Optimal usage of SSDs under Linux:

Optimize your I/O Subsystem

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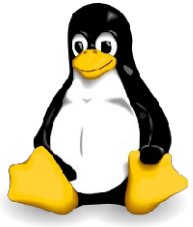
Introduction

who I am

Werner Fischer

from Australia

Linux user since 2001



working for a Server vendor

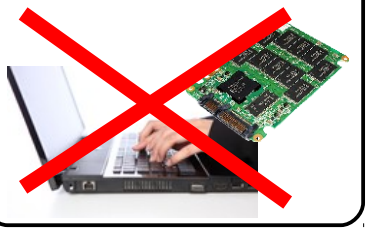
freelancer IT journalist

Piano learner

who I am not

Kernel developer

SSD developer

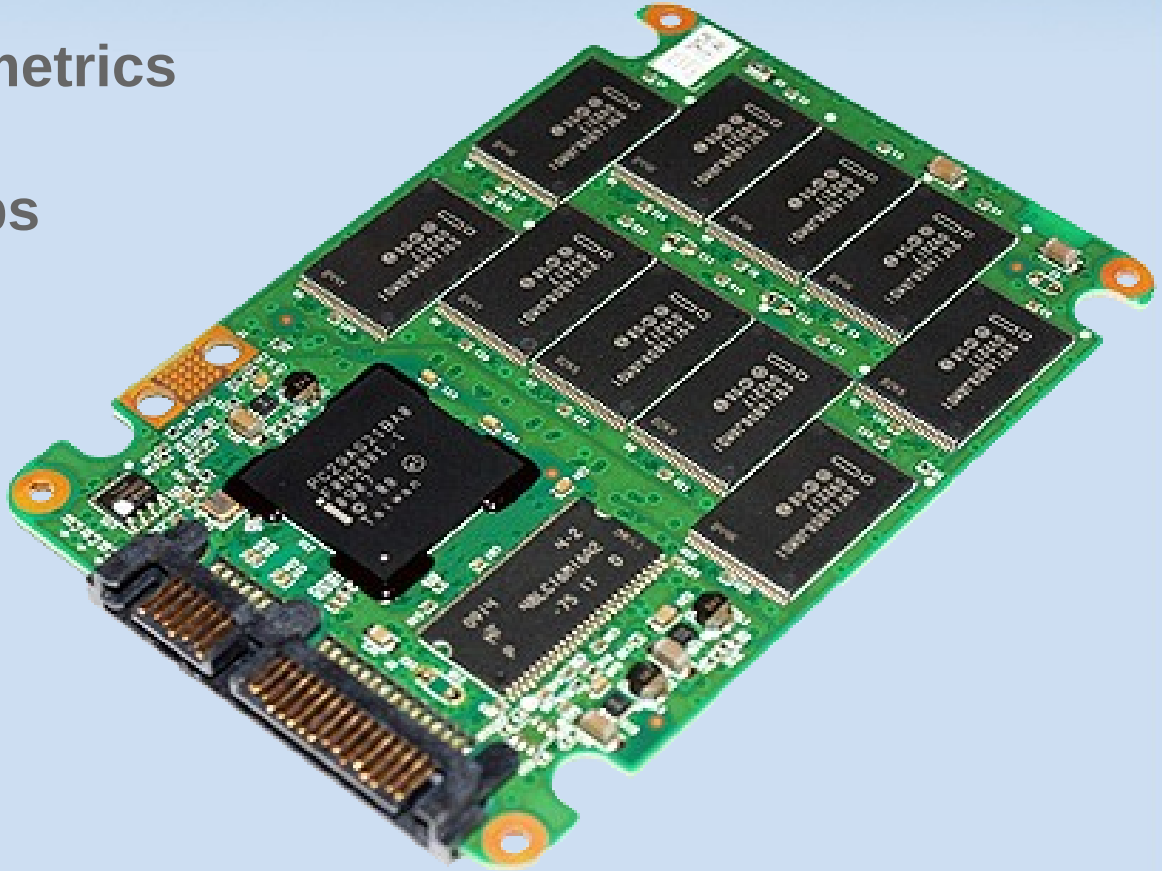


Agenda

1) **SSD layout**

2) I/O performance metrics

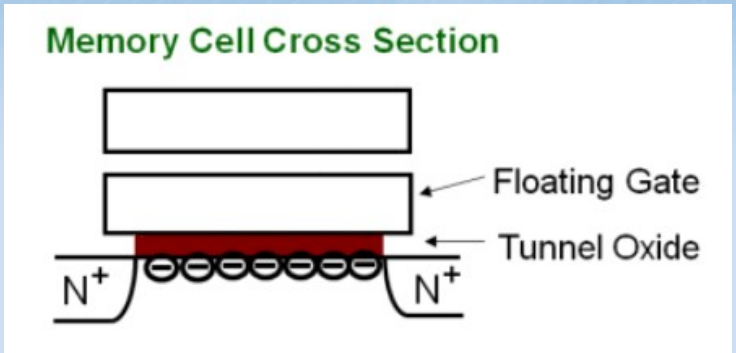
3) Configurations tips



Source: maximumpc.com

1) SSD layout: memory cell

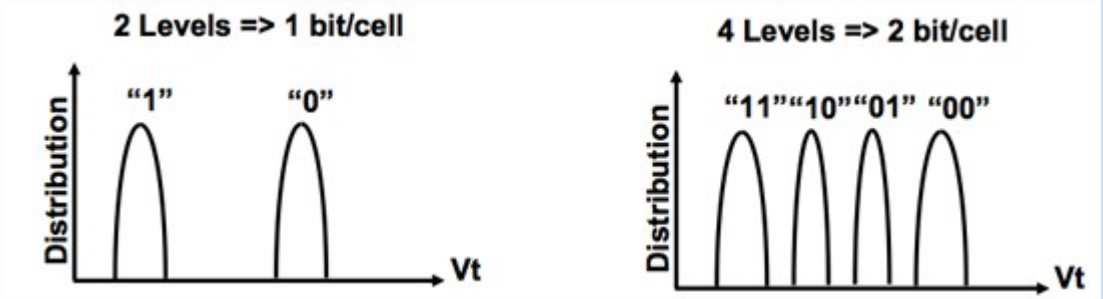
- **memory cells**
  - NAND memory cell = MOS transistor with floating gate
  - permanently store charge
    - programming puts electrons on floating gate
    - erase takes them off
  - one program/erase (p/e) cycle is a round trip by the electrons
  - back-and-forth round trips gradually damage the tunnel oxide
  - endurance is limited, measured in number of p/e cycles:
    - 50nm MLC ~ 10.000 p/e cycles
    - 34nm/25nm/20nm MLC ~ 3.000 – 5.000 p/e cycles



