

CS460: Intro to Database Systems

# Class 27: Log-Structured-Merge Trees

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<https://bu-disc.github.io/CS460/>

# Useful when?

- Massive dataset
- Rapid updates/insertions
- Fast lookups

⇒ LSM-trees are for you.

# Why now?

Patrick O'Neil  
UMass Boston



Invented in  
1996



1980

1990

2000

2010

Time



levelDB



DynamoDB



cassandra



HBASE

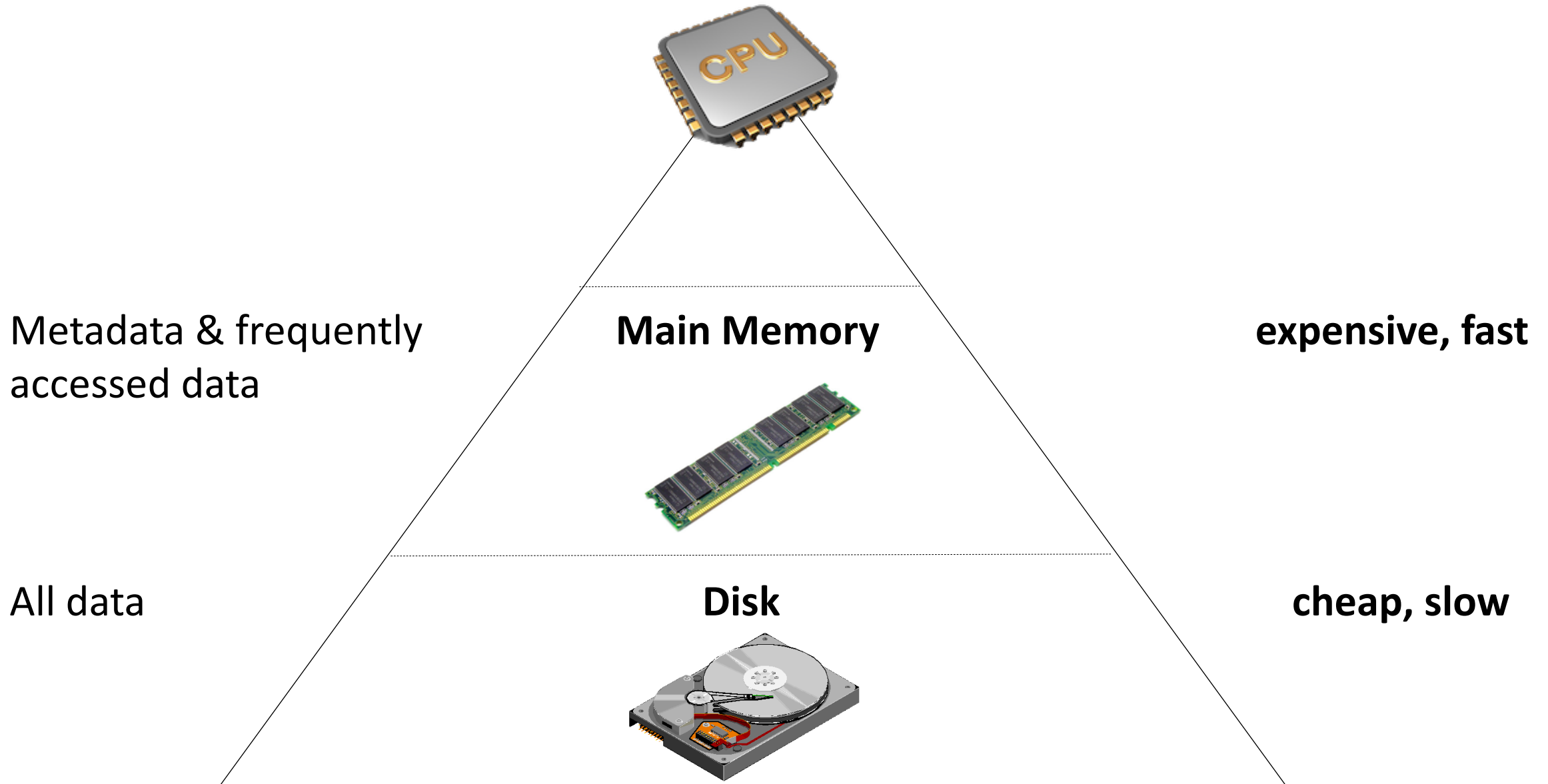


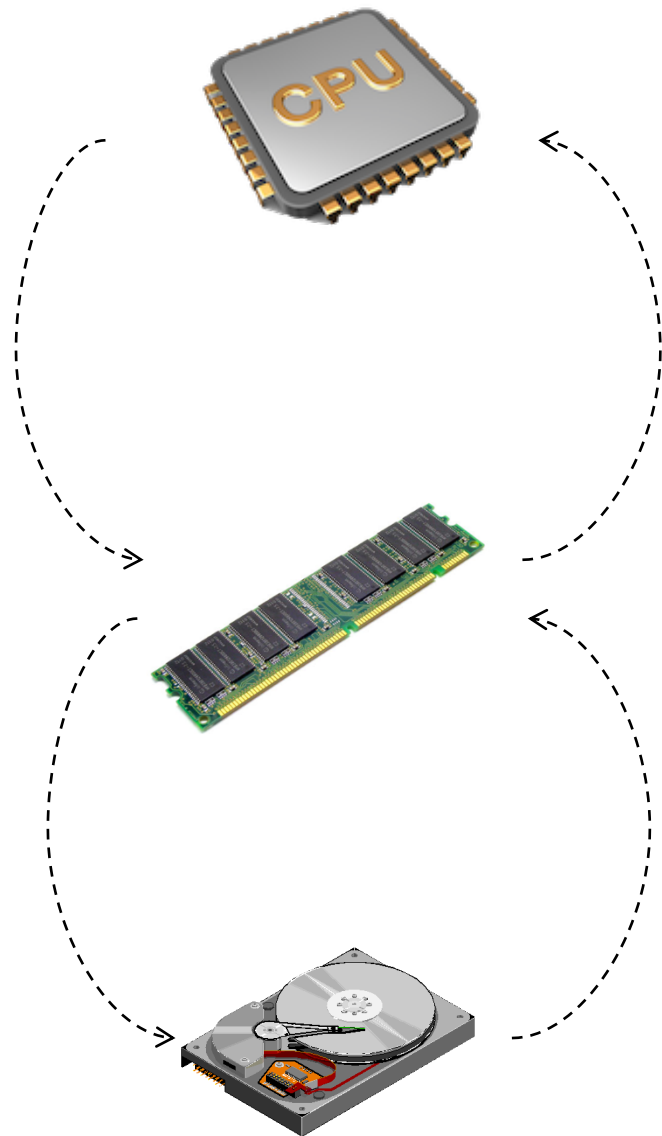
# Outline

1. Storage devices
2. Indexing problem & basic solutions
3. Basic LSM-trees
4. Leveled LSM-trees
5. Tiered LSM-trees
6. Bloom filters

# Storage devices

# The Memory Hierarchy

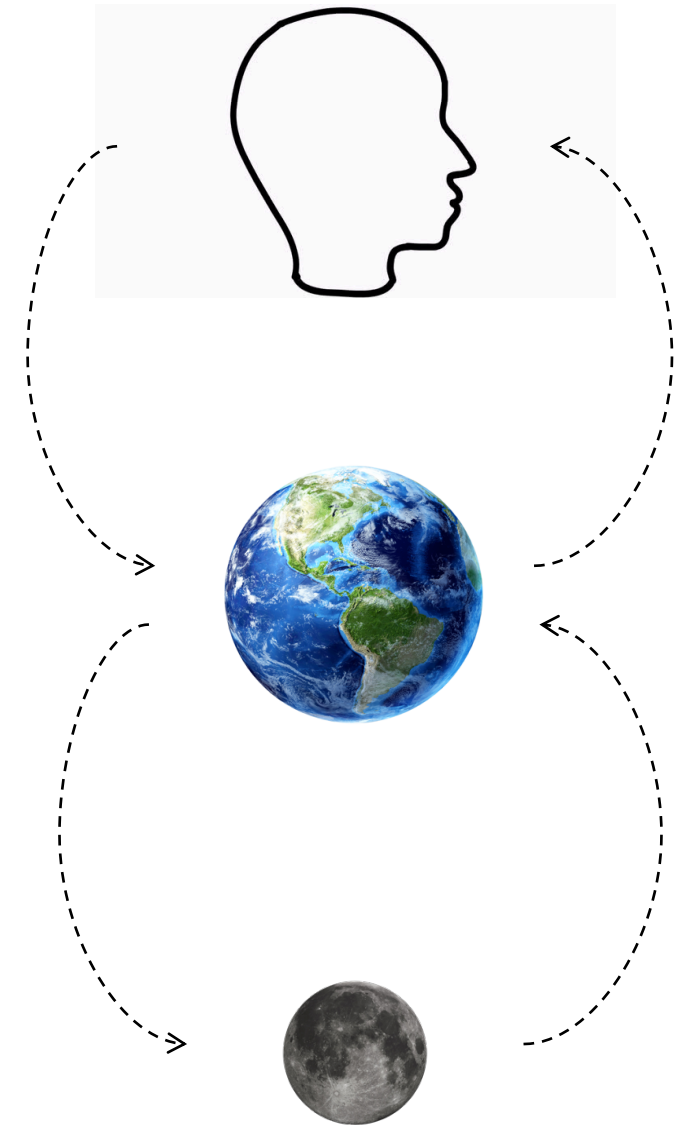




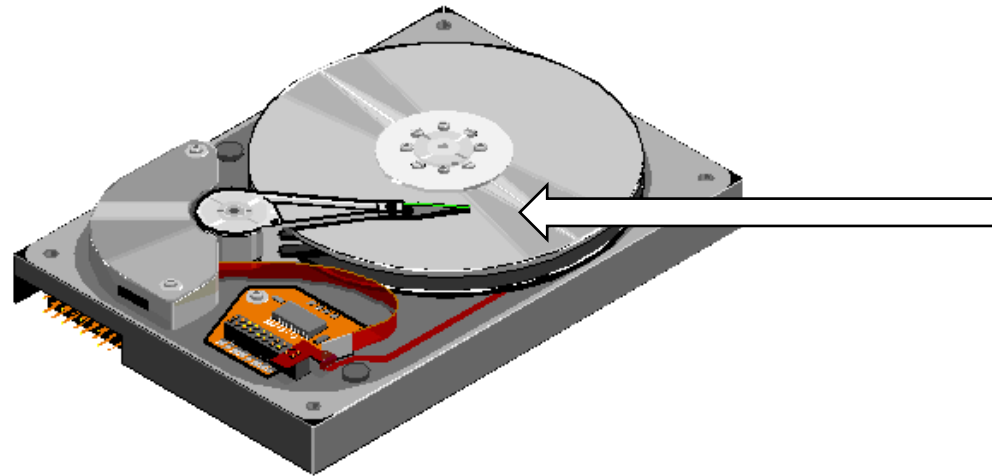
$\approx 100$  ns

$\approx 10$  ms

$\approx 5-6$  order of magnitude difference



# Why is disk slow?



Disk head

Random access is slow



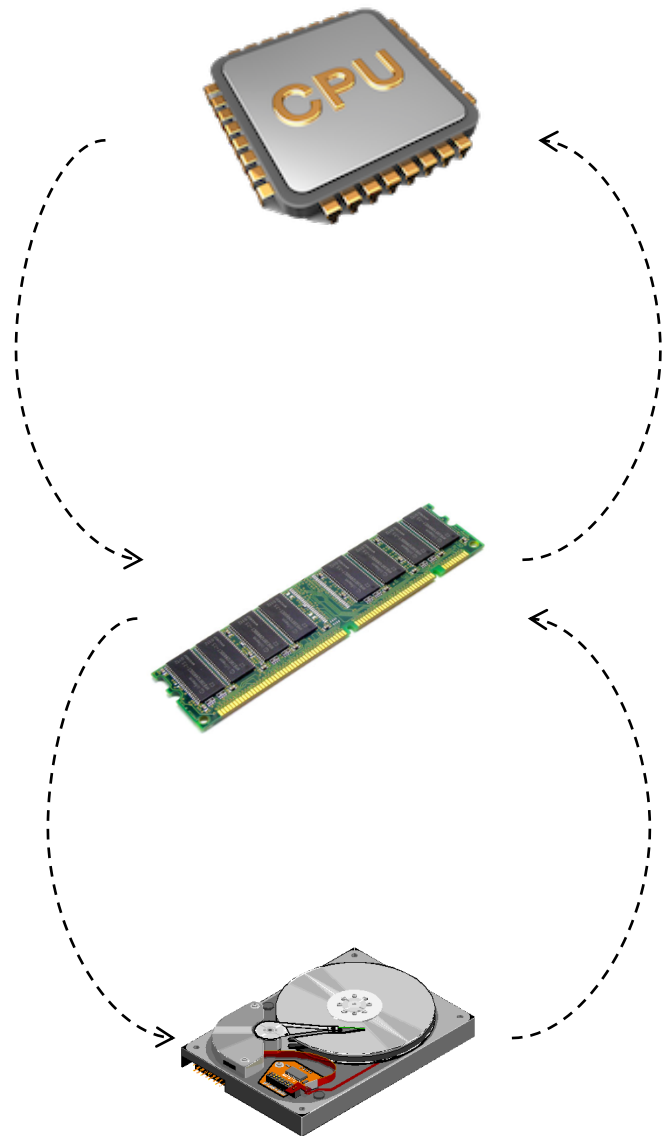
move disk head

Sequential access is faster



let disk spin



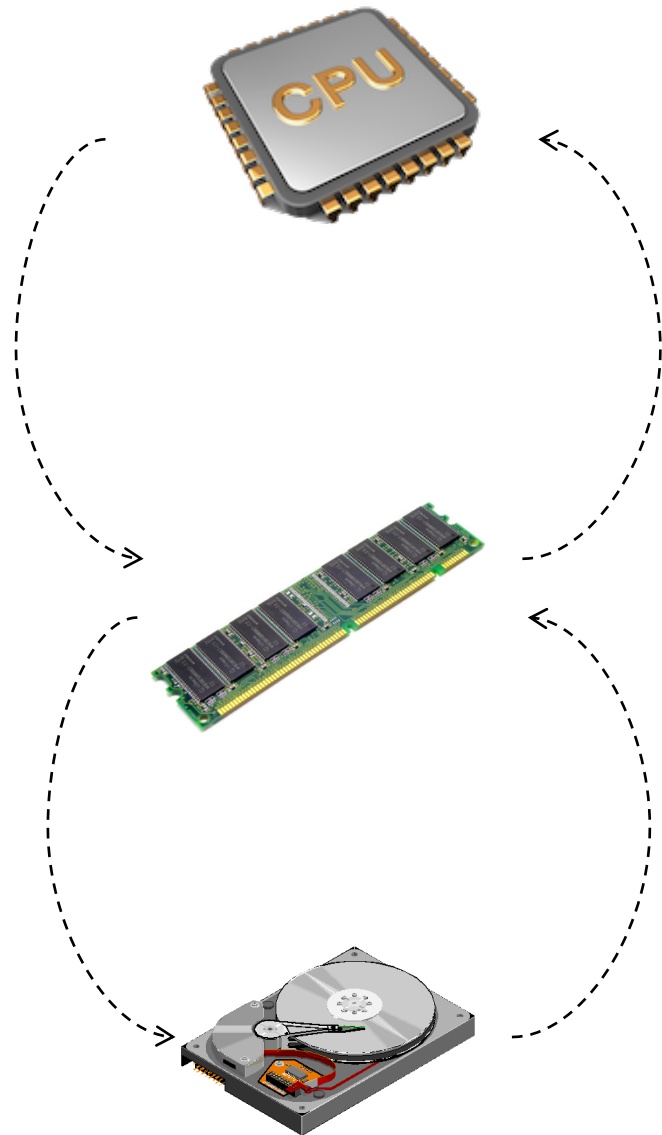


64 byte chunks  
Words

**Fine access granularity**

4 kilobyte chunks  
Blocks

**Coarse access granularity**



64 byte chunks  
Words

**Fine access granularity**

4 kilobyte chunks  
**Blocks**

**Coarse access granularity**

# Outline

- 1. Storage devices**
2. Indexing problem & basic solutions
3. Basic LSM-trees
4. Leveled LSM-trees
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# Outline

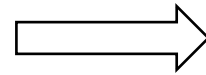
1. Storage devices
2. **Indexing problem & basic solutions**
3. Basic LSM-trees
4. Leveled LSM-trees
5. Tiered LSM-trees
6. Bloom filters

# Indexing Problem & Basic Solutions

# Indexing Problem



names

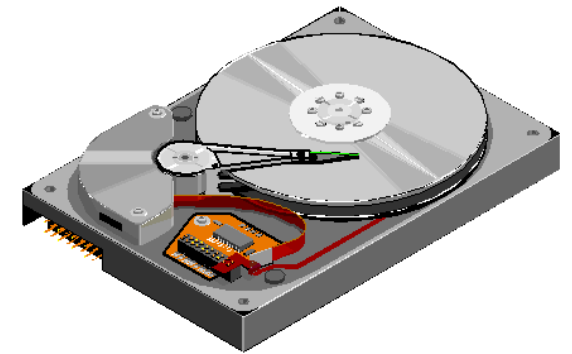


phone numbers

Structure on disk?

Lookup cost?

Insertion cost?



# Results Catalogue

Compare and contrast data structures.

What to use when?

| Data Structure      | Lookup cost | Insertion cost |
|---------------------|-------------|----------------|
| <b>Sorted array</b> |             |                |
| Log                 |             |                |
| B-tree              |             |                |
| Basic LSM-tree      |             |                |
| Leveled LSM-tree    |             |                |
| Tiered LSM-tree     |             |                |

# Results Catalogue

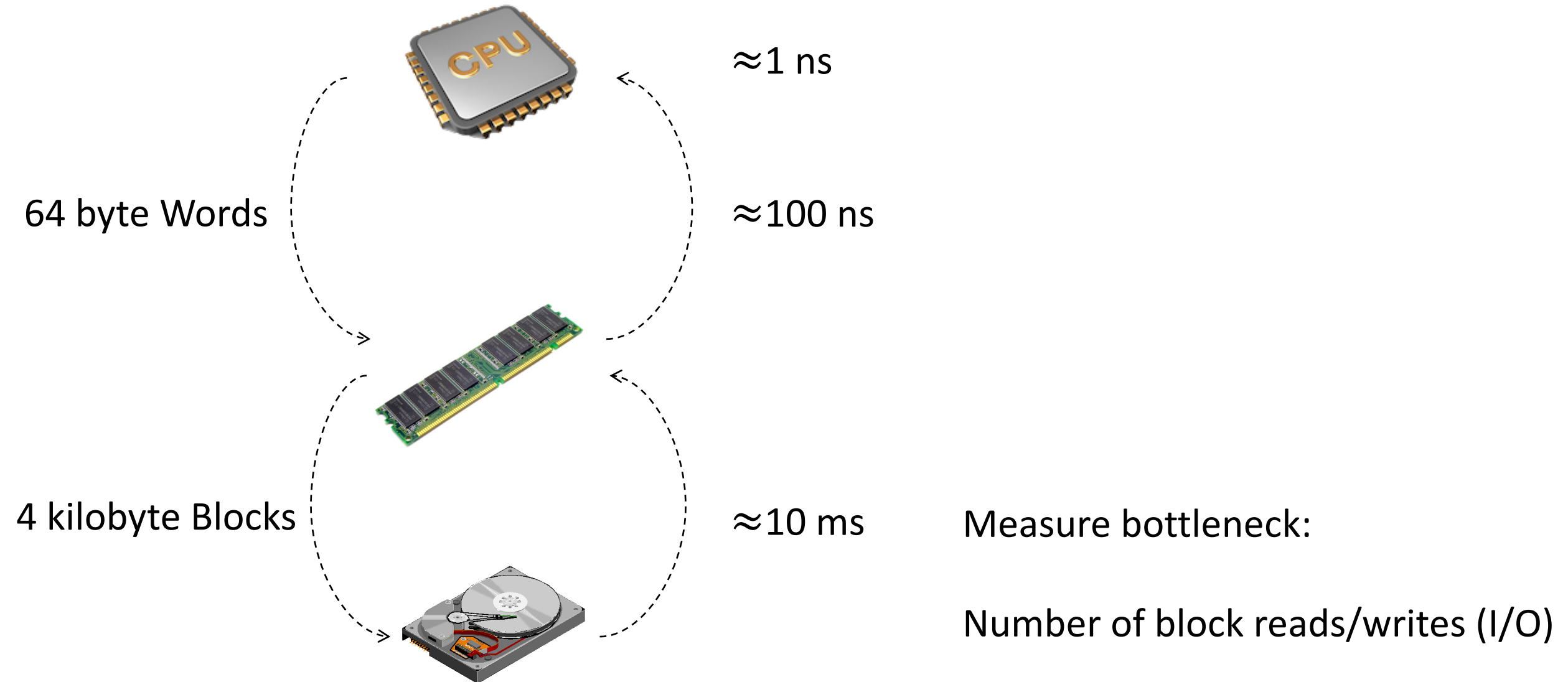
Compare and contrast data structures.

What to use when?

| Data Structure   | Lookup cost | Insertion cost |
|------------------|-------------|----------------|
| Sorted array     |             |                |
| Log              |             |                |
| B-tree           |             |                |
| Basic LSM-tree   |             |                |
| Leveled LSM-tree |             |                |
| Tiered LSM-tree  |             |                |



# Modeling Performance

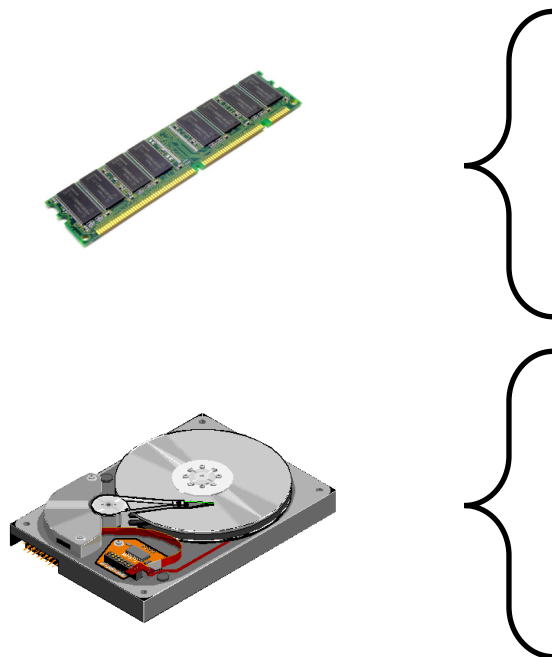


# Sorted Array

**N** entries

**B** entries fit into a disk block

Array spans **N/B** disk blocks



| Buffer |
|--------|
| James  |
| Sara   |
|        |

| Array size | Pointer |
|------------|---------|
|------------|---------|



| Block 1 | Block 2 | ... | Block N/B |
|---------|---------|-----|-----------|
| Anne    | Bob     |     | Yulia     |
| Arnold  | Corrie  |     | Zack      |
| Barbara | Doug    |     | Zelda     |

Lookup method & cost?

Binary search:  $O\left(\log_2\left(\frac{N}{B}\right)\right)$  I/Os

Insertion cost?

Push entries:  $O\left(\frac{1}{B} \cdot \frac{N}{B}\right)$  I/Os

# Results Catalogue

|                     | Lookup cost      | Insertion cost |
|---------------------|------------------|----------------|
| <b>Sorted array</b> | $O(\log_2(N/B))$ | $O(N/B^2)$     |
| Log                 |                  |                |
| B-tree              |                  |                |
| Basic LSM-tree      |                  |                |
| Leveled LSM-tree    |                  |                |
| Tiered LSM-tree     |                  |                |

# Results Catalogue

|                  | Lookup cost      | Insertion cost |
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| Sorted array     | $O(\log_2(N/B))$ | $O(N/B^2)$     |
| <b>Log</b>       |                  |                |
| B-tree           |                  |                |
| Basic LSM-tree   |                  |                |
| Leveled LSM-tree |                  |                |
| Tiered LSM-tree  |                  |                |

# Log (append-only array)

**N** entries

**B** entries fit into a disk block

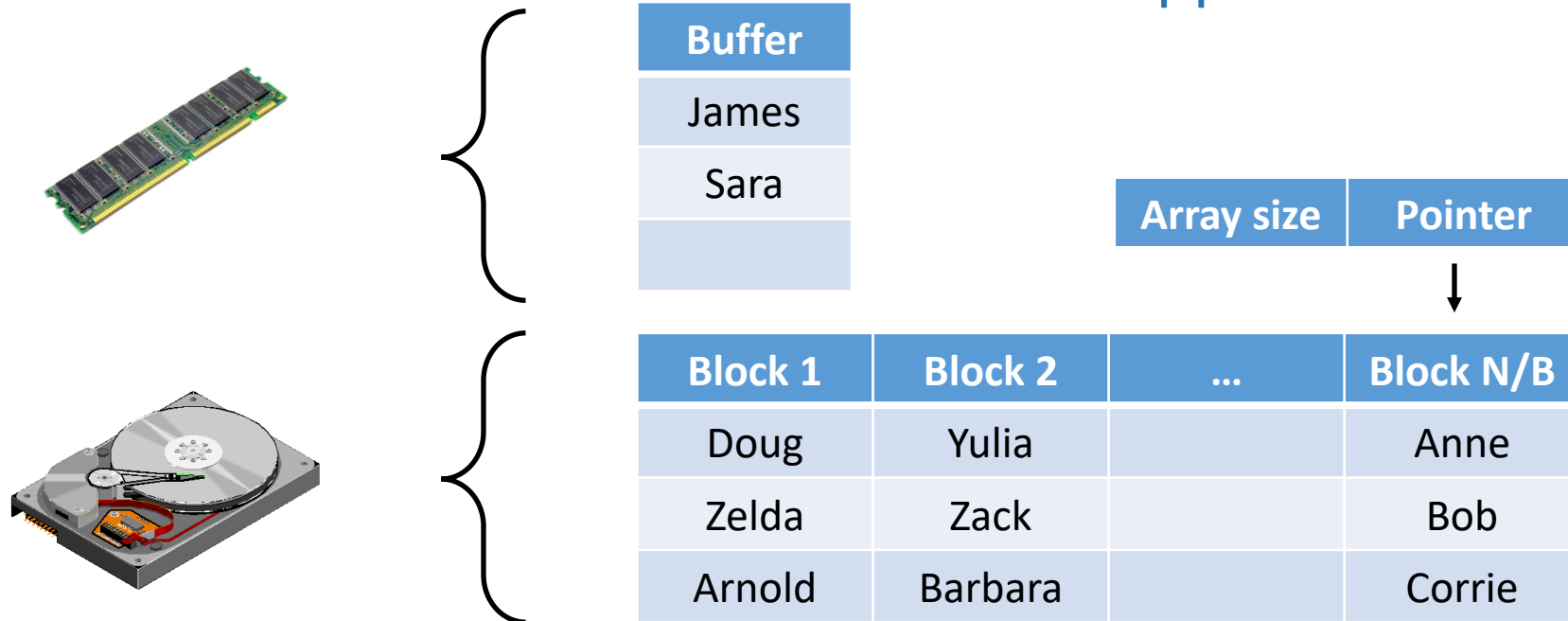
Array spans **N/B** disk blocks

Lookup method & cost?

Scan:  $O\left(\frac{N}{B}\right)$

Insertion cost?

Append:  $O\left(\frac{1}{B}\right)$



# Results Catalogue

|                  | Lookup cost      | Insertion cost |
|------------------|------------------|----------------|
| Sorted array     | $O(\log_2(N/B))$ | $O(N/B^2)$     |
| <b>Log</b>       | $O(N/B)$         | $O(1/B)$       |
| B-tree           |                  |                |
| Basic LSM-tree   |                  |                |
| Leveled LSM-tree |                  |                |
| Tiered LSM-tree  |                  |                |

# Results Catalogue

|                  | Lookup cost      | Insertion cost |
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| Sorted array     | $O(\log_2(N/B))$ | $O(N/B^2)$     |
| Log              | $O(N/B)$         | $O(1/B)$       |
| <b>B-tree</b>    |                  |                |
| Basic LSM-tree   |                  |                |
| Leveled LSM-tree |                  |                |
| Tiered LSM-tree  |                  |                |

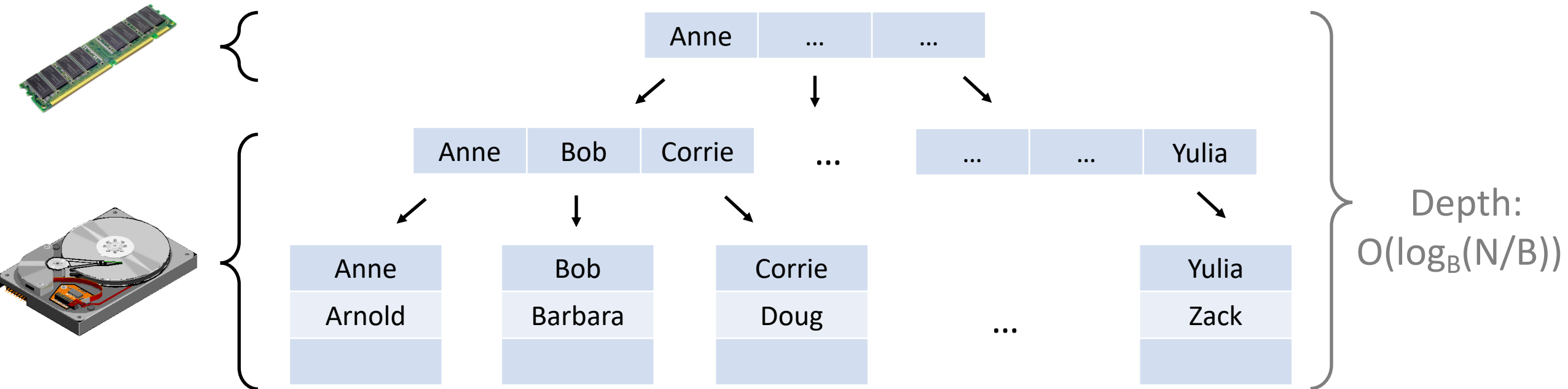
# B-tree

Lookup method & cost?

Tree search:  $O\left(\log_B\left(\frac{N}{B}\right)\right)$

Insertion method & cost?

Tree search & append:  $O\left(\log_B\left(\frac{N}{B}\right)\right)$





# Results Catalogue

|                  | Lookup cost      | Insertion cost   |
|------------------|------------------|------------------|
| Sorted array     | $O(\log_2(N/B))$ | $O(N/B^2)$       |
| Log              | $O(N/B)$         | $O(1/B)$         |
| <b>B-tree</b>    | $O(\log_B(N/B))$ | $O(\log_B(N/B))$ |
| Basic LSM-tree   |                  |                  |
| Leveled LSM-tree |                  |                  |
| Tiered LSM-tree  |                  |                  |

# B-trees



“It could be said that the world’s information is at our fingertips because of B-trees”

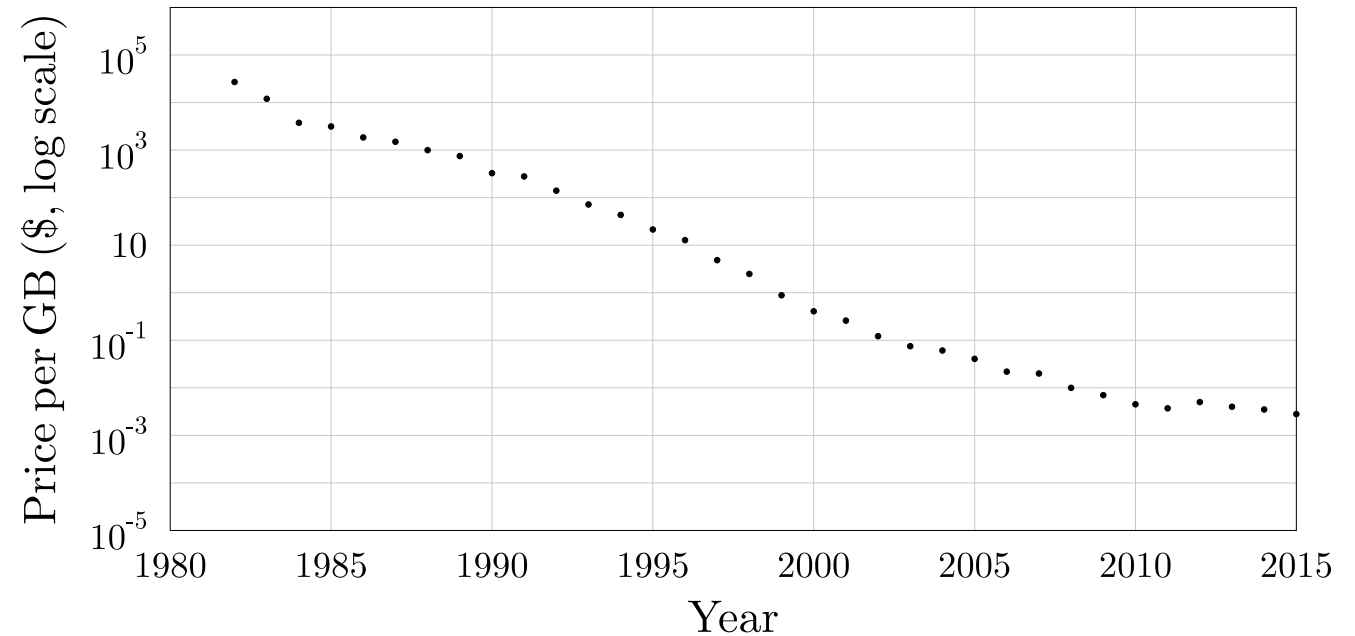
Goetz Graefe Microsoft, HP Fellow, now  
Google ACM Software System Award

# B-trees are no longer sufficient

Cheaper to store data

Workloads more insert-intensive

We need better insert-performance.



