DB+Storage is All You Need

Jonghyeok Park

Dept of Computer Science and Engineering

March. 26, 2025

Who Am I

Jonghyeok Park 박종혁

- Experiences
  - 2013.03 ~ 2016.08: B.S. in Software from Sungkyunkwan University
  - 2016.09 ~ 2022.08: Ph.D. in Computer Science from Sungkyunkwan University
    (Advisor Prof. Sang-Won Lee)
  - 2019.11 ~ 2020.03: Visiting research student at Simon Fraser University
    (Host Prof. *Tianzheng Wang*)
  - 2023.03 ~ 2024.08: Assistant Professor at Hankuk University of Foreign Studies
  - 2024.09 ~ current: Assistant Professor at Korea University

- Research Areas
  - Database systems, Storage Systems, Flash/NVM-based DBMS

Overview

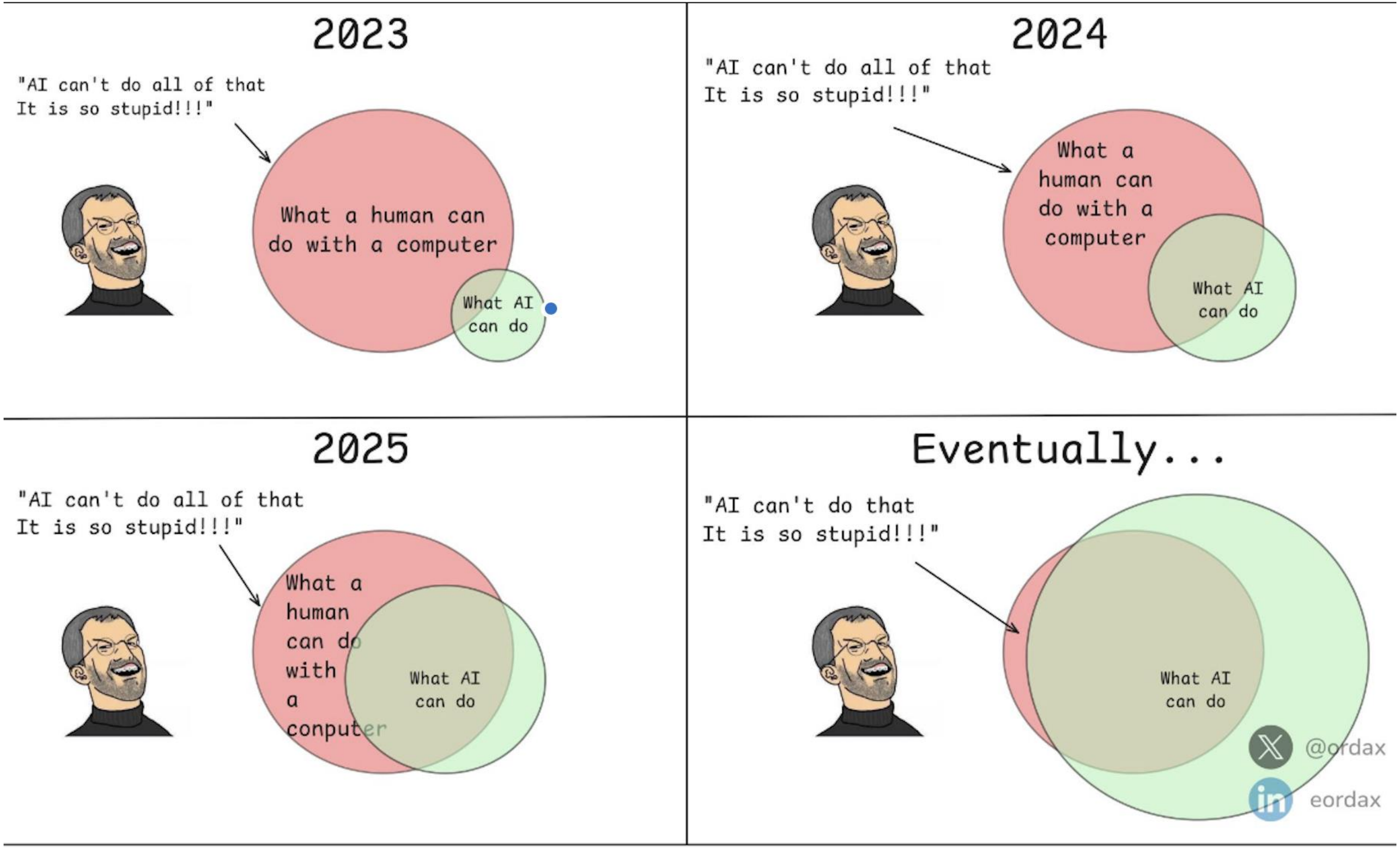
- Experiences
- Why do we study Database and Storage
- SaS: SSD as SQL engine
- DBS Lab.
- Advice

In 2013 …

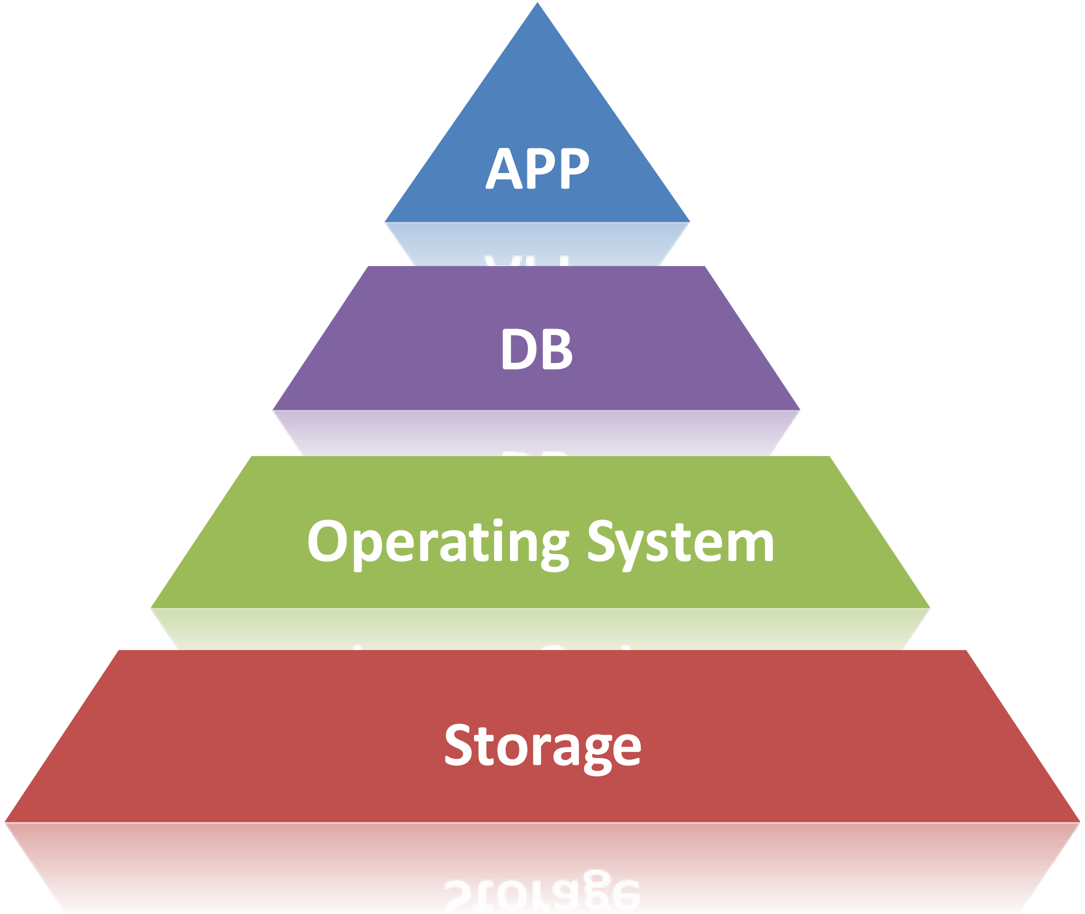
- 콩순이
- Find employment vs. **Graduate School**

* *generated from GPT*

Now ...


2023
"AI can't do all of that
It is so stupid!!!"
What a human can do with a computer
What AI can do
2024
"AI can't do all of that
It is so stupid!!!"
What a human can do with a computer
What AI can do
2025
"AI can't do all of that
It is so stupid!!!"
What a human can do with a conputer
What AI can do
Eventually...
"AI can't do that
It is so stupid!!!"
What AI can do
@ordax
eordax

Why Do we Study Database?



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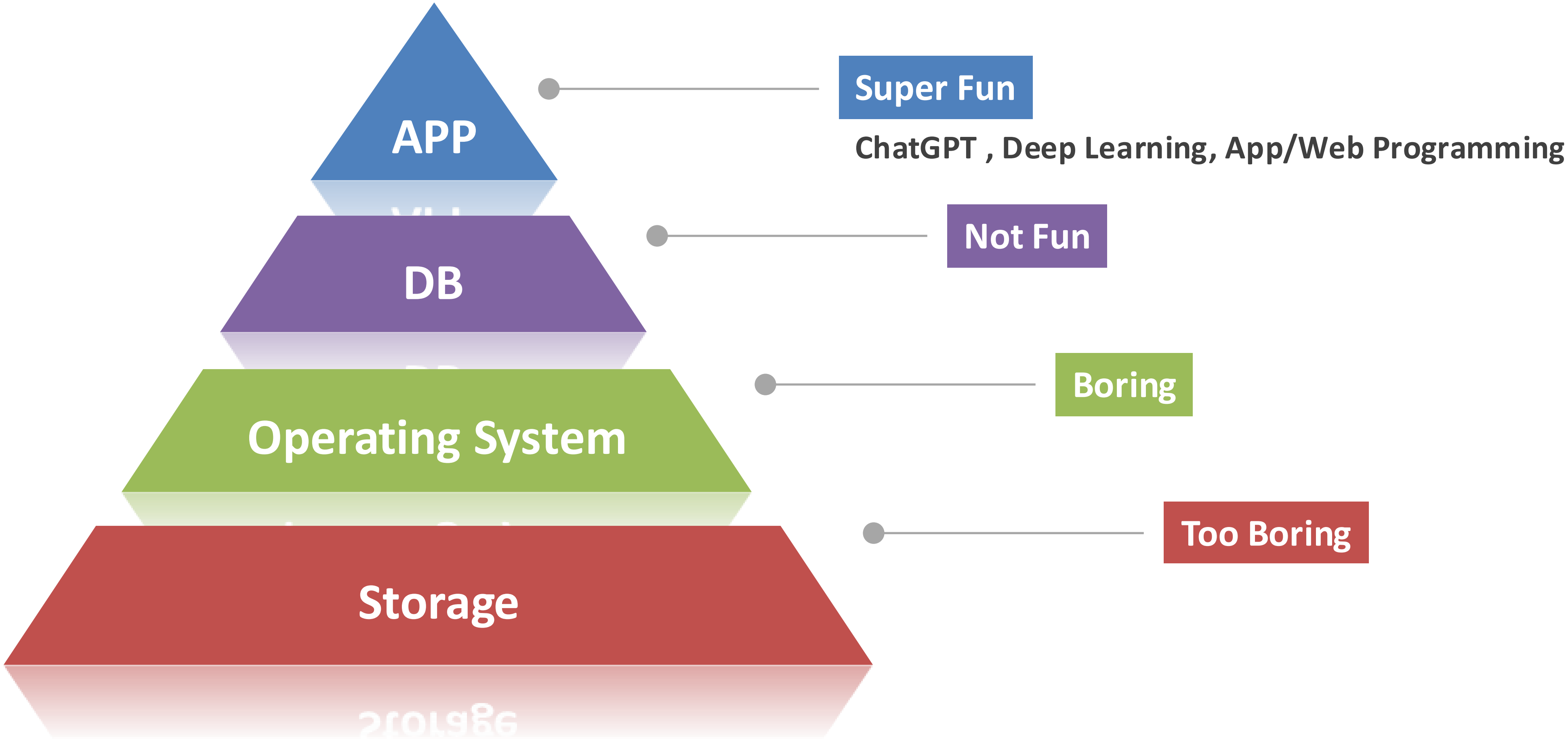