Source: Intel

1) SSD layout: memory cell

- **memory cells**
  - SLC (Single Level Cell) → 1 bit per memory cell
  - MLC (Multi Level Cell) → 2 bits per memory cell



Source: anandtech.com

  - TLC (Triple Level Cell) → 3 bits per memory cell
  - 16LC (16 Level Cell) → 4 bits per memory cell

- **multiple memory cells (e.g. 16.384) build up a "page"**
  - page = smallest area, which can be read/written

1) SSD layout: page

- **one line = page within a SSD**
  - 8.192 Bytes (8 kiB)
  - can be read/written individually
  - cannot be changed/erased individually

Note: example sizes of pages and blocks are taken from Intel's Series 320 SSDs (with IMFT's 25nm Flash chips)

1) SSD layout: block

- **one line = page within a SSD**
  - 8.192 Bytes (8 kiB)
  - can be read/written individually
  - cannot be changed/erased individually
- **one blackboard = block within a SSD**
  - consists of 256 lines (pages), 2.097.152 Bytes (2 MiB)
  - smallest area which can be individually erased (we have only watering-cans for that ;-)

Note: example sizes of pages and blocks are taken from Intel's Series 320 SSDs (with IMFT's 25nm Flash chips)

1) SSD layout: change page

- **easier way to change lines?**

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- **easier way to change lines!**
  - (1) mark old line as invalid

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  - (1) mark old line as invalid
  - (2) store new content in a free line

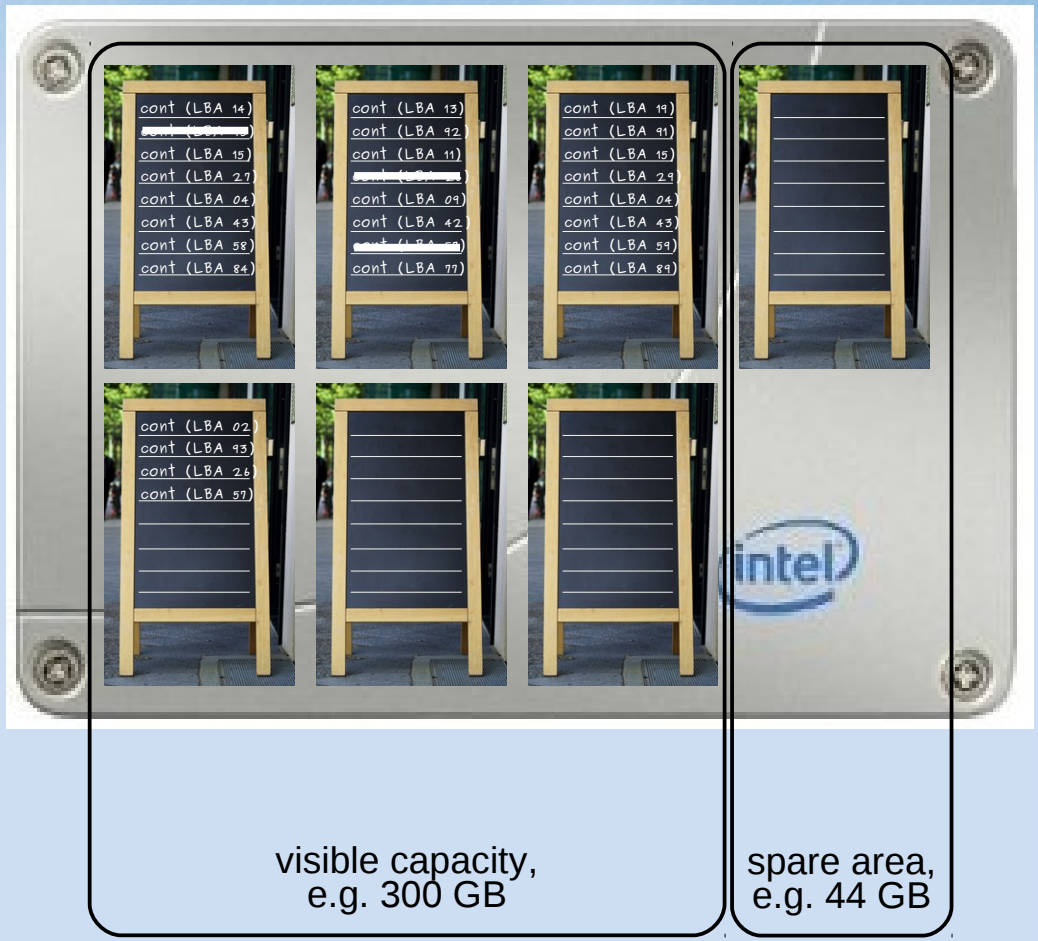
1) SSD layout: change page

- **easier way to change lines!**
  - (1) mark old line as invalid
  - (2) store new content in a free line
- **this can be done as long as there are enough free lines left...**

we need spare blackboards to have enough free lines!