# Results Catalogue

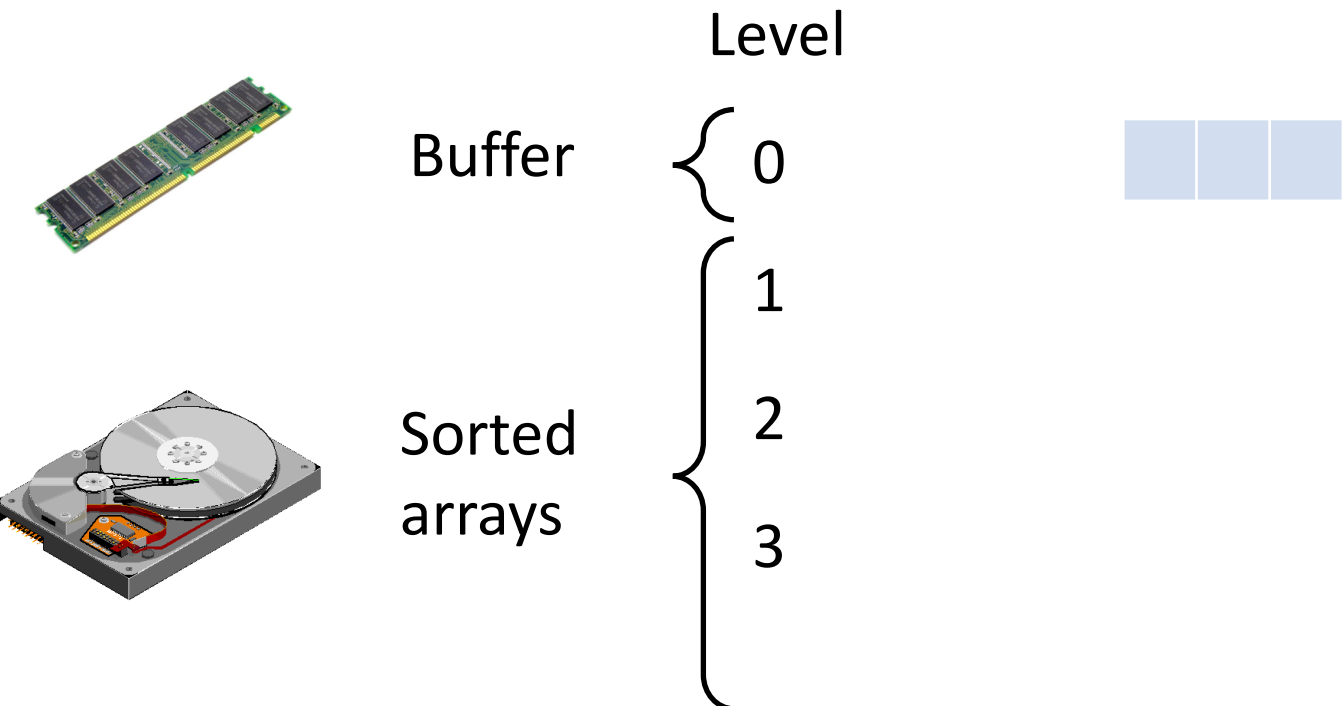
Goal to combine

sub-constant insertion cost  
logarithmic lookup cost

|                     | Lookup cost                        | Insertion cost             |
|---------------------|------------------------------------|----------------------------|
| <b>Sorted array</b> | $O(\log_2(N/B))$                   | $O(N/B^2)$                 |
| <b>Log</b>          | $O(N/B)$                           | <b><math>O(1/B)</math></b> |
| <b>B-tree</b>       | <b><math>O(\log_B(N/B))</math></b> | $O(\log_B(N/B))$           |
| Basic LSM-tree      |                                    |                            |
| Leveled LSM-tree    |                                    |                            |
| Tiered LSM-tree     |                                    |                            |

# Basic LSM-trees

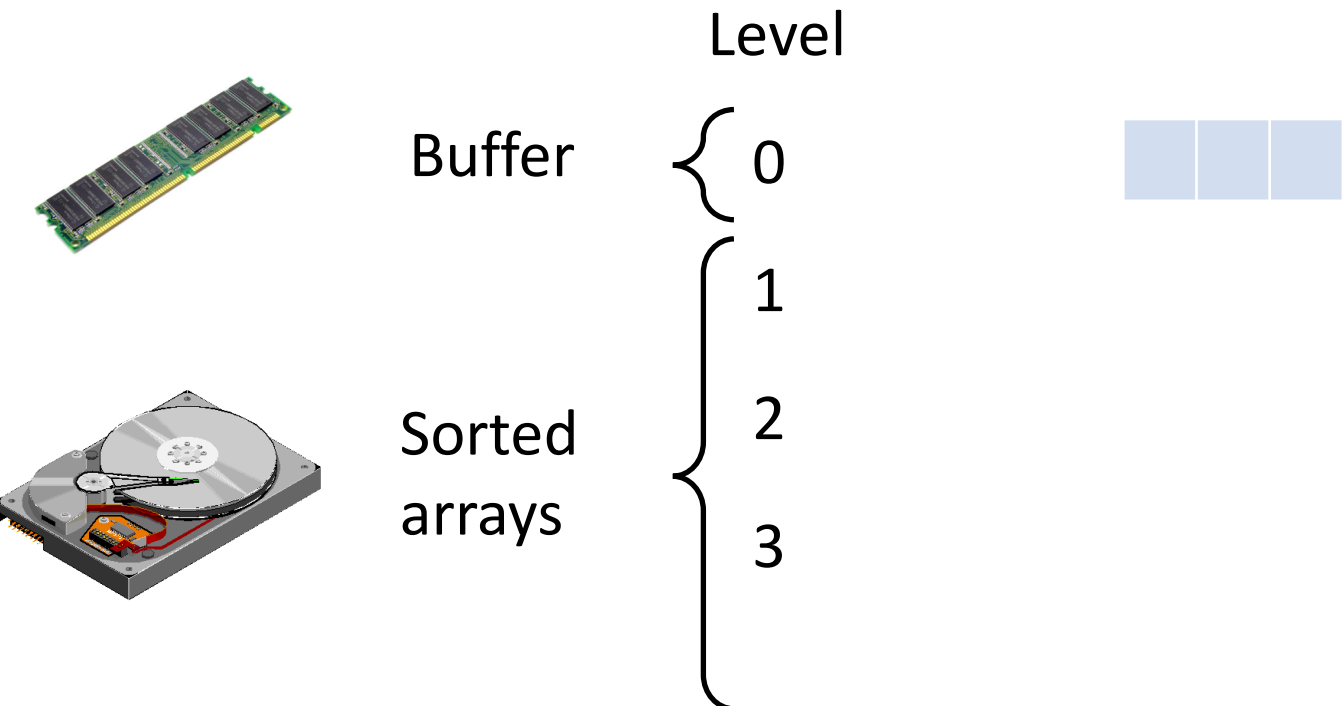
# Basic LSM-tree



# Basic LSM-tree

*Design principle #1:*

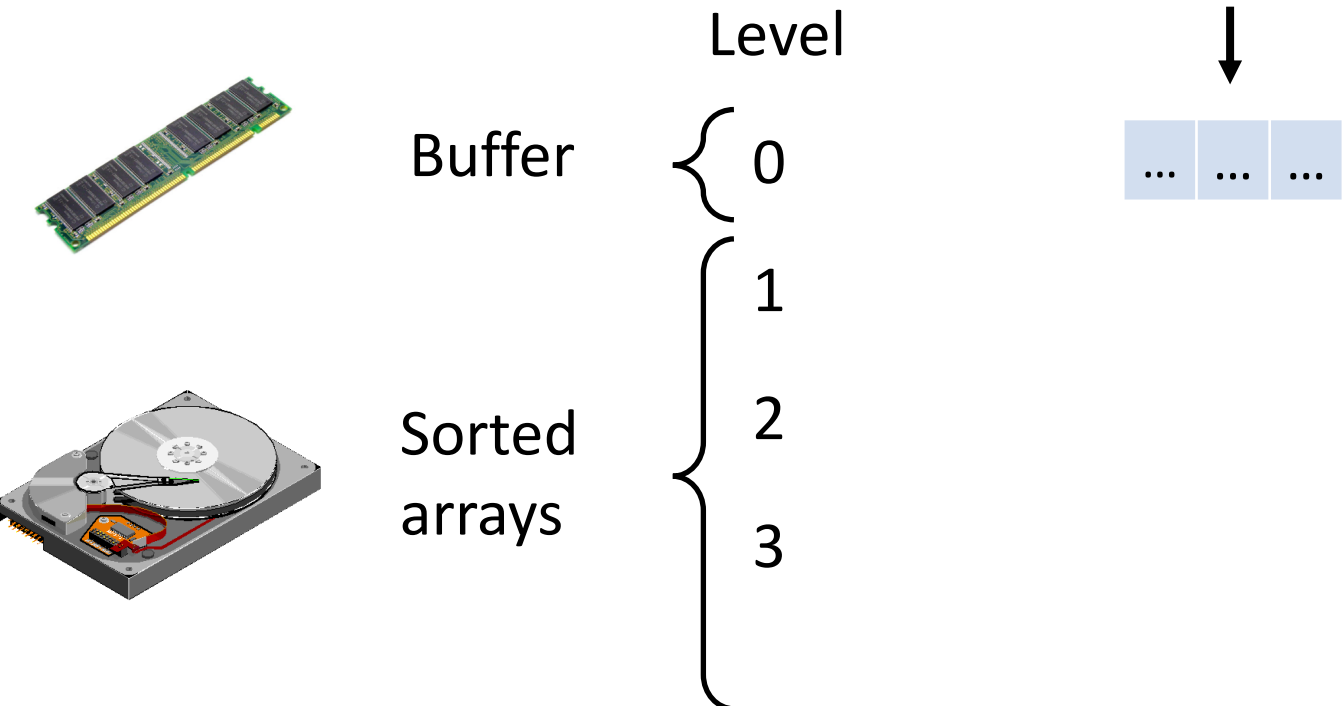
optimize for insertions by buffering



# Basic LSM-tree

*Design principle #1:*

optimize for insertions by buffering

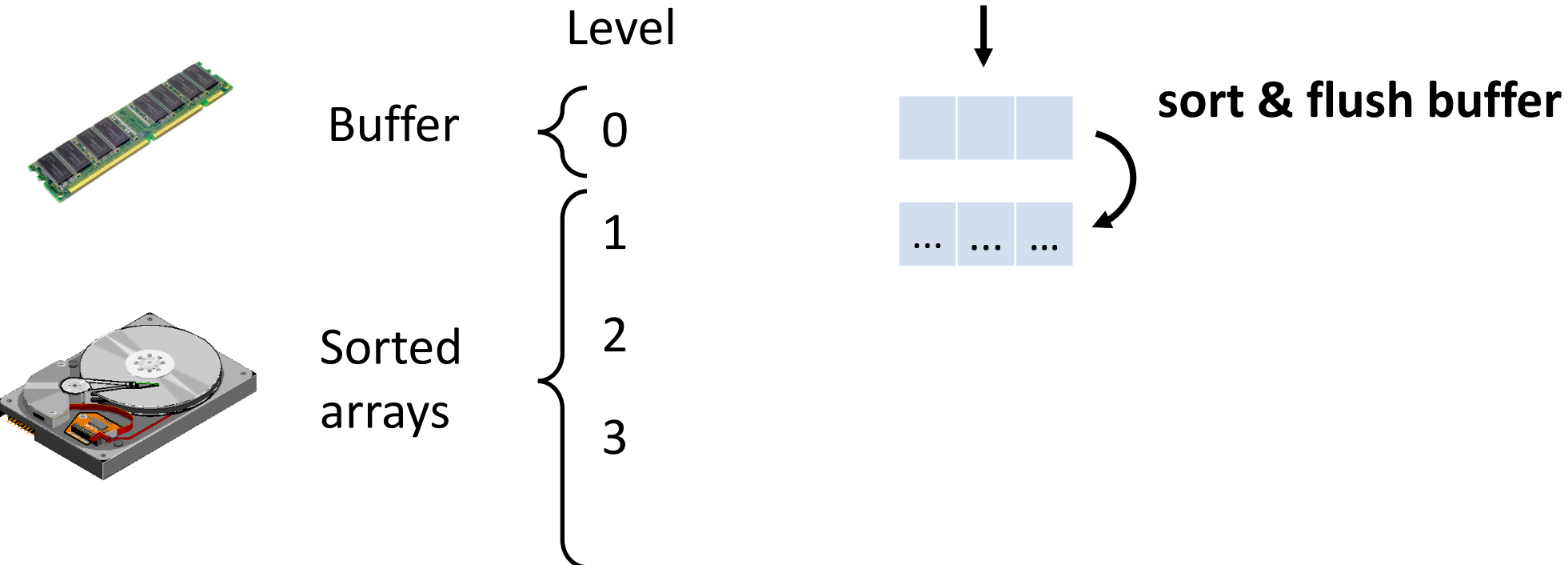




# Basic LSM-tree

*Design principle #1:*

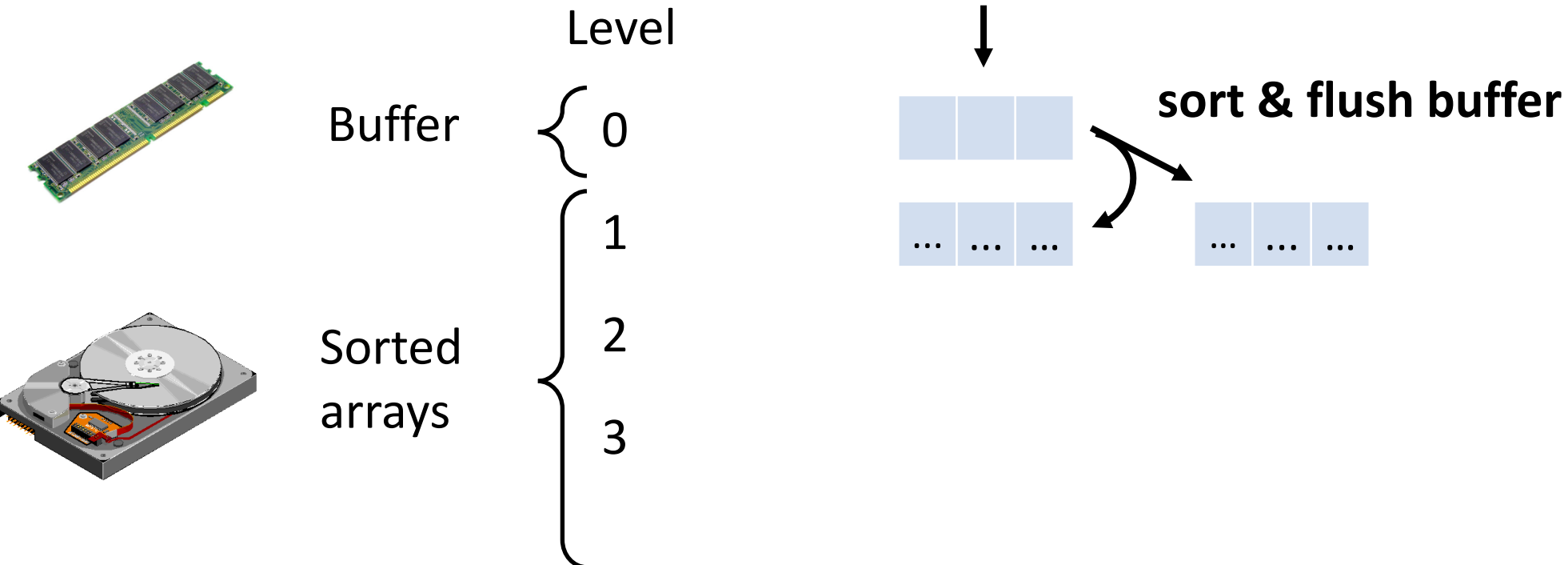
optimize for insertions by buffering



# Basic LSM-tree

*Design principle #1:*

optimize for insertions by buffering



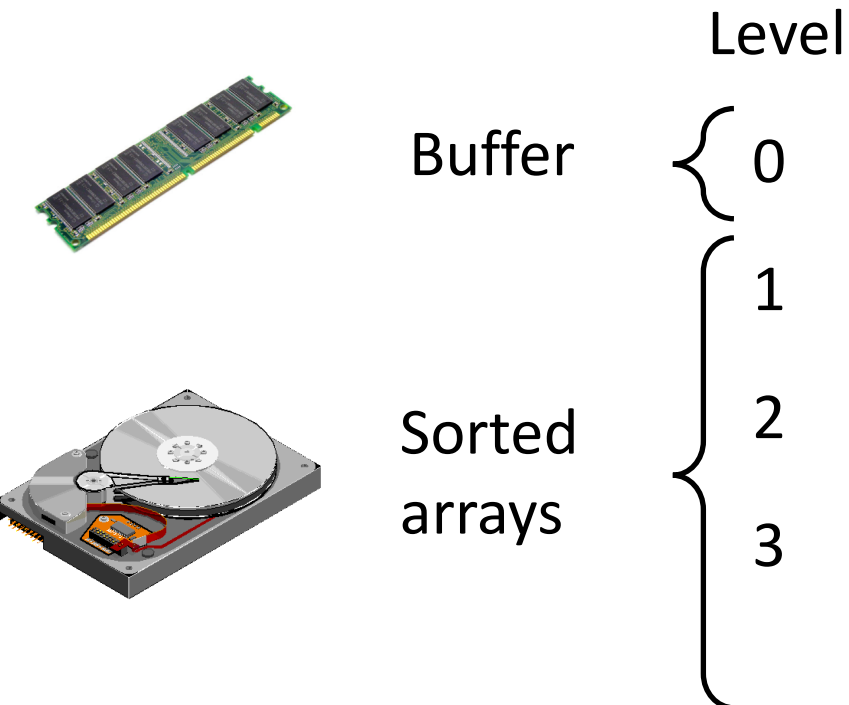
# Basic LSM-tree

*Design principle #1:*

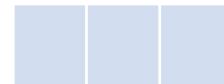
optimize for insertions by buffering

*Design principle #2:*

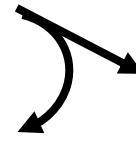
optimize for lookups by sort-merging arrays



**Inserts**



**sort & flush buffer**



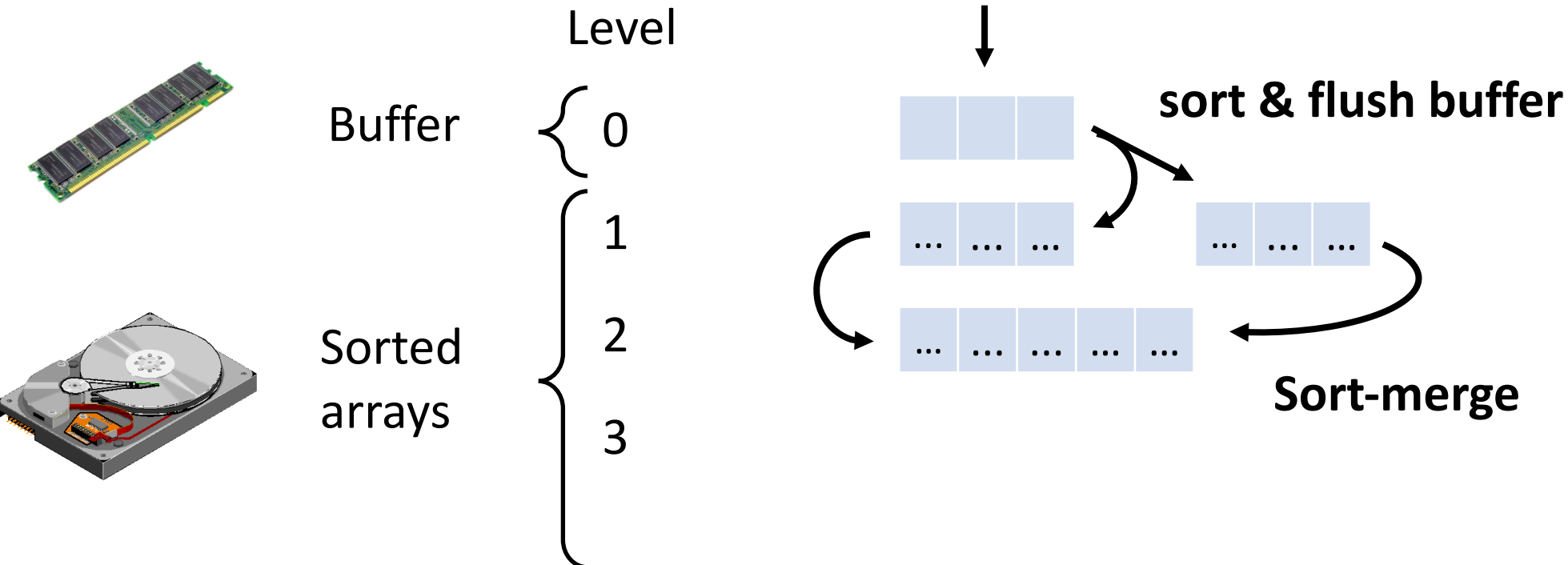
# Basic LSM-tree

*Design principle #1:*

optimize for insertions by buffering

*Design principle #2:*

optimize for lookups by sort-merging arrays



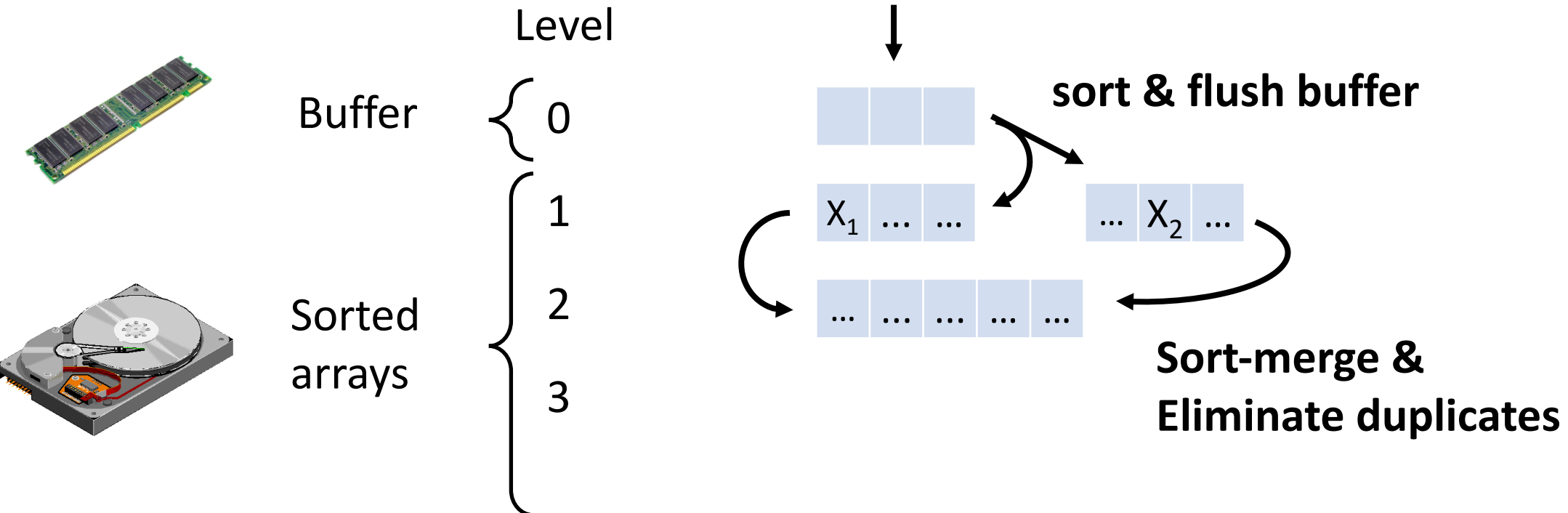
# Basic LSM-tree

*Design principle #1:*

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*Design principle #2:*

optimize for lookups by sort-merging arrays



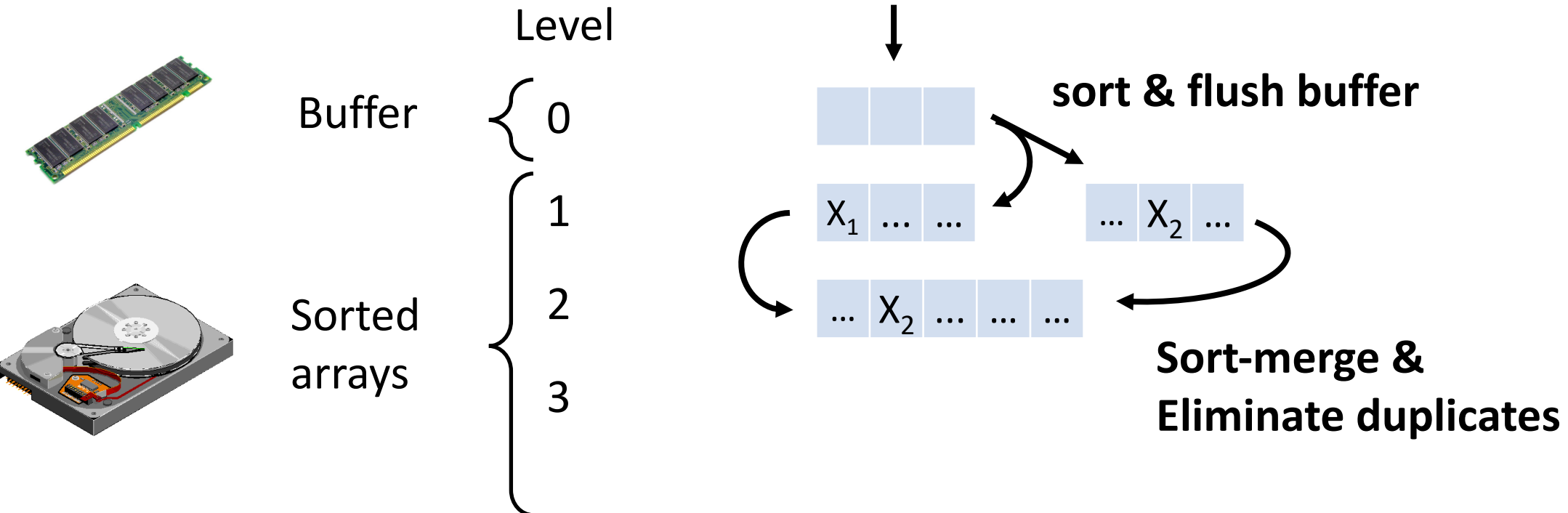
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*Design principle #1:*