APP

DB

Operating System

Storage

Super Fun

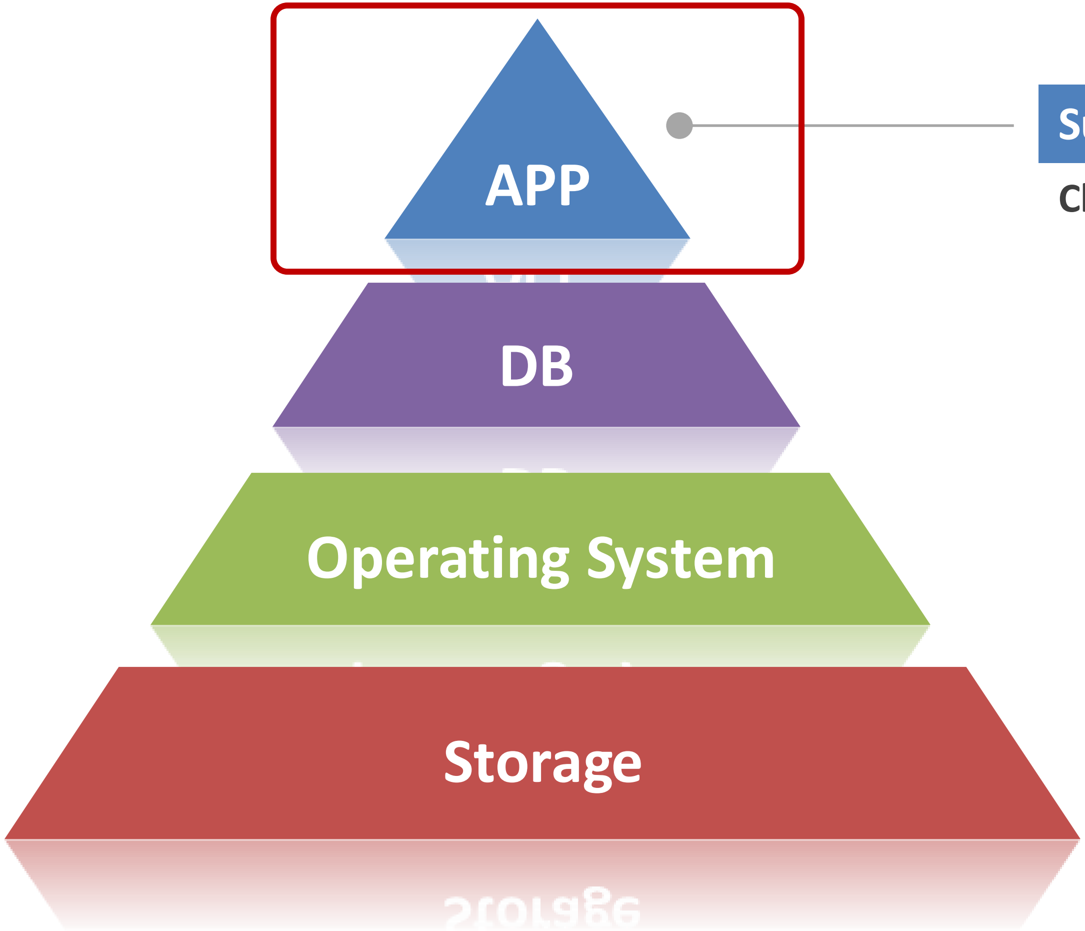
ChatGPT , Deep Learning, App/Web Programming

Not Fun

Boring

Too Boring

Why Do we Study Database?

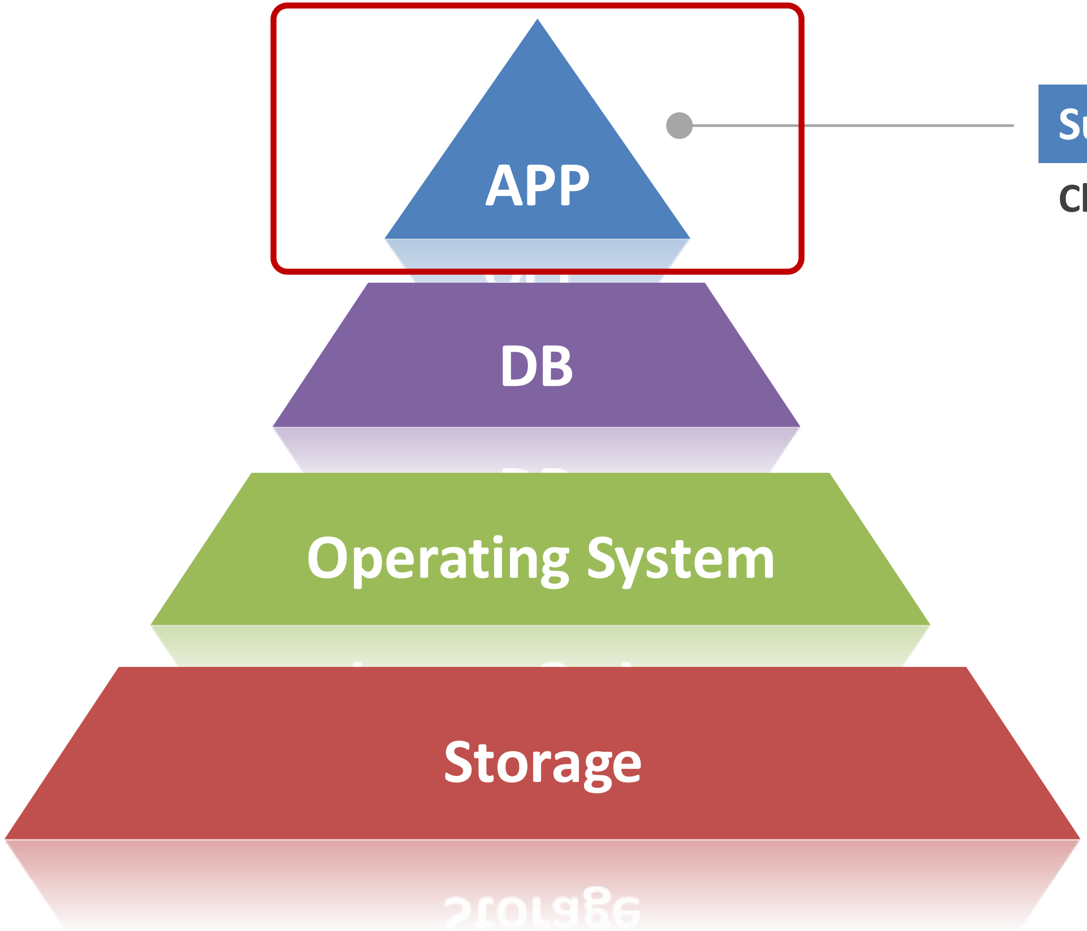


Super Fun

ChatGPT , Deep Learning, App/Web Programming

- Easy and Fun
- Fancy
- Low entry barriers
- Rapidly changing

Why Do we Study Database?



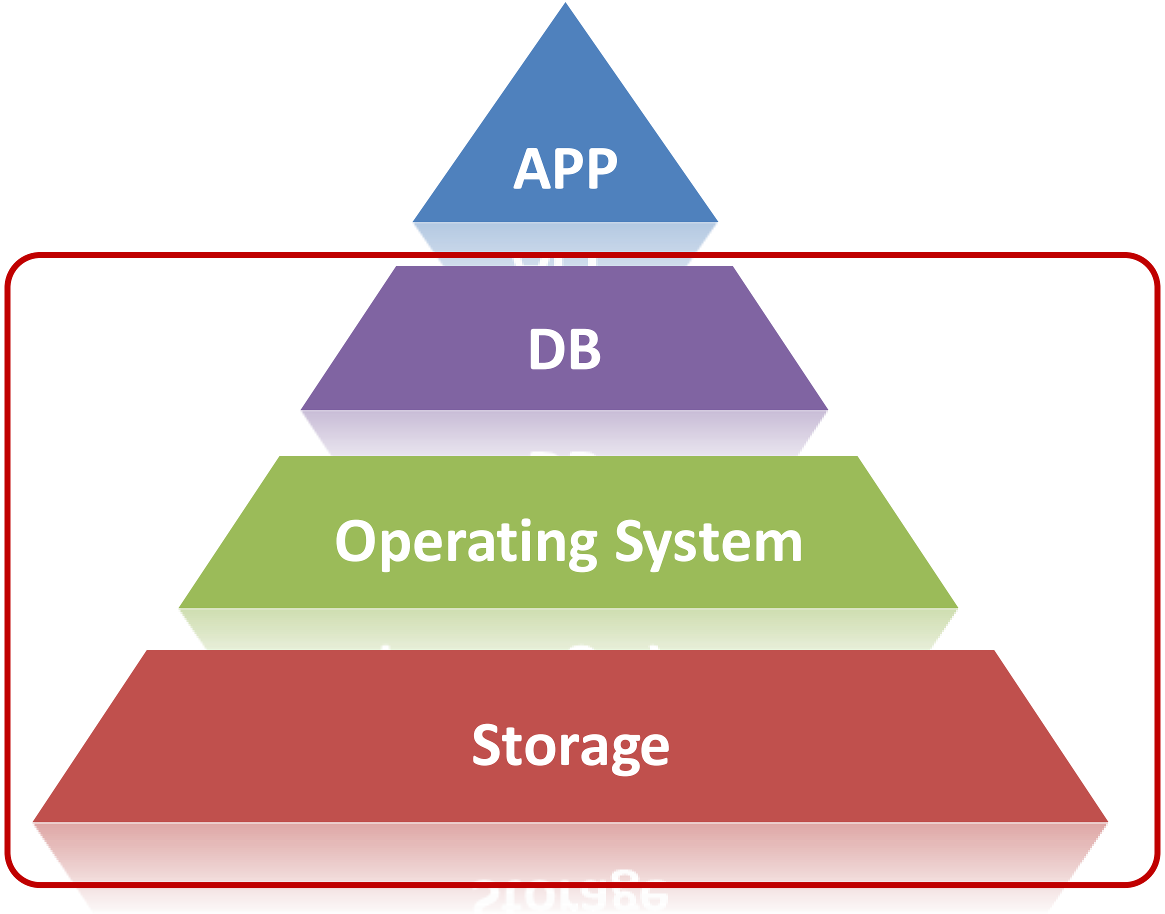
Super Fun

ChatGPT , Deep Learning, App/Web Programming

- Easy and Fun
- Fancy
- Low entry barriers
- Rapidly changing

Anyone can do it; Replaceable

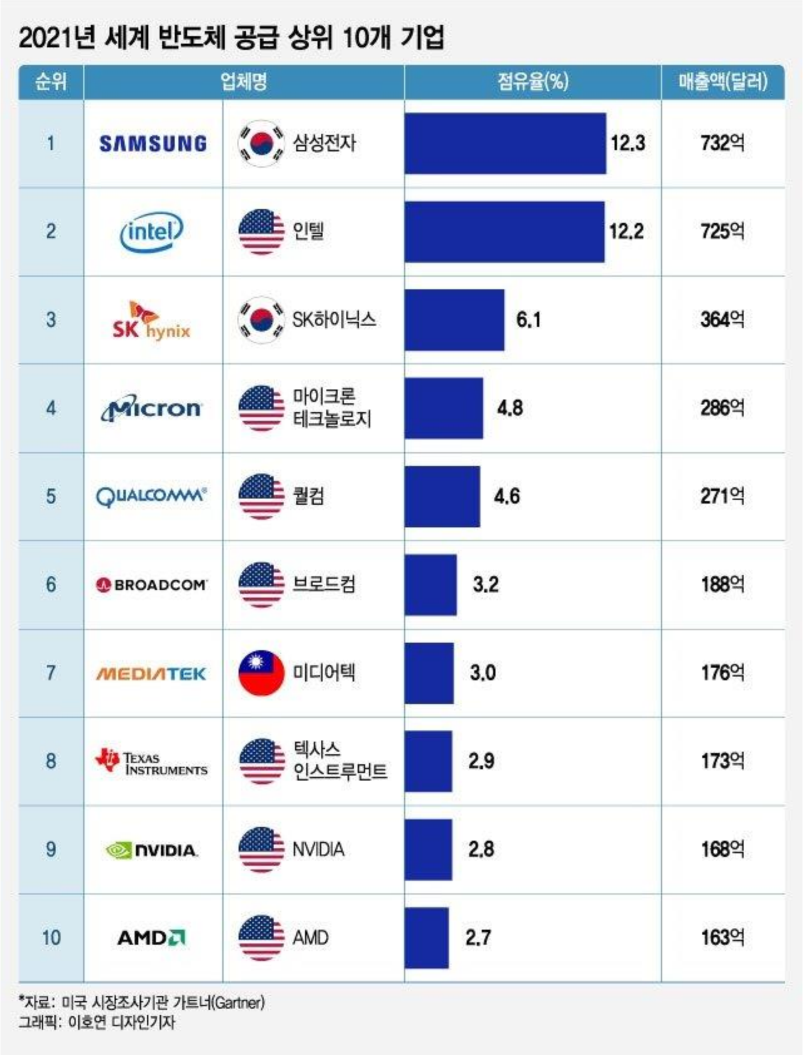
Why Do we Study Database?



- Difficult
- Hard
- High entry barrier
- Steep learning curve
- Slowly Changing

Not everyone can do it; Irreplaceable

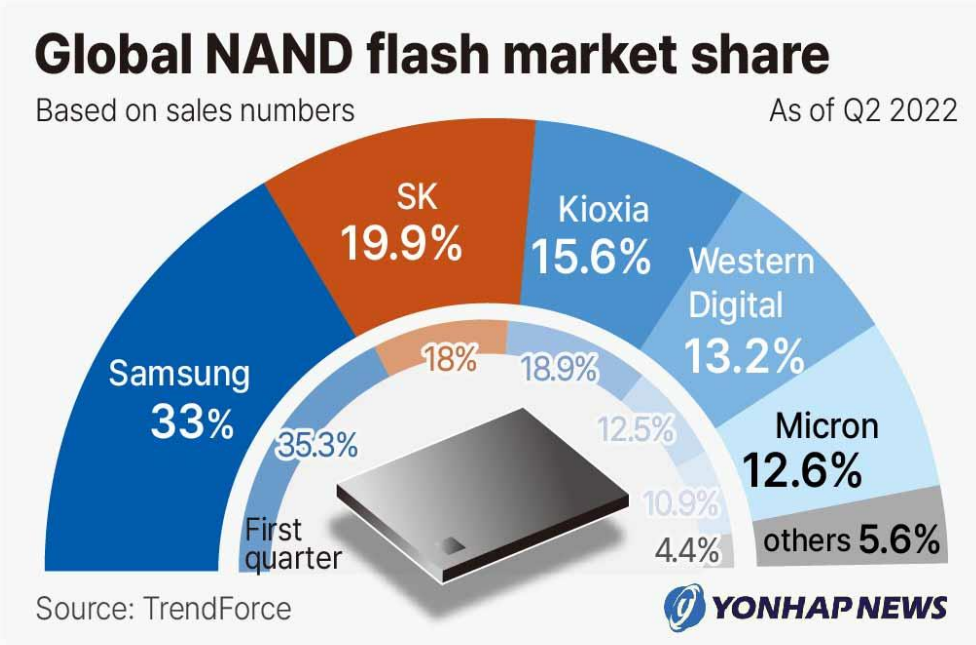
Why Should we study DB&Storage in Korea?