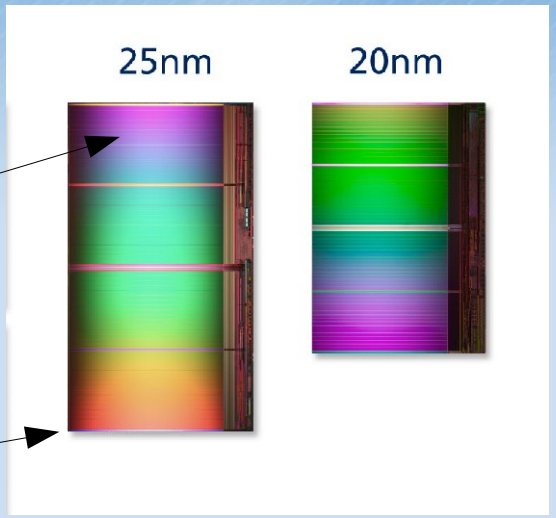
1) SSD layout: spare area

- **SSDs need spare area**
  - avoids the erasement of a block when a single page is changed
  - after some time spare area will be filled up, too
  - cleaning gets necessary (garbage collection)

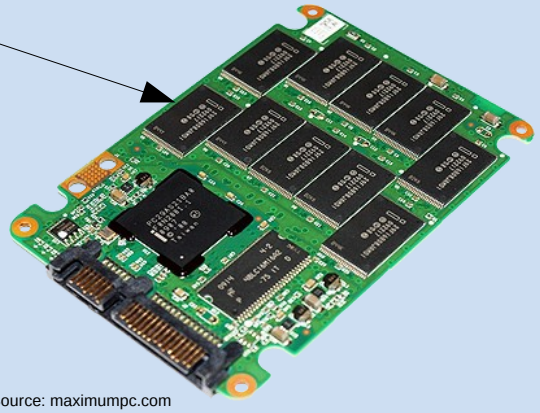


1) SSD layout: blocks → planes → dies → TSOPs

- **planes**
  - multiple blocks make up a plane
  - e.g. 1.024 blocks = 1 plane
- **dies**
  - multiple planes make up a die
  - e.g. 4 planes = 1 die
- **TSOP (thin small outline package)**
  - multiple dies (e.g. 1 - 8)
- **SSDs**
  - e.g. 10 TSOPs



Source: http://newsroom.intel.com/community/intel_newsroom/blog/2011/04/14



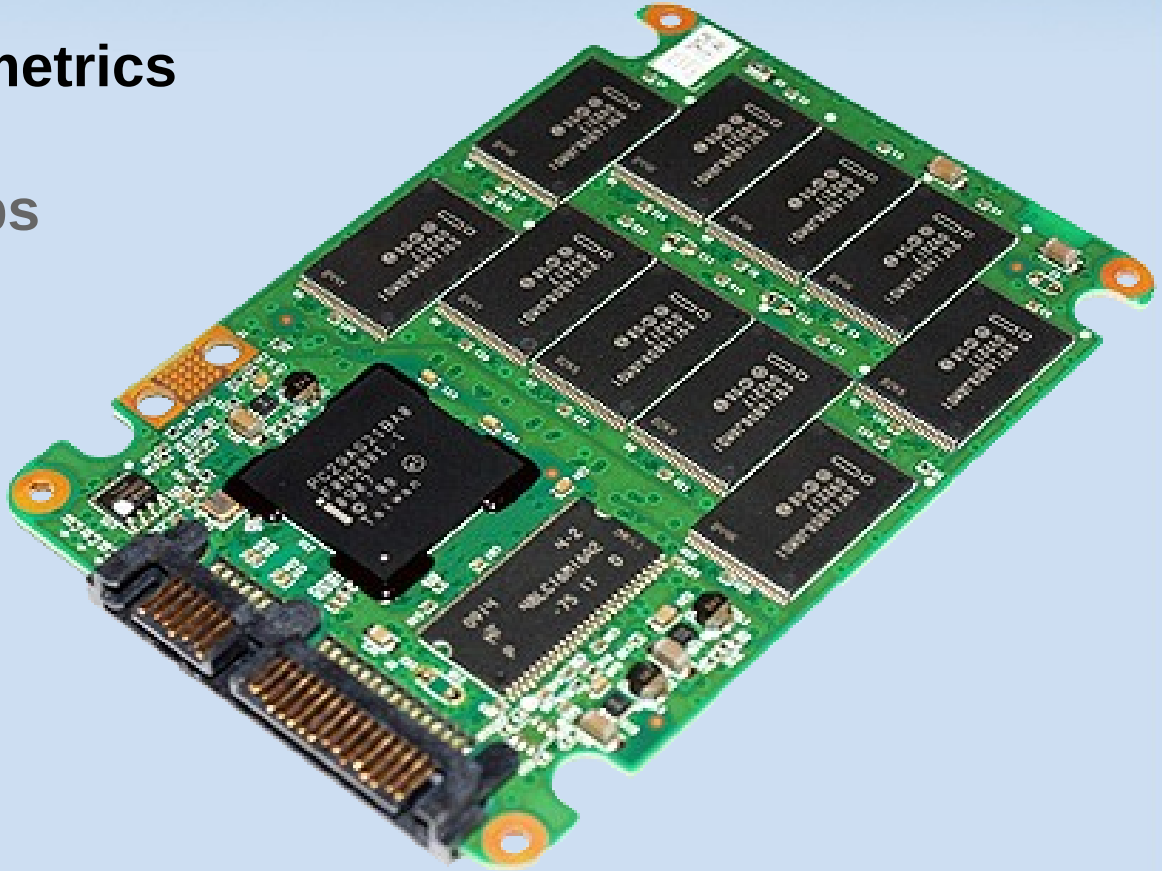
Source: maximumpc.com

Agenda

1) SSD layout

2) **I/O performance metrics**

3) Configurations tips



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2) I/O performance metrics

- **throughput**
  - MByte/s
  - throughput analogy:
    - # of persons/h from Berlin → Prague

- **# of I/O operations per second**
  - IOPS analogy:
    - # of individual trips to Prague (from Berlin, Vienna, Paris, Rome, ...)

- **latency because of queue depth**
  - queue depth analogy:
    - vehicles must use a ferry to reach destination
    - with how many vehicles does the ferry depart?