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*Design principle #2:*

optimize for lookups by sort-merging arrays



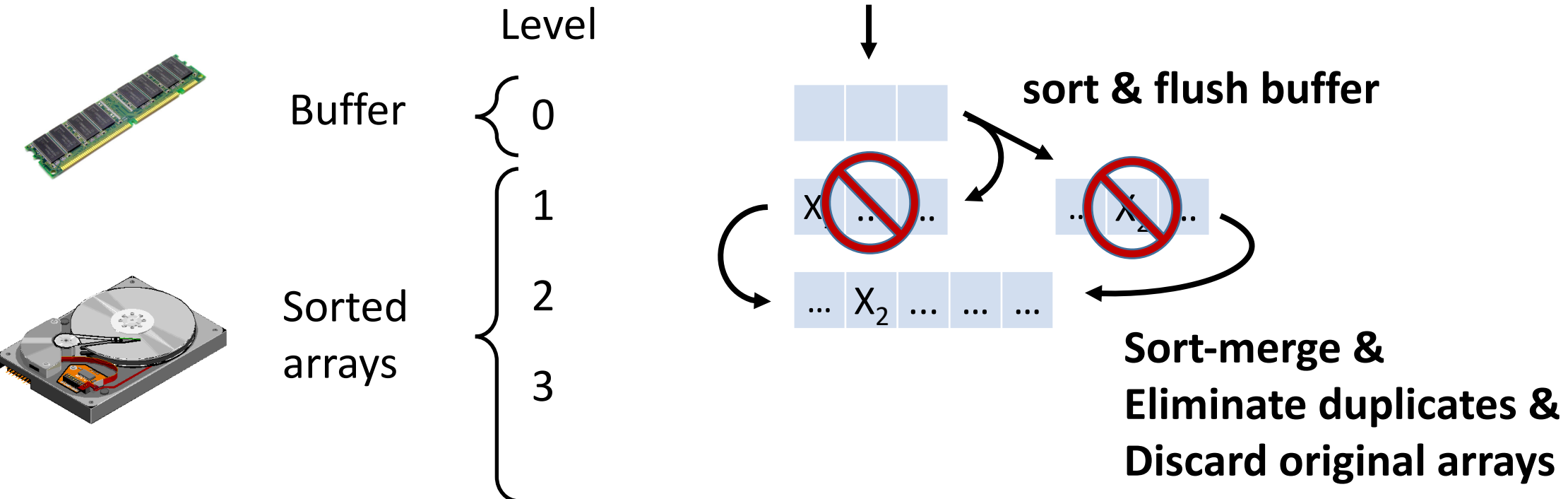
# Basic LSM-tree

*Design principle #1:*

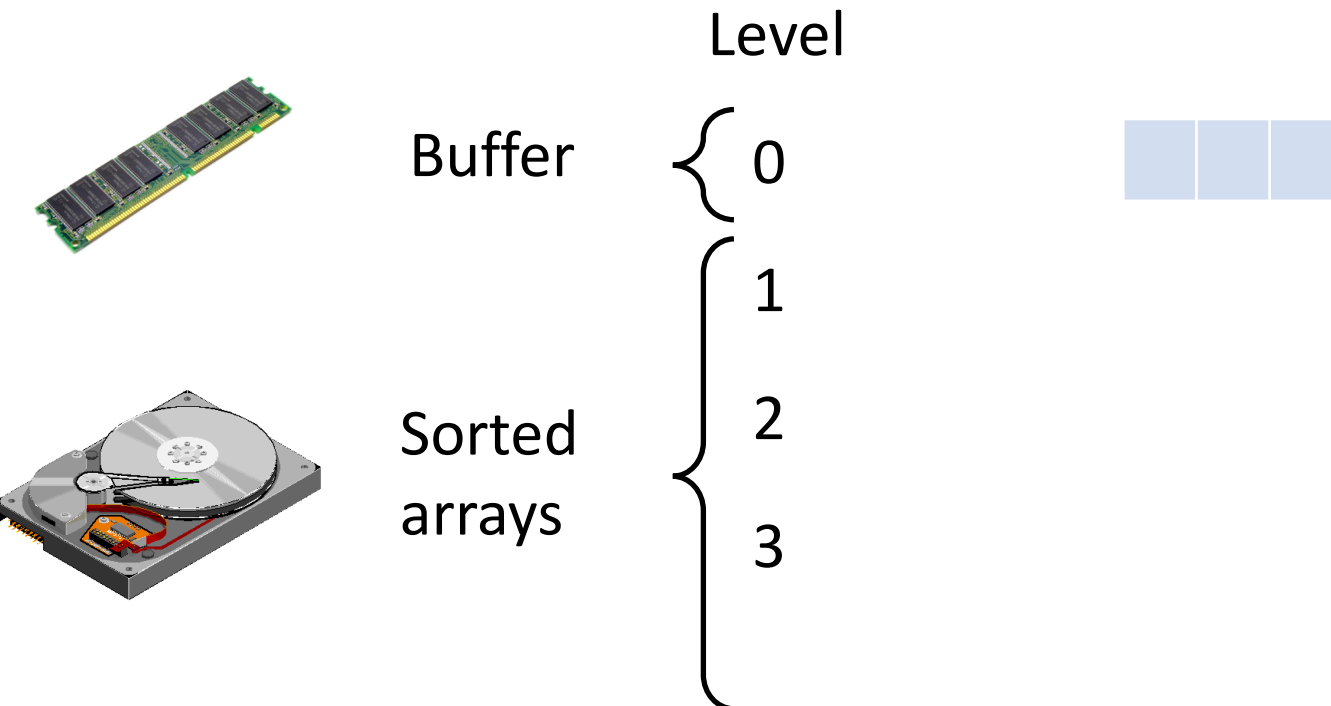
optimize for insertions by buffering

*Design principle #2:*

optimize for lookups by sort-merging arrays

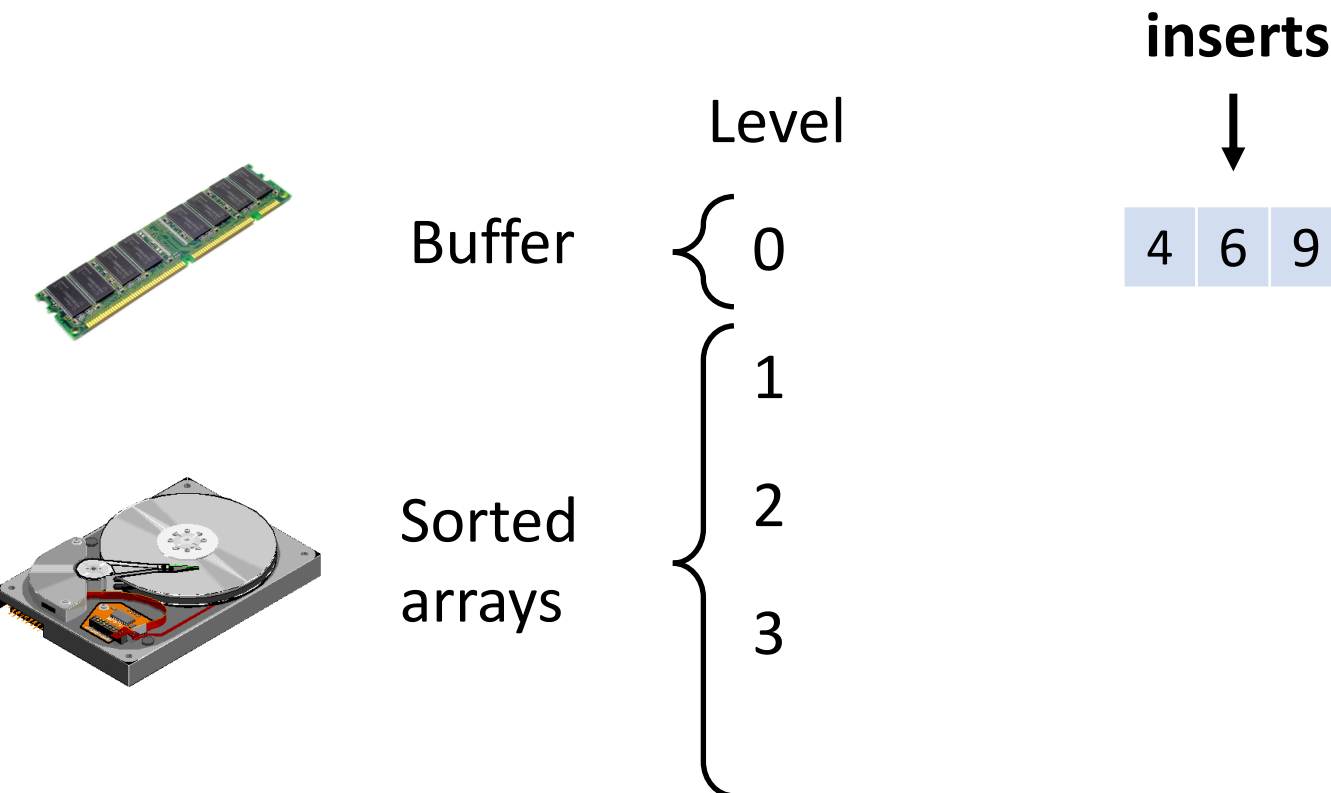


# Basic LSM-tree – Example

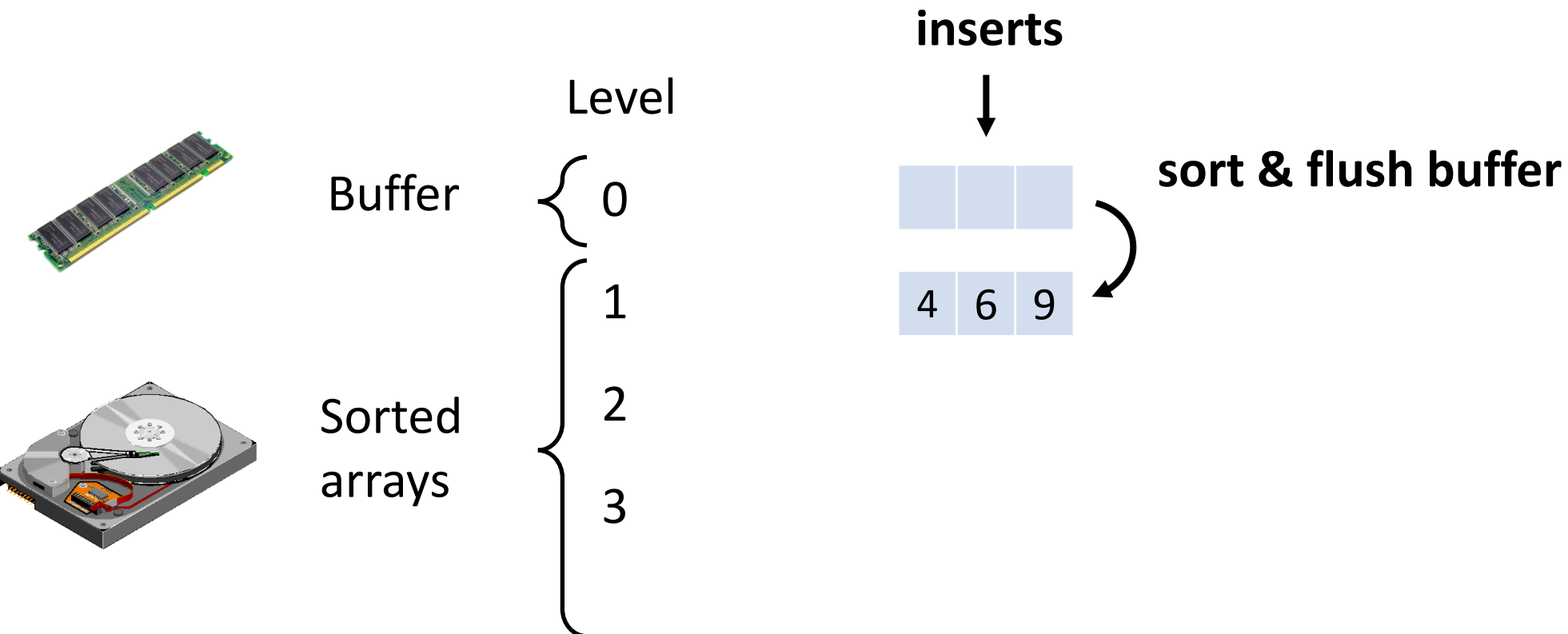




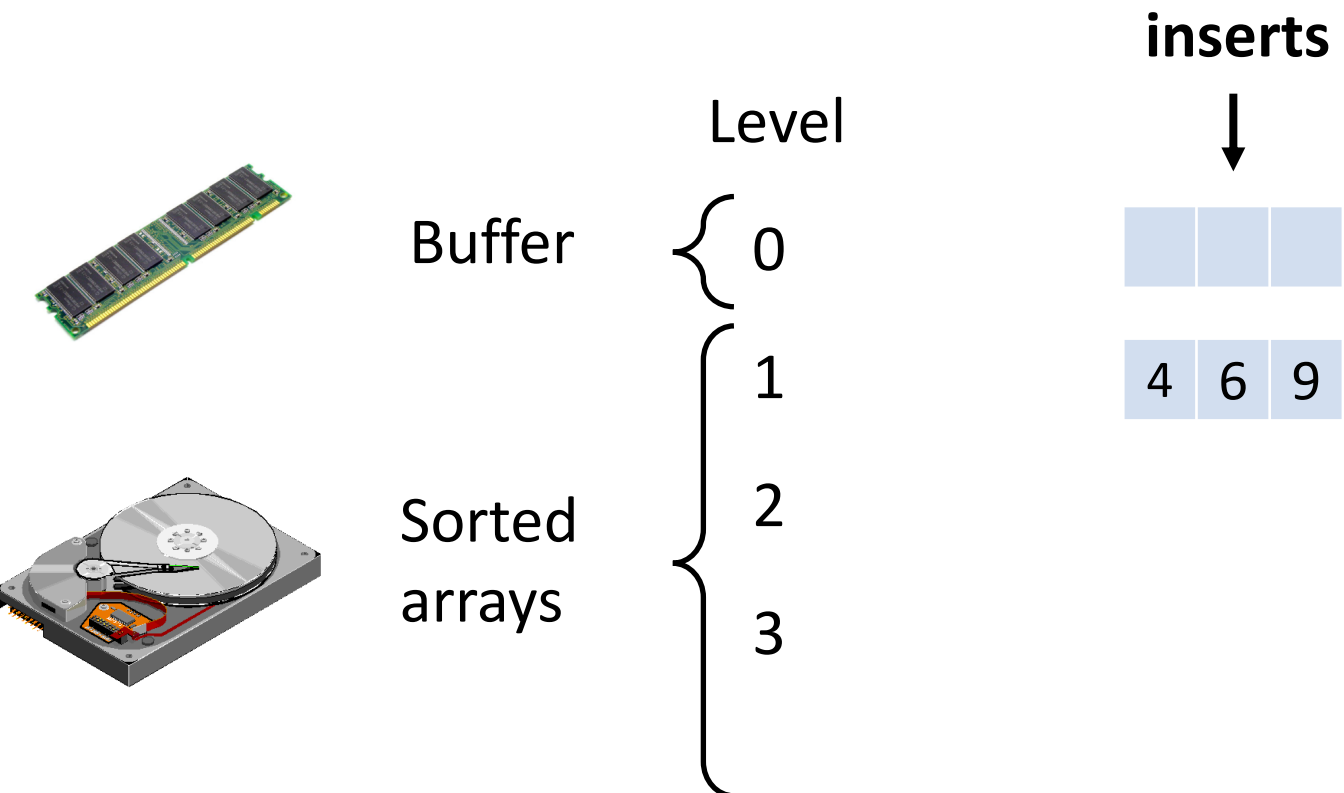
# Basic LSM-tree – Example



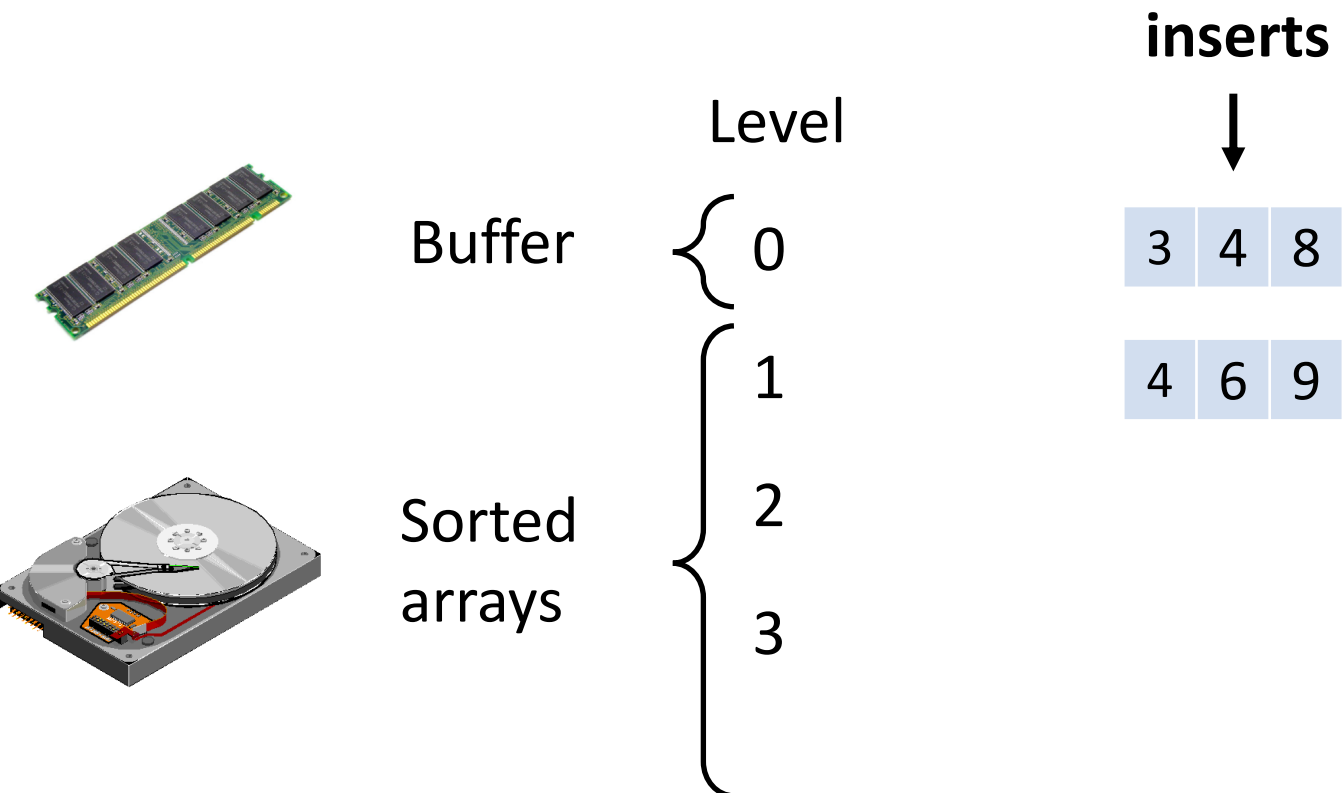
# Basic LSM-tree – Example



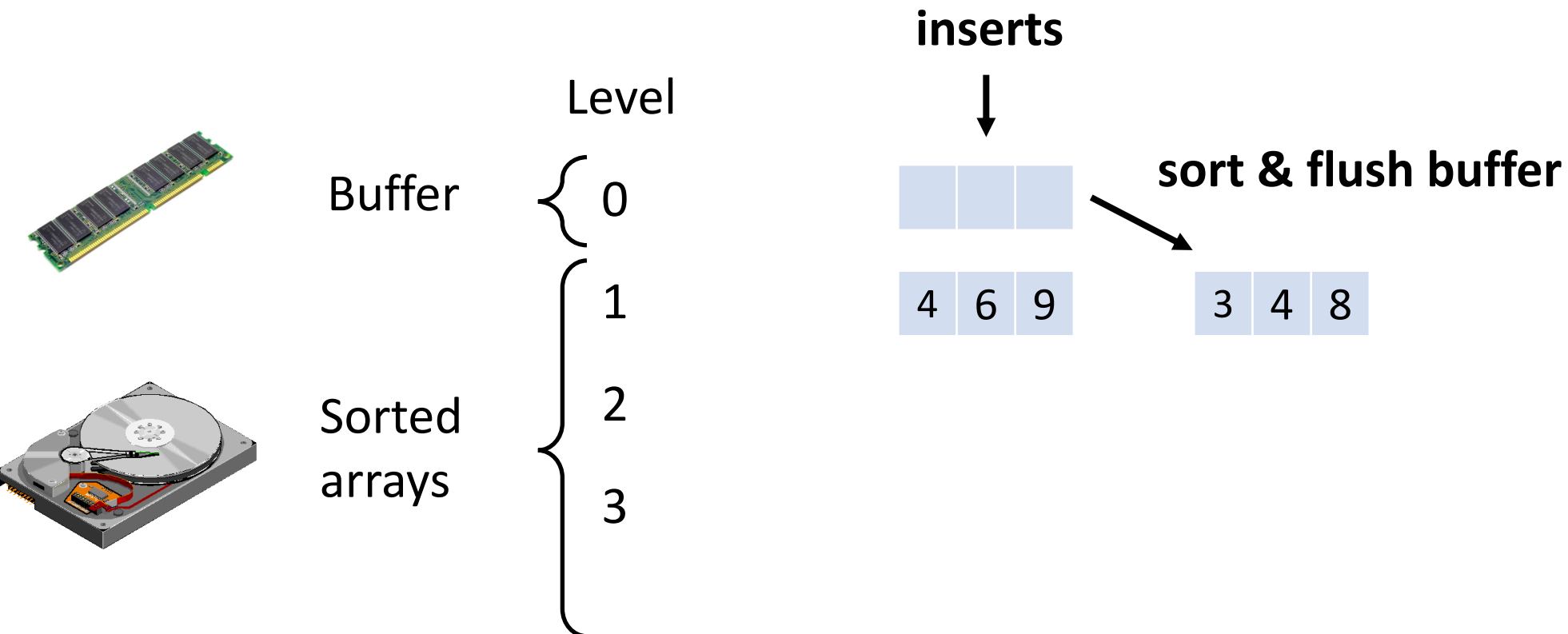
# Basic LSM-tree – Example



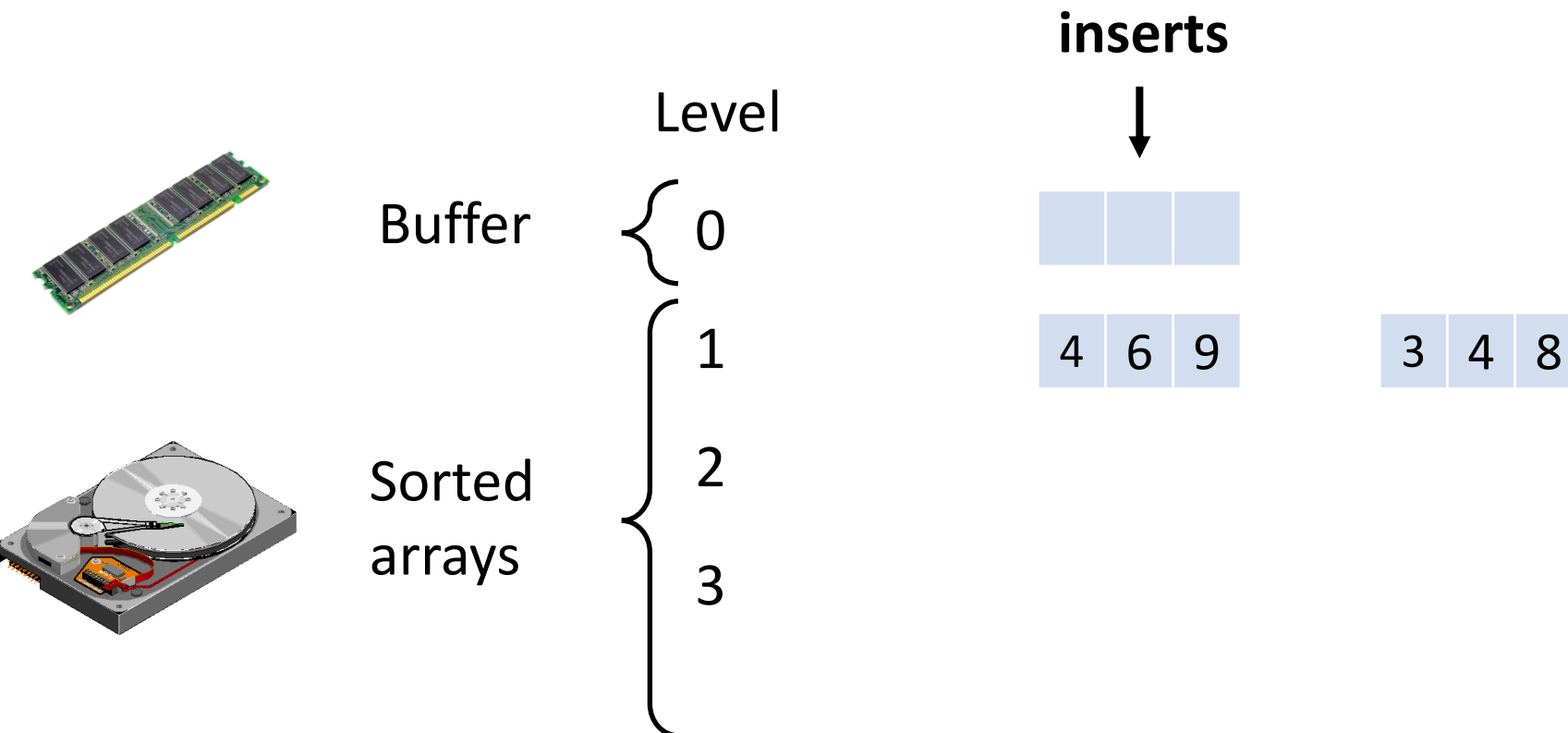
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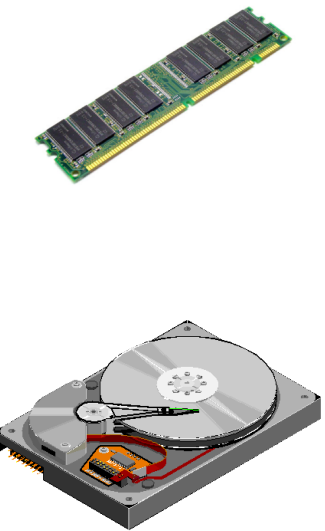
# Basic LSM-tree – Example



# Basic LSM-tree – Example



# Basic LSM-tree – Example



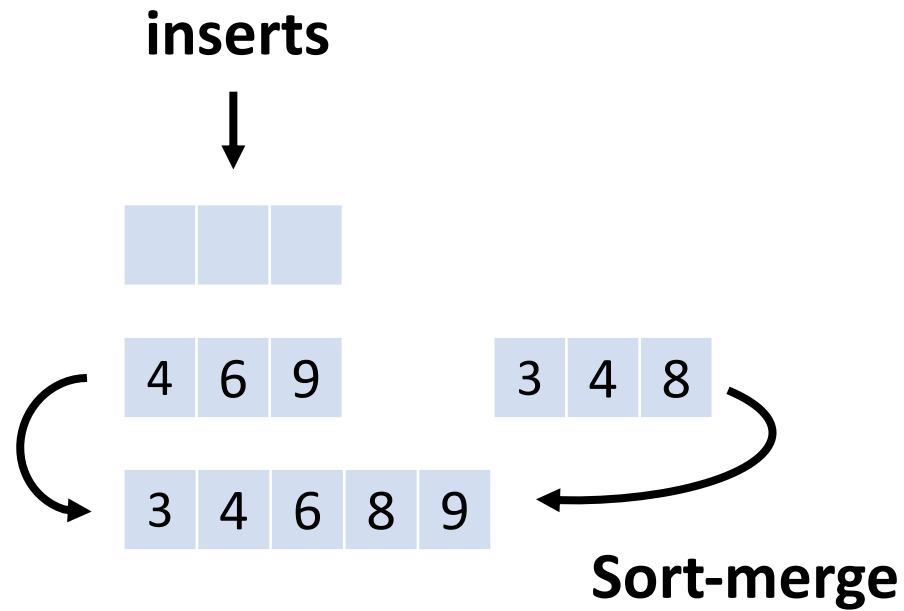
Level

Buffer { 0

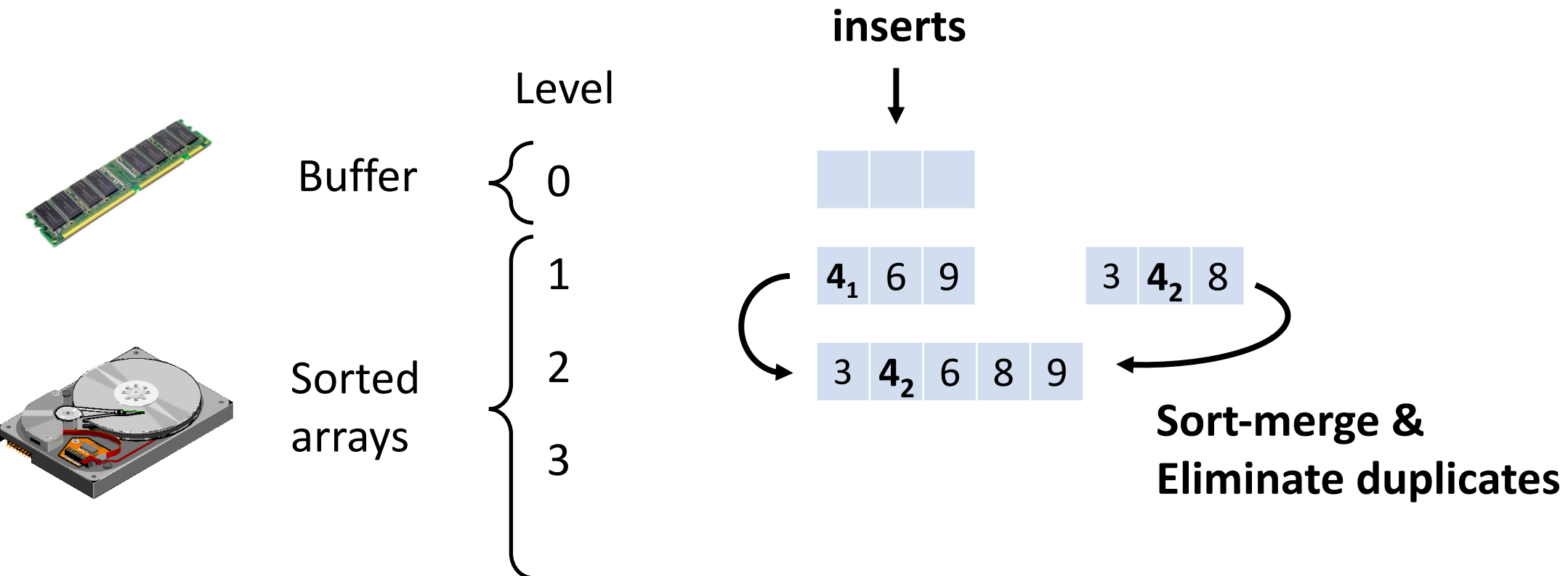
Sorted arrays { 1

2

3

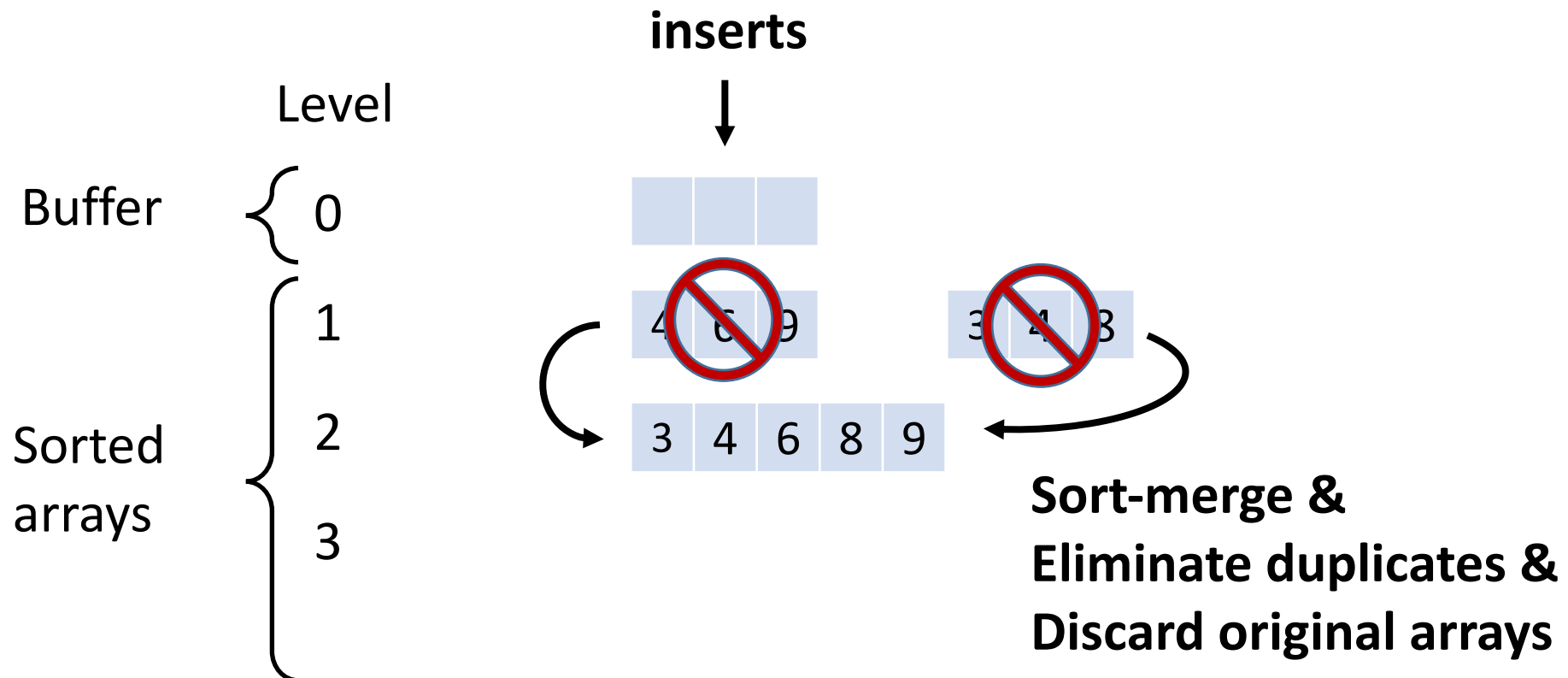
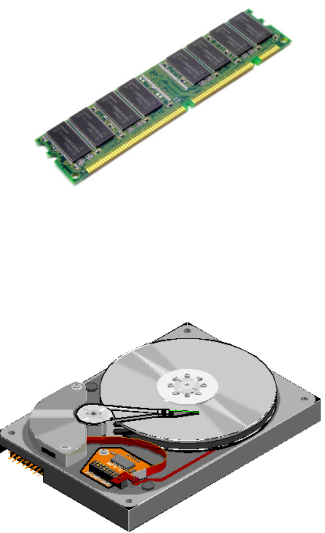


# Basic LSM-tree – Example

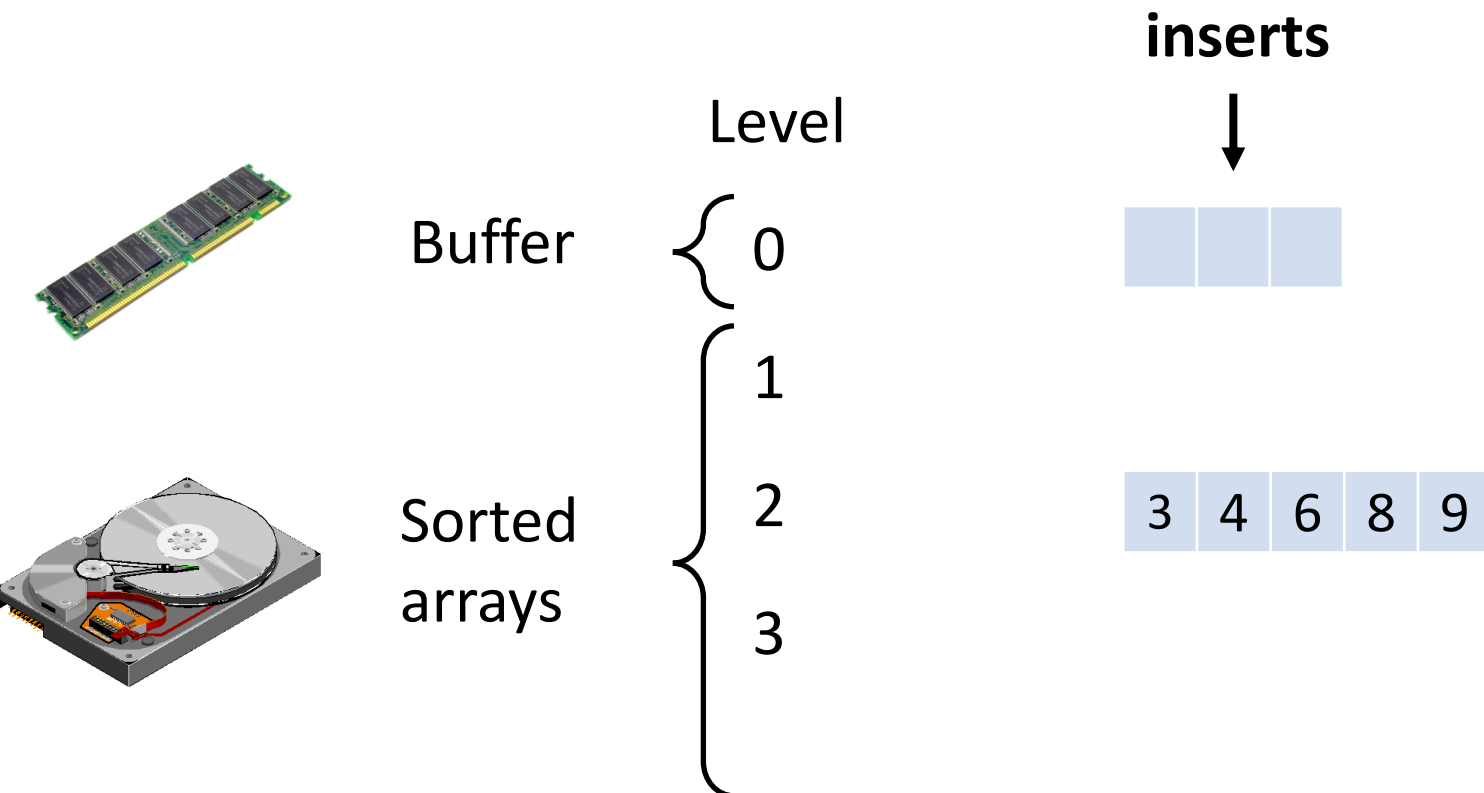




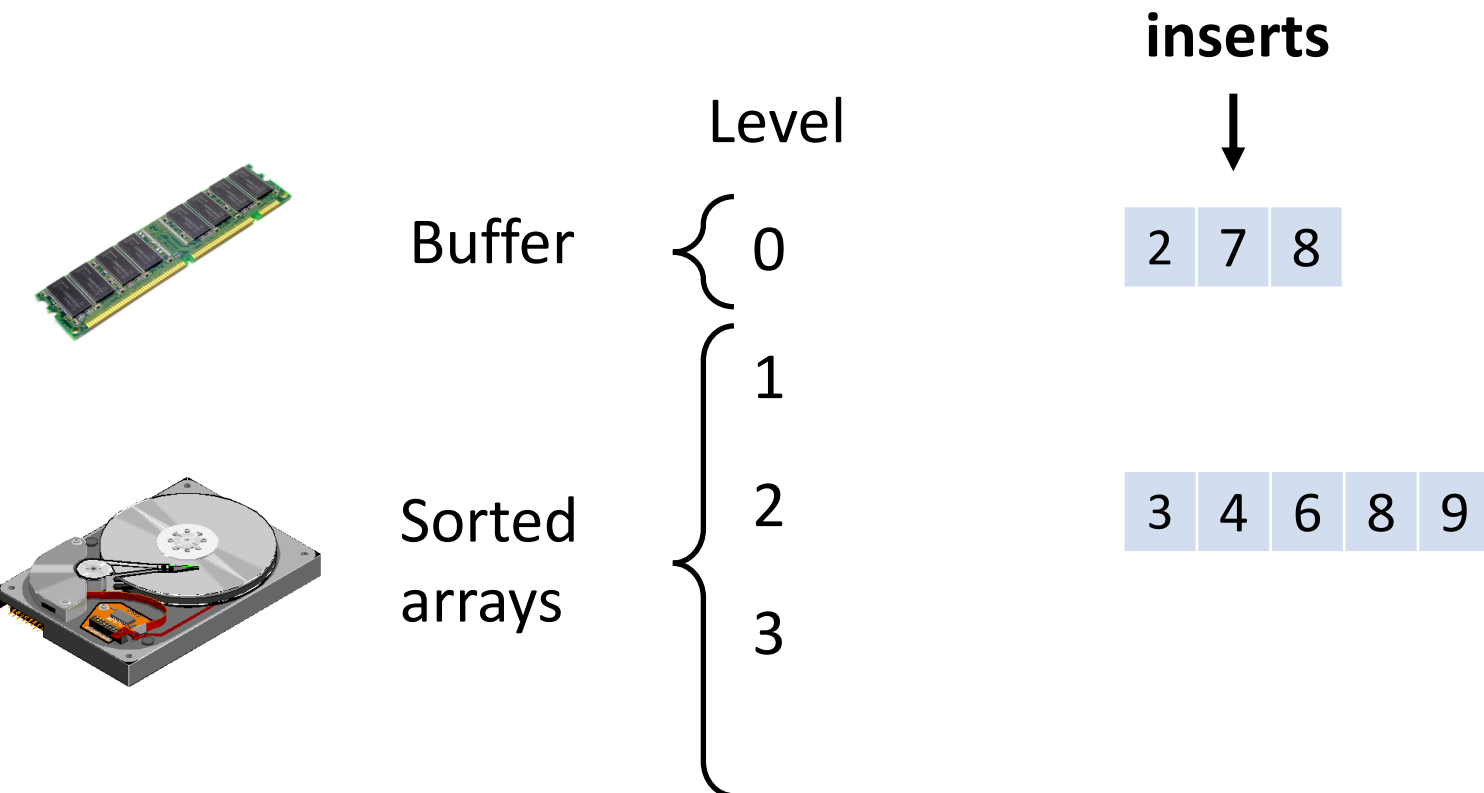
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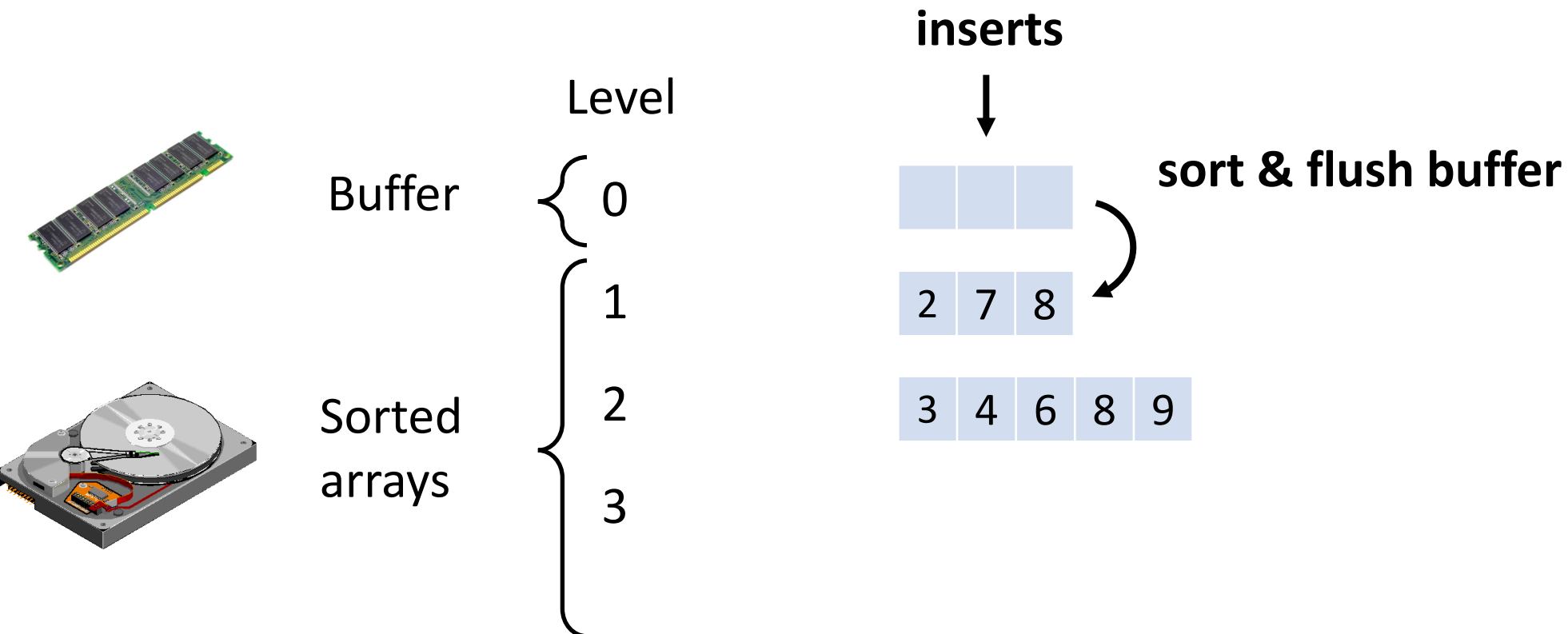
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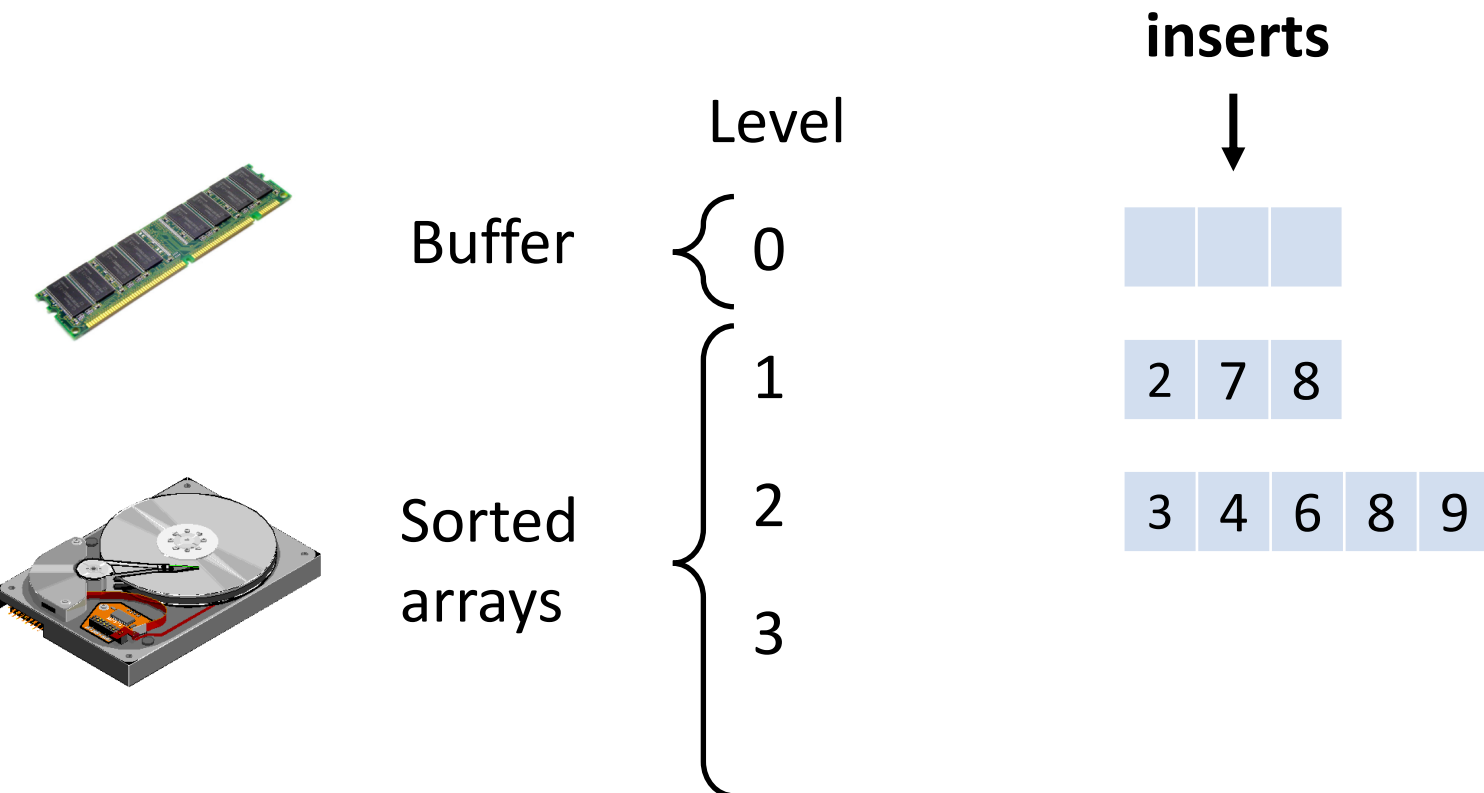
# Basic LSM-tree – Example