2021년 세계 반도체 공급 상위 10개 기업

순위	업체명		점유율(%)	매출액(달러)
1	SAMSUNG	삼성전자	12.3	732억
2	intel	인텔	12.2	725억
3	SK hynix	SK하이닉스	6.1	364억
4	Micron	마이크론 테크놀로지	4.8	286억
5	QUALCOMM	퀄컴	4.6	271억
6	BROADCOM	브로드컴	3.2	188억
7	MEDIATEK	미디어텍	3.0	176억
8	TEXAS INSTRUMENTS	텍사스 인스트루먼트	2.9	173억
9	NVIDIA	NVIDIA	2.8	168억
10	AMD	AMD	2.7	163억

*자료: 미국 시장조사기관 가트너(Gartner)
그래픽: 이호연 디자인기자



Global NAND flash market share

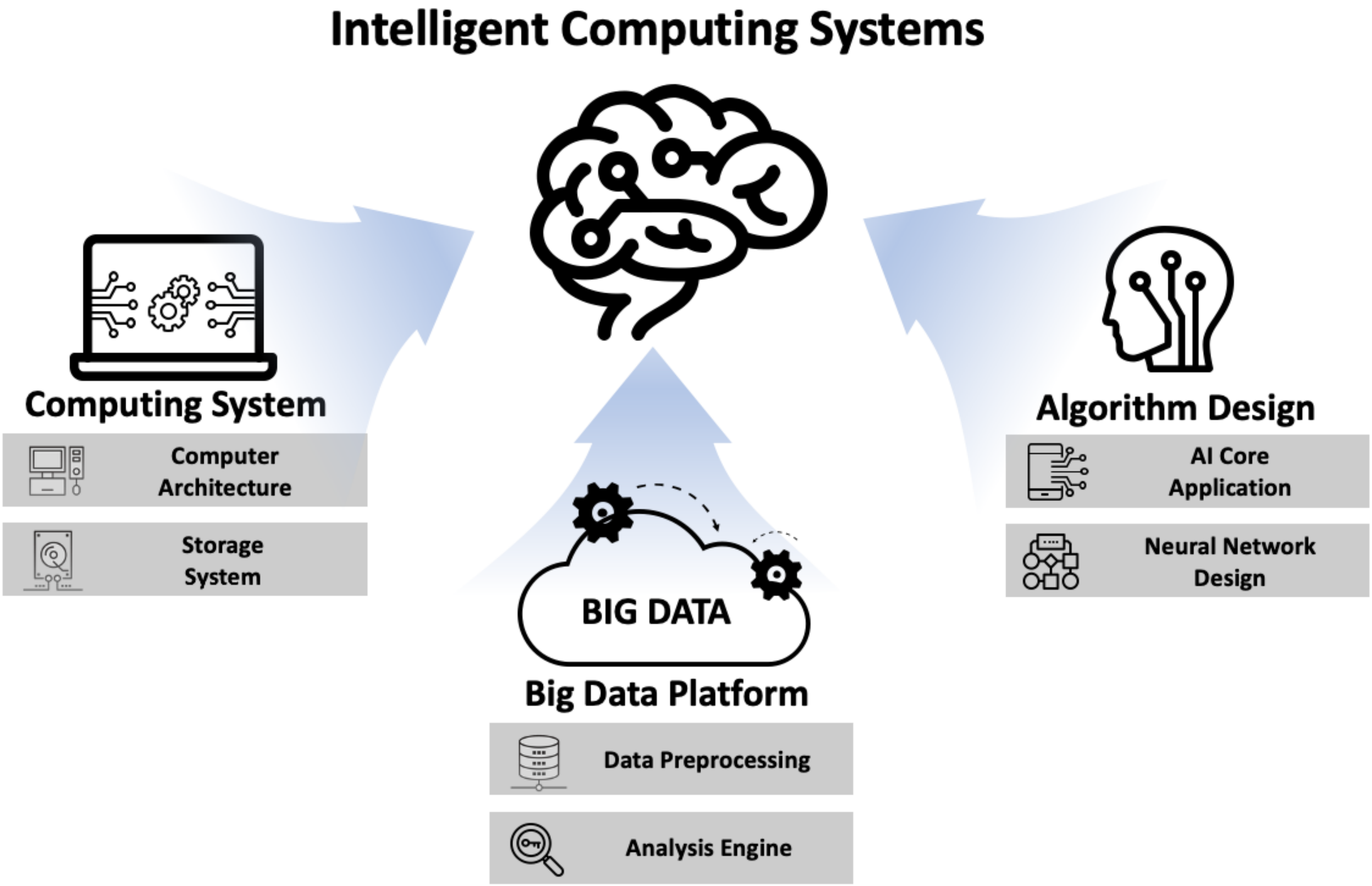
Based on sales numbers

As of Q2 2022

Source: TrendForce

YONHAP NEWS

Core Technology for AI



Intelligent Computing Systems

Computing System

- Computer Architecture
- Storage System

Algorithm Design

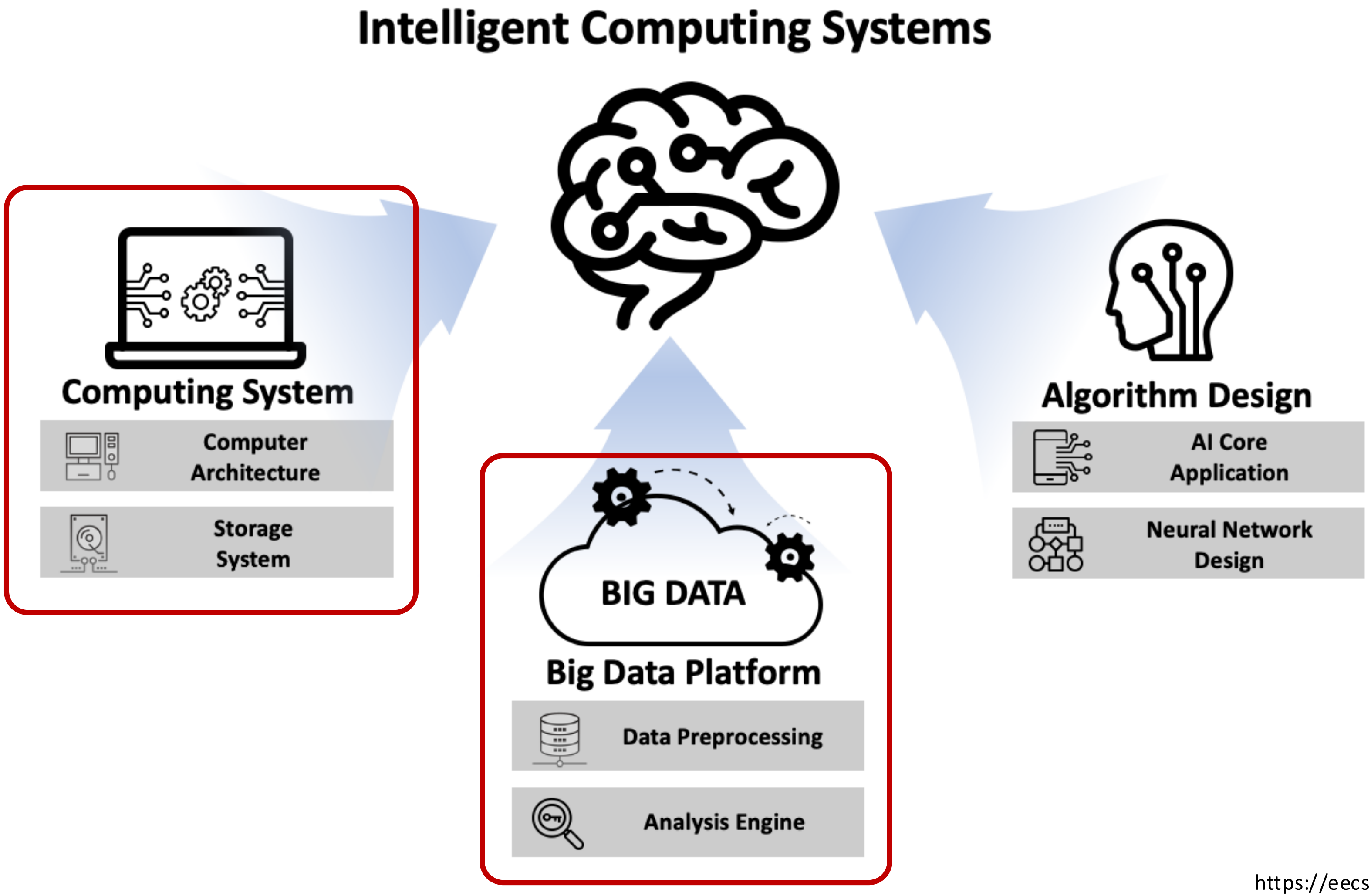
- AI Core Application
- Neural Network Design

