Allow the disk to be treated as a group of independent data blocks
    - e.g. partitions for root, home, swap
    - Former Suggestions:
        - /var, /tmp
            - Separated partition (for backup issue)
        - Make a copy of root filesystem for emergency
- Establishing logical volumes
    - Combine multiple partitions into a logical volume
    - Related to RAID
    - Software RAID technology
        - GEOM: geom(4)、geom(8)
        - ZFS: zpool(8)、zfs(8)、zdb(8)

Disk Installation Procedure (3)

- Creating UNIX filesystems within disk partitions
  - Use "newfs(8)" to install a filesystem for a partition
  - Establish all filesystem components
    - A set of inode storage cells
    - A set of data blocks
    - A set of superblocks
    - A map of the disk blocks in the filesystem
    - A block usage summary

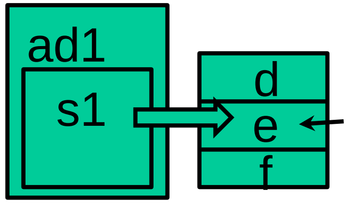
Reference:
https://man.freebsd.org/newfs

Disk Installation Procedure (4)

- Superblock contents
  - The length of a disk block
  - Size and location of inode table
  - Disk block map
  - Usage information
  - Other filesystem’s parameters
- sync
  - The ***sync(2) system call*** forces a write of dirty (modified) buffers in the block buffer cache out to disk.
  - The ***sync(8) utility*** can be called to ensure that all disk writes have been completed before the processor is halted in a way not suitably done by reboot(8) or halt(8).

Disk Installation Procedure (5)

- mount
  - Bring the new partition (with a filesystem) to the filesystem tree (as a sub-tree)
  - mount point can be any directory (empty)
  - $ mount /dev/ad1s1e /home2
- Setting up automatic mounting
  - Automount at boot time
    - /etc/fstab
    - $ mount -t ufs /dev/ad2s1a /backup
    - $ mount -t cd9600 -o ro,noauto /dev/acd0c /cdrom



partition,
newfs

Mount CD
Also for ISO image file

dump(8)

fsck(8)

```
$ cat /etc/fstab
# Device           Mountpoint Fstype  Options        Dump    Pass#
/dev/ad0s1b        none       swap    sw             0       0
/dev/ad2s1b        none       swap    sw             0       0
/dev/ad0s1a        /          ufs     rw             1       1
/dev/acd0          /cdrom     cd9660  ro,noauto      0       0
/dev/ad2s1a        /backup    ufs     rw,noauto      2       2
csduty:/bsdhome    /bsdhome   nfs     rw,noauto      0       0
```

Mount from the network; will talk about it in "NFS"

Usually: 2, 1 for root;
0: No need to check

Reference: https://man.freebsd.org/fstab

Disk Installation Procedure (6)

- Setting up swapping on swap partitions
  - swapon(8), swapoff(8), swapctl(8)
    - $ swapon -a
      - mount all partitions for swap usage
  - swapinfo(8), pstat(8)

```
$ swapinfo
Device                 1K-blocks     Used    Avail          Capacity
/dev/da0p2             2097152       42772   2054380        2%
```

fsck – check and repair filesystem (1)

- System crashes will cause
  - Inconsistency between memory image and disk contents
- fsck(8)
  - Examine filesystem listed in /etc/fstab with (pass > 0 & option in "rw", "rq", "ro“)
  - Automatically correct the following damages:
    - Unreferenced inodes
    - Inexplicably large link counts
    - Unused data blocks not recorded in block maps
    - Data blocks listed as free but used in file
    - Incorrect summary information in the superblock
    - fsck(8)、fsck_ffs(8)
    - ffsinfo(8): dump metadata

Check if filesystem is clean…
1: clean (ro)
0: dirty (rw)

fsck – check and repair filesystem (2)

- Run fsck in manual to fix serious damages
  - Blocks claimed by more than one file
  - Blocks claimed outside the range of the filesystem
  - Link counts that are too small
  - Blocks that are not accounted for
  - Directories that refer to unallocated inodes
  - Other errors
- fsck will suggest you the action to perform
  - Delete, repair, …

There is no guarantee that fsck will fully recover your disk.