# Basic LSM-tree – Example

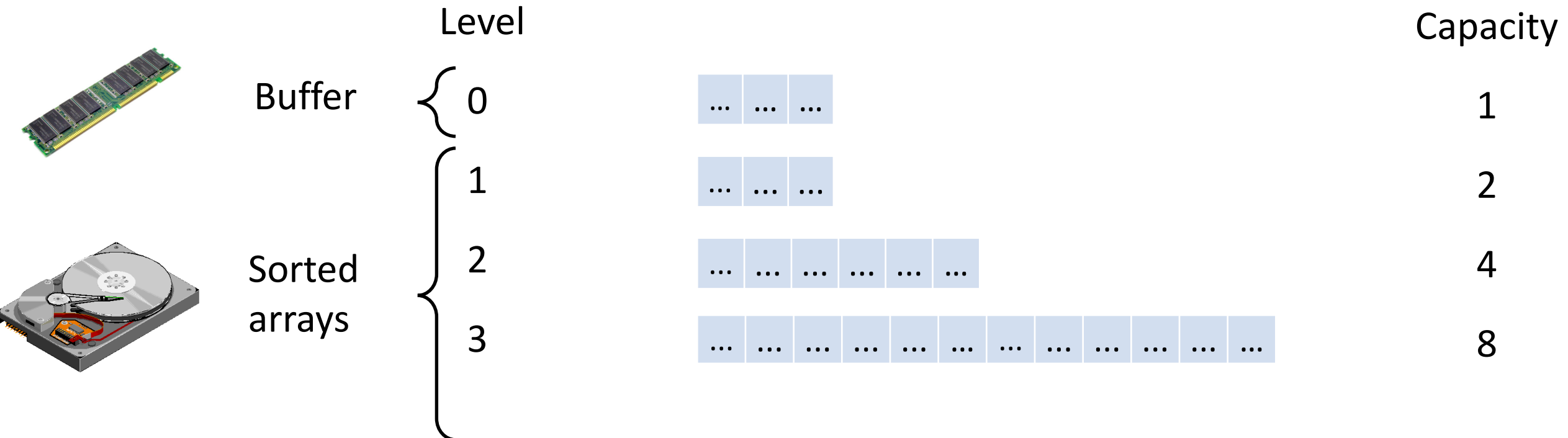


# Basic LSM-tree – Example



# Basic LSM-tree

Levels have exponentially increasing capacities.



# Basic LSM-tree – Lookup cost

*Lookup method?*

Search youngest to oldest.

$$O\left(\log_2\left(\frac{N}{B}\right)\right)$$

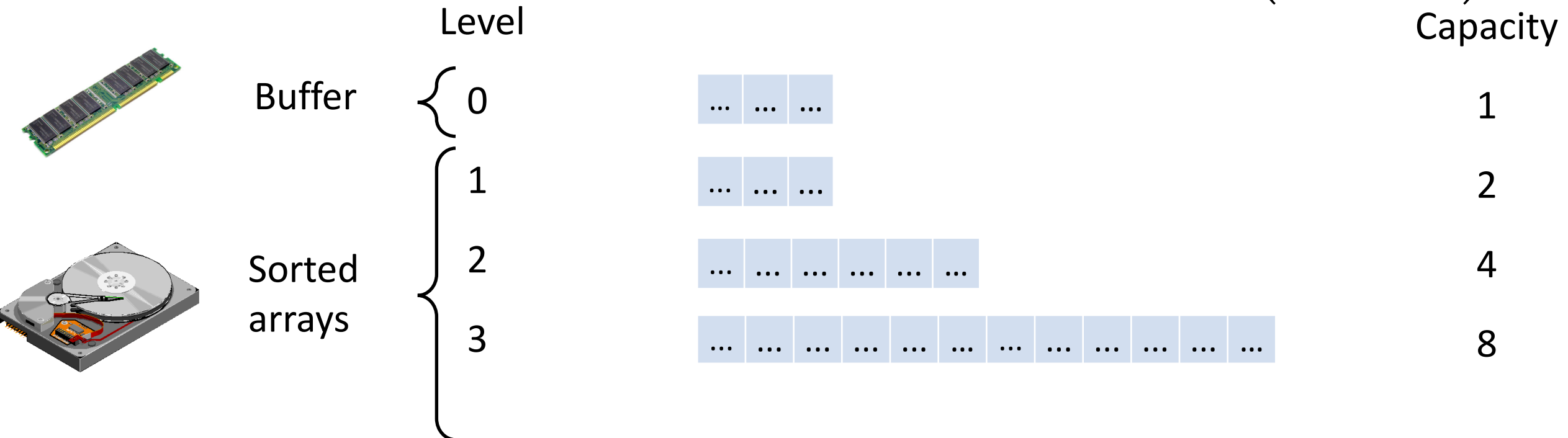
*How?*

Binary search.

$$O\left(\log_2\left(\frac{N}{B}\right)\right)$$

*Lookup cost?*

$$O\left(\log_2\left(\frac{N}{B}\right)^2\right)$$



# Basic LSM-tree – Insertion cost

*How many times is each entry copied?*

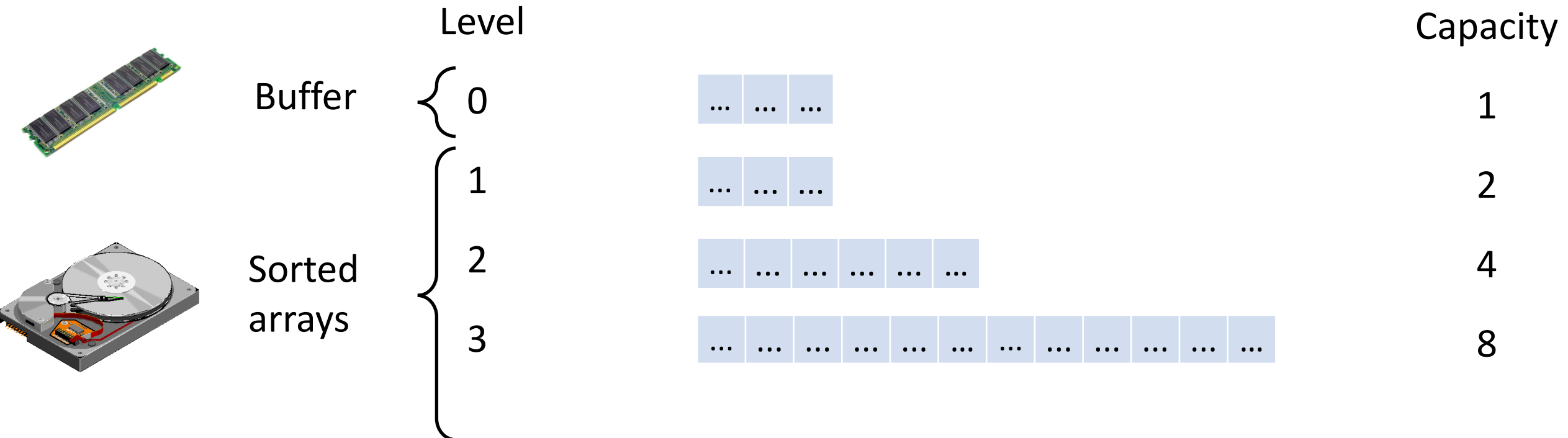
*What is the price of each copy?*

Total insert cost?

$$O\left(\log_2\left(\frac{N}{B}\right)\right)$$

$$O\left(\frac{1}{B}\right)$$

$$O\left(\frac{1}{B} \cdot \log_2\left(\frac{N}{B}\right)\right)$$





# Results Catalogue

|                       | Lookup cost        | Insertion cost             |
|-----------------------|--------------------|----------------------------|
| Sorted array          | $O(\log_2(N/B))$   | $O(N/B)$                   |
| Log                   | $O(N/B)$           | $O(1/B)$                   |
| B-tree                | $O(\log_B(N/B))$   | $O(\log_B(N/B))$           |
| <b>Basic LSM-tree</b> | $O(\log_2(N/B)^2)$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree      |                    |                            |
| Tiered LSM-tree       |                    |                            |

# Results Catalogue

Better insert cost and worst lookup cost compared with B-trees

|                       | Lookup cost        | Insertion cost             |
|-----------------------|--------------------|----------------------------|
| Sorted array          | $O(\log_2(N/B))$   | $O(N/B)$                   |
| Log                   | $O(N/B)$           | $O(1/B)$                   |
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| Leveled LSM-tree      |                    |                            |
| Tiered LSM-tree       |                    |                            |

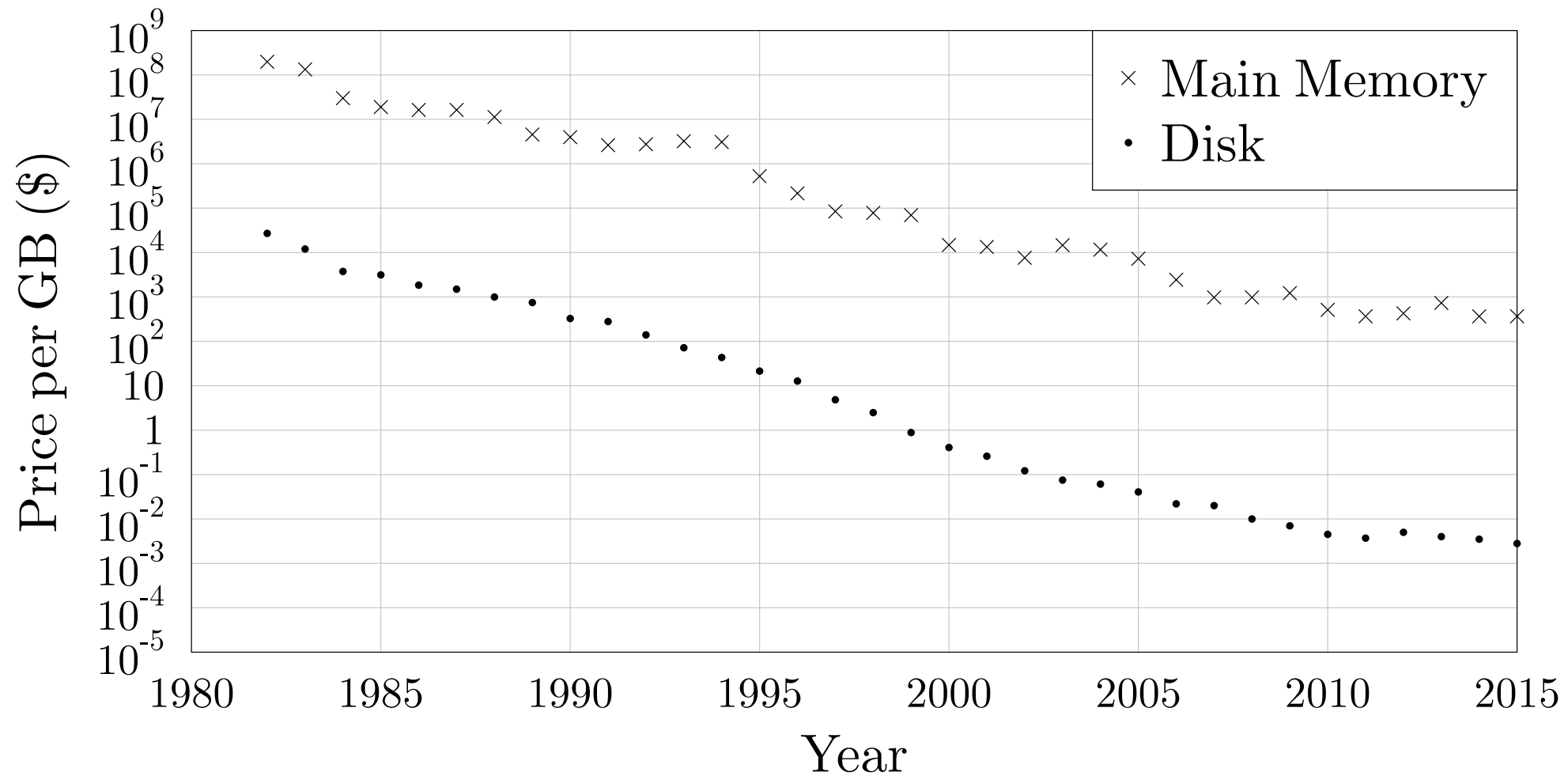
# Results Catalogue

**Better insert cost** and **worst lookup cost** compared with B-trees

Can we improve lookup cost?

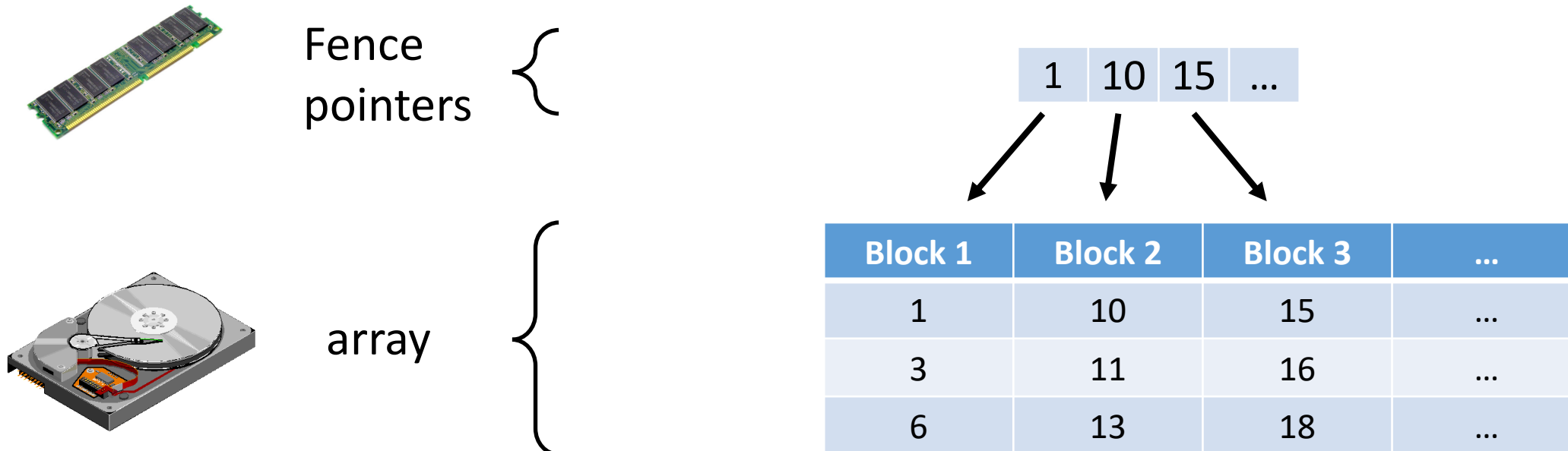
|                       | Lookup cost        | Insertion cost             |
|-----------------------|--------------------|----------------------------|
| Sorted array          | $O(\log_2(N/B))$   | $O(N/B)$                   |
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| B-tree                | $O(\log_B(N/B))$   | $O(\log_B(N/B))$           |
| <b>Basic LSM-tree</b> | $O(\log_2(N/B)^2)$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree      |                    |                            |
| Tiered LSM-tree       |                    |                            |

# Declining Main Memory Cost



# Declining Main Memory Cost

Store a fence pointer for every block in main memory



# Results Catalogue – with fence pointers

|                  | Lookup cost        | Insertion cost             |
|------------------|--------------------|----------------------------|
| Sorted array     | $O(\log_2(N/B))$   | $O(N/B)$                   |
| Log              | $O(N/B)$           | $O(1/B)$                   |
| B-tree           | $O(\log_B(N/B))$   | $O(\log_B(N/B))$           |
| Basic LSM-tree   | $O(\log_2(N/B)^2)$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree |                    |                            |
| Tiered LSM-tree  |                    |                            |

# Results Catalogue – with fence pointers

|                     | Lookup cost        | Insertion cost             |
|---------------------|--------------------|----------------------------|
| <b>Sorted array</b> | $O(\log_2(N/B))$   | $O(N/B)$                   |
| Log                 | $O(N/B)$           | $O(1/B)$                   |
| B-tree              | $O(\log_B(N/B))$   | $O(\log_B(N/B))$           |
| Basic LSM-tree      | $O(\log_2(N/B)^2)$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree    |                    |                            |
| Tiered LSM-tree     |                    |                            |

# Results Catalogue – with fence pointers

|                     | Lookup cost        | Insertion cost             |
|---------------------|--------------------|----------------------------|
| <b>Sorted array</b> | $O(1)$             | $O(N/B)$                   |
| Log                 | $O(N/B)$           | $O(1/B)$                   |
| B-tree              | $O(\log_B(N/B))$   | $O(\log_B(N/B))$           |
| Basic LSM-tree      | $O(\log_2(N/B)^2)$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree    |                    |                            |
| Tiered LSM-tree     |                    |                            |



# Results Catalogue – with fence pointers

|                  | Lookup cost        | Insertion cost             |
|------------------|--------------------|----------------------------|
| Sorted array     | $O(1)$             | $O(N/B)$                   |
| <b>Log</b>       | $O(N/B)$           | $O(1/B)$                   |
| B-tree           | $O(\log_B(N/B))$   | $O(\log_B(N/B))$           |
| Basic LSM-tree   | $O(\log_2(N/B)^2)$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree |                    |                            |
| Tiered LSM-tree  |                    |                            |

# Results Catalogue – with fence pointers

|                  | Lookup cost        | Insertion cost             |
|------------------|--------------------|----------------------------|
| Sorted array     | $O(1)$             | $O(N/B)$                   |
| Log              | $O(N/B)$           | $O(1/B)$                   |
| <b>B-tree</b>    | $O(\log_B(N/B))$   | $O(\log_B(N/B))$           |
| Basic LSM-tree   | $O(\log_2(N/B)^2)$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree |                    |                            |
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|                  | Lookup cost        | Insertion cost             |
|------------------|--------------------|----------------------------|
| Sorted array     | $O(1)$             | $O(N/B)$                   |
| Log              | $O(N/B)$           | $O(1/B)$                   |
| <b>B-tree</b>    | $O(1)$             | $O(1)$                     |
| Basic LSM-tree   | $O(\log_2(N/B)^2)$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree |                    |                            |
| Tiered LSM-tree  |                    |                            |

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| Leveled LSM-tree      |                    |                            |
| Tiered LSM-tree       |                    |                            |

# Results Catalogue – with fence pointers

|                       | Lookup cost      | Insertion cost             |
|-----------------------|------------------|----------------------------|
| Sorted array          | $O(1)$           | $O(N/B)$                   |
| Log                   | $O(N/B)$         | $O(1/B)$                   |
| B-tree                | $O(1)$           | $O(1)$                     |
| <b>Basic LSM-tree</b> | $O(\log_2(N/B))$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree      |                  |                            |
| Tiered LSM-tree       |                  |                            |

# Results Catalogue – with fence pointers

Quick sanity check:

suppose

$$N = 2^{42}$$

and

$$B = 2^{10}$$

|                       | Lookup cost      | Insertion cost             |
|-----------------------|------------------|----------------------------|
| Sorted array          | $O(1)$           | $O(N/B)$                   |
| Log                   | $O(N/B)$         | $O(1/B)$                   |
| B-tree                | $O(1)$           | $O(1)$                     |
| <b>Basic LSM-tree</b> | $O(\log_2(N/B))$ | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree      |                  |                            |
| Tiered LSM-tree       |                  |                            |

# Results Catalogue – with fence pointers

Quick sanity check:

suppose

$$N = 2^{42}$$

and

$$B = 2^{10}$$

|                       | Lookup cost | Insertion cost       |
|-----------------------|-------------|----------------------|
| Sorted array          | $O(1)$      | $O(2^{32})$          |
| Log                   | $O(2^{32})$ | $O(2^{-10})$         |
| B-tree                | $O(1)$      | $O(1)$               |
| <b>Basic LSM-tree</b> | $O(5)$      | $O(2^{-10} \cdot 5)$ |
| Leveled LSM-tree      |             |                      |
| Tiered LSM-tree       |             |                      |

# Leveled LSM-tree

 Lookup cost

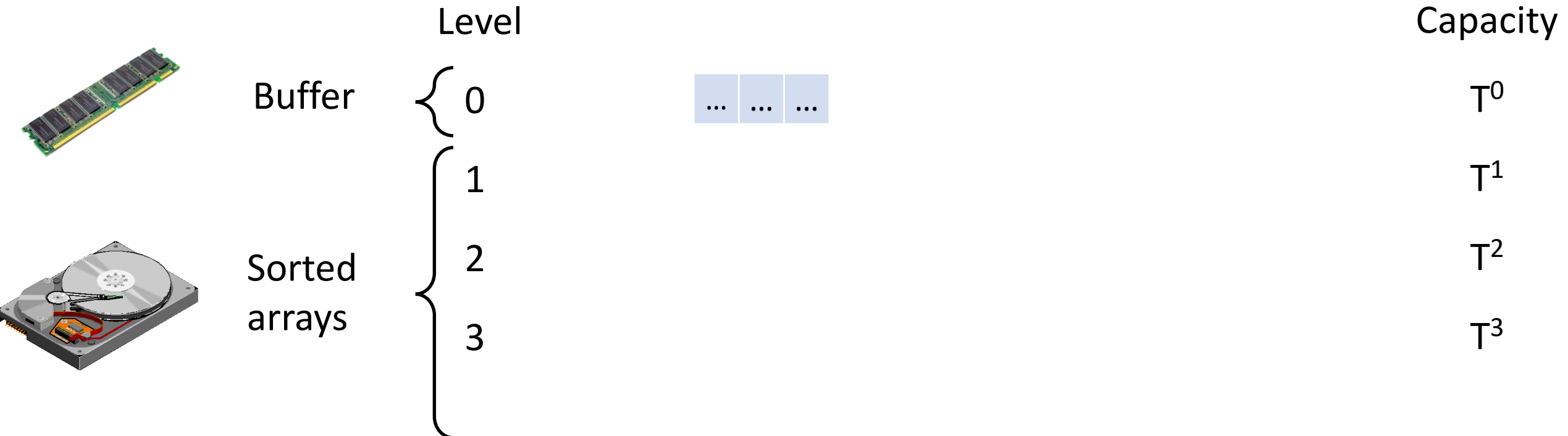
 Update cost



# Leveled LSM-tree

Lookup cost depends on number of levels  
How to reduce it?

Increase size ratio  $T$



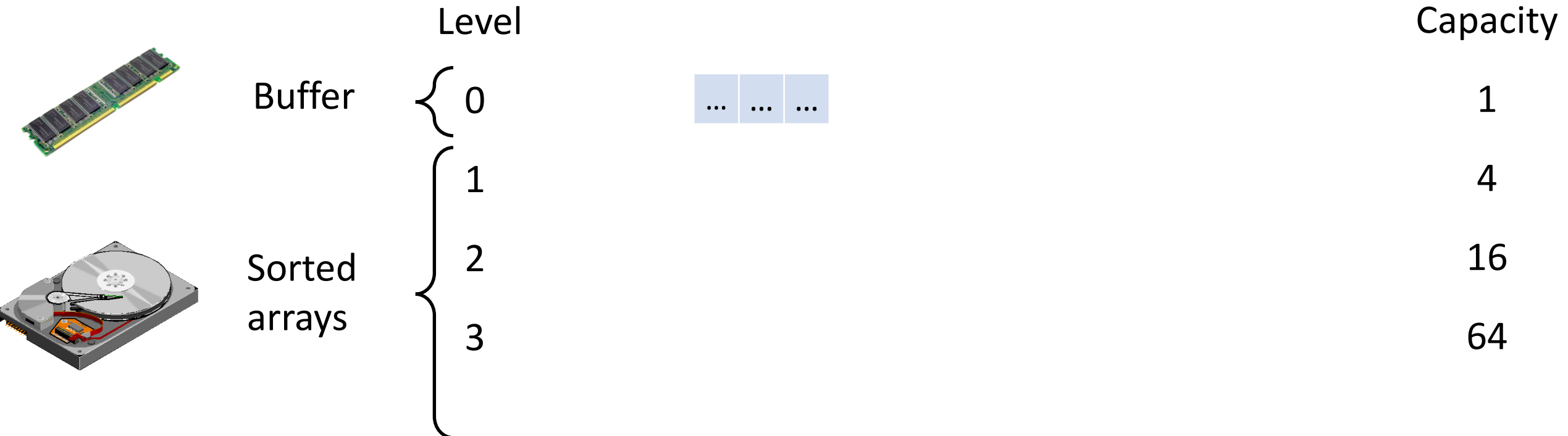
# Leveled LSM-tree

Lookup cost depends on number of levels

How to reduce it?

E.g. size ratio of 4

Increase size ratio  $T$



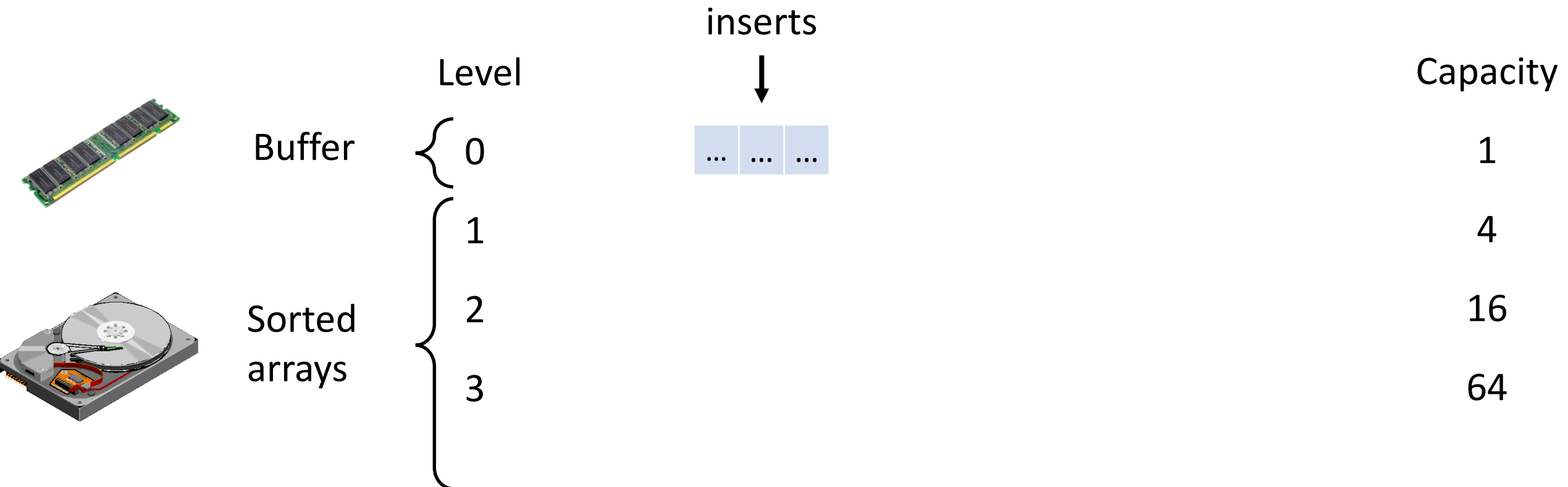
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Lookup cost depends on number of levels

How to reduce it?

E.g. size ratio of 4

Increase size ratio  $T$



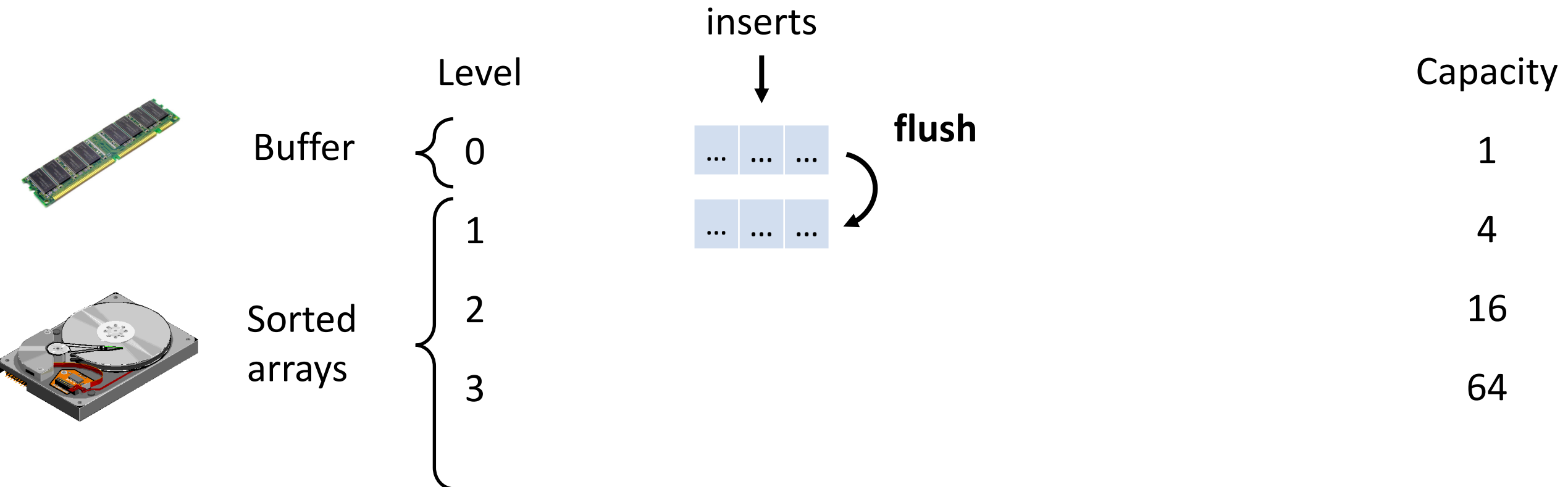
# Leveled LSM-tree

Lookup cost depends on number of levels

How to reduce it?