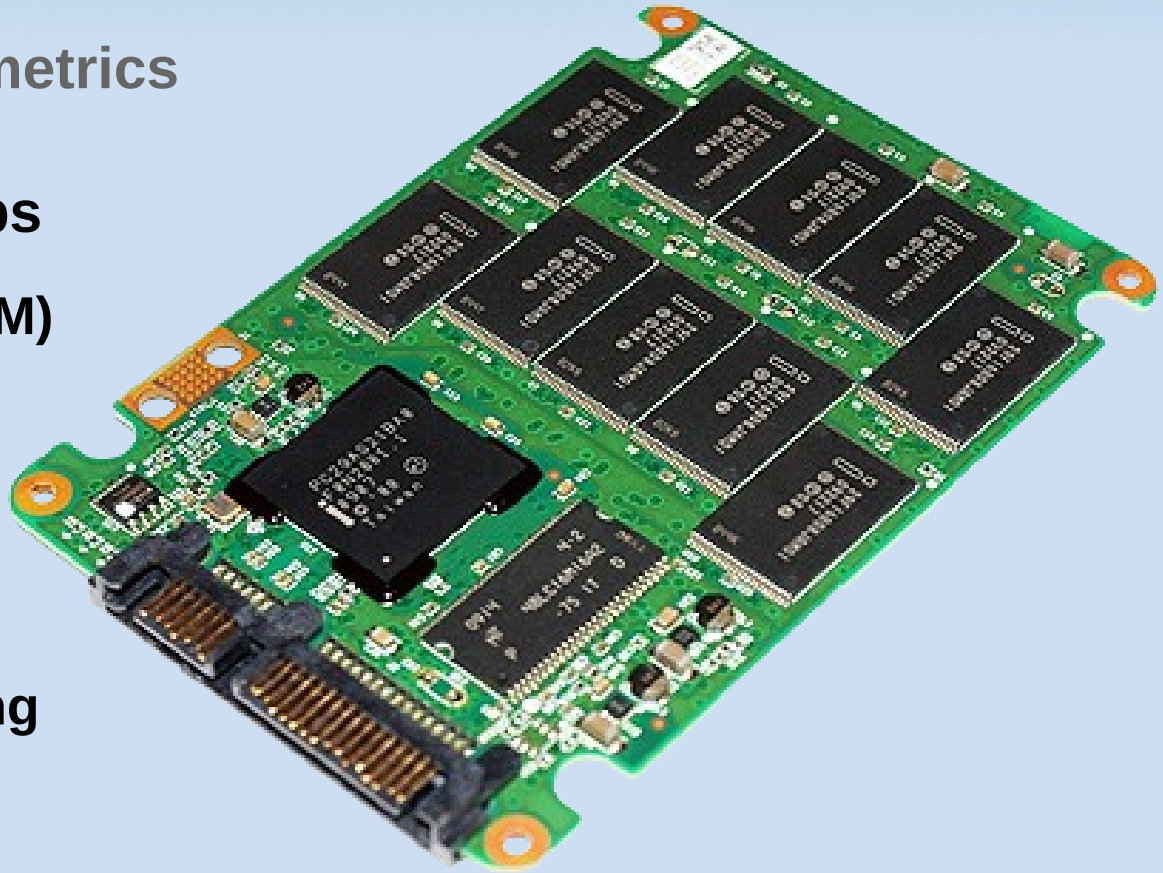
Agenda

1) SSD layout

2) I/O performance metrics

3) **Configurations tips**

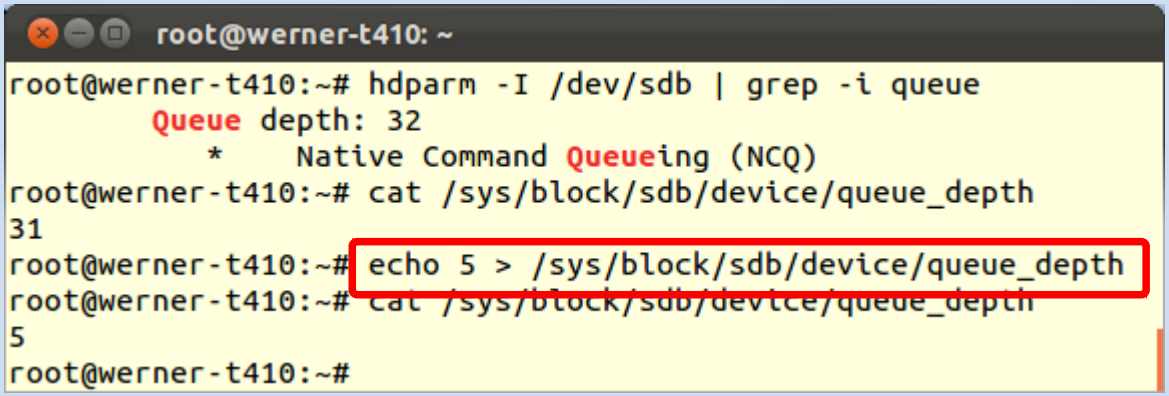
- **AHCI (NCQ+DIPM)**
- **TRIM (discard)**
- **noatime**
- **tmpfs**
- **alignment**
- **over-provisioning**



Source: maximumpc.com

3) Configuration tips: AHCI (NCQ+DIPM)

- **NCQ (Native Command Queuing)**
  - allows SSD to execute multiple I/O requests in parallel
  - boosts throughput
  - configure queue depth to get your optimal balance between max. # of IOPS and lowest latency



3) Configuration tips: AHCI (NCQ+DIPM)