Big Data Platform

- Data Preprocessing
- Analysis Engine

https://eecs.dgist.ac.kr/en/page/36/

Core Technology for AI



Intelligent Computing Systems

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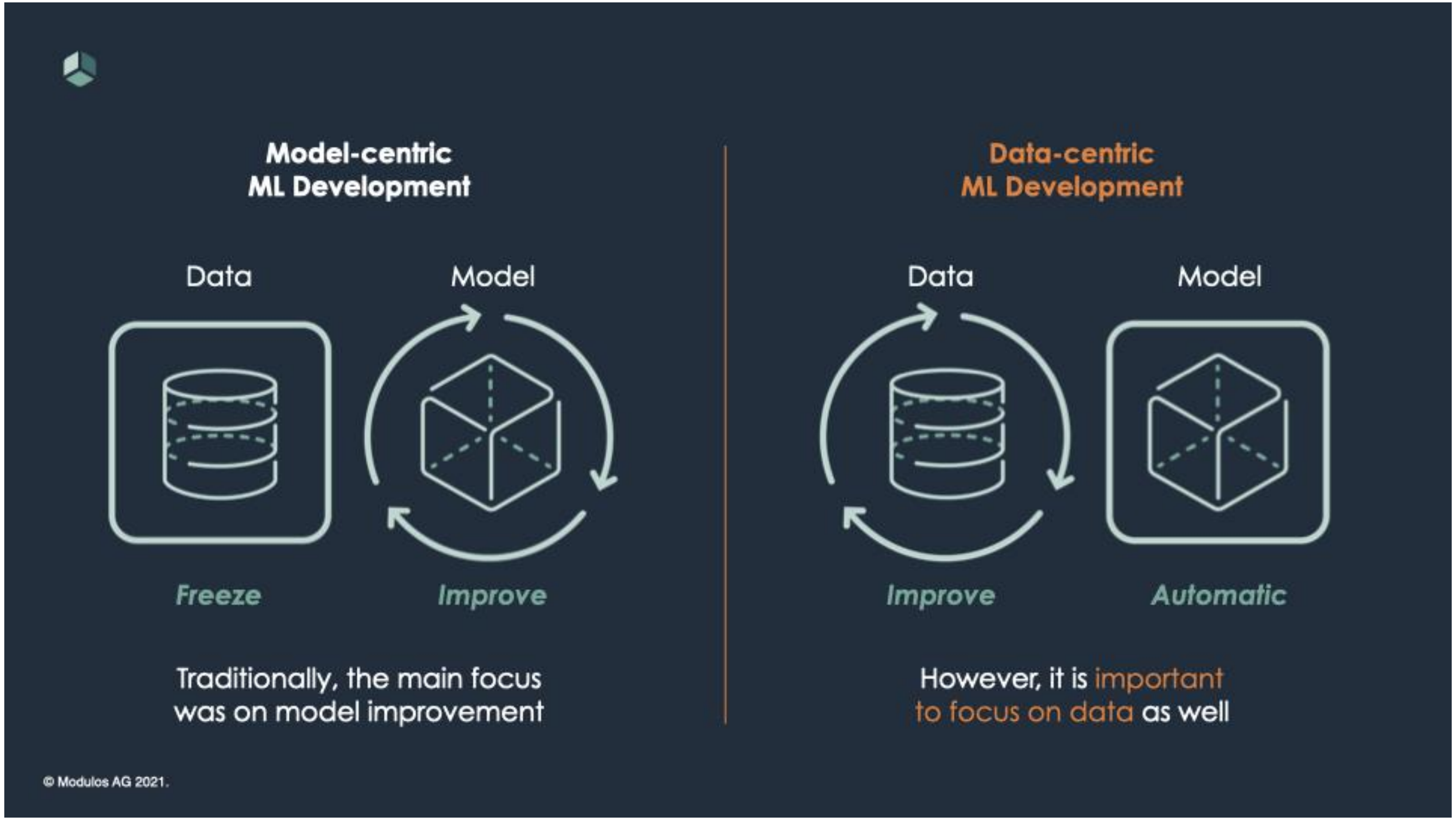
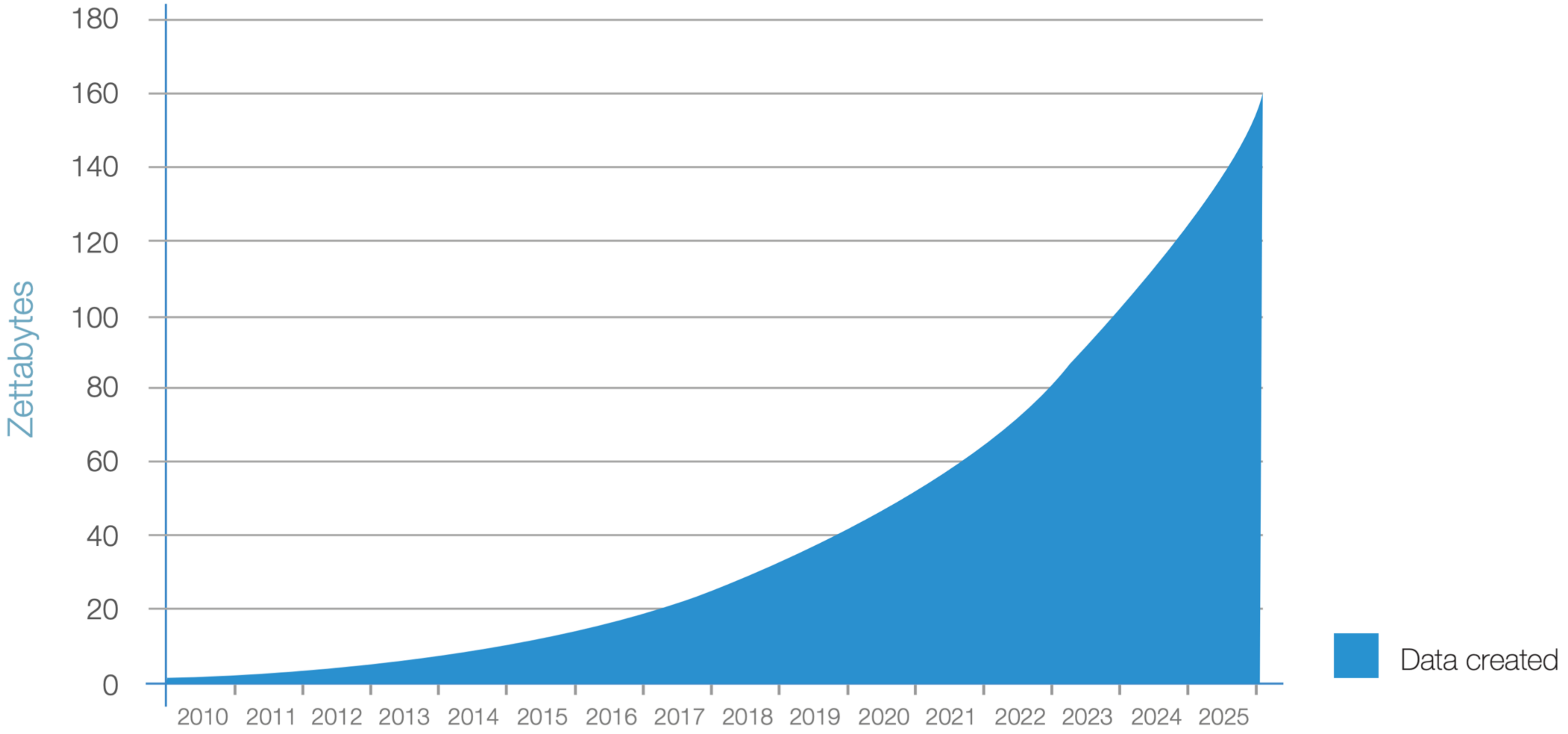
Dear AI, IT is Data

- Data-centric AI



Big Data : Big in Growth Too

1ZB = 1,000,000,000,000,000,000,000 bytes



Source: IDC's Data Age 2025 study, sponsored by Seagate, April 2017

Big Data : Big in Growth Too

1ZB = 1,000,000,000,000,000,000,000 bytes

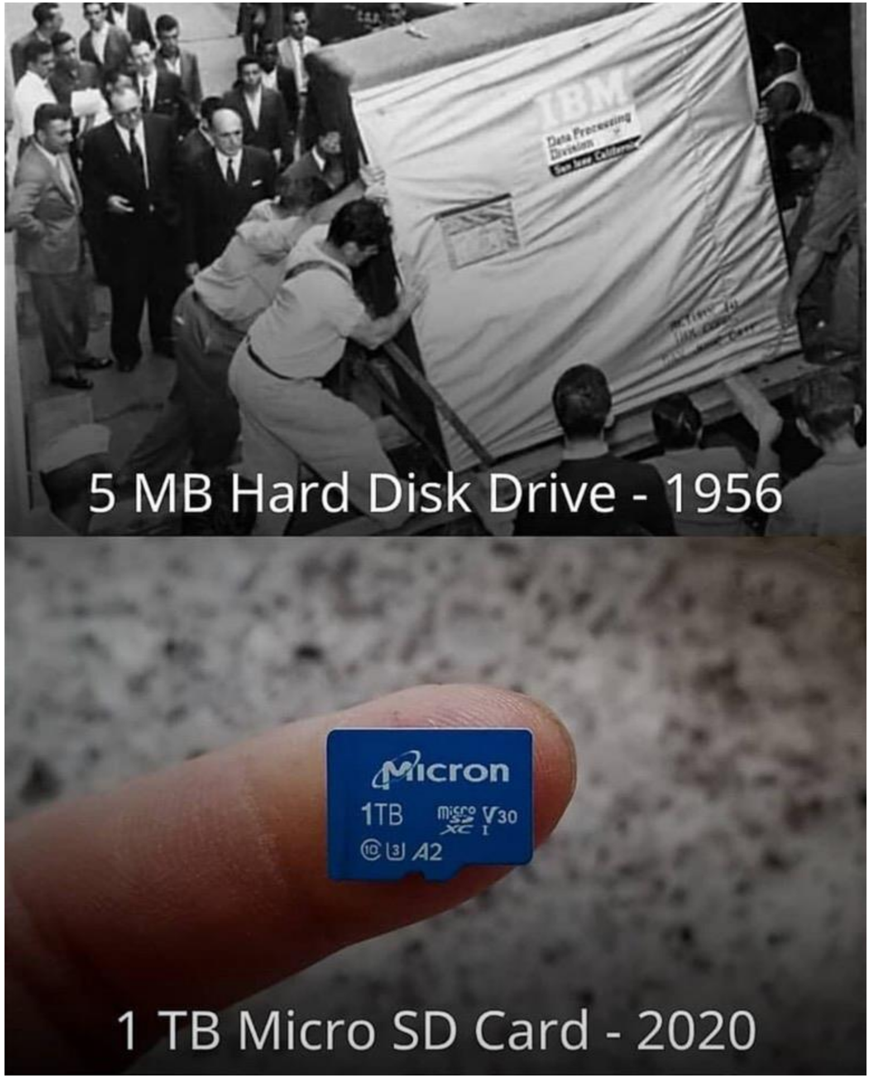
How to manage BIG DATA efficiently?

Speed, Durability, Cost

180
160
20
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Data created

Source: IDC's Data Age 2025 study, sponsored by Seagate, April 2017

Storage Systmes

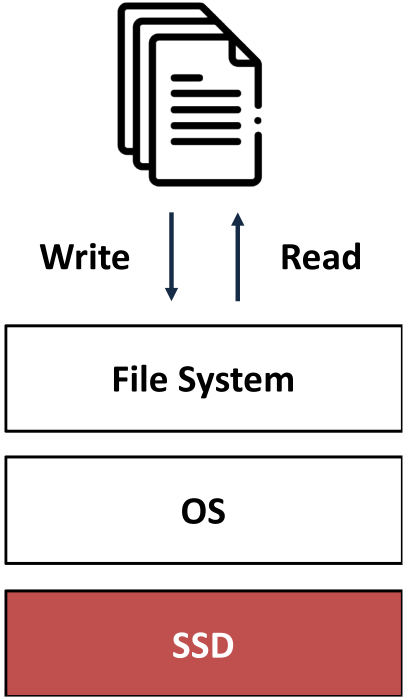


5 MB Hard Disk Drive - 1956

1 TB Micro SD Card - 2020

SSD (Solid State Drive)

- Charcteristics of Flash memory

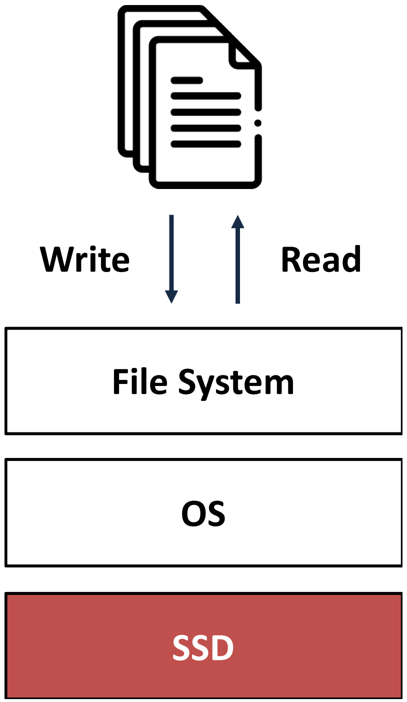


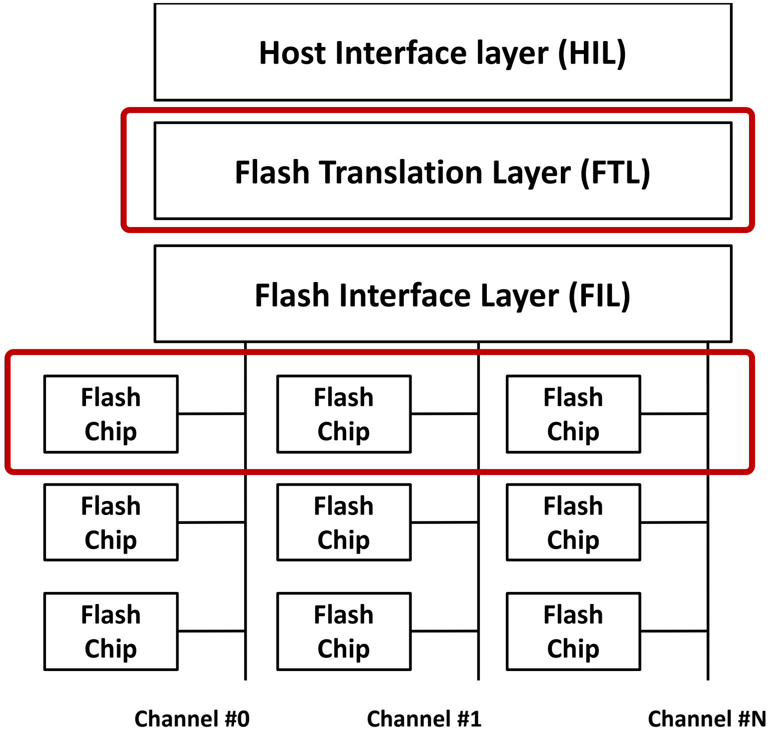
SSD (Solid State Drive)

1. Parallelism & Translation

Translate Logical address to Physical address!