E.g. size ratio of 4

Increase size ratio  $T$



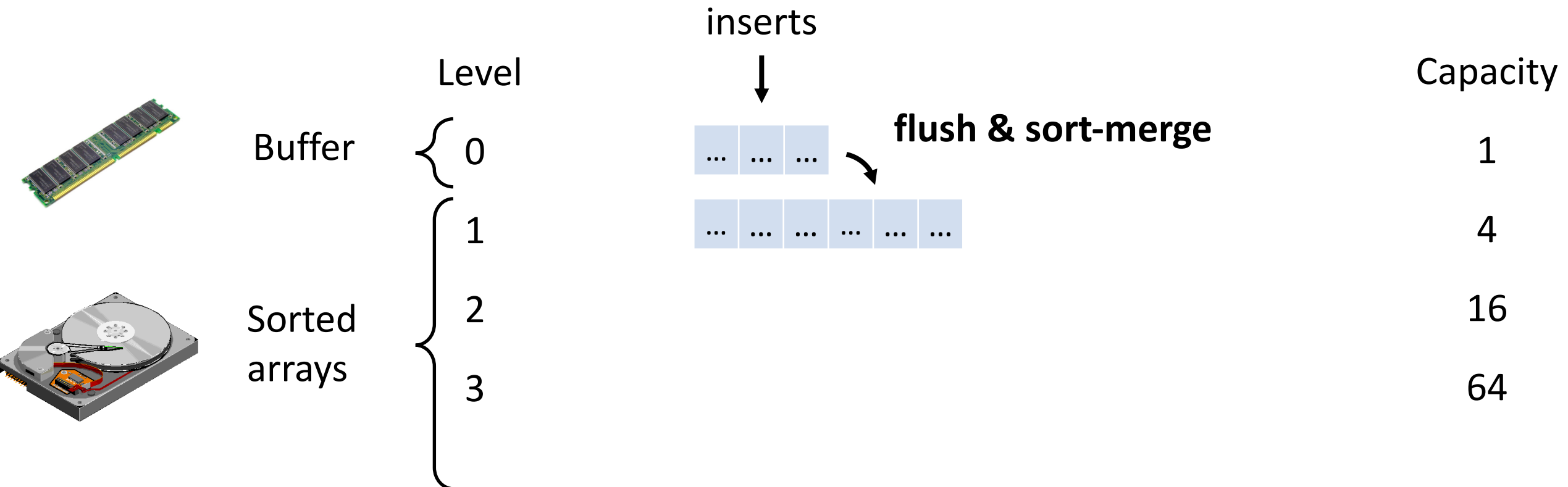
# Leveled LSM-tree

Lookup cost depends on number of levels

How to reduce it?

E.g. size ratio of 4

Increase size ratio T



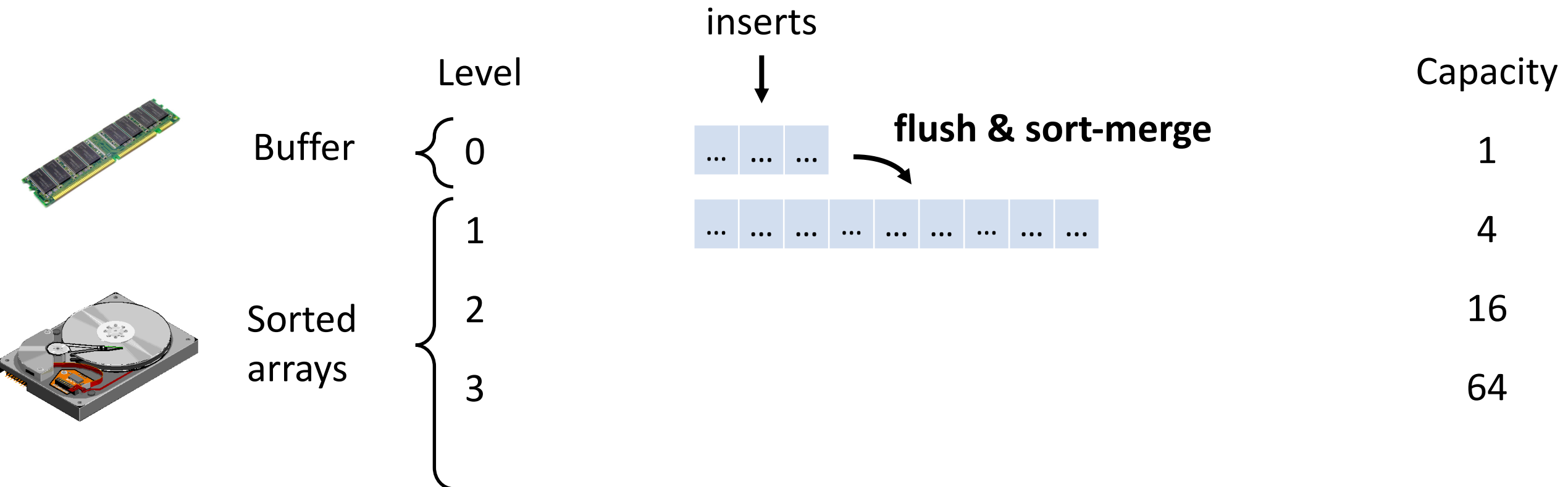
# Leveled LSM-tree

Lookup cost depends on number of levels

How to reduce it?

E.g. size ratio of 4

Increase size ratio  $T$



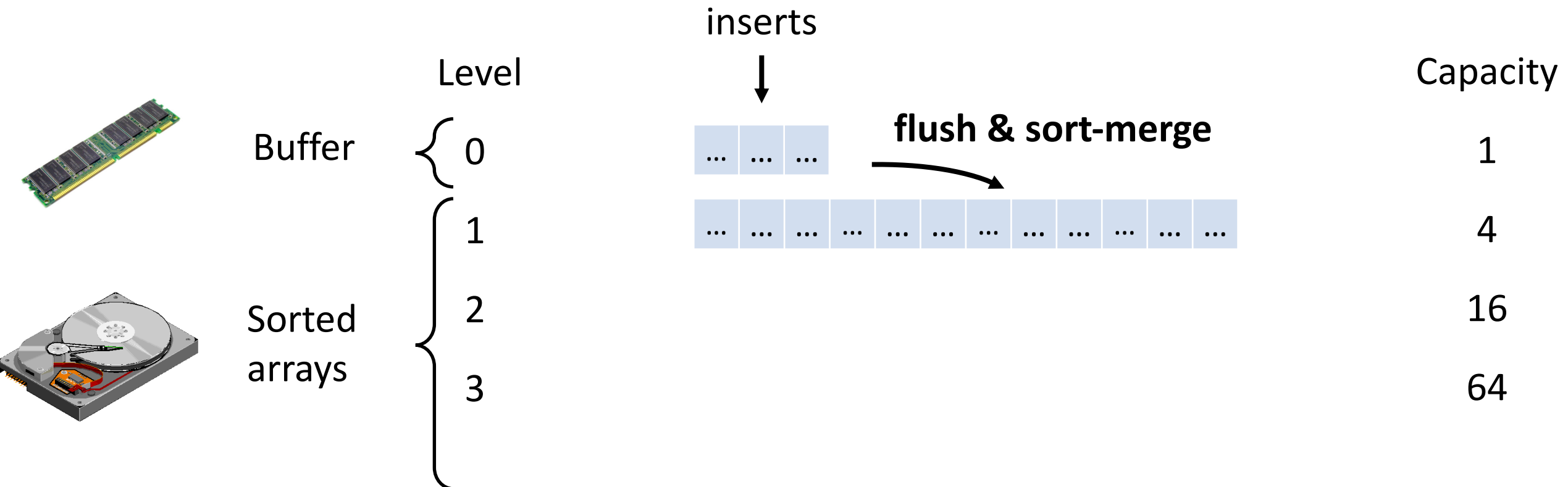
# Leveled LSM-tree

Lookup cost depends on number of levels

How to reduce it?

E.g. size ratio of 4

Increase size ratio  $T$



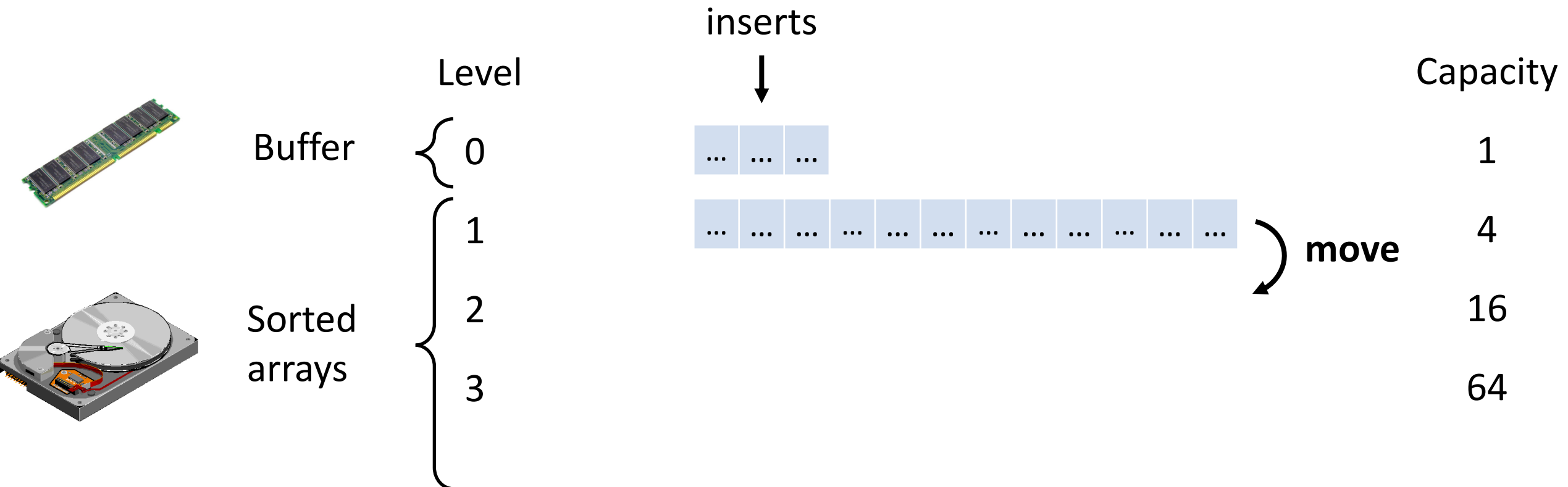
# Leveled LSM-tree

Lookup cost depends on number of levels

How to reduce it?

E.g. size ratio of 4

Increase size ratio  $T$





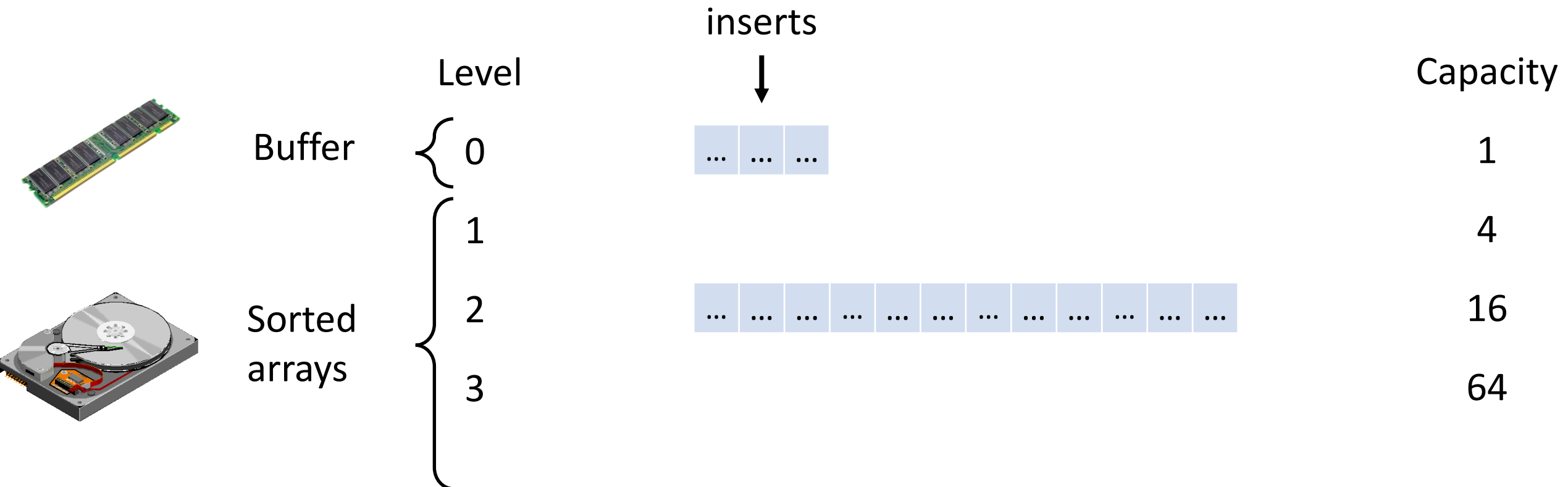
# Leveled LSM-tree

Lookup cost depends on number of levels

How to reduce it?

E.g. size ratio of 4

Increase size ratio  $T$



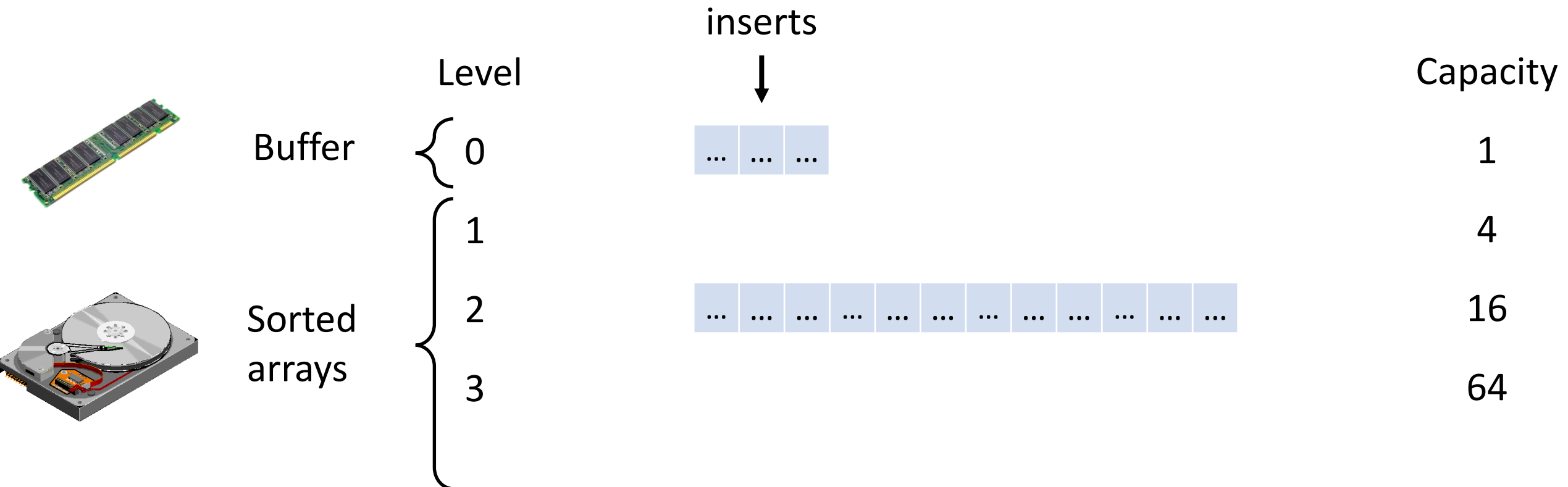
# Leveled LSM-tree

Lookup cost?

$$O\left(\log_T\left(\frac{N}{B}\right)\right)$$

Insertion cost?

$$O\left(\frac{T}{B} \cdot \log_T\left(\frac{N}{B}\right)\right)$$



# Leveled LSM-tree

↓ Lookup cost?  
 $O\left(\log_T\left(\frac{N}{B}\right)\right)$

Insertion cost? ↑  
 $O\left(\frac{T}{B} \cdot \log_T\left(\frac{N}{B}\right)\right)$

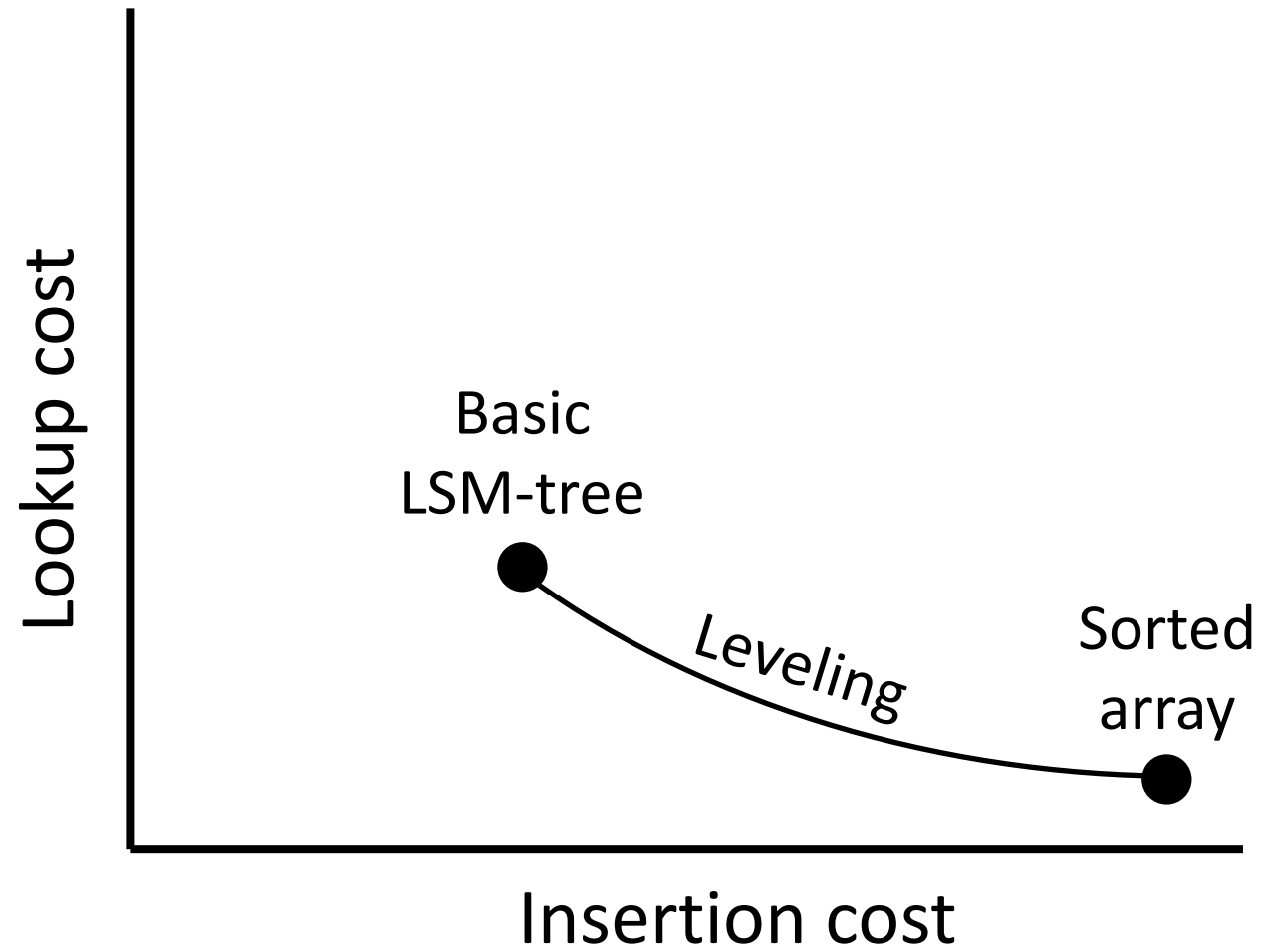
What happens as we increase the size ratio  $T$ ?

What happens when size ratio  $T$  is set to be  $N/B$ ?

Lookup cost becomes:  
 $O(1)$

Insert cost becomes:  
 $O(N/B^2)$

The LSM-tree becomes a sorted array!



# Results Catalogue – with fence pointers

|                         | Lookup cost      | Insertion cost             |
|-------------------------|------------------|----------------------------|
| Sorted array            | $O(1)$           | $O(N/B)$                   |
| Log                     | $O(N/B)$         | $O(1/B)$                   |
| B-tree                  | $O(1)$           | $O(1)$                     |
| Basic LSM-tree          | $O(\log_2(N/B))$ | $O(1/B \cdot \log_2(N/B))$ |
| <b>Leveled LSM-tree</b> | $O(\log_T(N/B))$ | $O(T/B \cdot \log_T(N/B))$ |
| Tiered LSM-tree         |                  |                            |

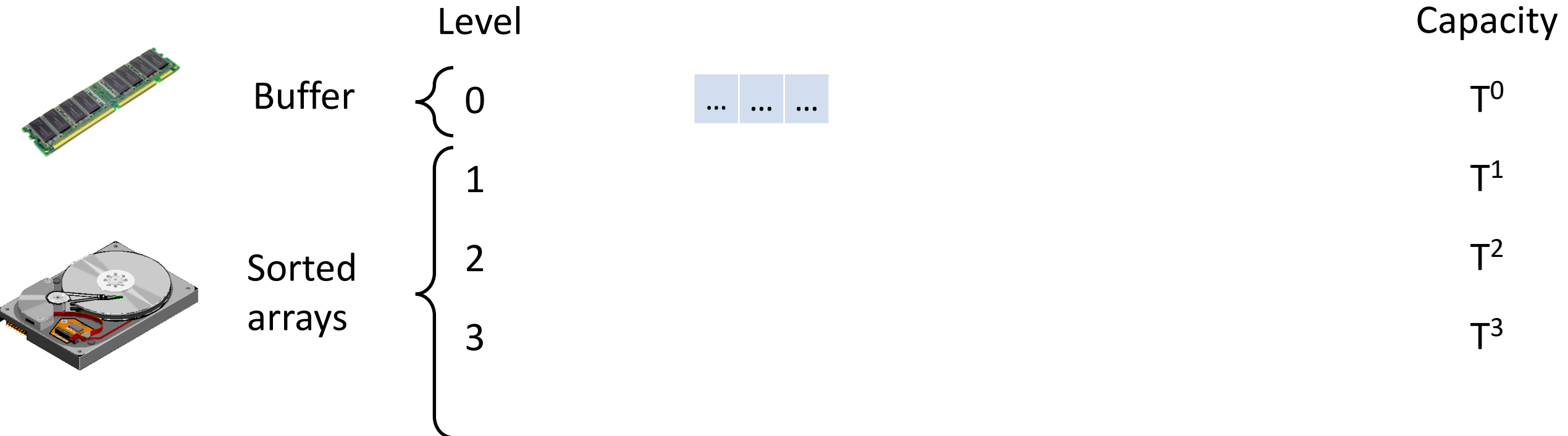
# Tiered LSM-tree

 Lookup cost

 Insertion cost

# Tiered LSM-tree

Reduce the number of levels by increasing the size ratio.  
Do not merge within a level.

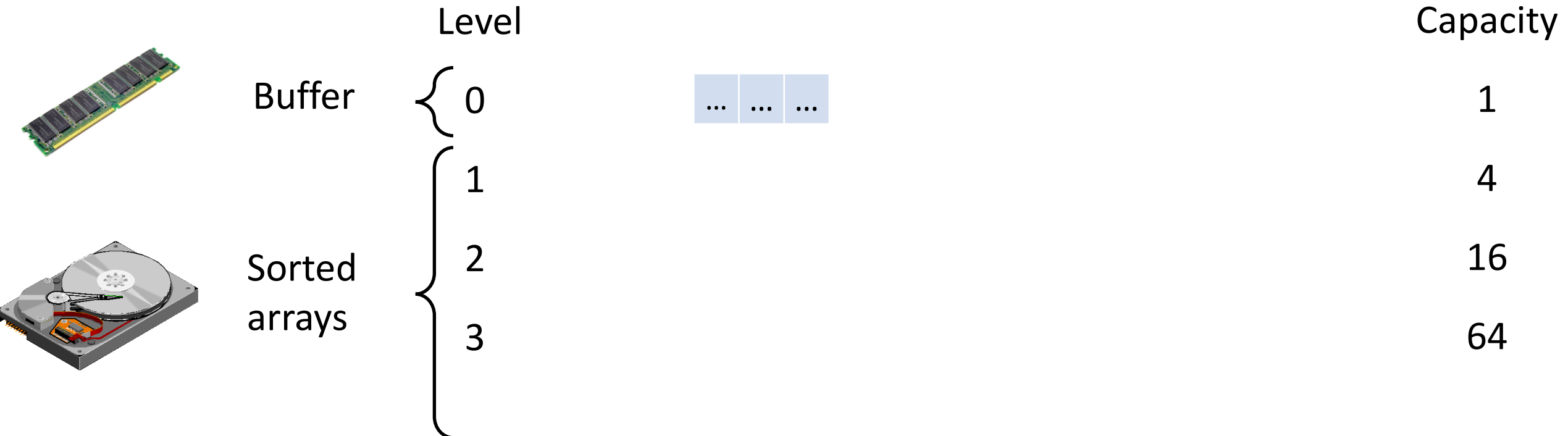


# Tiered LSM-tree

Reduce the number of levels by increasing the size ratio.

Do not merge within a level.

E.g. size ratio of 4



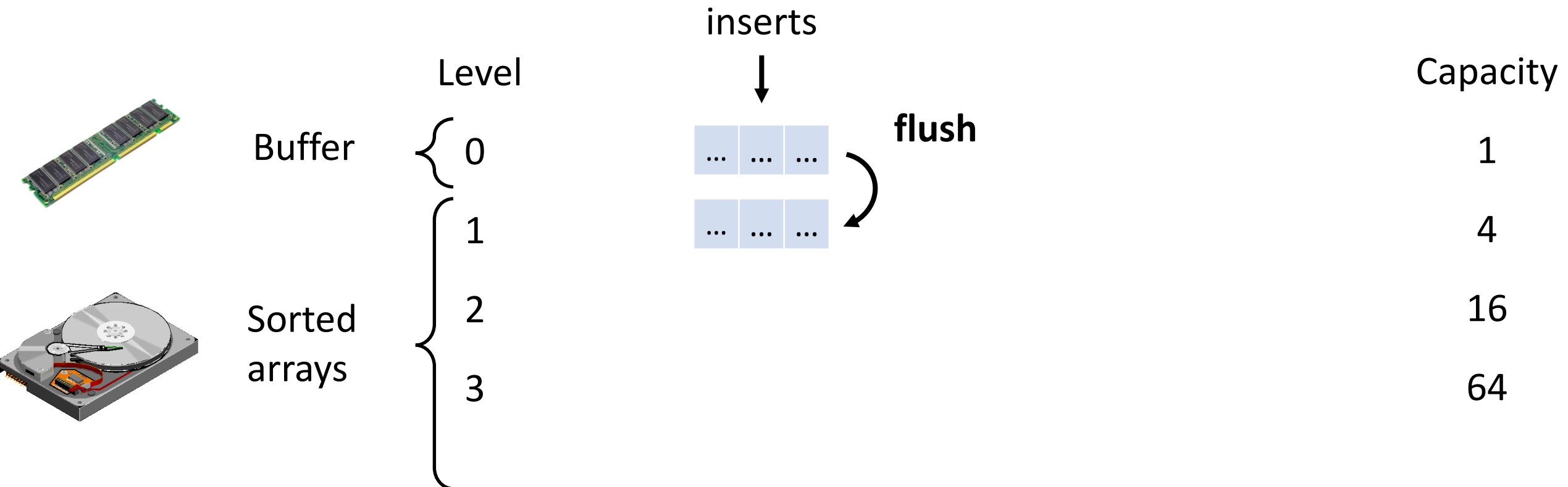


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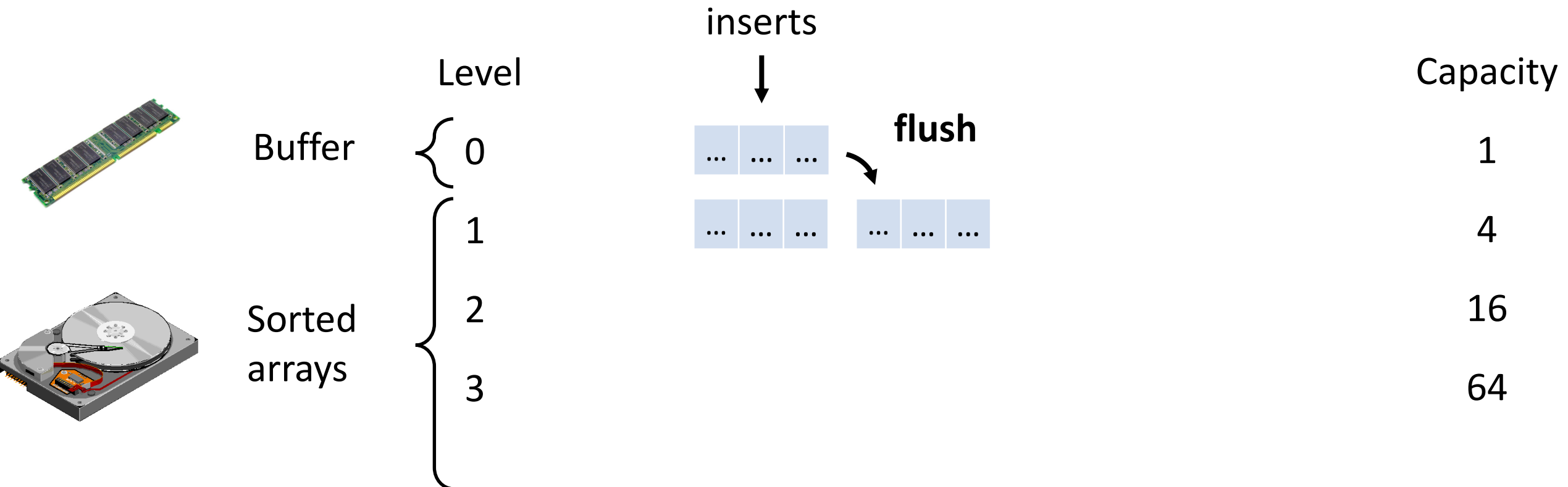


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E.g. size ratio of 4

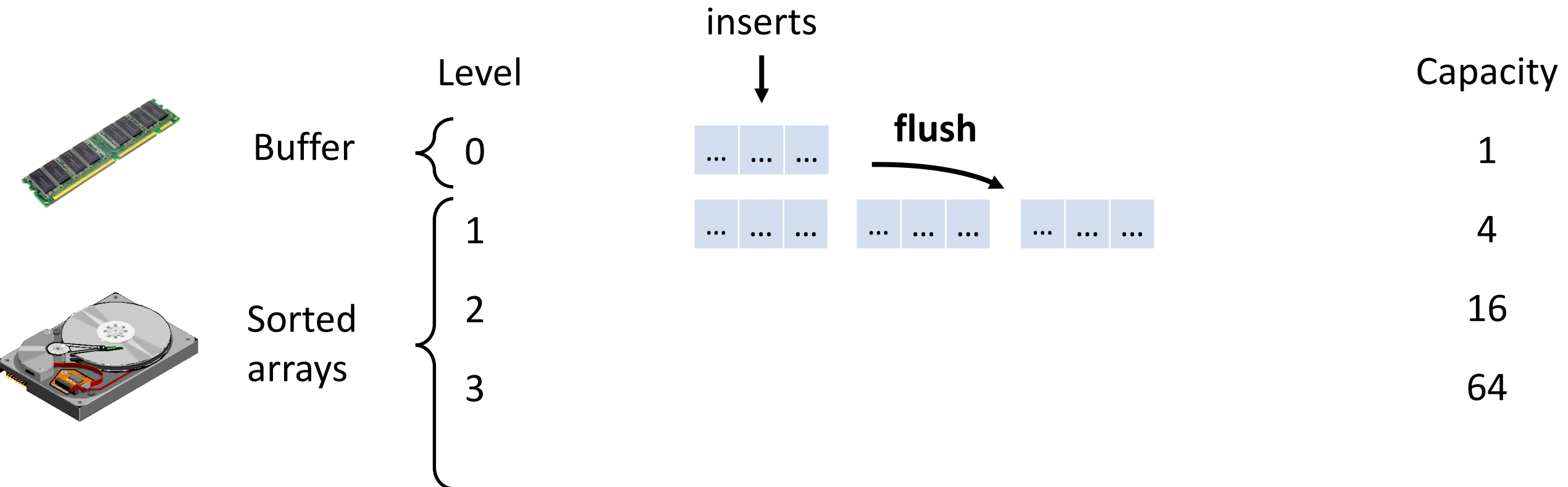


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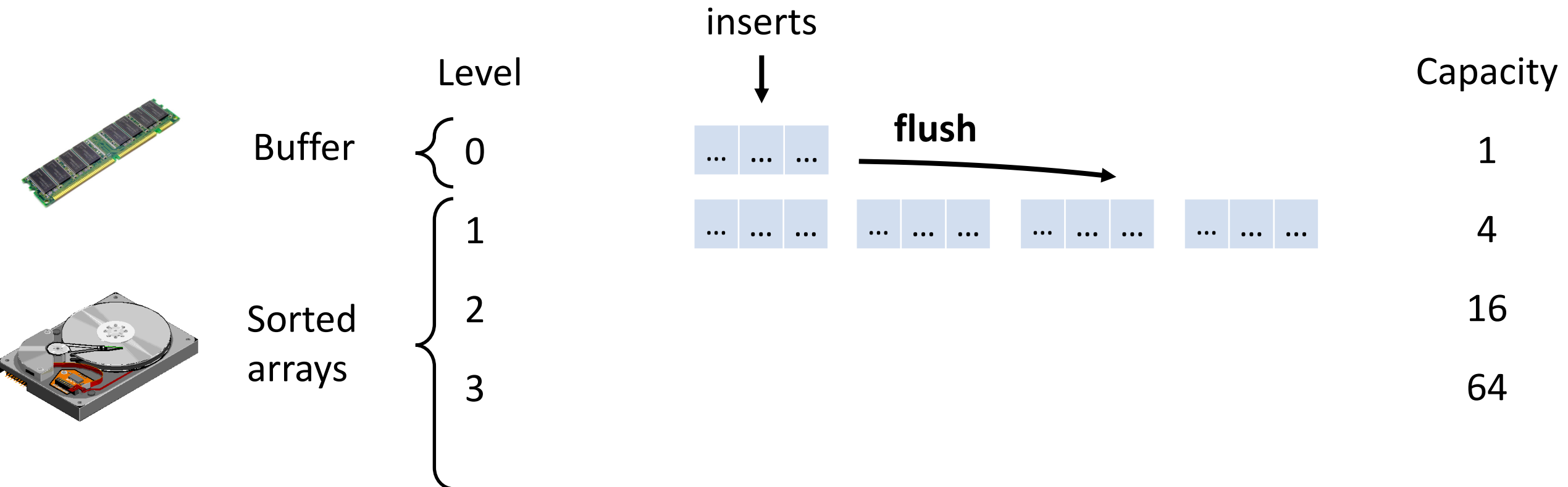


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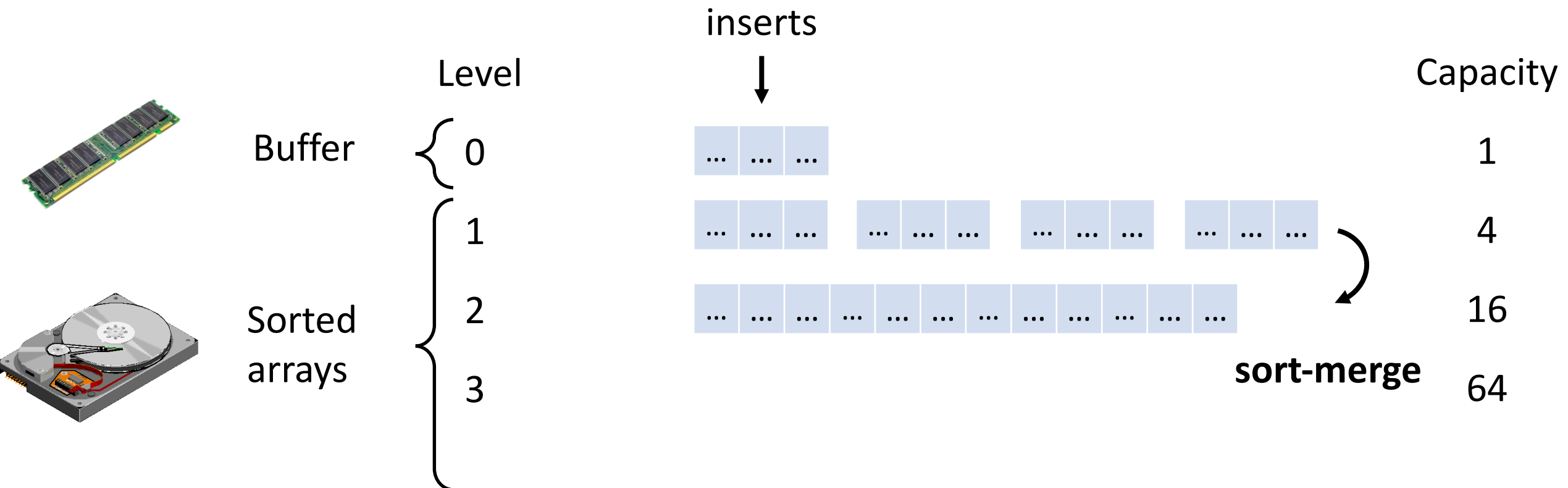


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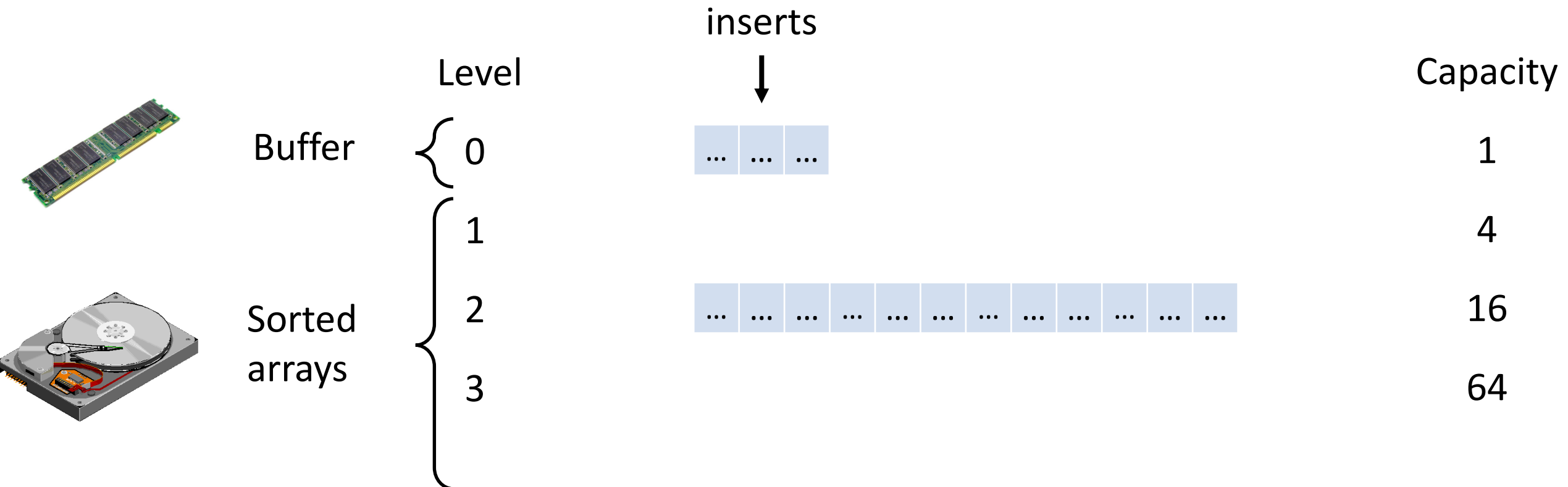


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Reduce the number of levels by increasing the size ratio.