- **DIPM (Device Initiated Interface Power Management)**
  - reduces idle power down to 0,1 Watt

root@werner-t410: ~

```
root@werner-t410:~# cat /proc/scsi/scsi
Attached devices:
Host: scsi0 Channel: 00 Id: 00 Lun: 00
  Vendor: ATA      Model: INTEL SSDSA2M160 Rev: 2CV1
  Type:   Direct-Access                    ANSI  SCSI revision: 05
Host: scsi1 Channel: 00 Id: 00 Lun: 00
  Vendor: HL-DT-ST Model: DVDRAM GU10N     Rev: MX05
  Type:   CD-ROM                           ANSI  SCSI revision: 05
Host: scsi5 Channel: 00 Id: 00 Lun: 00
  Vendor: ATA      Model: INTEL SSDSA2CW16 Rev: 4PC1
  Type:   Direct-Access                    ANSI  SCSI revision: 05
root@werner-t410:~# cat /sys/class/scsi_host/host5/link_power_management_policy
max_performance
root@werner-t410:~# echo medium_power > /sys/class/scsi_host/host5/link_power_management_policy
root@werner-t410:~# cat /sys/class/scsi_host/host5/link_power_management_policy
medium_power
root@werner-t410:~# echo min_power > /sys/class/scsi_host/host5/link_power_management_policy
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min_power
root@werner-t410:~#
```
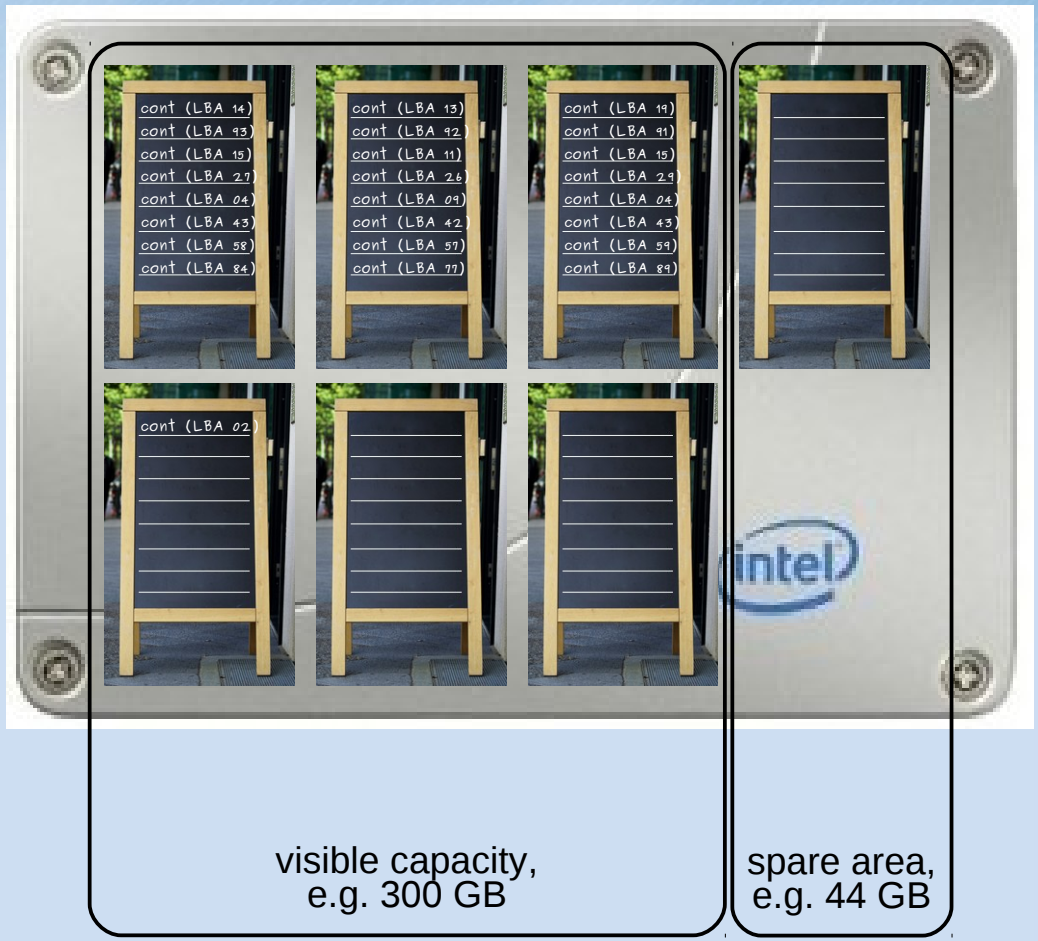

3) Configuration tips: TRIM (discard)