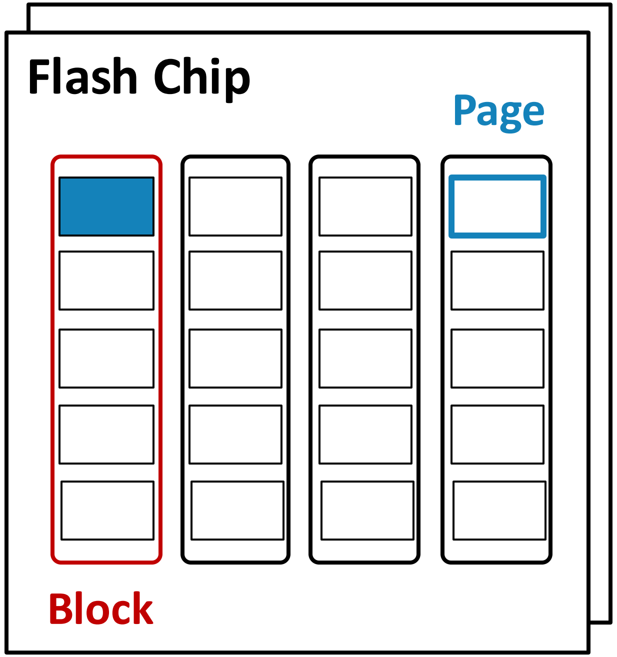
Logical Block Address → Physical Block Address





SSD (Solid State Drive)

2. Different operation granulality
   - Read and write operations are performed on a page level
   - Erase operation occurs at block level



LBA	PBA	Valid
0	(0,0)	Y

Mapping TBL

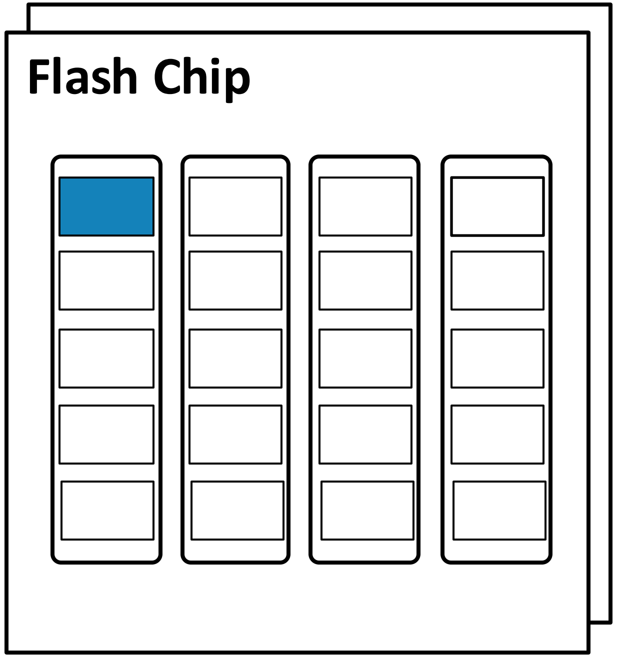
Translation

Write LBA 0 → **Write** Block #0, Page #0

Read LBA 0 → **Read** Block #0, Page #0

SSD (Solid State Drive)

3. No overwrite
   - Read and write operations are performed on a page level
   - Erase operation occurs at block level



LBA	PBA	Valid
0	(0,0)	Y

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Write LBA 0 → Write Block #0, Page #0

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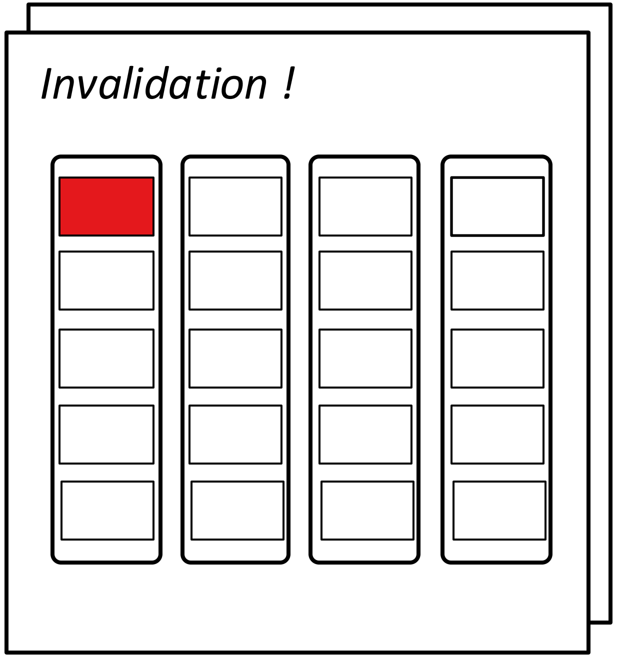

LBA	PBA	Valid
0	(0,0)	N

Mapping TBL

Translation

Write LBA 0 → **Write** Block #0, Page #0

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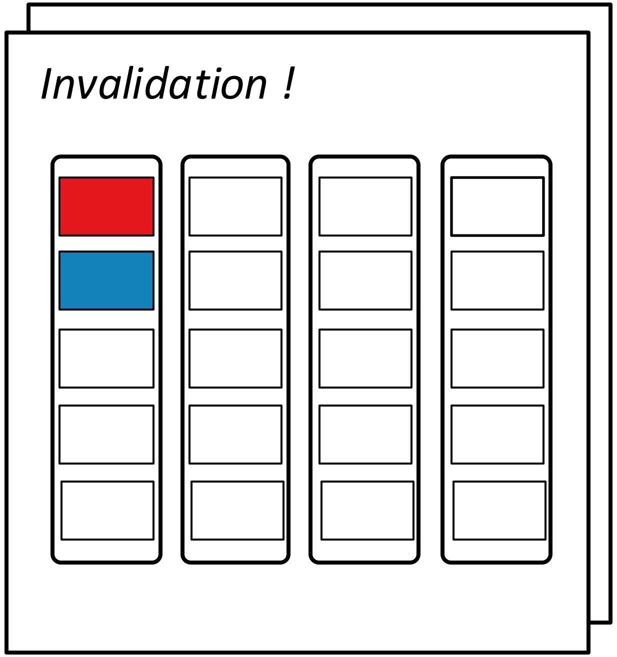
Write LBA 0 → **Write** Block #0, Page #1

SSD (Solid State Drive)

3. No overwrite
   - Flash chips have a finite lifespan



LBA	PBA	Valid
0	(0,1)	Y

Mapping TBL

Translation

Write LBA 0 → **Write** Block #0, Page #0

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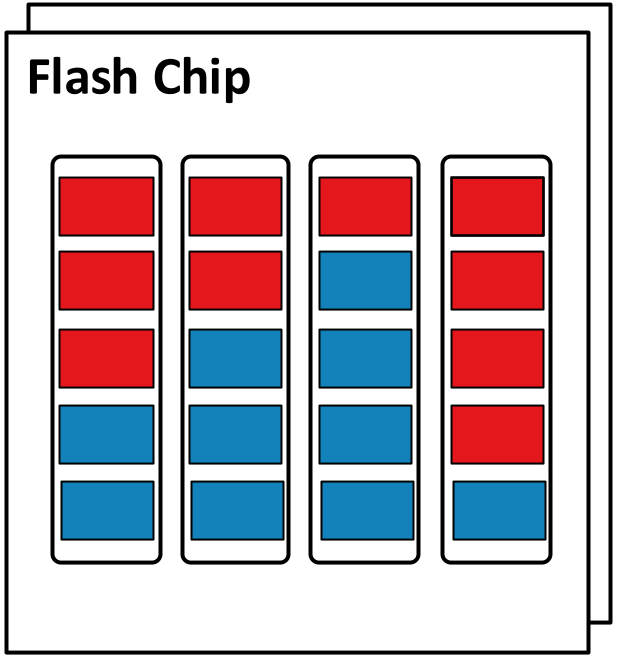
SSD (Solid State Drive)

4. When the block is full
   - Select the victim block with fewest valid pages (Greedy Algorithm)

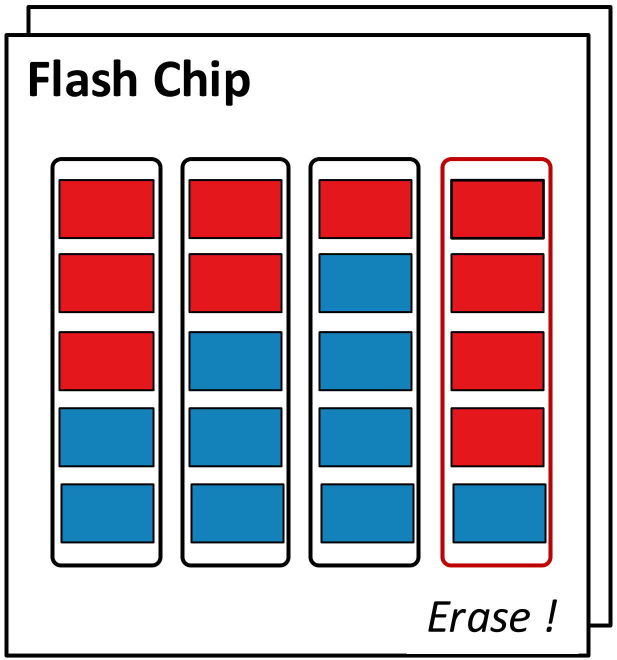


LBA	PBA	Valid
0	(0,1)	Y

Mapping TBL

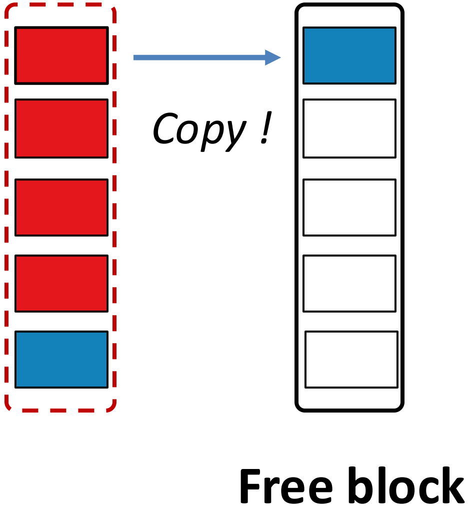
SSD (Solid State Drive)

4. When the block is full, we need GC (Garbage Collection)
   - Select the victim block with fewest valid pages (Greedy Algorithm)
   - Copy the valid pages to free block and then erase the original block



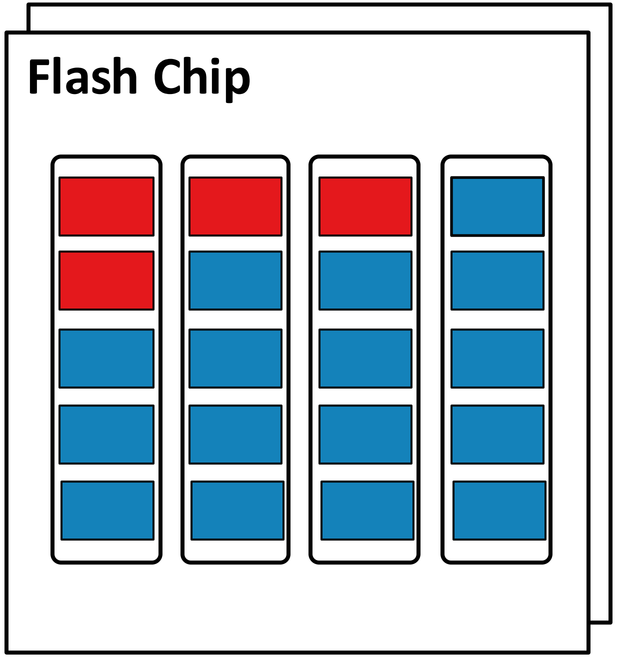
LBA	PBA	Valid
0	(0,1)	Y

Mapping TBL



The Achilles' heel of SSDs

- Write Amplification
  - Worsen the performance and shorten the lifespan of flash chips



…

Write LBA 0 → **Write** Block #0, Page #0

GC is triggered

The Achilles' heel of SSDs

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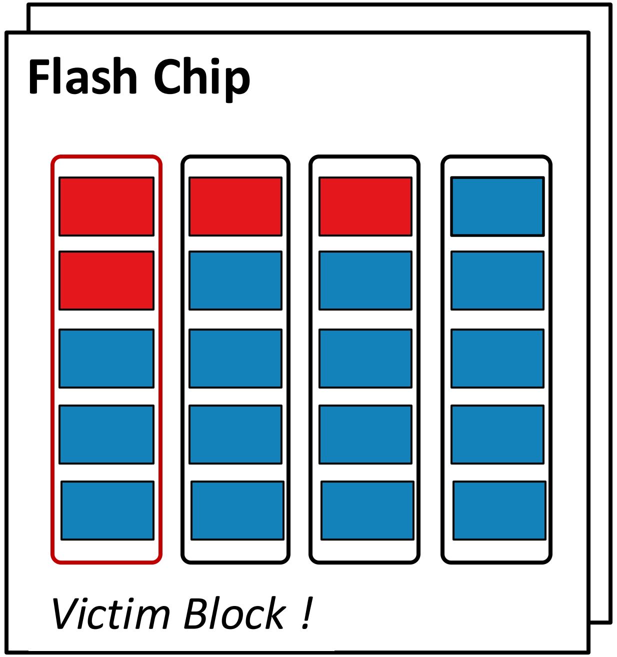