Do not merge within a level.

E.g. size ratio of 4



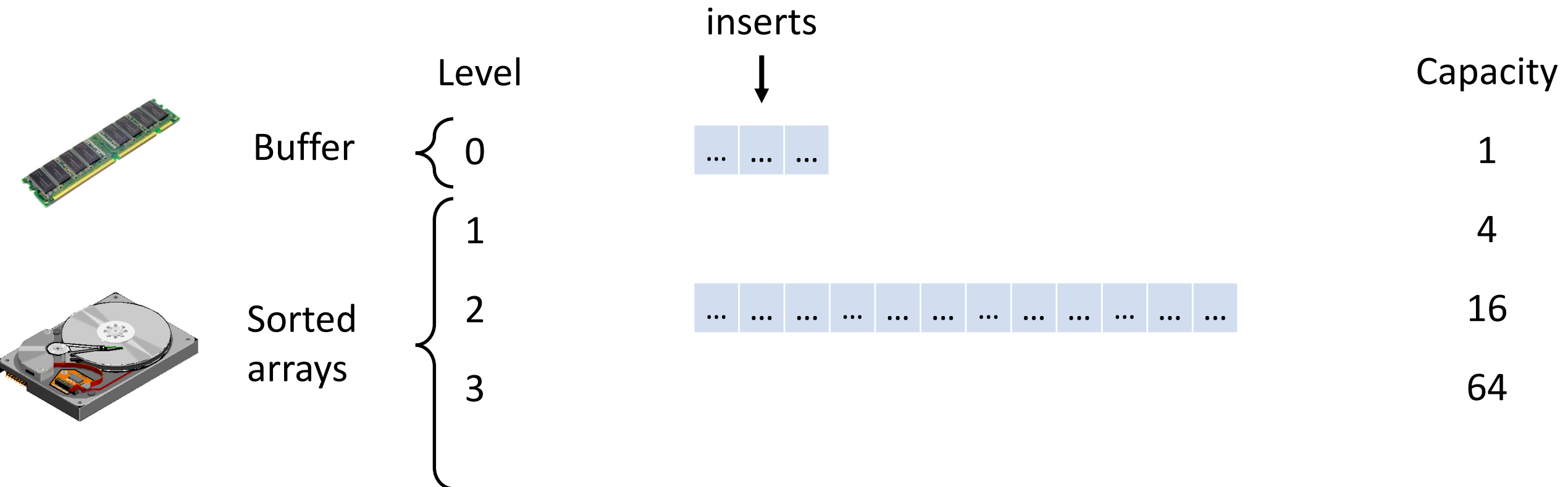
# Tiered LSM-tree

Lookup cost?


$$O\left(T \cdot \log_T \left(\frac{N}{B}\right)\right)$$


Insertion cost?

$$O\left(\frac{1}{B} \cdot \log_T \left(\frac{N}{B}\right)\right)$$



# Tiered LSM-tree

Lookup cost?  
  $O\left(T \cdot \log_T \left(\frac{N}{B}\right)\right)$

Insertion cost?  
 $O\left(\frac{1}{B} \cdot \log_T \left(\frac{N}{B}\right)\right)$  

What happens as we increase the size ratio  $T$ ?

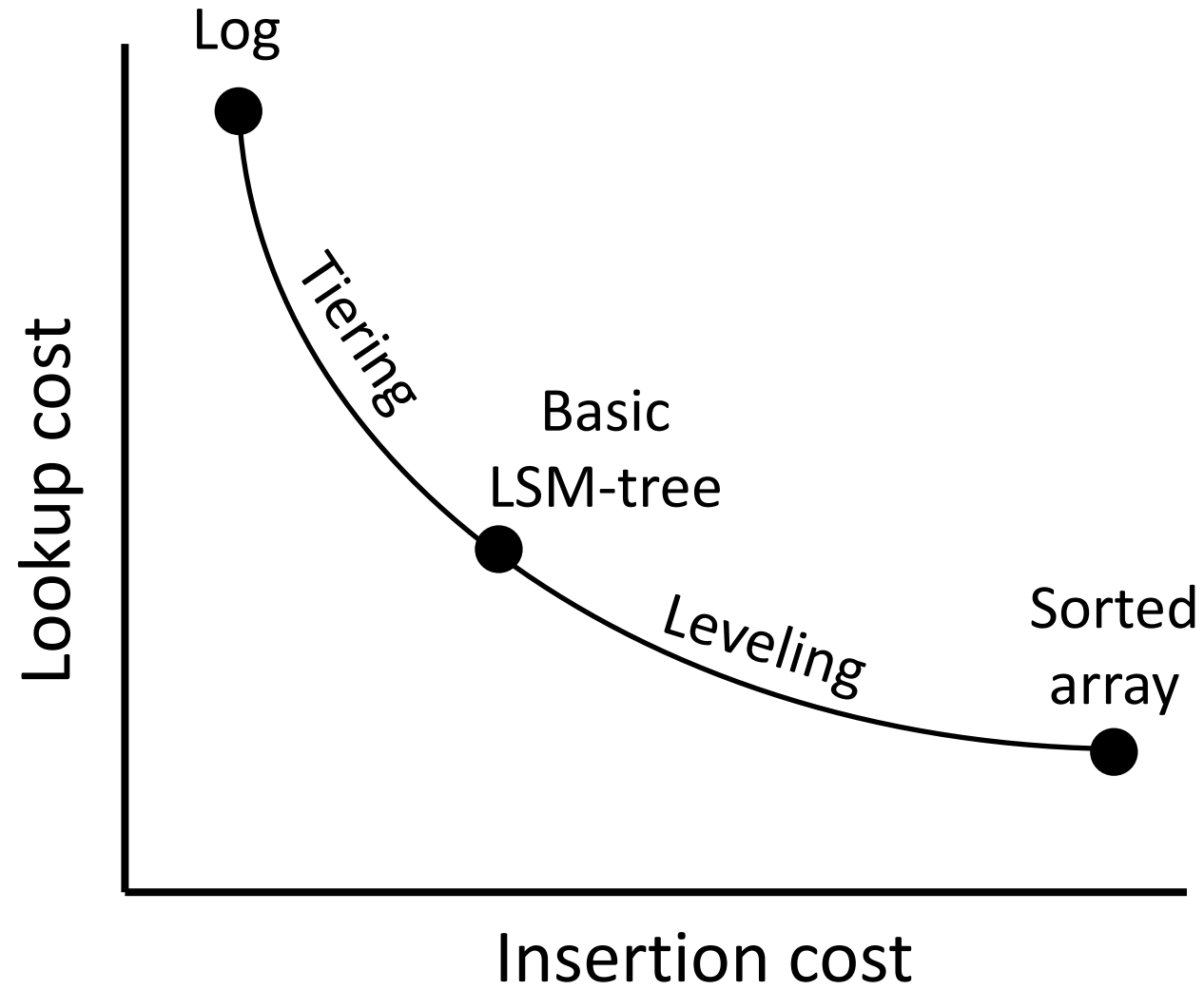
What happens when size ratio  $T$  is set to be  $N/B$ ?

Lookup cost becomes:  
 $O(N/B)$

Insert cost becomes:  
 $O(1/B)$

The tiered LSM-tree becomes a log!



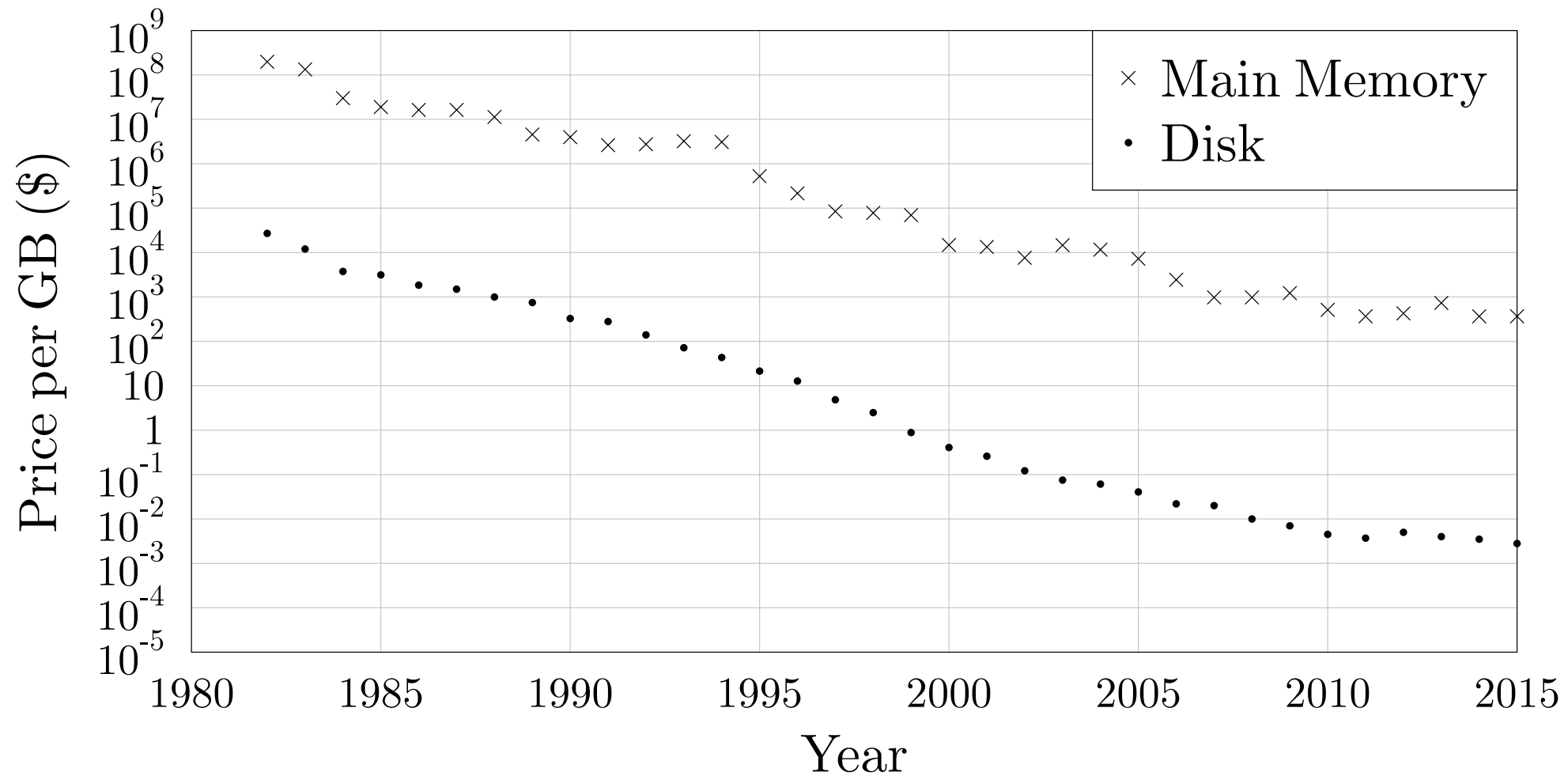


# Results Catalogue – with fence pointers

|                        | Lookup cost              | Insertion cost             |
|------------------------|--------------------------|----------------------------|
| Sorted array           | $O(1)$                   | $O(N/B)$                   |
| Log                    | $O(N/B)$                 | $O(1/B)$                   |
| B-tree                 | $O(1)$                   | $O(1)$                     |
| Basic LSM-tree         | $O(\log_2(N/B))$         | $O(1/B \cdot \log_2(N/B))$ |
| Leveled LSM-tree       | $O(\log_T(N/B))$         | $O(T/B \cdot \log_T(N/B))$ |
| <b>Tiered LSM-tree</b> | $O(T \cdot \log_T(N/B))$ | $O(1/B \cdot \log_T(N/B))$ |

# Bloom filters

# Declining Main Memory Cost



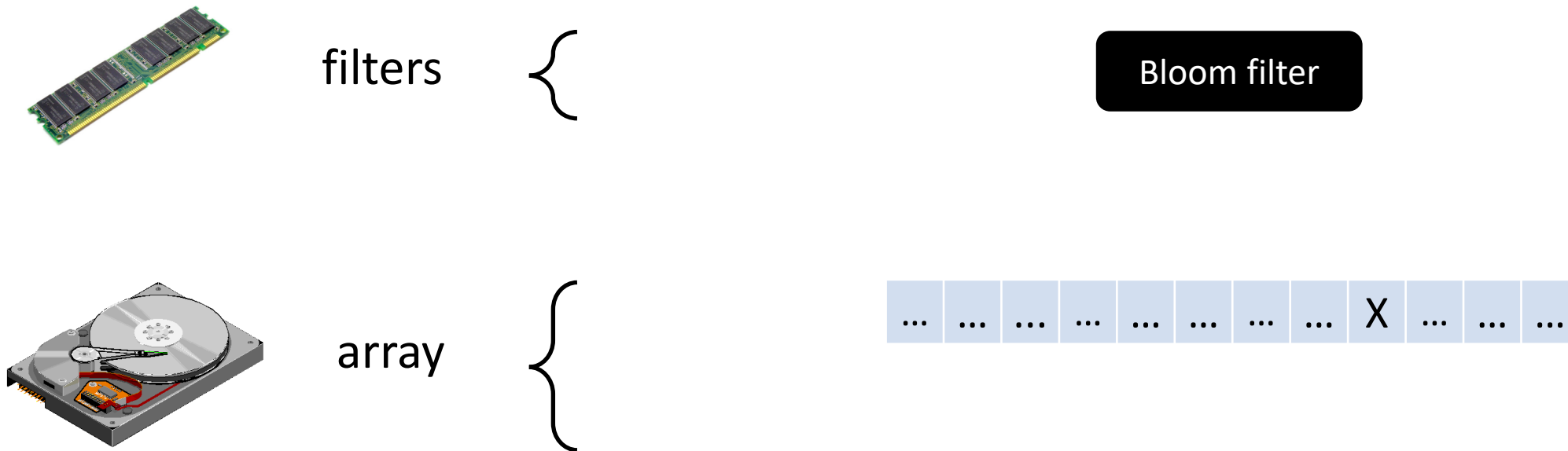
# Bloom Filters

Answers set-membership queries

Smaller than array, and stored in main memory

Purpose: avoid accessing disk if entry is not in array

Subtlety: may return false positives.



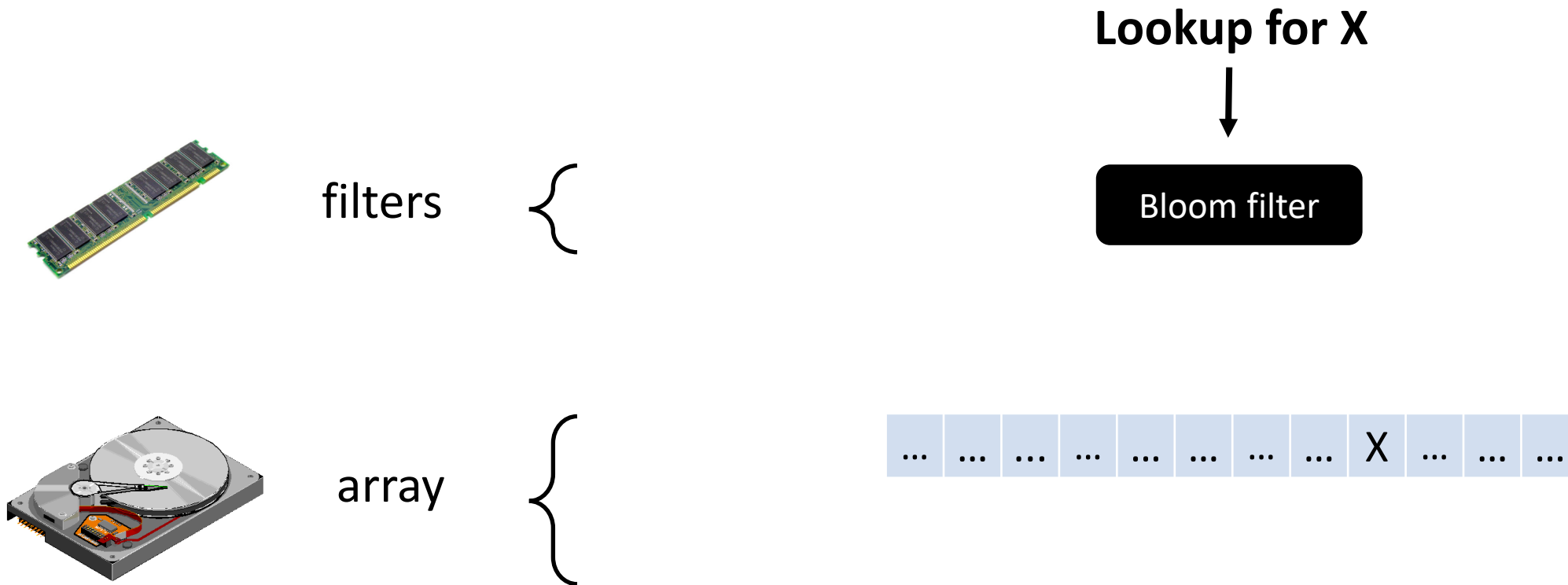
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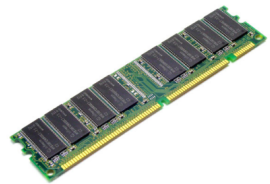
# Bloom Filters

Answers set-membership queries

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Subtlety: may return false positives.



filters



array



Lookup for X



Bloom filter



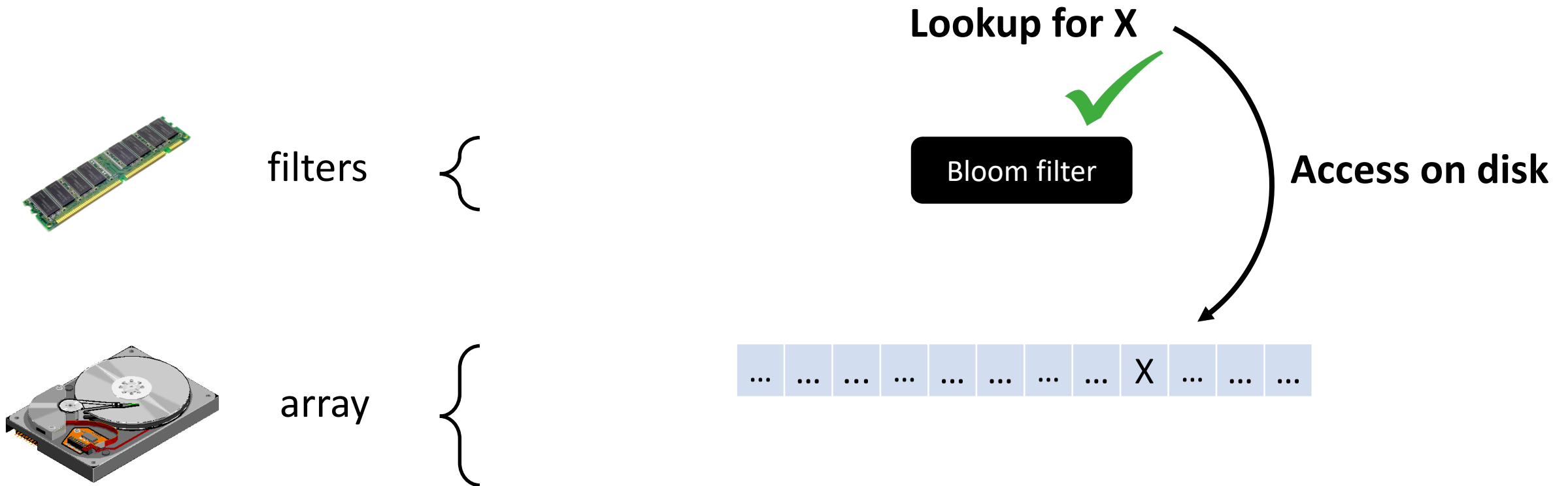
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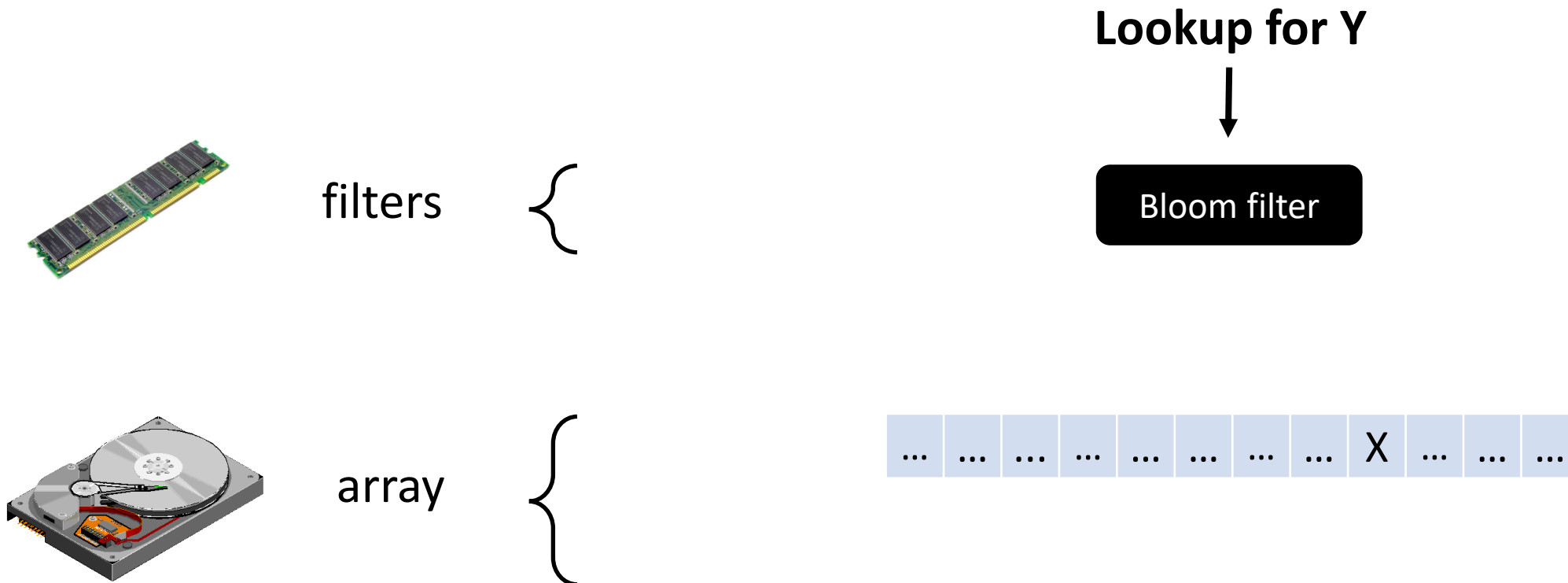
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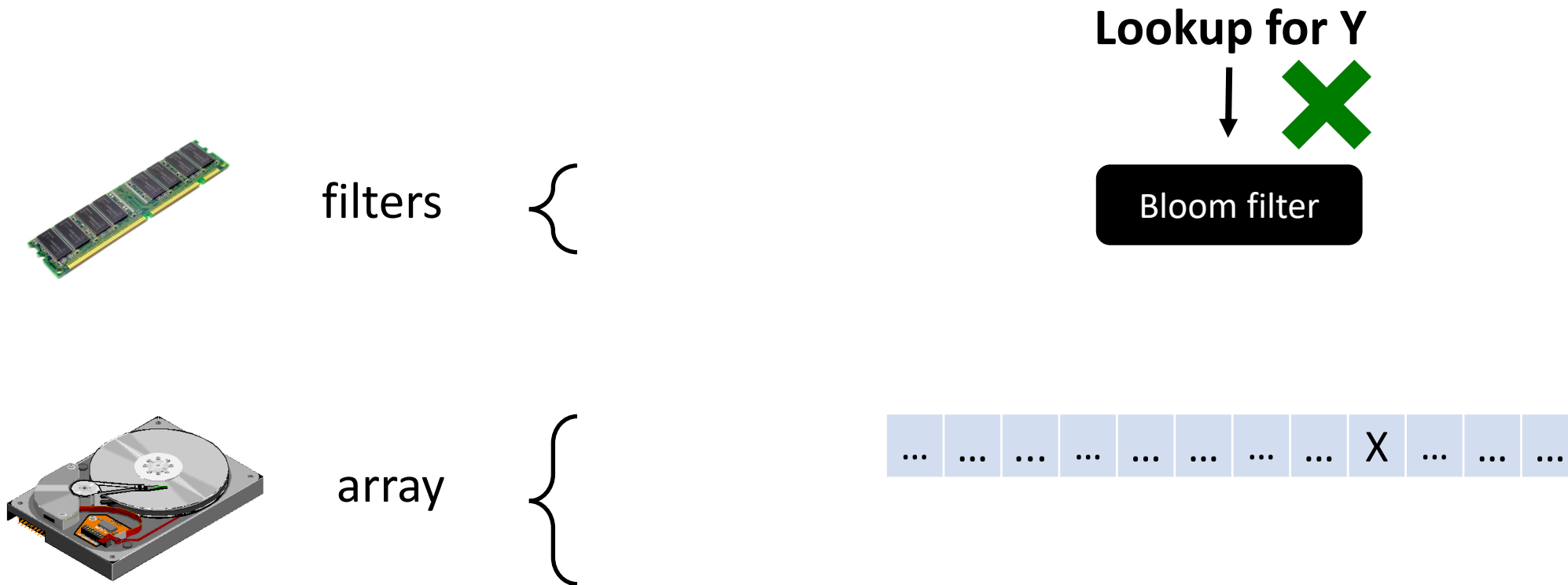
# Bloom Filters

Answers set-membership queries

Smaller than array, and stored in main memory

Purpose: avoid accessing disk if entry is not in array

Subtlety: may return false positives.



# Bloom Filters

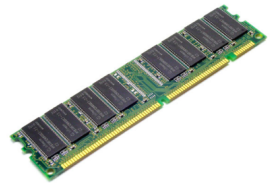
Answers set-membership queries

Smaller than array, and stored in main memory

Purpose: avoid accessing disk if entry is not in array

Subtlety: may return false positives.

**Lookup for Y**



filters



array



Bloom filter



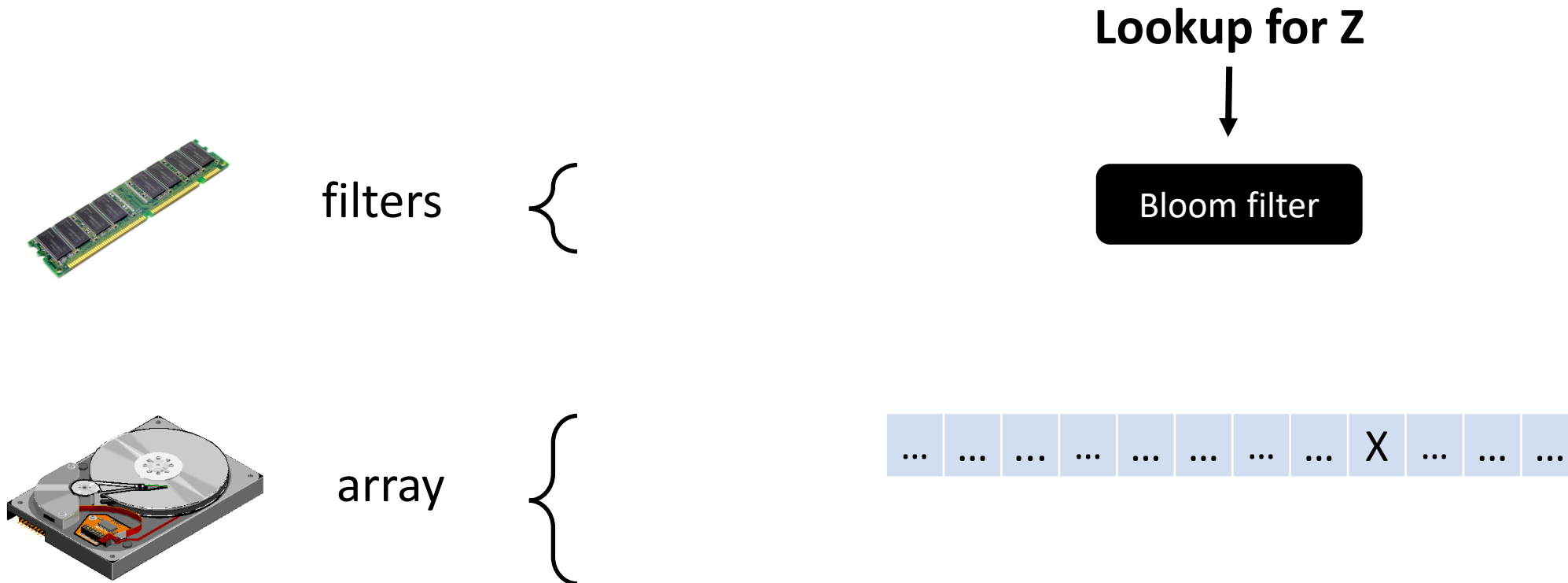
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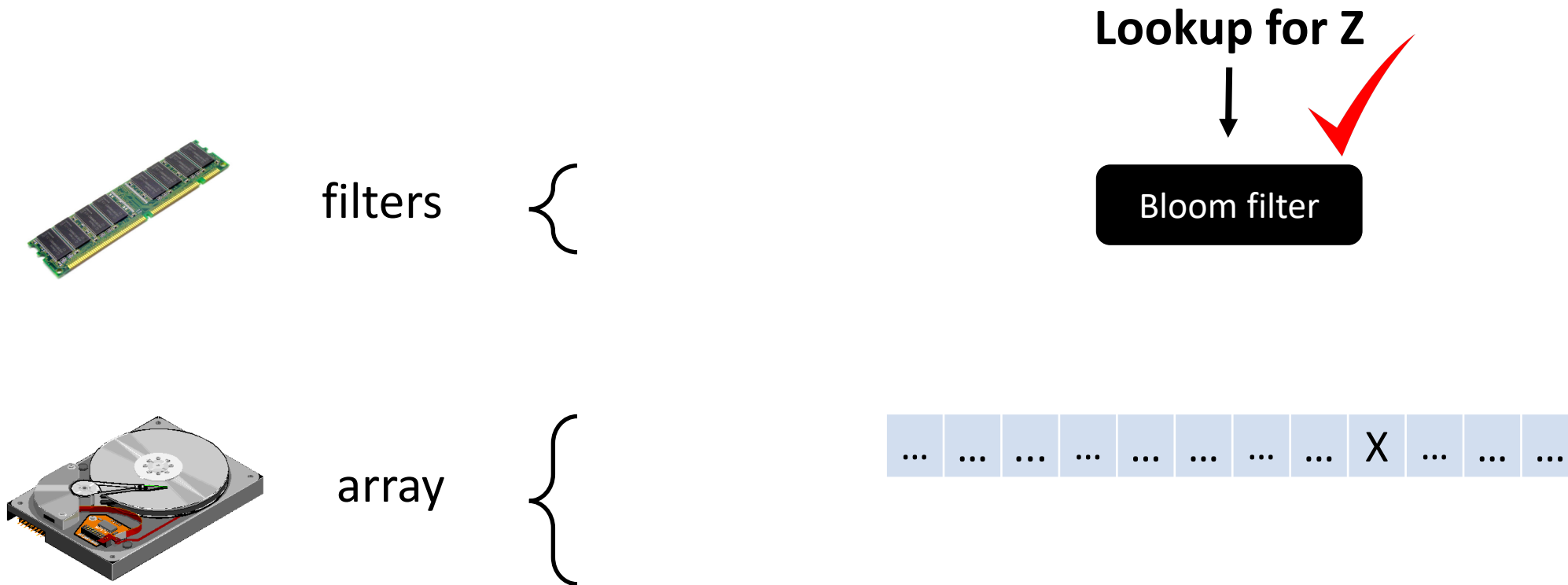
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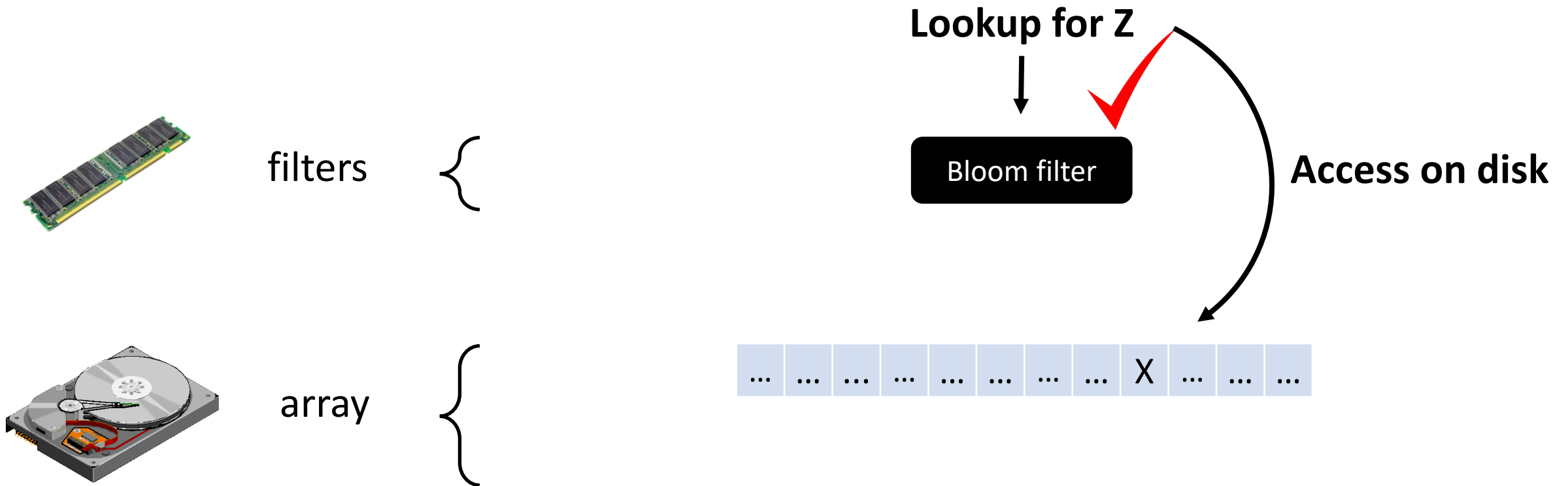
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Answers set-membership queries