- **ATA TRIM**
  - tells SSD which data can be discarded



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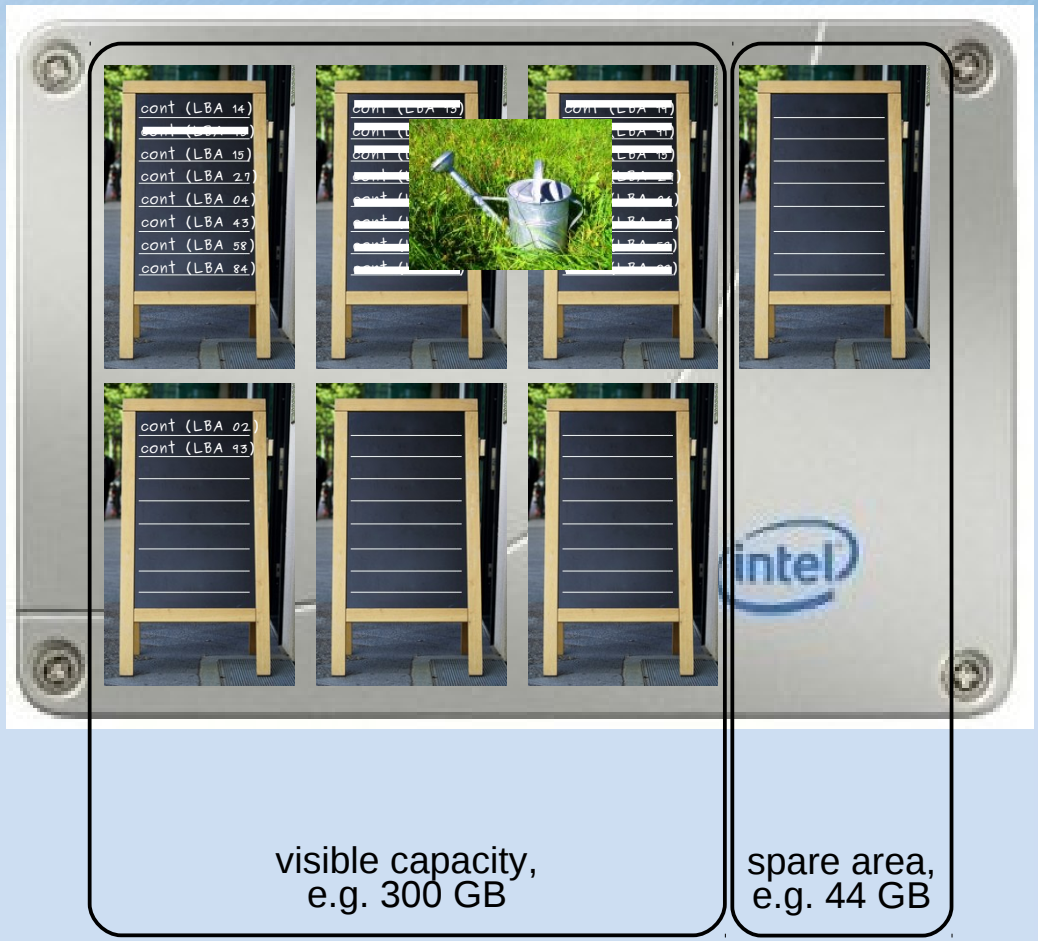
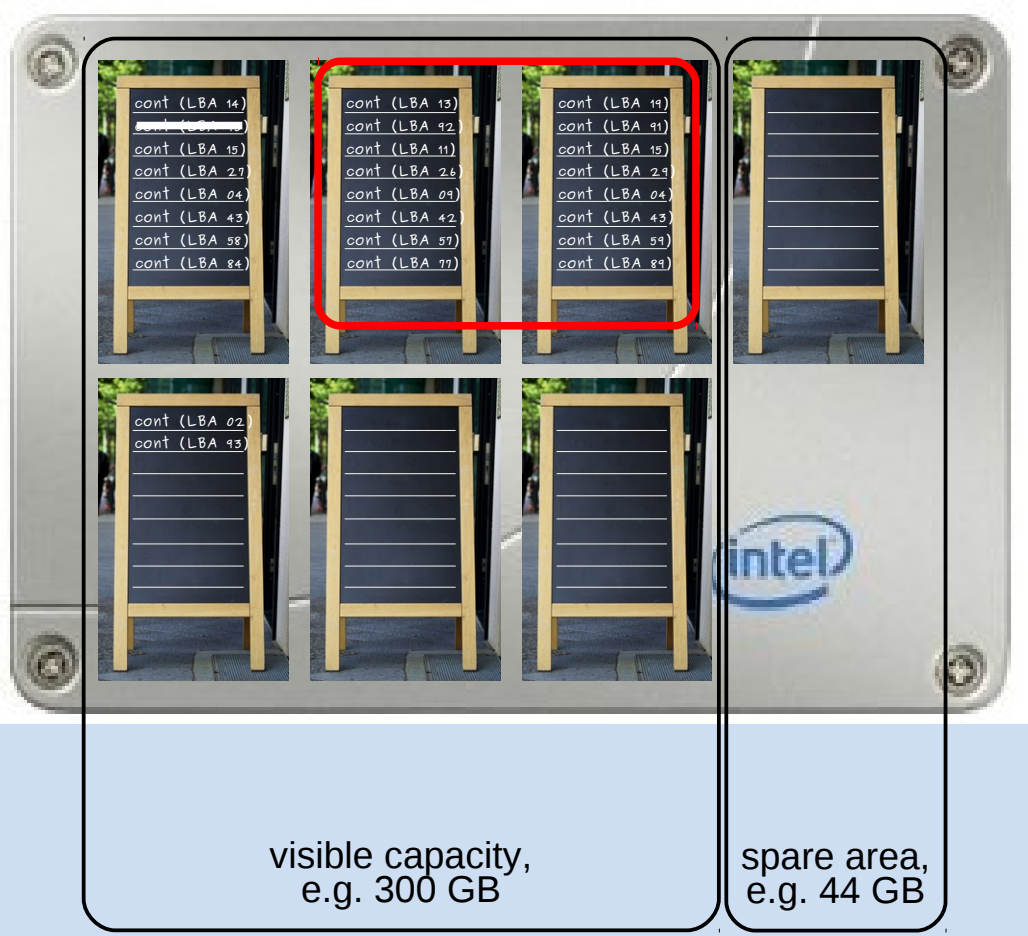


3) Configuration tips: TRIM (discard)

- **ATA TRIM**
  - tells SSD which data can be discarded
  - without TRIM:
    - deleting a big file (e.g. 100 GB) would lead to keep unusable data
    - unusable data will be maintained during garbage collection!
    - more overhead → lower performance & lower endurance!



3) Configuration tips: TRIM (discard)

- **ATA TRIM using discard infrastructure in Linux**
  - online discard
    - Ext4: since Kernel 2.6.33
    - XFS: since Kernel 3.0
    - Btrfs: since Kernel 2.6.32
  - batched discard (using fstrim command)
    - Ext4: since Kernel 2.6.37
    - XFS: since Kernel 2.6.38
    - Btrfs: since Kernel 2.6.39
  - pre-discard on format
    - E2fsprogs >= 1.41.10
    - Xfsprogs >= 3.1.0

3) Configuration tips: TRIM (discard)

- **ATA TRIM using discard infrastructure in Linux**
  - I/O stack discard support (device mapper):
    - since Kernel 2.6.36: DM targets delay, linear, mpath, stripe
    - since Kernel 2.6.38: DM mirror target
  - no I/O stack discard support yet:
    - MD raid
- **alternatives to discard: wiper.sh / raid1ext4trim.sh**
  - use hdparm --trim-sector-ranges-stdin
  - read warnings in the source of those scripts
  - cannot be used with device mapper