Adding a disk to FreeBSD (1)

1. Check disk connection
    - Look system boot message

```
ada3: 238475MB <Hitachi HDS722525VLAT80 V360A6MA> at ata1-slave UDMA100
```

1. Use gpart(8) to create a partition on the new HD

Line, speed

    - $ gpart create -s GPT ada3
    - $ gpart add -t freebsd-ufs -a 1M ada3
2. Use newfs(8) to construct new UFS file system
    - $ newfs -U /dev/ada3p1
3. Make mount point and mount it
    - # mkdir /home2
    - # mount -t ufs /dev/ada3p1 /home2
        - `-t ufs` is omittable
    - $ df
4. Edit /etc/fstab

Adding a disk to FreeBSD (2)

- If you forget to enable soft-update when you add the disk
  - $ umount /home2
  - $ tunefs -n enable /dev/ada3p1
  - $ mount -t ufs /dev/ada3p1 /home2
  - $ mount

```
/dev/ada0p2 on / (ufs, local, soft-updates)
/dev/ada1p1 on /home (ufs, local, soft-updates)
procfs on /proc (procfs, local)
/dev/ada3p1 on /home2 (ufs, local, soft-updates)
```

GEOM

Modular Disk Transformation Framework

Handbook and Manual pages

- Official guide can be found at
  - https://docs.freebsd.org/en/books/handbook/geom/

GEOM - (1)

- Support
  - ○ ELI – geli(8): cryptographic GEOM class
  - ○ JOURNAL – gjournal(8): journaled devices Journalize (logs) before write
  - ○ LABEL – glabel(8): disk labelization
  - ○ MIRROR – gmirror(8): mirrored devices Software RAID1
  - ○ STRIPE – gstripe(8): striped devices Software RAID0
  - ○ NOP – gnop(8): for setting metadata and testing
  - ○ GATE – ggatec(8), ggated(8), ggatel(8): share over network

GEOM - (2)

- GEOM framework in FreeBSD
  - Major RAID control utilities
  - Kernel modules (/boot/kernel/geom_*)
  - Name and Providers ← devices

    Logical volumes
    - "manual" or "automatic"
    - Metadata in the last sector of the providers
- Kernel support
  - {glabel,gmirror,gstripe,g*} load/unload
    - device GEOM_* in kernel config
    - geom_*_load="YES" in /boot/loader.conf

(1) On demand load/unload kernel modules

- load automatically at booting

(2) Build-in kernel and recompile

GEOM - (3)

- LABEL

  Bundle by name instead of bundle by provider

  - Used for GEOM provider labelization
  - Kernel
    - device GEOM_LABEL
    - geom_label_load="YES"

    e.g. ad0s1d => usr
  - glabel (for new storage)

    glabel label … => Create permanent labels
    glabel create … => Create transient labels
    - $ glabel label -v usr da2

      /dev/label/usr
    - $ newfs /dev/label/usr
    - $ mount /dev/label/usr /usr
    - $ glabel stop usr

      Stop using the name
    - $ glabel clear da2

      Clear metadata on provider
  - UFS label (for an using storage)
    - $ tunefs -L data /dev/da4s1a

      "data" is a name
    - $ mount /dev/ufs/data /mnt/data

GEOM - (4)

- MIRROR
  - Kernel
    - device GEOM_MIRROR
    - geom_mirror_load="YES"
  - gmirror
    - $ gmirror label -v -b round-robin data da0
    - $ newfs /dev/mirror/data ← logical volume called "data", using HD: da0, …
    - $ mount /dev/mirror/data /mnt
    - $ gmirror insert data da1 ← Add a HD into the volume
    - $ gmirror forget data ← Remove non-existent HDs
    - $ gmirror insert data da1
    - $ gmirror stop data
    - $ gmirror clear da0

GEOM - (5)

- STRIPE
  - Kernel
    - device GEOM_STRIPE
    - geom_stripe_load="YES"
  - gstripe
    - $ gstripe label -v -s 131072 data da0 da1 da2 da3
    - $ newfs /dev/stripe/data
    - $ mount /dev/stripe/data /mnt
    - $ gstripe stop data
    - $ gstripe clear da0

← Create logical volume "data", which stripe da0~da3 HDs

GEOM - (6)

- ELI
  - Passphrase and keyfile on USB

```
# dd if=/dev/random of=/mnt/pendrive/da2.key bs=64 count=1
# geli init -s 4096 -K /mnt/pendrive/da2.key /dev/da2
Enter new passphrase:
Reenter new passphrase:
# geli attach -k /mnt/pendrive/da2.key /dev/da2
Enter passphrase:
# dd if=/dev/random of=/dev/da2.eli bs=1m
# newfs /dev/da2.eli
# mount /dev/da2.eli /mnt/secret
...
# umount /mnt/secret
# geli detach da2.eli
```