Smaller than array, and stored in main memory

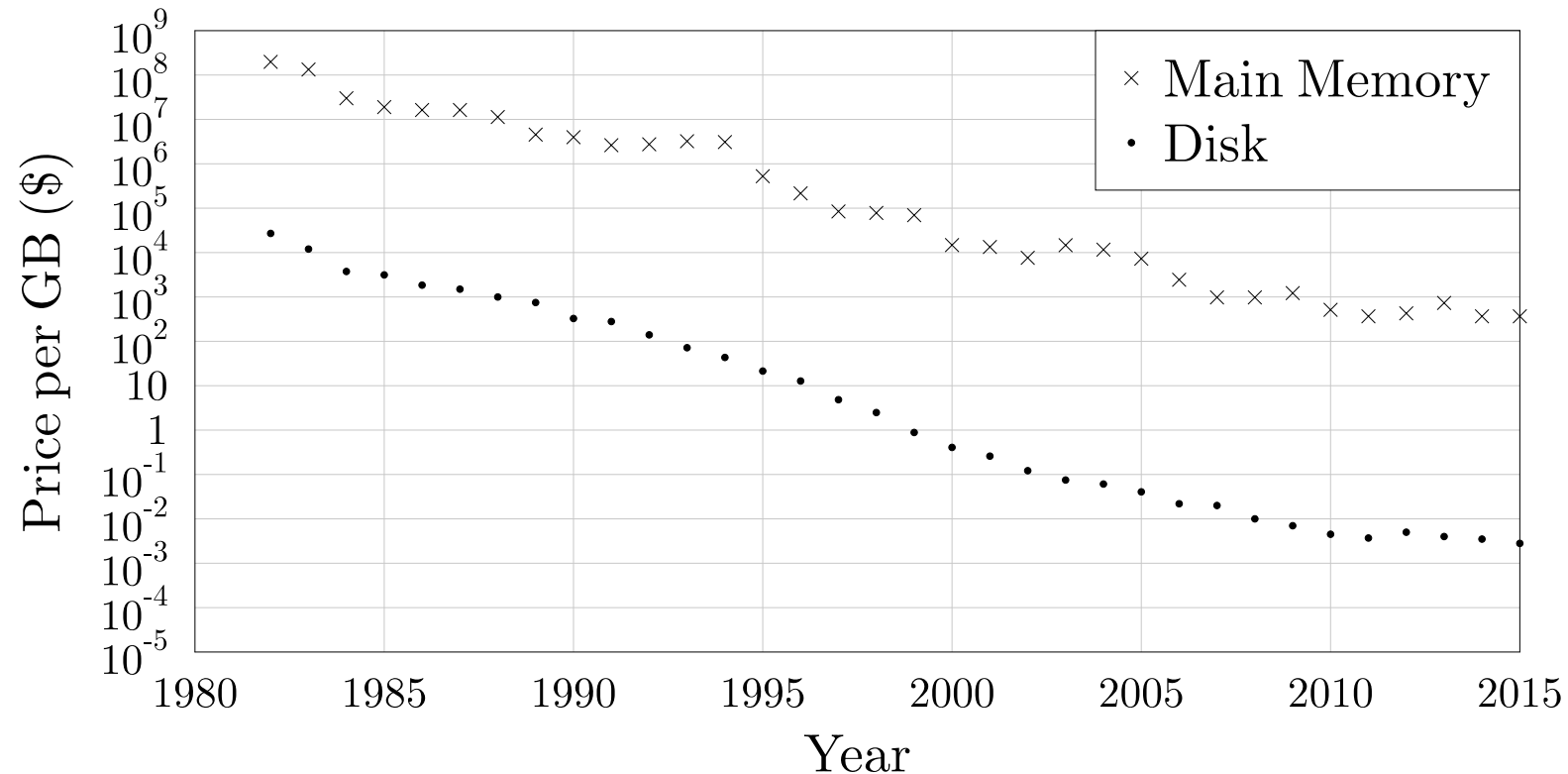
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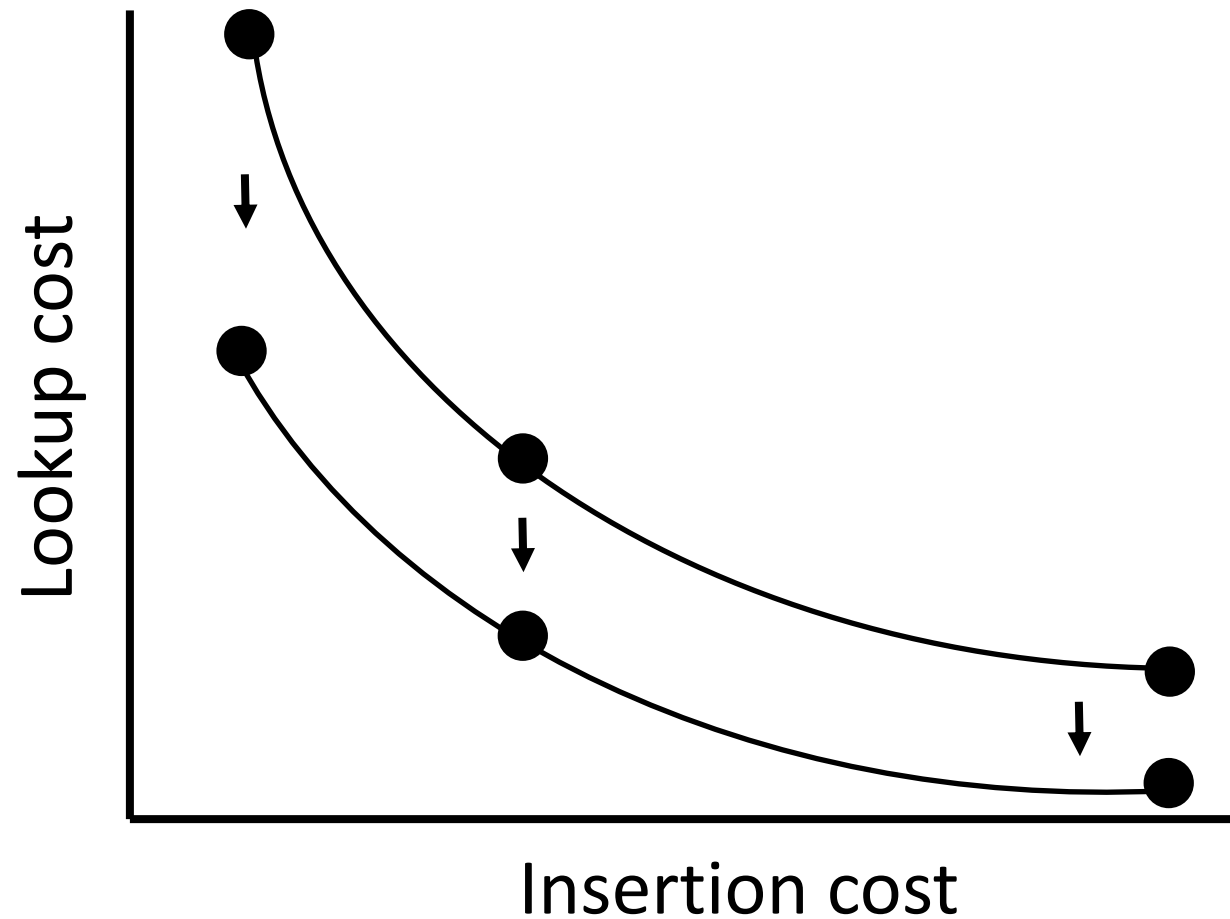
# Bloom Filters

The more main memory, the fewer false positives  $\Rightarrow$  cheaper lookups



# Bloom Filters

The more main memory, the fewer false positives  $\Rightarrow$  cheaper lookups





# Conclusions

Write-optimized

Highly tunable

Backbone of many modern systems

Trade-off between lookup and insert cost (tiering/leveling, size ratio)

Trade main memory for lookup cost (fence pointers, Bloom filters)

**Thank you!**

CS460: Intro to Database Systems

# Database Systems and Beyond

Instructor: Manos Athanassoulis

<https://bu-disc.github.io/CS460/>

# Database Systems

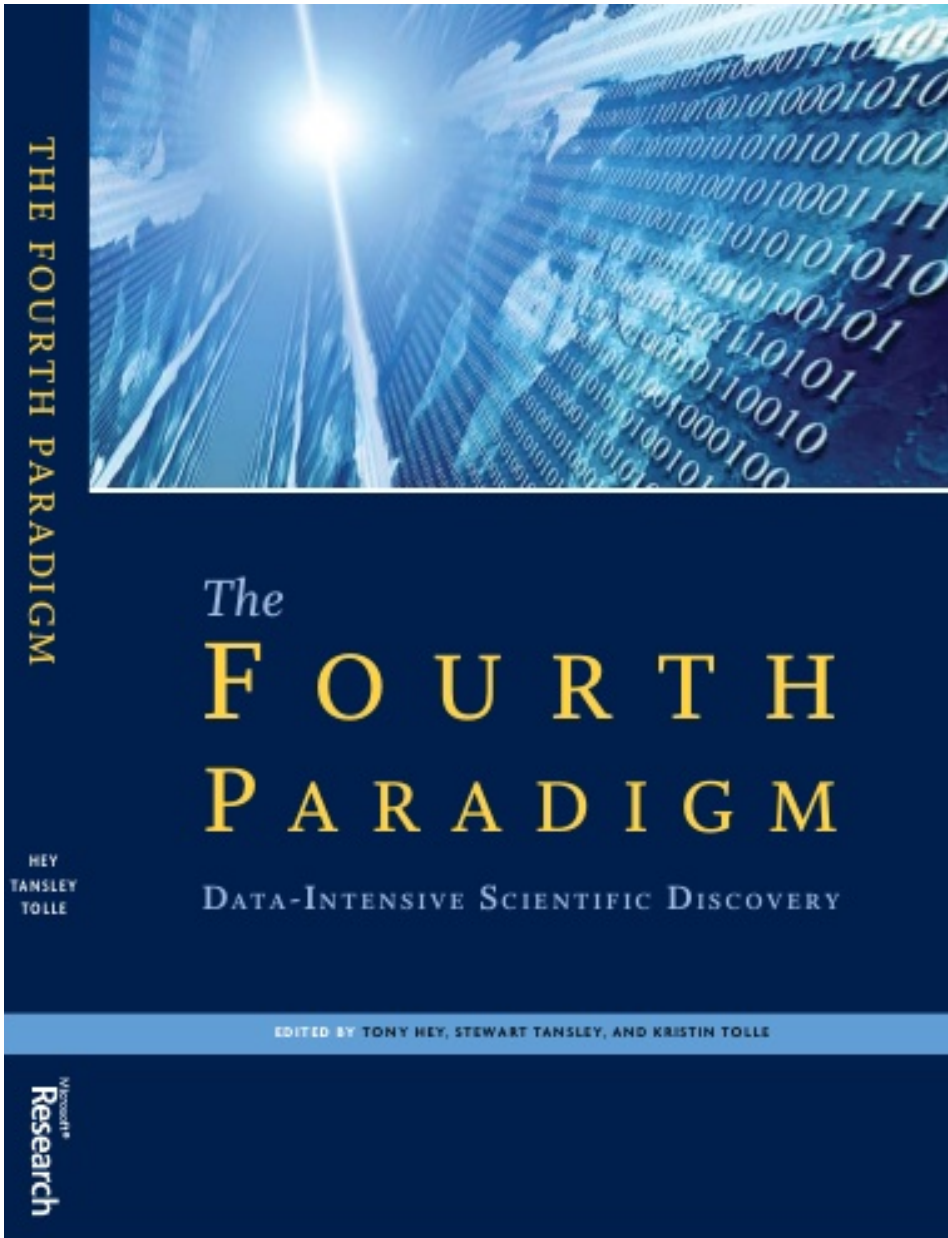
we spent a whole semester on Database Systems  
what is next?

***what can we do with data?***

data-driven science

data-driven discovery

data-driven governance



*“Experimental, theoretical, and computational science are all being affected by the data deluge, and a fourth, ‘**data-intensive**’ science paradigm is emerging.*”

*The goal is to have a world in which all of the science literature is online, all of the science data is online, and they interoperate with each other. **Lots of new tools are needed to make this happen.**”*

Faster Innovation through Data-Intensive Approaches

Need for Innovation in Data Management!

# DATA & AI LANDSCAPE 2019

## INFRASTRUCTURE

**HADOOP ON-PREMISE**  
cloudera Hortonworks  
MAPR Pivotal  
IBM InfoSphere  
jethro

**HADOOP IN THE CLOUD**  
aws Microsoft Azure  
Google Cloud  
SAP Cloud Platform  
IBM InfoSphere BigInsights  
arm  
Duble CAZENA

**STREAMING / IN-MEMORY**  
Amazon Kinesis  
databricks  
SAP Cloud Platform  
ORACLE  
confluent  
strimio hazelcast  
GridGain  
GIGASPACEs Wallaroo  
FASTDATA kx

**NoSQL DATABASES**  
Google Cloud AWS  
ORACLE  
MongoDB MarkLogic  
Couchbase DISTRAX  
redislabs KEROPIKE  
ArangoDB SCYLLA

**NewSQL DATABASES**  
SAP Clustrix  
Pivotal  
MongoDB  
MEMSQL infuxdata  
Cockroach LABS  
VOLTDB splice  
paradigm

**GRAPH DBs**  
neo4j  
Amazon Neptune  
IBM  
ORACLE  
OrientDB  
InfiniteGraph  
Objectivity

**MPP DBs**  
TERADATA  
IBM Data Warehouse Systems  
Qcon  
Kognitio  
Exasol  
dremio  
Yellowbrick

**CLOUD EDW**  
aws  
Google Cloud  
Microsoft Azure  
Pivotal  
snowflake  
Infoworks

**SERVERLESS**  
Amazon Lambda  
Google Cloud  
Microsoft Azure  
Pivotal  
snowflake  
PULSAR  
nuclio  
Pulsar Function Service

**DATA TRANSFORMATION**  
talend pentaho  
alteryx TRIFACTA  
tamr Paxata  
StreamSets UNIFI

**DATA INTEGRATION**  
SAP Data Services Informatica  
MuleSoft TEALUM  
snaplogic enigma  
Segment ATTUNITY  
xplenty ZALONI  
Import.io  
Informatics Fivetran  
SNOWFLOW MATILLION

**DATA GOVERNANCE**  
Informatica  
SailPoint  
IBM  
colibra  
Alation  
OKERA  
MANTA  
dataworld

**MGMT / MONITORING**  
aws New Relic  
actifio  
rubrik  
APPDYNAMICS  
dynatrace  
SignalFX  
drwuu  
splunk  
Moogsoft pagerduty  
unavai Numentry  
zabbix OpsRamp  
MAGNITUDE

**STORAGE**  
aws  
Microsoft Azure  
PURE STORAGE  
ALLUXIO wasabi  
Qumulo panache  
COHERITY

**CLUSTER SVCS**  
Amazon EMR  
IBM Storage  
Microsoft Azure  
MESOSPHERE  
packet  
nimbustorage  
Qumulo panache  
COHERITY

**DATA GENERATION & LABELLING**  
amazon mechanicalturk  
upwork  
open  
hive  
Mighty AI  
ALEXPERE  
LIONBRIDGE

**AI OPS**  
ALGORITHMIA  
SPILL comet  
Verta.ai datmo  
datastrat  
WhisperAI  
Determined AI  
tidder

**GPU DBs & CLOUD**  
kinetica  
SQUEAM  
bryllyt  
BLAZINGDB  
PG-Stream  
LOYDHUB

**HARDWARE**  
Google TPU arm  
intel AI NVIDIA  
GRAPHCORE MYTHIC  
Graphcore  
Movidius habana  
WAVE  
CERAMIC  
PULSAR  
DEFINIX

## CROSS-INFRASTRUCTURE/ANALYTICS

aws Google Cloud Microsoft IBM SAP Hewlett Packard Enterprise SAS IOIOWATA vmware TIBCO TERADATA ORACLE NetApp syncsort MAPR cloudera

## ANALYTICS & MACHINE INTELLIGENCE

**DATA ANALYST PLATFORMS**  
Microsoft pentaho alteryx  
Digital Reasoning  
GUAVUS AYASDI  
ATTIVO Datameer incorta  
interana MODE ENDOR  
sisu switchboard Starburst

**DATA SCIENCE PLATFORMS**  
IBM databricks dataiku  
DOMINO rapidminer TIBCO  
ANACONDA SAS  
KNIME MathWorks

**BI PLATFORMS**  
looker  
amazon analytics  
DOME  
ARCADIA DATA ThoughtSpot  
ATSCALE  
Qlik  
MicroStrategy Keon IO

**VISUALIZATION**  
tableau  
Power BI  
SAP  
Google Cloud  
celonis  
Periscope Data  
zepl  
CHARTIO

**MACHINE LEARNING**  
Amazon SageMaker  
Google Cloud  
H2O  
DataRobot gamalon  
VISENZE ELEMENT  
deepense.ai

**COMPUTER VISION**  
Microsoft Azure  
Amazon Rekognition  
Clarifai  
EVERAI  
neura  
UBIQUITY  
synthesia

**HORIZONTAL AI**  
IBM Watson Cortana  
sentient  
Affectiva  
Numenta  
narologics  
BLU VISION

**SPEECH & NLP**  
Google Cloud  
amazon alexa  
narrative science  
Mobval  
SoundHound Inc  
SMARTLING

**SEARCH**  
elasticsearch ORACLE  
algolia covéo  
Lucidworks ATTIVO  
swiftype  
omnius SINEQUA

**LOG ANALYTICS**  
splunk  
splunklog  
solarwinds  
TIMBER  
kibana  
logz.io

**SOCIAL ANALYTICS**  
Hootsuite  
NETBASE  
synthesio  
simplereach  
bitly SimilarWeb

**WEB / MOBILE / COMMERCE ANALYTICS**  
Google Analytics  
mixpanel  
Airtable RESCI  
SIGOPT  
granify  
custora

## APPLICATIONS - ENTERPRISE

**SALES**  
CHORUS  
INSIDESALES.COM  
conversica  
clari  
fuse

**MARKETING - B2B**  
RADIUS  
EVERSTRING  
MINTIGO  
sense  
tubular  
KNOTCH

**MARKETING - B2C**  
Zeta  
bloomreach  
SendGrid  
braze  
ACTIONIQ  
BLUECORE  
CONTENT SQUARE  
TEALUM  
mparticle  
Amplero  
amperity  
QUANTIFIND  
Simon  
Lytic  
PERSADO  
remesh

**CUSTOMER EXPERIENCE / SERVICE**  
qualtrics  
MEDALLIA  
SurveyMonkey  
CLARABRIDGE  
zendesk  
Kustomer  
freshdesk  
INTERCOM  
Drift  
LIVEXPERSON  
Gainsight  
pendo  
HEAP  
Amplitude  
Watson Assistant  
DigitalGenius  
A.S.A.P.P  
ada  
NUTOMAT  
afiniti  
CaDesk  
NORMI  
frame ai

**ENTERPRISE PRODUCTIVITY**  
slack  
ORACLE  
GURU  
lumiata  
DIFFBOT  
clara  
talla  
Kasisto

**HUMAN CAPITAL**  
HireVue  
pymetrics  
hiQ  
GOSTER  
mya  
Aillyo  
textlio  
Wade&Wendy  
Stella  
entelo  
uncommon  
eat  
beomey

**LEGAL**  
RAVEL  
Everlaw  
DISCO  
kairo  
JUDICATA  
BREVIA  
IRONCLAD  
PREMPTION  
ROSS  
Casetext

**REGTECH & COMPLIANCE**  
BigID  
Tessian  
text IQ  
Comply Advantage

**FINANCE**  
Fianplan  
ZUORA  
SAP  
SAHANA  
TRADESHIFT  
mineral tree  
SCALE FACTOR  
baulkeeper  
pilot

**BACK OFFICE AUTOMATION & RPA**  
UiPath  
hyperperformance  
blueprints  
VIDADO  
AppZen  
WorkFusion  
workato  
Reworks  
Catalytic  
ANTWORKS  
KRYON  
ALUKYI

**SECURITY**  
TANIUM  
CYLANCE  
zscaler  
StackPath  
illumio  
CODE42  
CyberCloud  
DARKTRACE  
ANOMALI  
Vectra  
Guardian  
DATAVISOR  
sift science  
pindrop  
exabeam  
SICNIFYD  
Sentinel  
SecurityScorecard  
SECURE  
Vade Secure  
bitglass  
BlueTalon  
Recorded Future  
frozdozi  
Cyber  
BITSIGHT  
sparkcognition  
CyberArk  
FIRTER  
riskrecon  
JASK  
ARCA SECURITY  
BLUEHEXAGON  
Semble  
OSSIM  
XANONIX  
SHIELD A  
ArmedBlock

## APPLICATIONS - INDUSTRY

**ADVERTISING**  
AppNexus  
critico  
ORACLE  
MOAT  
theTradeDesk  
dstillery  
Liventent  
TAPAD  
datax  
gumgum  
Cuppr

**EDUCATION**  
Lilishuo  
Knewton  
Clever  
Cleara  
kidaptive  
PANORAMA  
knowre  
gradescope

**REAL ESTATE**  
REDFIN  
Opndoor  
VTS  
CREDIFI  
GEOPHY  
geonomy  
COMPSTAK  
SPACEMAKER  
SKYLINE

**GOV'T**  
OPENGOV  
mark43  
LiveStories  
Passport  
SmartProcure  
STREETLIGHTDATA  
OpenDataSoft

**INTELLIGENCE**  
Palantir  
Dataminr  
Quid  
PRIMER  
FORGE

**FINANCE - INVESTING**  
KENSHC  
Quantopian  
ADAPER  
NUMERA  
SENTIUM  
ALGORIZ  
FlavourPack  
PAGAYA

**FINANCE - LENDING**  
ondeck  
affirm  
拍拍贷  
JIANPU.AI  
Kreditech  
AVANT  
TALA  
finance  
Upstart  
CLEARBANC  
Upgrade  
100Credit  
WeLab  
WeCASH  
TrueAccord  
MoneyLion  
Active AI  
aire  
cignifi

**INSURANCE**  
Metromile  
Lemonade  
CYENCE  
Hippo  
Shift Technology  
ROOT  
Zesty AI  
CAPE

## OPEN SOURCE

**FRAMEWORKS**  
Spark  
Flink  
YARN  
TEZ  
MESOS  
docker  
CDAP  
HELDX  
Red Hat

**QUERY / DATA FLOW**  
Spark SQL  
presto  
SLAMDATA  
APACHE DRILL  
ARCHE DRILL  
GraphQL  
Flink

**DATA ACCESS & DATABASES**  
cassandra  
mongoDB  
redis  
Cockroach LABS  
druid  
CouchDB  
OMEN  
SciDB  
riak  
riak

**ORCHESTRATION & MGMT**  
talend  
Apache Zookeeper  
Apache Ambari  
Apache Airflow  
MESOS  
etcd  
Kong

**STREAMING & MESSAGING**  
Spark  
nifi  
Flink  
beam  
kafka  
STORM  
Apache RocketMQ

**STAT TOOLS & LANGUAGES**  
python  
Scala  
Studio  
SciPy  
julia

**AI OPS & INFRA**  
miflow  
Kubeflow  
misp  
DC  
SELECON  
PyTorch  
PyLemon

**AI / MACHINE LEARNING / DEEP LEARNING**  
TensorFlow  
Keras  
theano  
DM TK  
OpenAI  
VELES  
Chainer  
MICHELANGLO  
ONNX  
neon  
DSSTNE  
mlib  
DL4J  
MAHOUT  
Aerosolve  
Fast.ai  
mir

**SEARCH**  
elasticsearch  
Solr

**LOGGING & MONITORING**  
elasticsearch  
kibana  
sentry  
logstash  
Prometheus  
fluentbit  
fluentd  
Grafana  
VECTOR

**VISUALIZATION**  
matplotlib  
TensorBoard  
seaborn  
Bokeh

**COLLABORATION**  
BeakerX  
jupyter  
Anaconda

**SECURITY**  
Apache Ranger  
KNOX  
Sentry  
accruML

## DATA SOURCES & APIs

HEALTH: Apple, VALIDIC, practicefusion  
IOT: GE Digital, IOTAKE  
FINANCIAL & ECONOMIC DATA: S&P 500, FINRA  
AIR / SPACE / SEA: NASA, NOAA  
PEOPLE / ENTITIES: LinkedIn, CLEARBANC  
LOCATION INTELLIGENCE: HERE, HERE  
OTHER: Various niche data providers

## DATA RESOURCES

DATA SERVICES: Various providers  
INCUBATORS & SCHOOLS: Various programs  
RESEARCH: facebook research, OpenAI, etc.

see full version at: <http://mattturck.com/wp-content/uploads/2019/07/2019-Matt-Turck-Big-Data-Landscape>

# DATA & AI LANDSCAPE 2019

## INFRASTRUCTURE

**HADOOP ON-PREMISE**  
cloudera Hortonworks  
MAPR Pivotal  
IBM InfoSphere  
jethro

**HADOOP IN THE CLOUD**  
aws Microsoft Azure  
Google Cloud  
SAP Cloud Platform  
IBM InfoSphere BigInsights  
arm  
Luible CAZENA

**STREAMING / IN-MEMORY**  
Amazon Kinesis  
databricks  
SAP Cloud Platform  
ORACLE  
confluent  
strim hazelcast  
GridGain  
GIGASPACE  
FASTDATA  
kx

**NO SQL DATABASES**  
aws  
ORACLE  
mongoDB MarkLogic  
Couchbase DISTRAX  
redislabs  
KEROPIKE  
MongoDB SCYLLA

**NEWSQL DATABASES**  
SAP Clustrix  
Pivotal  
MEMSQL  
infuxdata  
cockroach LABS  
VOLTDB splice  
paradigm  
IBM Amazon Neptune  
ORACLE  
Cognio  
Exasol  
dremio  
Yellowbrick  
Objectivity

**GRAPH DBs**  
neo4j  
Amazon Neptune  
IBM  
ORACLE  
InfinteGraph

**MPP DBs**  
TERADATA  
IBM Data Warehouse Systems  
Cognio  
Exasol  
dremio  
Yellowbrick

**CLOUD EDW**  
aws  
Microsoft Azure  
Pivotal  
snowflake  
Infoworks

**SERVERLESS**  
aws  
Microsoft Azure  
Pivotal  
snowflake  
Infoworks

**DATA TRANSFORMATION**  
talend pentaho  
alteryx TRIFACTA  
tamr Paxata  
StreamSets UNIFI

**DATA INTEGRATION**  
Microsoft Informatica  
snoplogic enigma  
Qlik Data Catalyst  
Segment ATUNITY  
splenty ZALONI  
Import.io  
InfoWorks Fivetran  
SNOWFLOW MATILLION

**DATA GOVERNANCE**  
Informatica  
IBM  
Maize Skyhigh Security Cloud  
colibra dremio  
Alation  
HDDTA  
OKERA  
MANTA data.world

**MGMT / MONITORING**  
New Relic octio  
rubrik APPDYNAMICS  
dynatrace WAVEFRONT  
SignalFx druva  
splunk Moogsoft pagerduty  
unavai Numentry  
SEALY VEBAM  
zabbix OpsRamp MAGNITUDE

**STORAGE**  
aws  
Microsoft Azure  
PURE STORAGE  
ALLUXIO wasabi  
Qumulo panache  
COHERITY

**CLUSTER SVCS**  
Amazon EMR  
IBM  
Microsoft Azure  
MESSENGER  
packet  
nimbustorage  
Quanto  
CYCLOCLOUD

**DATA GENERATION & LABELLING**  
amazon mechanicalturk  
upwork  
open scale  
HIVE Labelbox  
Mighty AI  
ALEXEE  
LIONBRIDGE

**AI OPS**  
ALGORITHMIA  
SPILL comet  
Verta.ai datmo  
datastrat  
WhisperAI  
Determined AI  
tidder

**GPU DBs & CLOUD**  
kinetica  
SQUEAM  
bryllyt  
BLAZINGDB  
PG-Stream  
LOYDHUB

**HARDWARE**  
Google TPU arm  
intel GPU NVIDIA  
GRAPHICORE MYTHIC  
Graphcore  
Cerebras  
Movidius habana  
WAVE  
CERAMAI  
PULSAR  
floggit DEFINIX

**CROSS-INFRASTRUCTURE/ANALYTICS**  
aws Google Cloud Microsoft IBM SAP Hewlett Packard Enterprise SAS IOIOWATA vmware TIBCO TERADATA ORACLE NetApp syncsort MAPR cloudera

## ANALYTICS & MACHINE INTELLIGENCE

**DATA ANALYST PLATFORMS**  
Microsoft pentaho alteryx  
Digital Reasoning  
GUAVUS AYASDI  
ATTIVO Datameer incorta  
interana MODE ENDOR  
sisu switchboard Starburst

**DATA SCIENCE PLATFORMS**  
IBM databricks dataiku  
DOMINO rapidminer TIBCO  
ANACONDA SAS  
KNIME MathWorks

**BI PLATFORMS**  
looker embed analytics  
aws  
DOMO ARCADIA DATA ThoughtSpot  
ATSCALE Qlik  
GoodData Information Builders birst  
MicroStrategy Keon IO

**VISUALIZATION**  
tableau Power BI  
SAP  
Google Cloud  
celonis Periscope Data  
zepl VIZIUM  
CHARTIO TOUCAN TCO

**MACHINE LEARNING**  
Amazon SageMaker  
Google Cloud  
H2O  
DataRobot gamalon  
VISENZE ELEMENT  
deepense.ai

**COMPUTER VISION**  
Microsoft Azure  
Amazon Rekognition  
Clarifai  
EVERAI deepomatic  
neura twentybn  
UBIQUITY AEE  
synthesis DataClz

**HORIZONTAL AI**  
IBM Watson Cortana Face  
sentient Voyager  
Affectiva PROPHESIE  
Numenta PETRUM  
narologics CURIOUS AI  
OSARO

**SPEECH & NLP**  
Google Cloud twilio  
amazon alexa Amazon Transcribe  
narrative science semantic machines  
Mobval  
SoundHound Inc. PRIMER  
Mindfield  
SMARTLING Unbabel PolyAI

**SEARCH**  
elasticsearch ORACLE ENDECA  
algolia covéo  
Lucidworks ATTIVO  
swiftype EXALEAD  
alphasense MAANA  
omnius SINEQUA

**LOG ANALYTICS**  
splunk sumologic  
solarwinds  
TIMBER  
kibana  
logz.io

**SOCIAL ANALYTICS**  
Hootsuite sprinklr  
NETBASE  
synthesio track  
simple reach  
bitly SimilarWeb

**WEB / MOBILE / COMMERCE ANALYTICS**  
Google Analytics  
mixpanel AMPITUDE  
Airtable RESCI  
SIGOPT granify  
custora

## APPLICATIONS - ENTERPRISE

**SALES**  
CHORUS  
INSIDESALES.COM peopleai  
conversica  
clari aviso tact.ai  
fuse machines Clearbit

**MARKETING - B2B**  
RADIUS App Annie  
EVERSTRING Lattice  
MINTIGO sense  
tubular  
KNOTCH mrpe

**MARKETING - B2C**  
Zeta bloomreach SendGrid  
braze ACTIONIQ BLUECORE  
CONTENT SQUARE TEALIUM mparticle  
Amplero amperity QUANTIFIND  
Simon Lytice PERSADO  
remesh

**CUSTOMER EXPERIENCE / SERVICE**  
qualtrics MEDALLIA SurveyMonkey UserTesting  
CLARABRIDGE zendesk Customer freshdesk  
INTERCOM Drift LIVEPERSON Gainsight pendo  
HEAP Amplitude Watson Assistant  
DigitalGenius A.S.A.P. ada NUTOMAT ahniti  
CaDesk METORMI

**ENTERPRISE PRODUCTIVITY**  
slack  
ORACLE  
GURU lumia  
DIFFBOT clara  
talla Kasisto

**HUMAN CAPITAL**  
Hiive  
hiQ GOSTER mya  
Aillyo textio  
Wade&Wendy Stella  
entelo  
uncommon

**LEGAL**  
RAVEL  
Everlaw  
DISCO kiro  
JUDICATA  
BREVIA

**REGTECH & COMPLIANCE**  
BigID TESSIAN  
text IQ Comply Advantage  
PARTNERSHIPS  
CROSSCHECK  
DATA REPUBLIC

**FINANCE**  
fnaplan  
ZUORA  
SAP S/4HANA  
TRADESHIFT  
SCALE FACTOR  
baulkeeper  
pilot

**BACK OFFICE AUTOMATION & RPA**  
UiPath  
blueprints  
VIDADO AppZen  
WorkFusion workato  
SCALE FACTOR  
ANTWORKS  
ALUKYI