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The Achilles' heel of SSDs

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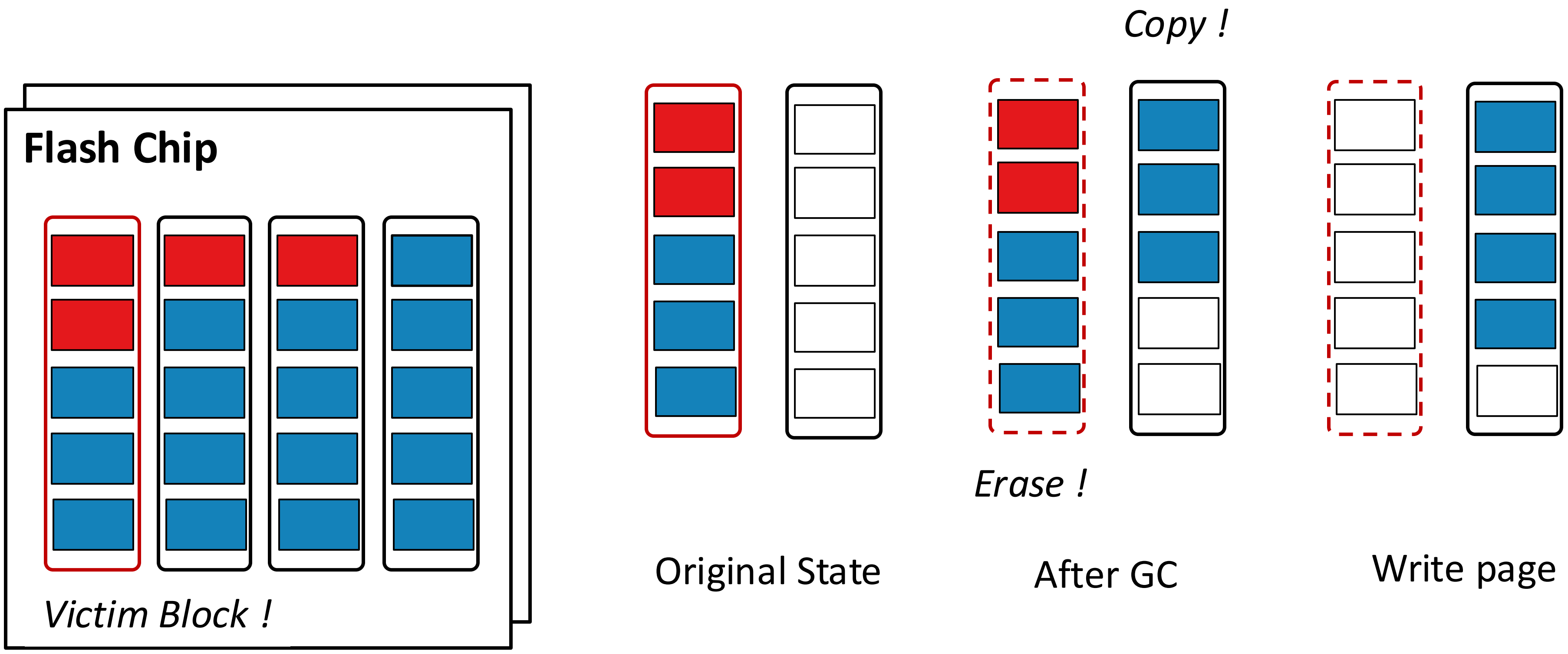

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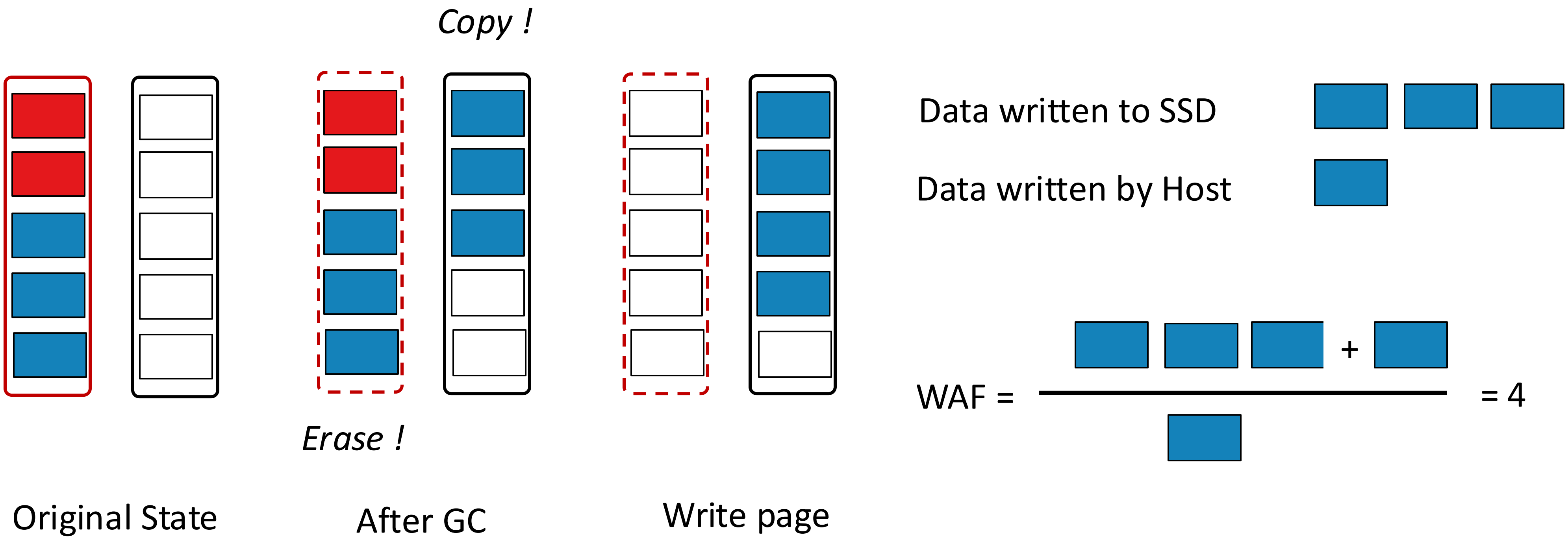


Copy !

Erase !

Original State

After GC

Write page

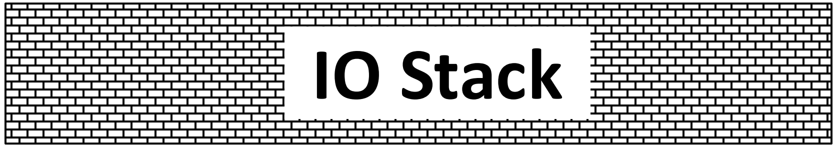
Data written to SSD

Data written by Host

WAF = = 4

We need the new storage

High Performance



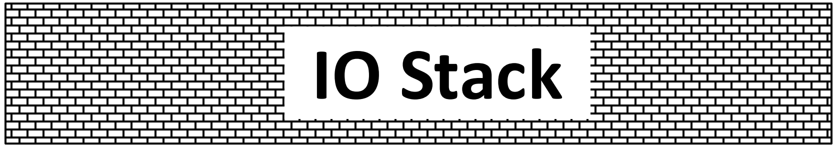
IO Stack

Bottleneck #2

Bottleneck #1

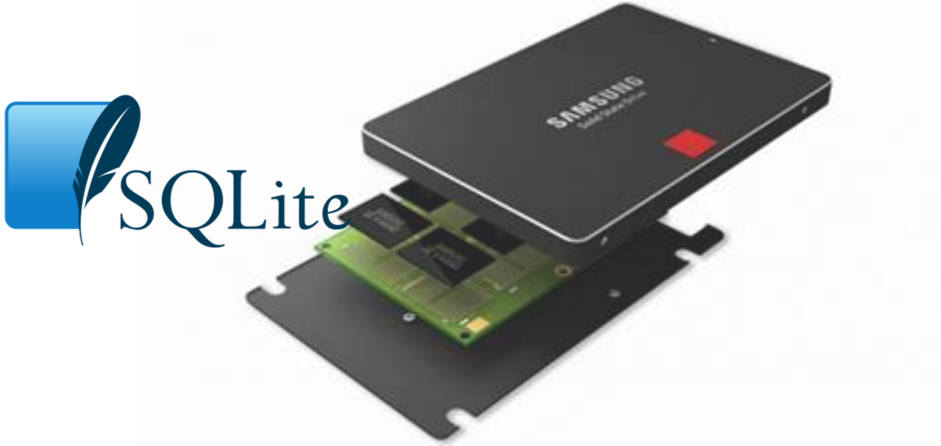
We need the new storage

PostgreSQL
amazon DynamoDB
OrientDB Community Edition
neo4j
SQLite
MySQL
redis
elasticsearch
mongoDB
cassandra
Microsoft SQL Server
ORACLE
IBM DB2
MariaDB
mobulous



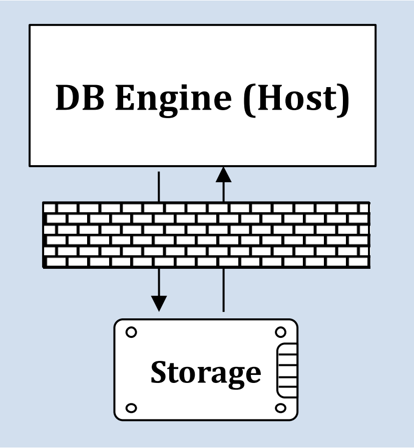
We need the new storage

- SaS: SSD as SQL Engine



Motivation

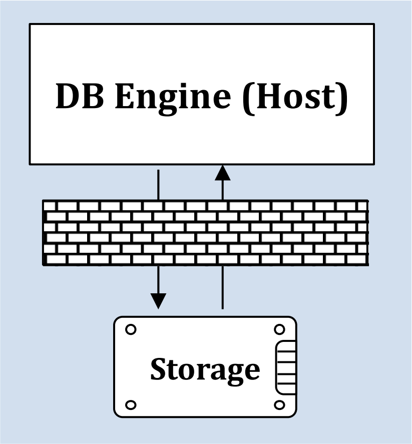
- **Databases: bedrock of modern service**
  - Meta, Google
  - MS Azure, Amazon Aurora, Data Bricks, Snowflake
- **Computer architecture**
  - Dichotomy of host and storage
  - In-host database engines (**IHDE**)
- **Era of flash memory SSDs**
  - "Flash is disk, disk is tape, and tape is dead." (Jim Gray)
- **DB computing paradigm**: host-centric → **SSD-centric**



IHDE

Why IHDEs are so Inefficient on SSDs (1)

- **Dichotomy** of Host and Storage
- In-Host Database Engine (IHDE)

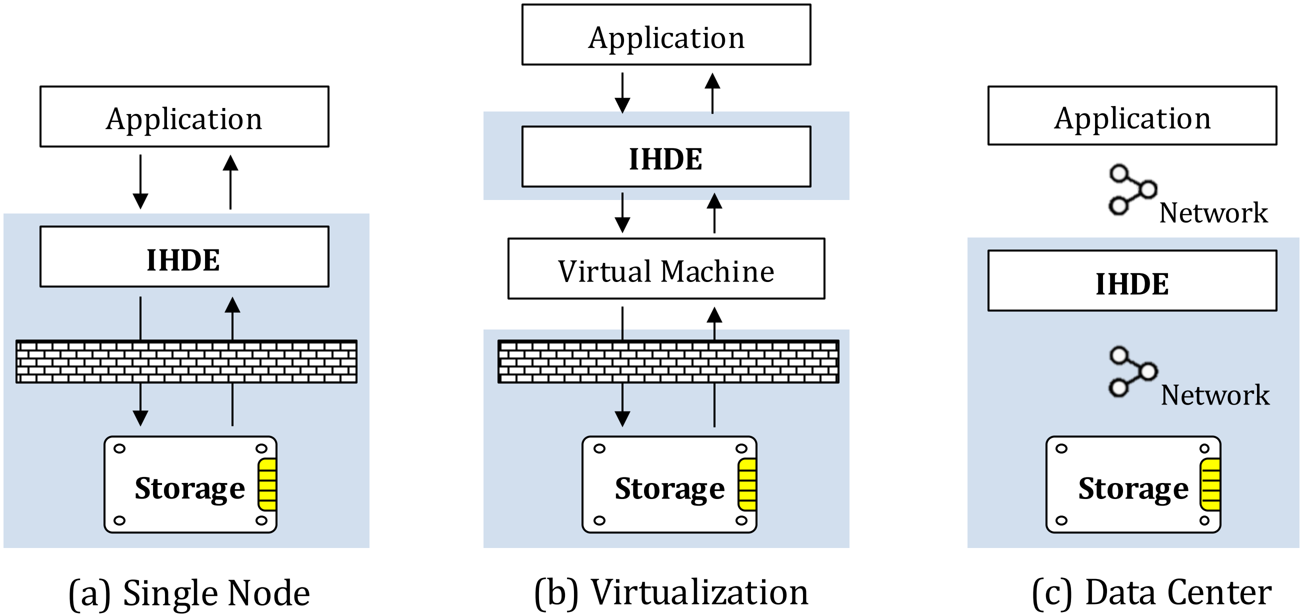


IHDE

1. IO Stack Overhead
2. Hinder Vertical Optimization
3. Architectural Inefficiencies

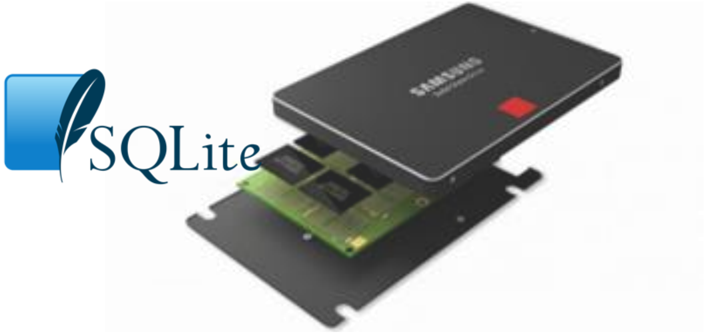
Why IHDEs are so Inefficient on SSDs (2)

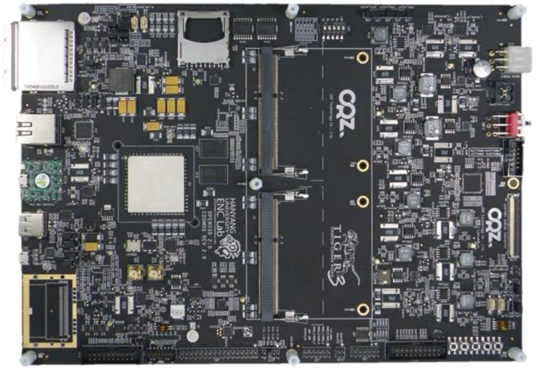
- **Legacy IO stack overhead**
  - Latency, CPU instructions, interrupt, etc.
  - (+) Virtualization barrier: Docker, Container
  - (+) Network latency barrier : Serverless / Disaggregation (e.g., Amazon Aurora)



Jim Gray's Vision and Ours

> *All storage systems will eventually evolve to be database systems*

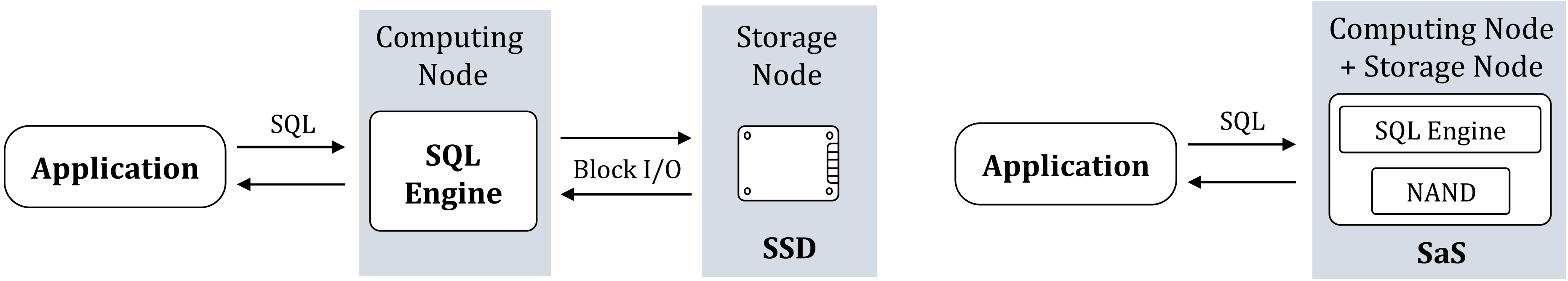




Cosmos+ Open SSD

SaS: SSD as SQL Engine

- **Let’s a full-blown DB engine run inside SSD**
  - Eliminate IO stack overhead
  - Enable seamless vertical optimizations
  - More elegant and economical architecture

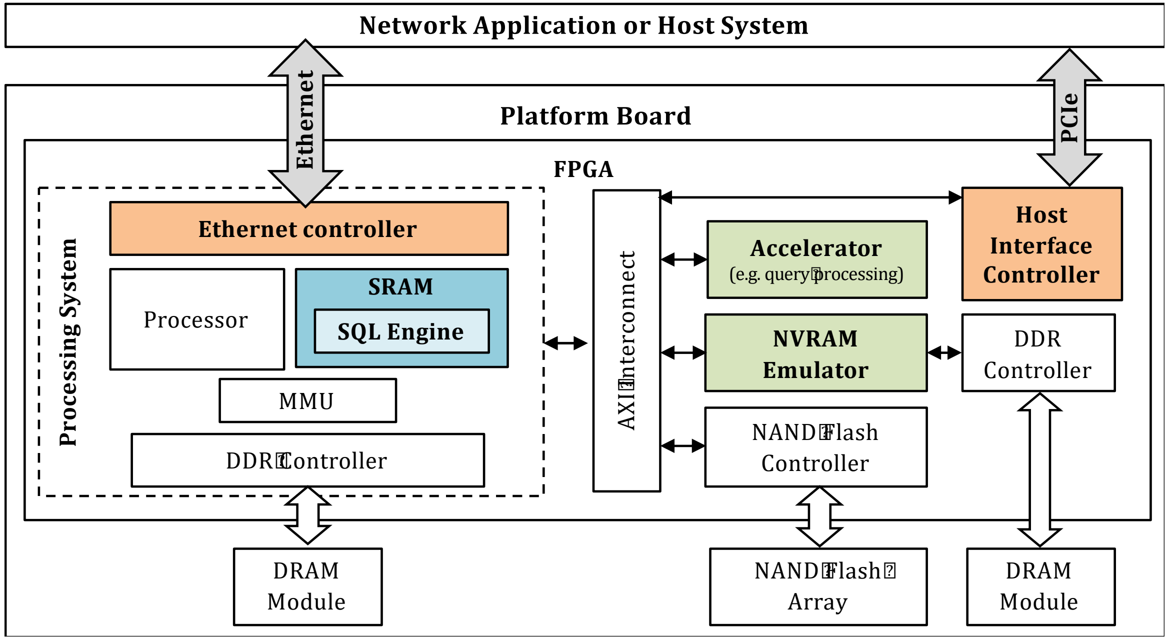


(a) IHDE Architecture

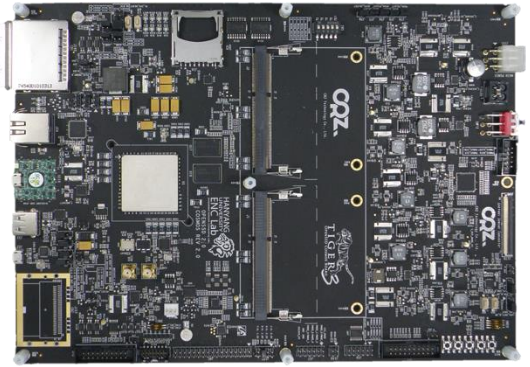
(b) SaS Architecture

SaS: SSD as SQL Database System

- SQL Interface
- Vertical IO Optimization
- Hardware-assisted Acceleration



SaS Architecture

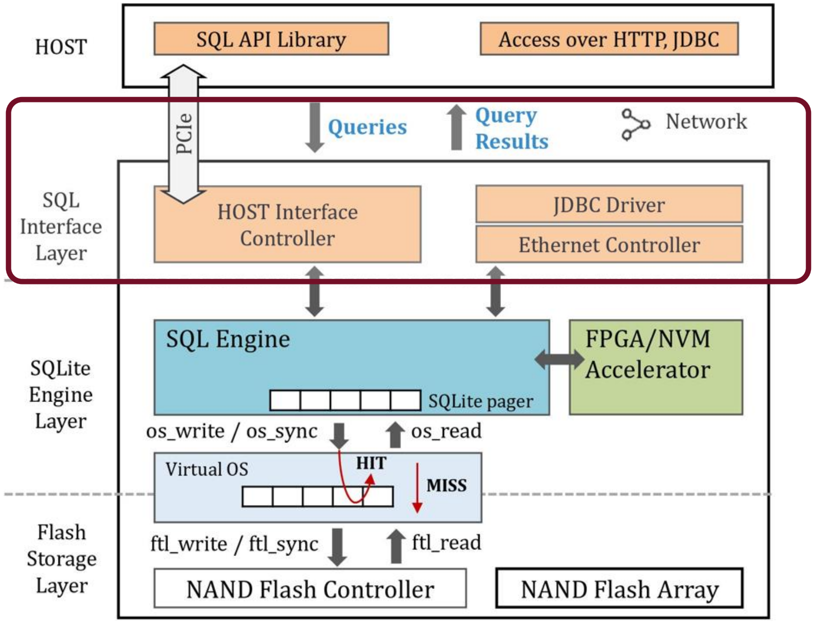


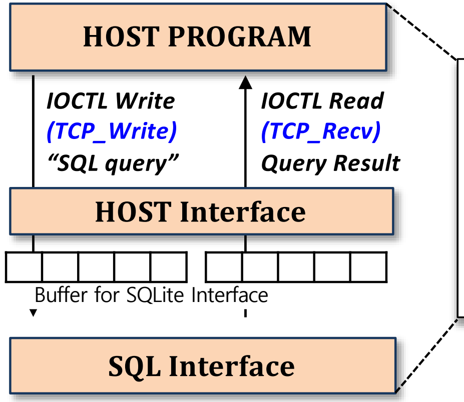
SaS : HW specification	
CPU	Dural ARM Cortex-A9 1 GHz
DRAM	1 GB
SRAM	256 KB

Cosmos+ Open SSD

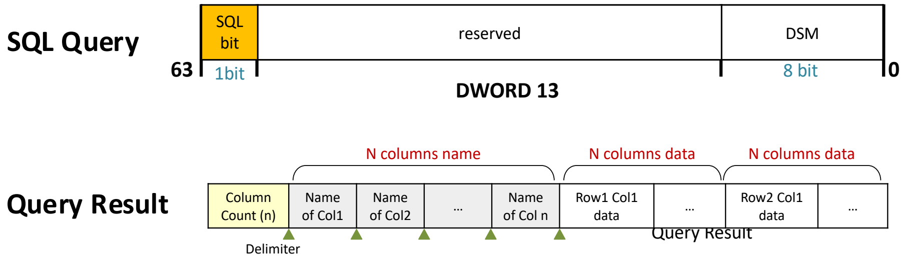
SQL Interface

- Support **tuple-oriented** SQL interface over **block-oriented** interface
- SQL Query IO command (NVMe command)
- Ethernet network Interface (LwIP)



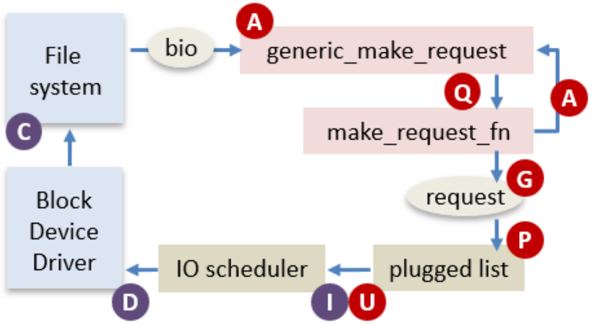


- HOST program issue R/W command with **SQL bit**
- SQL interface extract SQL from HOST Write Buffer
- Support Ethernet Interface via LwIP library

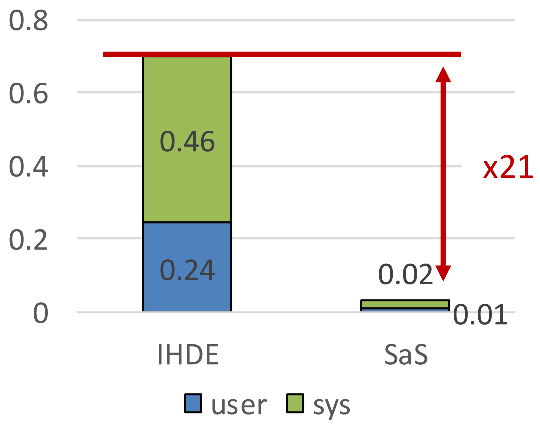


SQL Interface

- Host CPU Time (IHDE vs. SaS)



Block Trace Event Flow



CPU Time (IHDE vs. SaS)

IHDE

```
Event Process Length
--------------------
A                 4K
Q      sqlite3    4K
G      sqlite3    4K
P      sqlite3
A                 4K
Q      sqlite3    4K
G      sqlite3    4K
A                 4K
Q      sqlite3    4K
G      sqlite3    4K
U      sqlite3
D      sqlite3    4K
D      sqlite3    4K
D      sqlite3    4K
C                 4K
C                 4K
C                 4K
Q      sqlite3
G      sqlite3
D
C               flush
```

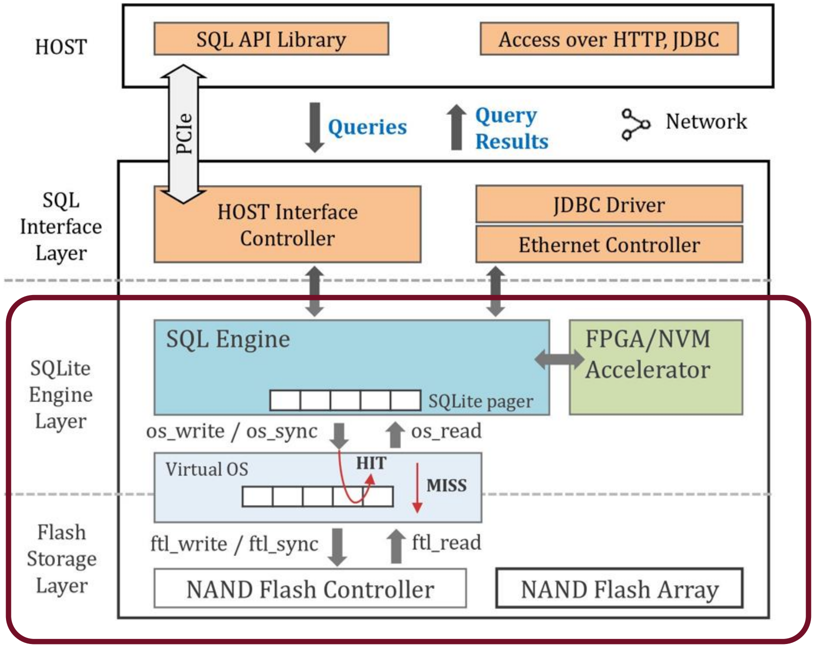
SaS

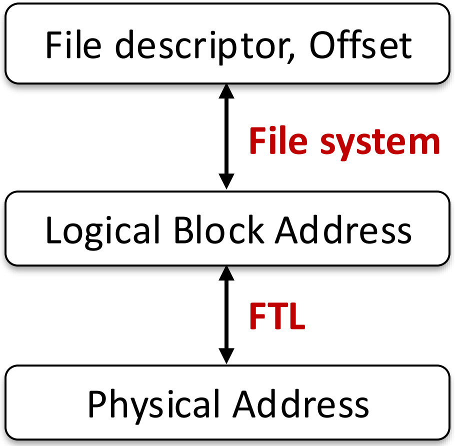
```
Event Process Length
--------------------
I      ioctl     512
D      ioctl     512
C                0
```