  - Encrypt swap

```
# dd if=/dev/random of=/dev/ada0s1b bs=1m
# geli onetime –d ada0s1b
# swapon /dev/ada0s1b.eli
```

Appendix

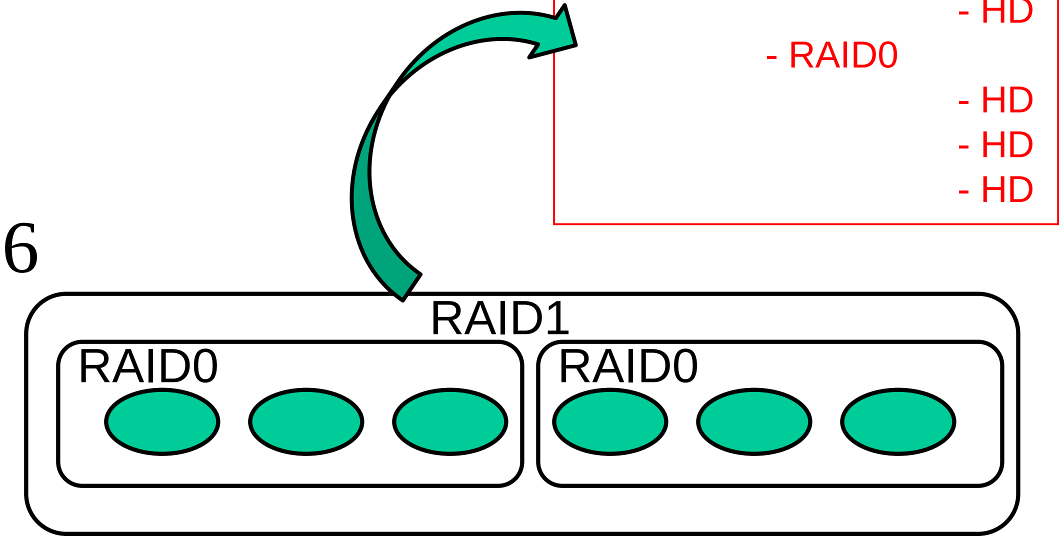
RAID - (1)

- Redundant Array of Inexpensive Disks
  - A method to combine several physical hard drives into one logical unit

e.g. HD1, HD2 v.s D:\ in windows

- Depending on the type of RAID, it has the following benefits:
  - Fault tolerance
  - Higher throughput
  - Real-time data recovery
- RAID Level
  - RAID 0, 1, 0+1, 2, 3, 4, 5, 6
  - Hierarchical RAID

RAID1
- RAID0
  - HD
  - HD
  - HD
- RAID0
  - HD
  - HD
  - HD

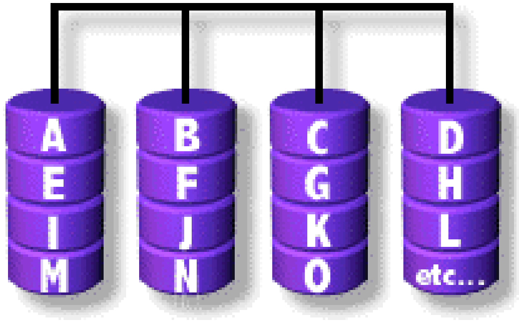


RAID - (2)

- Hardware RAID
  - There is a dedicate controller to take over the whole business
  - RAID Configuration Utility after BIOS
    - Create RAID array, build Array
- Software RAID
  - GEOM
    - CACHE、CONCAT、ELI、JOURNAL、LABEL、MIRROR、MULTIPATH、NOP、PART、RAID3、SHSEC、STRIPE、VIRSTOR
  - ZFS
    - JBOD、STRIPE
    - MIRROR
    - RAID-Z、RAID-Z2、RAID-Z3

RAID 0 (normally used)

(500GB+500GB=1TB)



- Stripped data intro several disks
- Minimum number of drives: 2

e.g. HD1 (500GB), HD2 (500GB)
v.s. D:\ in windows (1TB)

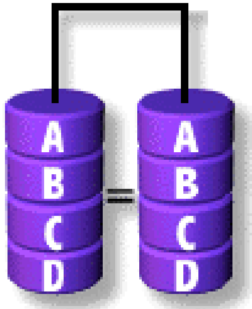
- Advantage
  - Performance increase in proportional to n theoretically
  - Simple to implement

parallel file io from/to different HDs

- Disadvantage
  - No fault tolerance
- Recommended applications
  - Non-critical data storage
  - Application requiring high bandwidth (such as video editing)