**SECURITY**  
TANIUM CYLANCE zscaler StackPath illumio  
CODE42 CipherCloud  
VECTRA  
pindrop exabeam  
CyberSecure bitglass  
BlueTalon Recorded Future  
sparkcognition  
ARCA SECURITY BLUEHEXAGON Semble

## APPLICATIONS - INDUSTRY

**ADVERTISING**  
AppNexus  
critico  
ORACLE MOAT  
theTradeDesk  
dstillery  
Cuppr

**EDUCATION**  
Liluisihou  
Knewton  
Clever  
Credifi  
geomy  
COMPSTAK  
skyline

**REAL ESTATE**  
REDFIN  
Opndoor  
VTS  
Credifi  
geomy  
COMPSTAK  
skyline

**GOV'T**  
OPENGOV  
mark43  
LiveStories  
Passport  
SmartProcure  
STREETLIGHTDATA  
OpenDataSoft

**INTELLIGENCE**  
Palantir  
Dataminr  
Quid  
PRIMER  
FORGE

**FINANCE - INVESTING**  
KENSHC  
Quantopian  
ADAPER  
NUMERA  
SENTIUM  
ALGORIT  
FlavourPack  
PAGAYA

**FINANCE - LENDING**  
ondeck affirm  
JIANPU.AI  
Kreditech AVANT  
TALA  
CLEARBANC  
100Credit WeLab  
TrueAccord MoneyLion  
aire cignifi

**INSURANCE**  
Metromile  
Lemonade  
CYENCE  
Hippo  
Shift Technology  
ROOT  
zesty.ai  
CAPE

**HEALTHCARE**  
flatiron Clover KYRUS  
METABIOTA Gingerio Glow  
3DMed zebra PathAI Ovia  
TEMPUS patientslikem  
LIMAKO  
notable  
Qventus ARTERYS IMA GEN  
innovaccer

**LIFE SCIENCES**  
Zelus  
BenevolentAI verily  
WuXiNextCODE  
Clear Labs  
Phosphorix  
twoAR  
QWIKIN

**TRANSPORTATION**  
UBER TESLA  
CLEARPATH CRUISE  
drive ai CAMBRIDGE  
nauto AMOTIVE G7 PILOT AI  
NIO OPTIMUS moovit  
netradynye  
thinc INRIX

**AGRICULTURE**  
FARMERS  
Granular  
JOHN DEERE  
BLUERIVER  
FarmersEdge  
AgroStar  
FarmLogs  
TARANIS  
GAMAYA  
Terraviva  
prospera

**COMMERCE**  
instacart  
FAIRFIRE  
STITCH FIX  
Doo & Co  
lowGood  
heuristic  
eHarmony stem Amper  
happn select  
VERDIGR duolet  
Electric ZINER

**INDUSTRIAL**  
AVEVA SIEMENS  
PREDIX UPTAKE  
SCORTEX  
TACHYUS  
OTHER  
ByteDance  
SJOERN BBOXEVER  
Spoke

## OPEN SOURCE

**FRAMEWORKS**  
Spark  
Flink YARN TEZ  
MESOS  
docker CDAP  
RedHat

**QUERY / DATA FLOW**  
Spark SQL  
presto  
SLM

**DATA ACCESS & DATABASES**  
cassandra mongoDB redis  
cockroachdb

**ORCHESTRATION & MGMT**  
talend  
Apache Zookeeper

**STREAMING & MESSAGING**  
Spark  
nifi

**STAT TOOLS & LANGUAGES**  
python  
Scala

**AI OPS & INFRA**  
miflow

**AI / MACHINE LEARNING / DEEP LEARNING**  
TensorFlow Keras  
theano  
PyTorch  
mxnet  
ONNX  
MAHOUT Aerosolve FastAI

**SEARCH**  
elasticsearch  
Solr

**LOGGING & MONITORING**  
elasticsearch kibana SENTRY  
logstash Prometheus  
fluentbit fluentd Grafana  
VECTOR

**VISUALIZATION**  
matplotlib  
TensorBoard  
seaborn  
Bokeh

**COLLABORATION**  
BeakerX  
jupyter  
ANACONDA

**SECURITY**  
Apache Ranger  
KNOX  
Sentry  
accruiolo

**HEALTH**  
Apple VALIDIC  
practicefusion

**IOT**  
GE Digital  
MISTAKE

**FINANCIAL & ECONOMIC DATA**  
SAS

**AIR / SPACE / SEA**  
Airbus

**PEOPLE / ENTITIES**  
Microsoft Cognitive Toolkit

**LOCATION INTELLIGENCE**  
Microsoft Cognitive Toolkit

**OTHER**  
Microsoft Cognitive Toolkit

**DATA SERVICES**  
Microsoft Cognitive Toolkit

**INCUBATORS & SCHOOLS**  
Microsoft Cognitive Toolkit

**RESEARCH**  
facebook research  
OpenAI

The Backbone is Database Systems, Storage Engines, & Frameworks for Parallelization

increase throughput by parallelization

“scale-up”

use more powerful machines (>#CPUs, >RAM)

“scale-out”

use more machines

# Scale Up Execution

how to use more cores (threads)?

## **inter-query parallelism**

each query runs on one processor

## **inter-operator parallelism**

each query runs on multiple processors

an operator runs on one processor

## **intra-operator parallelism**

An operator runs on multiple processors



# Scale Up Storage

needs more disks!

how to distribute data?

**block partition**

**hash partition**

**range partition**

how to distribute data accesses?

# Scale Out

similar questions across machines

new bottlenecks?

move data across machines: network!

# DATA & AI LANDSCAPE 2019

## INFRASTRUCTURE

**HADOOP ON-PREMISE**  
 cloudera Hortonworks  
 MAPR Pivotal  
 IBM InfoSphere  
 jethro

**HADOOP IN THE CLOUD**  
 aws Microsoft Azure  
 Google Cloud  
 SAP Cloud Platform  
 IBM InfoSphere BigInsights arm  
 Dubble CAZENA

**STREAMING / IN-MEMORY**  
 Amazon Kinesis  
 SAP Cloud Platform ORACLE  
 Confluent  
 Strimzi hazelcast GridGain  
 GIGASPACEs Wallaroo.ai FASTDATA kx

**SQL DATABASES**  
 Google Cloud AWS  
 ORACLE Microsoft Azure  
 mongoDB MarkLogic  
 Couchbase DISTRAXT  
 redislabs KERO SPIKE  
 ArangoDB SCYLLA

**NewSQL DATABASES**  
 SAP Clustrix Pivotal  
 Microsoft Azure  
 MEMSQL infuxdata  
 Cockroach LABS  
 VOLTDB splice  
 paradigms

**GRAPH DBs**  
 Amazon Neptune  
 IBM  
 ORACLE  
 OrientDB  
 InfiniteGraph  
 Objectivity

**MPP DBs**  
 TERADATA  
 IBM Data Warehouse Systems  
 Kognitio  
 Exasol  
 dremio  
 Yellowbrick

**CLOUD EDW**  
 aws  
 Microsoft Azure  
 Pivotal  
 snowflake  
 Infoworks

**SERVERLESS**  
 Amazon SageMaker  
 Microsoft Azure  
 PULSAR  
 nuclio  
 Oracle Functions  
 Amazon Lambda

**DATA TRANSFORMATION**  
 SAP Data Services Informatica  
 MuleSoft TEALUM  
 snoplogic enigma  
 alteryx TRIFACTA  
 tamr Paxata  
 StreamSets UNIFI

**DATA INTEGRATION**  
 SAP Data Services Informatica  
 MuleSoft TEALUM  
 snoplogic enigma  
 Segment ATUNITY  
 splenty ZALONI import.io  
 Infoworks Fivetran  
 SNOWFLOW MATILLION

**DATA GOVERNANCE**  
 Informatica  
 IBM  
 colibra  
 Alation  
 OKERA  
 MANTA dataworld

**MGMT / MONITORING**  
 AWS New Relic octio  
 rubrik  
 dynatrace  
 SignalFx  
 splunk  
 Unavai  
 zentao OpsRamp

**STORAGE**  
 aws Google Cloud  
 Microsoft Azure IBM Storage  
 PURE STORAGE  
 ALLUXIO wasabi  
 nimbustorage  
 Quando panamasso  
 COHERITY

**CLUSTER SVCS**  
 Amazon EMR  
 IBM  
 Microsoft Azure  
 MESSORIDGE  
 packet  
 nimbustorage  
 Quando panamasso  
 COHERITY

**DATA GENERATION & LABELLING**  
 amazon mechanicalturk  
 Upwork  
 unity

**AI OPS**  
 ALGORITHMIA  
 SPILL comet  
 Verta.ai datmo

**GPU DBs & CLOUD**  
 kinetica  
 SQUEAM  
 intel AI NVIDIA  
 GRAPHCORE MYTHIC

**HARDWARE**  
 Google TPU arm  
 intel AI NVIDIA  
 GRAPHCORE MYTHIC

**CROSS-INFRASTRUCTURE/ANALYTICS**  
 aws Google Cloud Microsoft IBM SAP Hewlett Packard Enterprise SAS IOI DATA vmware TIBCO TERADATA ORACLE NetApp syncsort MAPR cloudera

**FRAMEWORKS**  
 Databricks Spark  
 Flink YARN TEZ  
 MESOS  
 docker CDAP  
 Red Hat HELIX

**QUERY / DATA FLOW**  
 Spark SQL  
 presto  
 SLAM DATA  
 APACHE DRILL  
 GraphQL  
 Flink

**DATA ACCESS & DATABASES**  
 cassandra mongoDB redis  
 CouchDB  
 Cockroach LABS ddruid  
 riak HBASE  
 Oracle Cloud  
 OCCULTULO

**ORCHESTRATION & MGMT**  
 talend  
 Apache Ambari  
 Apache Airflow  
 MESOS  
 etcd Kong

**STREAMING & MESSAGING**  
 Spark  
 nifi  
 Flink  
 beam  
 kafka STORM  
 Apache RocketMQ

**STAT TOOLS & LANGUAGES**  
 python  
 Scala  
 R  
 Studio  
 SciPy julia

**AI OPS & INFRA**  
 miflow  
 Kubeflow  
 mlops  
 SELDON  
 Polyaxon

**AI / MACHINE LEARNING / DEEP LEARNING**  
 TensorFlow Keras  
 OpenAI DM TK  
 theano  
 Apache SINGA  
 DIMSUM FeatureFu  
 mxnet VELES  
 Chainer  
 PyTorch  
 neon DSSTNE mlDl  
 DL4J MAHOUT Aerosolve FastAI mir

## ANALYTICS & MACHINE INTELLIGENCE

**DATA ANALYST PLATFORMS**  
 Microsoft pentaho alteryx  
 Digital Reasoning  
 GUAVUS AYASDI  
 ATTIVO Datameer incorta  
 interana MODE ENDOR  
 sisu switchboard Starburst

**DATA SCIENCE PLATFORMS**  
 IBM databricks dataiku  
 DOMINO rapidminer TIBCO  
 ANACONDA SAS  
 KNIME MathWorks

**BI PLATFORMS**  
 looker  
 DOME  
 ATSCALE  
 Qlik  
 MicroStrategy Keon IO

**VISUALIZATION**  
 tableau Power BI  
 SAP  
 Google Cloud  
 celonis  
 zepl  
 CHARTIO

**MACHINE LEARNING**  
 Azure Machine Learning  
 Google Cloud  
 H2O  
 DataRobot gamalon  
 VISENZE ELEMENT  
 deepsense.ai

**COMPUTER VISION**  
 Microsoft Azure  
 Amazon Rekognition  
 Clarifai  
 EVERAI  
 neuro  
 UBUIQUITY  
 trax

**HORIZONTAL AI**  
 IBM Watson Cortana  
 IBM Watson  
 Cortana  
 Face++  
 sentiment  
 Voyager  
 Affective  
 Numenta  
 narologies  
 BLUE VISION

**SPEECH & NLP**  
 Google Cloud  
 Amazon Translate  
 narrative science  
 Movable  
 SoundHound Inc  
 Mindfield  
 SMARTLING Unbabel PolyAI

**SEARCH**  
 elasticsearch ORACLE  
 algolia COVEO  
 Lucidworks ATTIVO

**LOG ANALYTICS**  
 splunk  
 sumologic  
 solarwinds

**SOCIAL ANALYTICS**  
 Hootsuite  
 sprinklr  
 NETBASE

**WEB / MOBILE / COMMERCE ANALYTICS**  
 Google Analytics  
 mixpanel AMPITUDE

**DATA SOURCES & APIs**  
 HEALTH IOT FINANCIAL & ECONOMIC DATA AIR / SPACE / SEA PEOPLE / ENTITIES LOCATION INTELLIGENCE OTHER

**DATA SERVICES**  
 DATA SERVICES INCUBATORS & SCHOOLS RESEARCH

## APPLICATIONS - ENTERPRISE

**SALES**  
 CHORUS  
 INSIDESALES.COM people.ai  
 conversica  
 clari aviso tact.ai  
 fusesmachines Clearbit

**MARKETING - B2B**  
 RADIUS App Annie  
 EVERSTRING  
 MINTIGO  
 tubular  
 KNOTCH mrpe

**MARKETING - B2C**  
 ZETA bloomreach SendGrid  
 braze ACTIONIQ BLUECORE  
 CONTENTSQUARE TEALUM  
 Ampero amperity QUANTIFIND  
 Simon Lytice PERSADO  
 remesh

**CUSTOMER EXPERIENCE / SERVICE**  
 qualtrics MEDALLIA SurveyMonkey  
 CLARABRIDGE zendesk Customer  
 HEAR Amplitude Watson Assistant  
 DigitalGenius A.S.A.P. ada NUTOMAT  
 CaDesk

**ENTERPRISE PRODUCTIVITY**  
 slack  
 ORACLE  
 GURU lumina  
 DIFFBOT clara  
 talla Kasisto

**HUMAN CAPITAL**  
 Hiive  
 hiIQ  
 Allyo textio  
 Wadi & Wendy Stella  
 entelo  
 uncommon

**LEGAL**  
 RAVEL  
 Everlaw  
 DISCO kiro  
 JUDICATA  
 BREVIA  
 IRONCLAD  
 PREPOSITION  
 ROSS  
 Casetext

**REGTECH & COMPLIANCE**  
 BigID  
 text IQ  
 Partnerships  
 CROSSBRAIN  
 DATA REPUBLIC

**FINANCE**  
 fnanplan  
 ZUORA  
 S3 SAHANA  
 TRADESHIFT  
 SCALE FACTOR  
 baakeeper  
 pilot

**BACK OFFICE AUTOMATION & RPA**  
 UiPath  
 blueprints  
 VIDADO  
 AppZen  
 WorkFusion workato  
 Reworks  
 Catalytic  
 ANTWORKS  
 KRYON  
 ALKYM

**SECURITY**  
 TANIUM CYLANCE zscaler StackPath illumio  
 CODE42 CyberCloud  
 VECTRA  
 pindrop exabeam  
 Vade Secure bitglass  
 Recorded Future  
 sparkcognition  
 ARCA SECURITY BLUEHEXAGON Semble

## APPLICATIONS - INDUSTRY

**ADVERTISING**  
 AppNexus  
 critico  
 ORACLE MOAT  
 theTradeDesk  
 dstillery  
 CUPPER

**EDUCATION**  
 Lullishoo  
 KNEWTON  
 Clever  
 Cleara  
 kidaptive  
 PANORAMA  
 knowre  
 gradescope

**REAL ESTATE**  
 REDFIN  
 Opendoor  
 VTS  
 CREDIFI  
 GEOPHY  
 GEOMY  
 COMPSTAK  
 SKYLINE

**GOVT**  
 OPENGOV  
 mark43  
 LiveStories  
 Passport  
 SmartProcure  
 STREETLIGHTDATA  
 OpenDataSoft

**INTELLIGENCE**  
 Palantir  
 Dataminr  
 Quid  
 PRIMER  
 FORGE

**FINANCE - INVESTING**  
 KENSHC  
 Quantopian  
 ADEPAR  
 HUBNER  
 ISENTIUM  
 ALGORIT  
 PlavonPack  
 PAGAYA

**FINANCE - LENDING**  
 ondeck affirm  
 JIANPU.AI  
 Kreditech  
 AVANT  
 TALA  
 CLEARBANC  
 Upgrade  
 100Credit  
 WeLab  
 WeCASH  
 TrueAccord  
 MoneyLion  
 aircignif

**INSURANCE**  
 Metromile  
 Lemonade  
 CYENCE  
 Hippo  
 Shift Technology  
 ROOT  
 zesty.ai  
 CAPE

**HEALTHCARE**  
 flatiron Clover KYRUS  
 METABIOTA Gingerio Glow  
 3D Med zebra PathAI ovvia

**LIFE SCIENCES**  
 color  
 BenevolentAI  
 verily  
 WuXiNextCODE

**TRANSPORTATION**  
 UBER TESLA  
 CLEARPATH CRUISE  
 nuro  
 drive ai  
 CAMBRIDGE  
 Aurora  
 nauto AMOTIVE G7 PILOT.AI  
 NIO OPTIMUS moovit  
 nexar Kodiak comma.ai  
 netradynye  
 thinc INRIX

**AGRICULTURE**  
 FARMERS  
 Granular  
 JOHN DEERE  
 BLUE RIVER  
 FarmersEdge  
 AgroStar  
 FarmLogs  
 TARANIS  
 GAMAYA  
 Terraviva  
 prospera

**COMMERCE**  
 instacart  
 FAIRFIRE  
 STITCH FIX  
 Doo & Co  
 lowGood  
 heuristics  
 eharmony stem  
 hoppers select  
 VERDIGIR  
 duoeto  
 Electric ZINER

**INDUSTRIAL**  
 AVEVA SIEMENS  
 PREDIX UPTAKE  
 SCORTEX  
 TACHYUS  
 ByteDance  
 BBOXEVER  
 Sentry  
 occurrulo

**DATA SOURCES & APIs**  
 HEALTH IOT FINANCIAL & ECONOMIC DATA AIR / SPACE / SEA PEOPLE / ENTITIES LOCATION INTELLIGENCE OTHER

**DATA SERVICES**  
 DATA SERVICES INCUBATORS & SCHOOLS RESEARCH

see full version at: <http://mattturck.com/wp-content/uploads/2019/07/2019-Matt-Turck-Big-Data-Landscape>

diving into the internals of modern data systems

*cutting-edge* designs / *research* projects / *engineering* projects

# CS 561: Data Systems Architectures

Spring 2021

# DATA & AI LANDSCAPE 2019

## INFRASTRUCTURE

**HADOOP ON-PREMISE**  
 cloudera Hortonworks  
 MAPR Pivotal  
 IBM InfoSphere  
 jethro

**HADOOP IN THE CLOUD**  
 aws Microsoft Azure  
 Google Cloud  
 SAP Cloud Platform  
 IBM InfoSphere BigInsights arm  
 Dubble CAZENA

**STREAMING / IN-MEMORY**  
 Amazon Kinesis  
 SAP Cloud Platform  
 ORACLE  
 confluent  
 strimzi hazelcast GridGain  
 GIGASPACEs Wallaroo AI FASTDATA kx

**NoSQL DATABASES**  
 Google Cloud AWS  
 ORACLE Microsoft Azure  
 mongoDB MarkLogic  
 Couchbase DISTRAXT  
 redislabs KEROPIKE  
 ArangoDB SCYLLA

**NewSQL DATABASES**  
 SAP Clustrix Pivotal  
 MEMSQL infuxdata  
 Cockroach LABS  
 VOLTDB splice  
 paradigms

**GRAPH DBs**  
 Amazon Neptune  
 IBM ORACLE  
 OrientDB  
 InfiniteGraph  
 Objectivity

**MPP DBs**  
 TERADATA  
 IBM Data Warehouse Systems  
 Kognitio  
 Exasol  
 dremio Yellowbrick

**CLOUD EDW**  
 aws  
 Microsoft Azure  
 Pivotal  
 snowflake  
 Infoworks

**SERVERLESS**  
 Amazon Lambda  
 Microsoft Azure  
 PULSAR  
 nuclio  
 Oracle Functions  
 PaaS Function Service

**DATA TRANSFORMATION**  
 SAP Data Services Informatica  
 MuleSoft TEALUM  
 snoplogic enigma  
 alteryx TRIFACTA  
 tamr Paxata  
 StreamSets UNIFI

**DATA INTEGRATION**  
 SAP Data Services Informatica  
 MuleSoft TEALUM  
 snoplogic enigma  
 Segment ATTUNITY  
 ZALONI import.io  
 Infosys Fivetran  
 SNOWFLOW MATILLION

**DATA GOVERNANCE**  
 Informatica  
 SailPoint  
 IBM  
 Alation  
 HMDTA  
 OKERA  
 MANTA dataworld

**MGMT / MONITORING**  
 AWS New Relic actifio  
 rubrik  
 dynatrace  
 SignalFx  
 splunk  
 Moogsoft pagerduty  
 UNRAVEL  
 OKERA  
 ZEPHYRUS OpsRamp  
 MAGNITUDE

**STORAGE**  
 aws Google Cloud  
 Microsoft Azure  
 PURE STORAGE  
 ALLUXIO wasabi  
 nimbustorage  
 Qumulo panopticon  
 COHERITY

**CLUSTER SVCS**  
 Amazon EMR  
 IBM  
 Microsoft Azure  
 MESSAGING  
 packet  
 nimbustorage  
 aigis  
 CYCLECLOUD

**DATA GENERATION & LABELLING**  
 amazon mechanicalturk  
 upwork  
 appen  
 HIVE  
 Labelbox  
 Mighty AI  
 ALBERTE  
 LIONBRIDGE

**AI OPS**  
 ALGORITHMIA  
 SPILL comet  
 Verta.ai datmo  
 datastaton  
 Whiggle AI  
 Determined AI  
 tidder

**GPU DBs & CLOUD**  
 kinetica  
 SQUEAM  
 bryllyt  
 BLAZINGDB  
 PG-Stream  
 LOYDHUB

**HARDWARE**  
 Google TPU arm  
 intel AI NVIDIA  
 GRAPHCORE MYTHIC  
 Movidius habarana  
 WAVE  
 CERAMIC  
 PULSAR  
 DEFNIX

## CROSS-INFRASTRUCTURE/ANALYTICS

aws Google Cloud Microsoft IBM SAP Hewlett Packard Enterprise SAS IOIOWATA vmware TIBCO TERADATA ORACLE NetApp syncsort MAPR cloudera

## ANALYTICS & MACHINE INTELLIGENCE

**DATA ANALYST PLATFORMS**  
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 sisu switchboard Starburst

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 IBM databricks dataiku  
 DOMINO rapidminer TIBCO  
 ANACONDA SAS Altair  
 KNIME MathWorks

**BI PLATFORMS**  
 looker embed analytics aws  
 DOME ARCADIA DATA ThoughtSpot  
 ATSCALE Qlik  
 GoodData Information Builders birst  
 MicroStrategy Keon IO

**VISUALIZATION**  
 tableau Power BI  
 SAP Google Cloud  
 celonis Periscope Data  
 zepl  
 CHARTIO TOUCAN TCO

**MACHINE LEARNING**  
 Azure Machine Learning  
 Amazon SageMaker  
 Google Cloud AI Platform Vision H2O  
 DataRobot gamalon  
 VISENZE ELEMENT  
 deepsense.ai

**COMPUTER VISION**  
 Microsoft Azure  
 Amazon Rekognition  
 Clarifai  
 EVERAI deepomatic  
 neuro  
 UBUIQUITY AEE  
 YITU trax  
 synthesis DataClz

**HORIZONTAL AI**  
 IBM Watson Cortana Face++  
 sentient Voyager  
 Affective  
 Numenta  
 narologics  
 BLUE VISION  
 Fortra

**SPEECH & NLP**  
 Google Cloud twilio  
 amazon alexa Amazon Transcribe  
 narrative science semantic machine  
 Mobval  
 SoundHound Inc  
 Mindfield  
 SMARTLING Unbabel

**SEARCH**  
 ORACLE ENCEGA  
 elasticsearch algolia covéo  
 Lucidworks ATTIVO  
 swifttype  
 alphahsense MAANA  
 omnius SINEQUA

**LOG ANALYTICS**  
 splunk sumologic  
 solarwinds  
 TIMBER  
 kibana  
 logz.io

**SOCIAL ANALYTICS**  
 Hootsuite sprinklr  
 NETBASE  
 synthosio trackx  
 simple reach  
 bitly SimilarWeb

**WEB / MOBILE / COMMERCE ANALYTICS**  
 Google Analytics  
 mixpanel AMP  
 Airtable RES  
 SIGOPT gra  
 custora

## OPEN SOURCE

**FRAMEWORKS**  
 TensorFlow PyTorch Keras Caffe  
 Spark YARN TEZ  
 MESOS Kubernetes  
 docker CDAP  
 Red Hat HELIX

**QUERY / DATA FLOW**  
 Spark SQL  
 presto  
 SLAMDATA  
 ARAPACHE DRILL  
 GraphQL  
 Flink

**DATA ACCESS & DATABASES**  
 cassandra mongoDB redis  
 CouchDB Cockroach LABS druid  
 riak HBASE  
 Oracle Cloud  
 SCALLO  
 OCCULTULO

**ORCHESTRATION & MGMT**  
 talend  
 Apache Zookeeper  
 Apache Ambari  
 Apache Airflow  
 MESOS  
 etcd Kong

**STREAMING & MESSAGING**  
 Spark nifi  
 Flink beam  
 kafka STORM  
 Apache RocketMQ

**STAT TOOLS & LANGUAGES**  
 python R  
 Scala Numpy  
 Jupyter Studio  
 SciPy julia

**AI OPS & INFRA**  
 miflow  
 Kubeflow  
 mlops  
 SELDON  
 Polyaxon

**AI / MACHINE LEARNING**  
 TensorFlow OpenAI  
 IBM Watson  
 Microsoft Cognitive Toolkit  
 Apache SINGA DIMSUM FeatureFu  
 ONNX  
 NVIDIA TAO  
 PyTorch

**SEARCH**  
 elasticsearch Solr  
 kibana SENTRY

**LOGGING & MONITORING**  
 elasticsearch kibana SENTRY  
 logstash Prometheus  
 fluentbit fluentd Grafana  
 VECTOR

**VISUALIZATION**  
 matplotlib  
 TensorBoard  
 seaborn  
 Bokeh

**COLLABORATION**  
 BeakerX  
 jupyter  
 ANACONDA

**SECURITY**  
 Apache Ranger  
 KNOX  
 Sentry  
 OCCURNULO

## DATA SOURCES & APIs

HEALTH IOT FINANCIAL & ECONOMIC DATA AIR / SPACE / SEA PEOPLE / ENTITIES LOCATION INTELLIGENCE OTHER

## DATA RESOURCES

DATA SERVICES INCUBATORS & SCHOOLS RESEARCH

see full version at: <http://mattturck.com/wp-content/uploads/2019/07/2019-Matt-Turck-Big-Data-Landscape>

# DATA & AI LANDSCAPE 2019

## INFRASTRUCTURE

**HADOOP ON-PREMISE**  
cloudera Hortonworks  
MAPR Pivotal  
IBM InfoSphere  
jethro

**HADOOP IN THE CLOUD**  
aws Microsoft Azure  
Google Cloud  
SAP Cloud Platform  
IBM InfoSphere BigInsights  
arm  
Dubble CAZENA

**STREAMING / IN-MEMORY**  
Amazon Kinesis  
databricks  
SAP Cloud Platform  
ORACLE  
confluent  
strimio hazelcast  
GridGain  
GIGASPACEs Wallaroo  
FASTDATA kx

## ANALYTICS & MACHINE INTELLIGENCE

**DATA ANALYST PLATFORMS**  
Microsoft pentaho alteryx  
Digital Reasoning  
GUAVUS AYASDI  
ATTIVO Datameer incorta.  
interana MODE ENDOR  
Sisense  
Sisense dashboard Starburst

**DATA SCIENCE PLATFORMS**  
IBM databricks dataiku  
DOMINO rapidminer TIBCO  
ANACONDA SAS  
KNIME MathWorks

Data Science

**NoSQL DATABASES**  
Google Cloud AWS  
ORACLE Microsoft Azure  
mongoDB MarkLogic  
Couchbase DISTRAX  
redislabs KERO SPIKE  
ArangoDB SCYLLA

**NewSQL DATABASES**  
SAP Clustrix Pivotal  
MEMSQL infuxdata  
Cockroach LABS  
VOLTDB splice  
paradigm

**GRAPH DBs**  
Amazon Neptune  
IBM ORACLE  
Kognitio  
InfinitoGraph  
dremio  
Yellowbrick

**MPP DBs**  
TERADATA  
IBM Data Warehouse Systems  
Cognitio  
Exasol  
dremio  
Yellowbrick

**CLOUD EDW**  
aws  
Microsoft Azure  
Pivotal  
snowflake  
Infoworks

**SERVERLESS**  
AWS Lambda  
Microsoft Azure Functions  
Google Cloud Functions  
Pulsar nuclio  
Pulsar nuclio  
Pulsar nuclio  
Pulsar nuclio

**BI PLATFORMS**  
looker  
amazon analytics  
aws  
DOME  
ARCADIA DATA ThoughtSpot  
ATSCALE Qlik  
GoodData Information Builders  
MicroStrategy Keon IO

**VISUALIZATION**  
tableau  
Google Cloud  
Periscope Data  
plotly  
CHARM

**MACHINE LEARNING**  
Amazon SageMaker  
Google Cloud AI Platform Vision  
H2O  
DataRobot gamalon  
VISENZE ELEMENT

Machine Learning

Visualization

**DATA TRANSFORMATION**  
talend pentaho  
alteryx TRIFACTA  
tamr Paxata  
StreamSets UNIFI

**DATA INTEGRATION**  
SAP Data Services Informatica  
MuleSoft TEALUM  
snaplogic enigma  
Segment ATTUNITY  
ZALONI import.io  
InfoWorks Fivetran  
SNOWFLOW MATILLION

**DATA GOVERNANCE**  
Informatica  
SailPoint  
colibra  
Alation  
OKERA  
MANTA dataworld

**MGMT / MONITORING**  
aws New Relic octio  
rubrik APPDYNAMICS  
dynatrace WAVEFRONT  
SignalFx  
splunk  
Moogsoft pagerDuty  
unavai Numerify  
zeross OpsRamp

**COMPUTER VISION**  
Microsoft Azure  
Amazon Rekognition  
Clarifai  
EVERAI  
neura  
UBIQUITY  
synthesisia

**HORIZONTAL AI**  
IBM Watson Cortana  
sentient  
Affectiva  
Numenta  
narologies  
BLISS VISION

**SPEECH & NLP**  
Google Cloud twilio  
amazon alexa Amazon Translate  
narrative science semantic machine  
Mobval  
SoundHound Inc  
Mindfield  
SMARTLING Unbabel

AI

Natural Language Processing

**STORAGE**  
aws  
Microsoft Azure  
PURE STORAGE  
ALLUXIO wasabi  
Qumulo panache  
COHERITY

**CLUSTER SVCS**  
Amazon EMR  
IBM  
Microsoft Azure  
MESOSPHERE  
packet  
bigm  
CYCLECLOUD

**DATA GENERATION & LABELLING**  
amazon mechanical turk  
upwork  
oppen  
HIVE Labelbox  
Mighty AI  
LIONBRIDGE

**AI OPS**  
ALGORITHMIA  
SPILL comet  
verta.ai datmo  
datastaton  
WhisperAI  
Determined AI  
tidder

**GPU DBs & CLOUD**  
kinetica  
SQUEAM  
bryllyt  
BLAZINGDB  
PG-Stream  
LOYDHUB

**HARDWARE**  
Google TPU arm  
intel AI NVIDIA  
GRAPHCORE MYTHIC  
Graphcore  
Movidius habana  
WAVE  
CERAMIC  
DEFINIX

**SEARCH**  
ORACLE  
elasticsearch ENGENCA  
algolia covéo  
Lucidworks ATTIVO  
swiftype EXALEAD  
alphasense MAANA  
omnius SINEOUA

**LOG ANALYTICS**  
splunk  
sumologic  
solarwinds  
TIMBER  
kibana  
logzio

**SOCIAL ANALYTICS**  
Hootsuite  
NETBASE  
synthesio track  
simplereach  
bitly SimilarWeb

**WEB / MOBILE / COMMERCE ANALYTICS**  
Google Analytics  
mixpanel AMP  
Airtable RES  
SIGOPT gra  
custora

CROSS-INFRASTRUCTURE/ANALYTICS  
aws Google Cloud Microsoft IBM SAP Hewlett Packard Enterprise SAS IOI DATA vmware TIBCO TERADATA ORACLE NetApp syncsort MAPR cloudera

## OPEN SOURCE

**FRAMEWORKS**  
Spark  
Flink YARN TEZ  
MESOS  
docker CDOP  
Red Hat HELIX

**QUERY / DATA FLOW**  
Spark SQL  
presto  
SLAM DATA  
GraphQL  
Flink

**DATA ACCESS & DATABASES**  
cassandra mongoDB redis  
CouchDB Cockroach LABS druid  
CouchDB  
OMNISTREAM SciDB  
riak HBASE  
Cloud Search ACCUTILLO

**ORCHESTRATION & MGMT**  
talend  
Apache Ambari  
Apache Airflow  
MESOS  
etcd Kong

**STREAMING & MESSAGING**  
Spark  
nifi  
Flink  
beam  
kafka STORM  
Apache RocketMQ

**STAT TOOLS & LANGUAGES**  
python  
Scala  
Studio  
SciPy julia

**AI OPS & INFRA**  
miflow  
Kubeflow  
misp  
DC  
SELECON  
PyLemon

**AI / MACHINE LEARNING**  
TensorFlow  
OpenAI  
DMTK  
mxnet VELES  
Chainer  
MICHELANGLO  
ONNX  
WEXA  
LUDWIG  
PyTorch  
neon DSSTNE ml4b DL4J MAHOUT Aerosolve FastAI mlr

**SEARCH**  
elasticsearch  
Solr

**LOGGING & MONITORING**  
elasticsearch kibana SENTRY  
logstash Prometheus  
fluentbit fluentd Grafana

**VISUALIZATION**  
matplotlib  
TensorBoard  
seaborn  
Bokeh

**COLLABORATION**  
BeakerX  
jupyter  
Anaconda

**SECURITY**  
Apache Ranger  
KNOX  
Sentry  
accutullo

DATA SOURCES & APIs HEALTH IOT FINANCIAL & ECONOMIC DATA AIR / SPACE / SEA PEOPLE / ENTITIES LOCATION INTELLIGENCE OTHER DATA SERVICES INCUBATORS & SCHOOLS DATA RESOURCES RESEARCH

# A path in data science

(1) strong data systems skills

(i) coding skills

(ii) system architecture insights

performance tradeoffs

(2) application domain knowledge

(3) statistics, machine learning, math tools

# Academic Research



# Industry