Block Trace for single *INSERT* query on IHDE vs. SaS

Vertical Optimizations

- **WITHOUT** operating system
  - Unified space management and transparent address translation





File descriptor, Offset

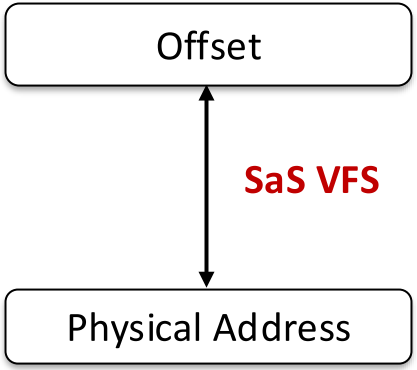
File system

Logical Block Address

FTL

Physical Address

IHDE



Offset

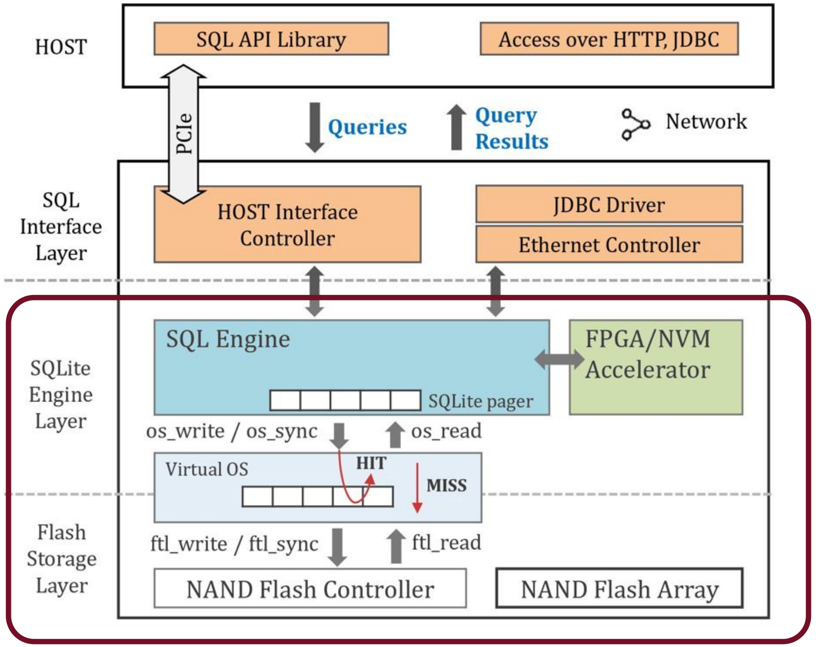
SaS VFS

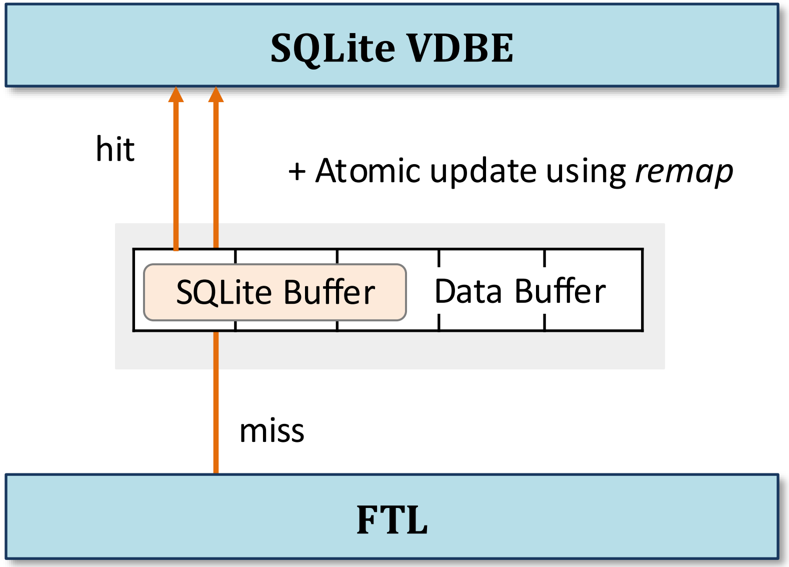
Physical Address

SaS

Vertical Optimizations

- **WITHOUT** operating system
  - Unified space management and transparent address translation
  - Unified memory management

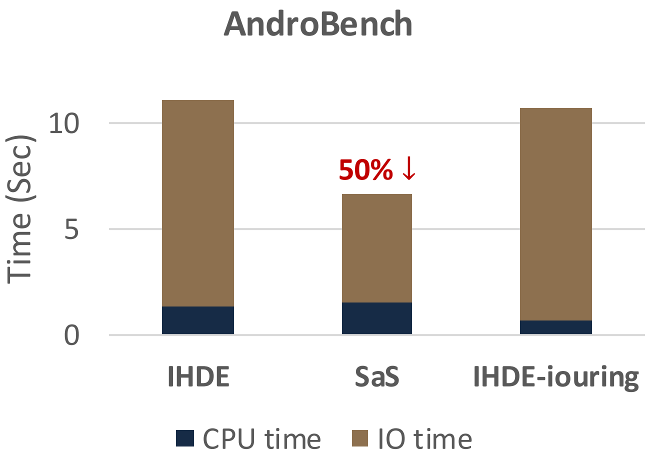


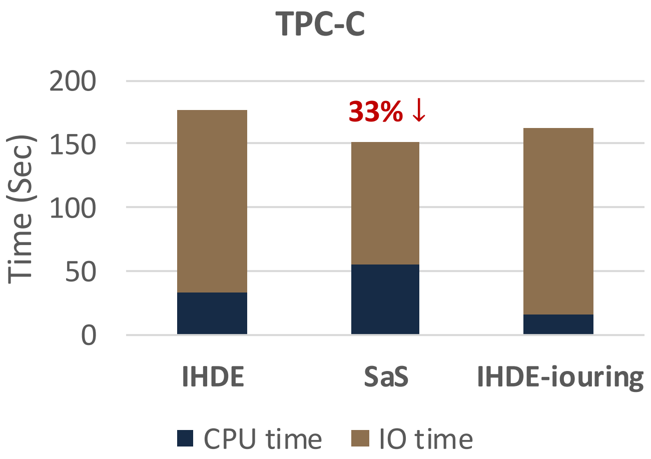


Performance Evaluation

- Source of Performance Gain in SaS
  - Bypass the kernel IO Stack
  - Memory copy reduction

- Challenges
  - Limited computing power (Intel vs. ARM)

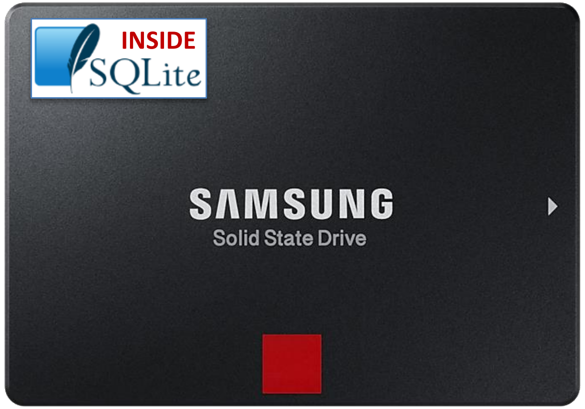




Summary

- New design alternatives
- Seamless vertical optimization
- HW-assisted accelerations

- **Target Applications**
  - Edge computing, IoT, Smart City
  - Serverless solution for small-scale blog DB



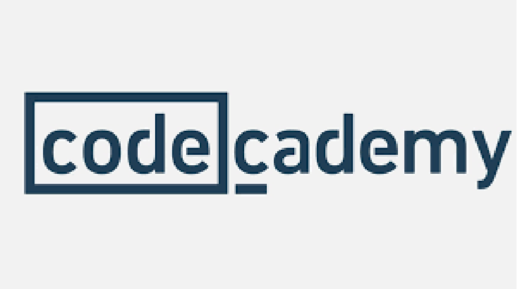
https://vldb.org/pvldb/vol14/p1481-lee.pdf

https://github.com/SSD-as-SQL-Engine/LibSaS

Some Advice …

- **WARNING!**
  - This is purely my personal opinion

Programming is not exclusive to CS people



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수강생 절찬 모집중!
선착순 모집중

Be the irreplacible Tenlent

- Devleoping your own unique skills
  - Programming (default)
  - Communication
  - Abstraction

- How..?

Do what others cannot do

- Normal users can not purchase these products!

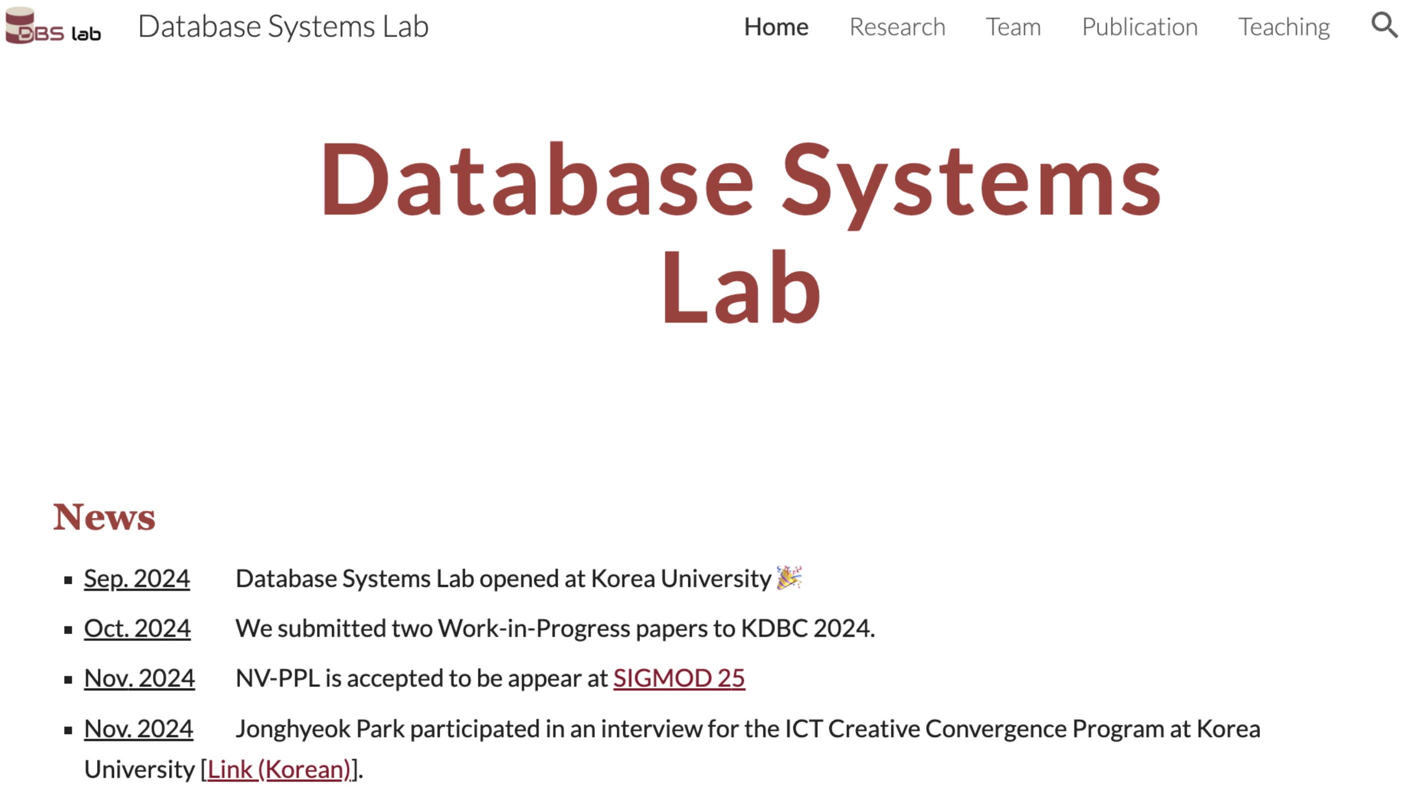
CXL (Compute Express Link)

Zoned Namespace SSD

Flexible Data Placement

DBS Lab.

- Database Systems Lab.



Database Systems Lab

News

- Sep. 2024 Database Systems Lab opened at Korea University 🎉
- Oct. 2024 We submitted two Work-in-Progress papers to KDBC 2024.
- Nov. 2024 NV-PPL is accepted to be appear at SIGMOD 25
- Nov. 2024 Jonghyeok Park participated in an interview for the ICT Creative Convergence Program at Korea University [Link (Korean)].

Research Collaborations

- SFU (NRF-Mitacs Visiting Research Internship)
- TUM
- UW
- Samsung
- SAP HANA
- Oracle

Thank You

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Join the DBS Lab.