RAID 1 (normally used)

(500GB+500GB=500GB)

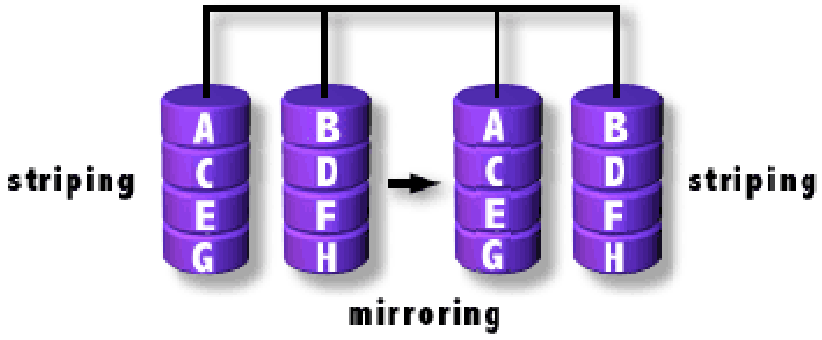


- Mirror data into several disks
- Minimum number of drives: 2
- Advantage
  - 100% redundancy of data
- Disadvantage
  - 100% storage overage
  - Moderately slower write performance
- Recommended application
  - Application requiring very high availability (such as home)

Caused by double check mechanisms on data…

RAID 0+1 (normally used)

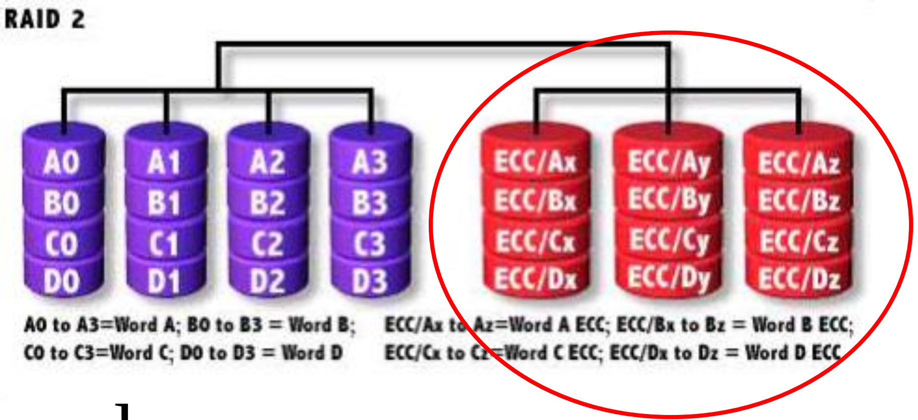
([(500GB+500GB)+(500GB+500GB)=1TB)



- Combine RAID 0 and RAID 1
- Minimum number of drives: 4

RAID1, RAID1
Them RAID0 above it

RAID 2


RAID 2
A0
B0
C0
D0
A1
B1
C1
D1
A2
B2
C2
D2
A3
B3
C3
D3
ECC/Ax
ECC/Bx
ECC/Cx
ECC/Dx
ECC/Ay
ECC/By
ECC/Cy
ECC/Dy
ECC/Az
ECC/Bz
ECC/Cz
ECC/Dz
A0 to A3=Word A; B0 to B3 = Word B;
C0 to C3=Word C; D0 to D3 = Word D
ECC/Ax to Az=Word A ECC; ECC/Bx to Bz = Word B ECC;
ECC/Cx to Cz=Word C ECC; ECC/Dx to Dz = Word D ECC

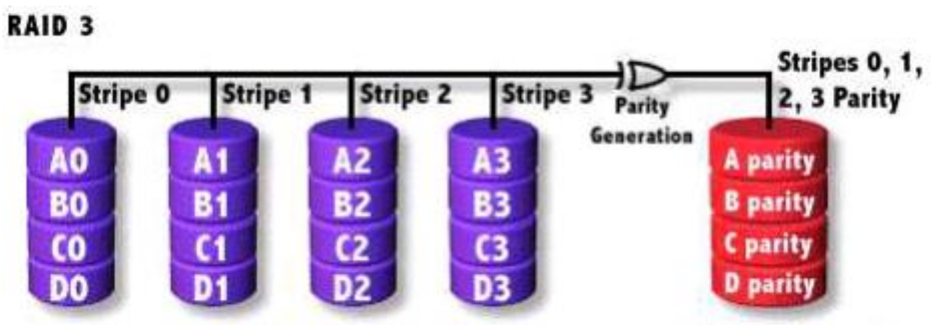
- Hamming Code ECC Each bit of data word
- Advantage
  - "On the fly" data error correction

Read, check if correct, then read

- Disadvantage
  - Inefficient
  - Very high ratio of ECC disks to data disks
- Recommended applications
  - No commercial implementations exist / not commercially viable

RAID 3

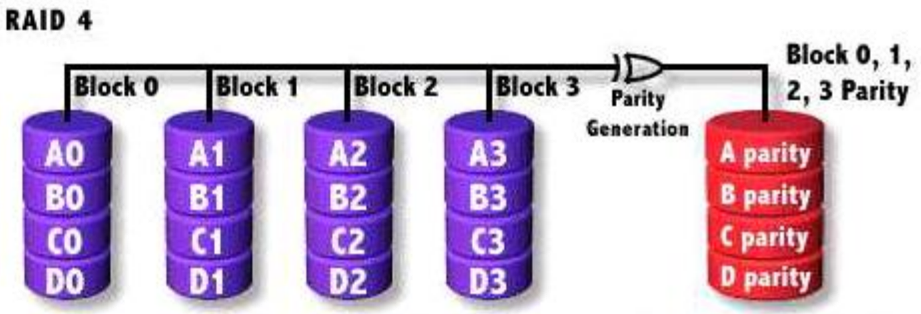
RAID1 if two HDs



Save parity

- Parallel transfer with Parity
- Minimum number of drives: 3
- Advantage
  - Very high data transfer rate
- Disadvantage
  - Transaction rate equal to that of a single disk drive at best
- Recommended applications
  - Any application requiring high throughput

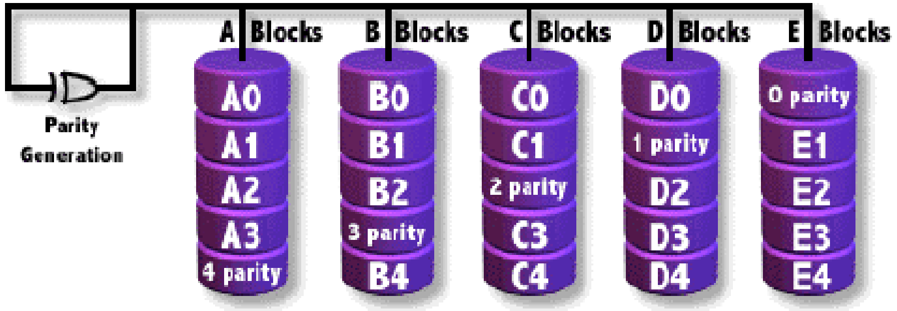
RAID 4



- Similar to RAID3
- RAID 3 V.S RAID 4
  - Byte Level V.S Block Level
  - Block interleaving
    - Small files (e.g. 4k)

Block normally 512bytes (4k for WD HDs)

RAID 5 (normally used)



- Independent Disk with distributed parity blocks
- Minimum number of drives: 3

Origin from RAID3

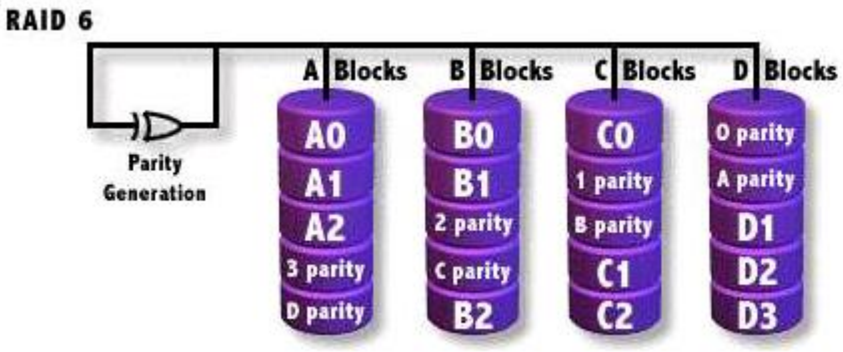
- Advantage

Parallel file I/O

  - Highest read data rate
  - Medium write data rate
- Disadvantage
  - Disk failure has a medium impact on throughput
  - Complex controller design
  - When one disk failed, you have to rebuild the RAID array

Can tolerate only 1 HD failure

RAID 6 (normally used)



- Similar to RAID5
- Minimum number of drives: 4
- 2 parity checks, 2 disk failures tolerable.

Slower than RAID5 because of storing 2 parities…