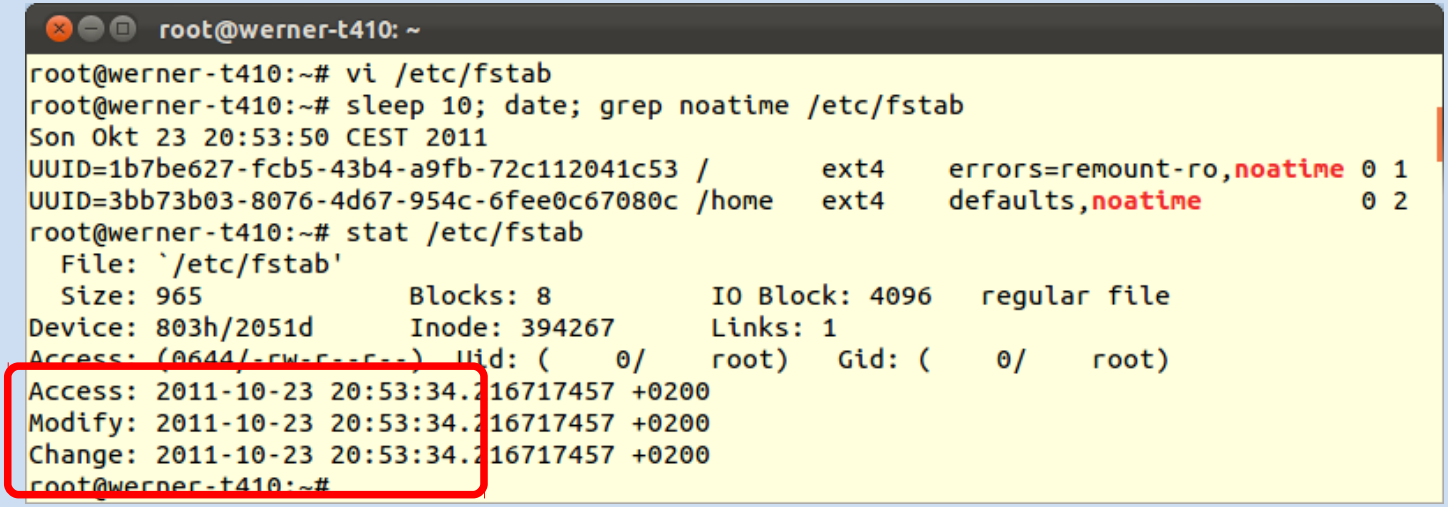
3) Configuration tips: TRIM (discard)

- **“does TRIM work?” howto**

```
root@werner-t410: ~
root@werner-t410:~# sudo hdparm -I /dev/sda | grep -i trim
           *    Data Set Management TRIM supported (limit 8 blocks)
           *    Deterministic read ZEROs after TRIM
root@werner-t410:~# echo "ABCD" > testfile; sync
root@werner-t410:~# hdparm --fibmap testfile

testfile:
 filesystem blocksize 4096, begins at LBA 61052928; assuming 512 byte sectors.
 byte_offset  begin_LBA    end_LBA    sectors
           0   73923472   73923479          8
root@werner-t410:~# hdparm --read-sector 73923472 /dev/sda | head -n 4

/dev/sda:
reading sector 73923472: succeeded
4241 4443 000a 0000 0000 0000 0000 0000
root@werner-t410:~# rm -f testfile
root@werner-t410:~# fstrim -v . ; sync
.: 3496751104 bytes was trimmed
root@werner-t410:~# hdparm --read-sector 73923472 /dev/sda | head -n 4

/dev/sda:
reading sector 73923472: succeeded
0000 0000 0000 0000 0000 0000 0000 0000
root@werner-t410:~#
```

3) Configuration tips: noatime & tmpfs

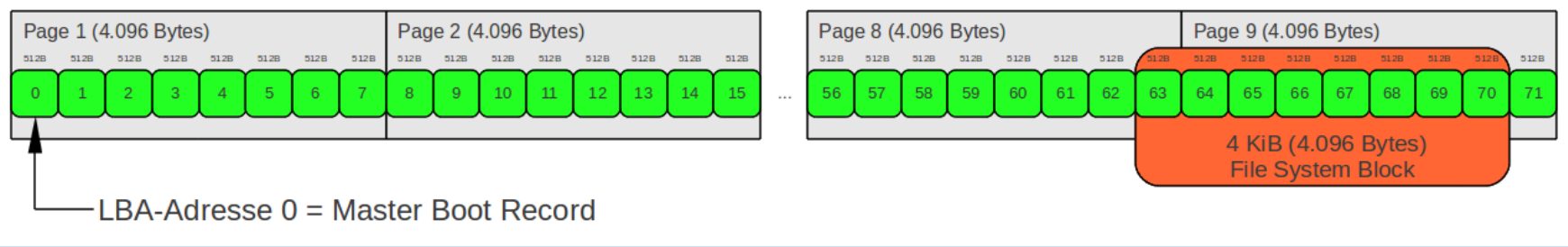
- **noatime / relatime**
  - omits writes of metadata on every read



- **tmpfs**
  - for temporary data like /tmp/, /var/tmp/, /var/cache/, ...

4) Configuration tips: alignment

- **align partition and file systems**
  - wrong alignment:



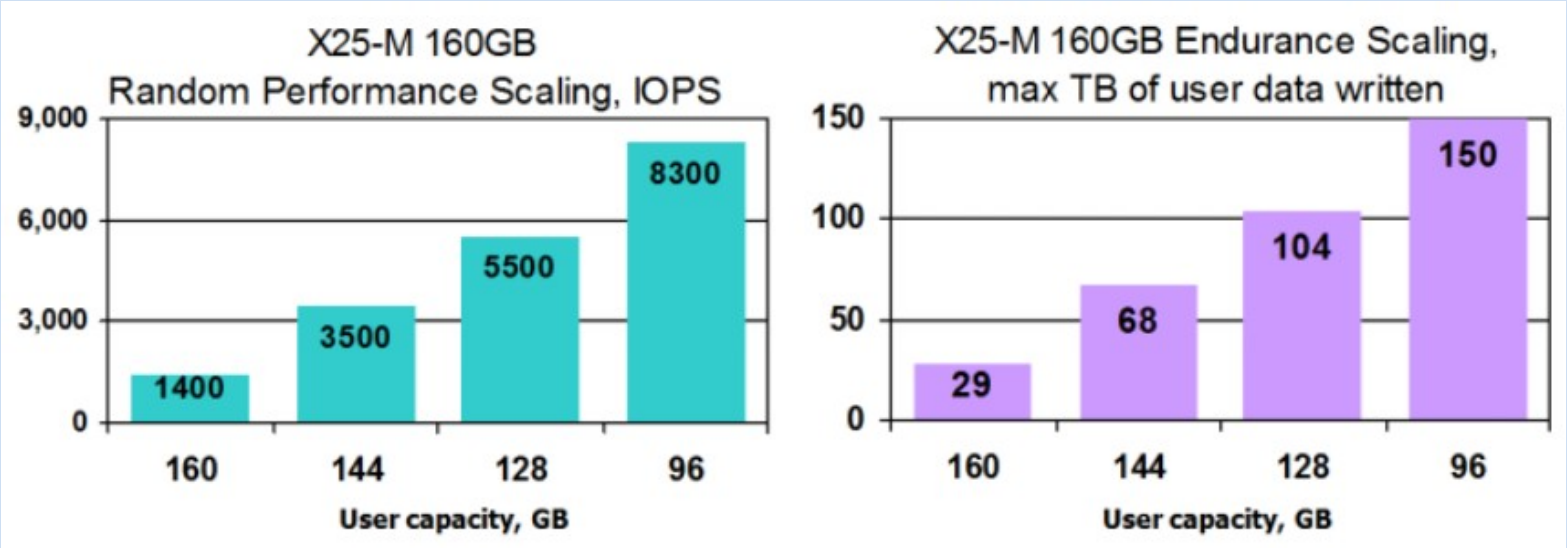
  - use fdisk parameters: fdisk -c -u /dev/sda
  - correct alignment:

4) Configuration tips: over-provisioning

- **do not use full normal visible capacity**
  - activate HPA (host protected area)
    - ATA8-ACS SET MAX ADDRESS
    - use hdparm -N
  - or simply do not partition full visible capacity
  - in either case if SSD has been used before:
    - do a secure erase to TRIM all blocks

4) Configuration tips: over-provisioning

- **over-provisioning is useful when discard cannot be used yet (e.g. MD-RAID, hardware RAID, ...)**
- **measurements by Intel:**



Source: Intel

Review:

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2) **I/O performance metrics**

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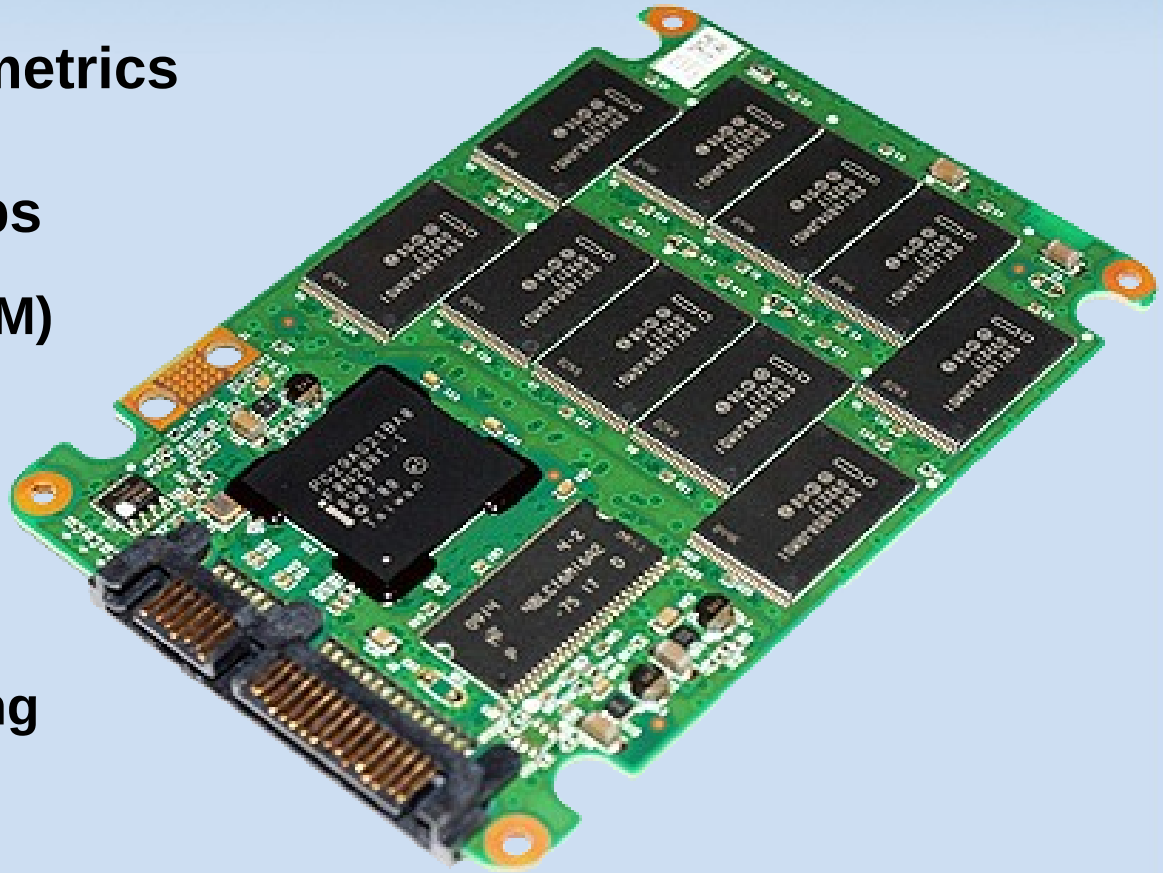

Source: maximumpc.com

Thanks for your time!

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Image sources: