BOSTON UNIVERSITY

# CS 561: **Data Systems Architectures**

## class 4

## Systems & Research Project

Prof. Manos Athanassoulis

https://bu-disc.github.io/CS561/

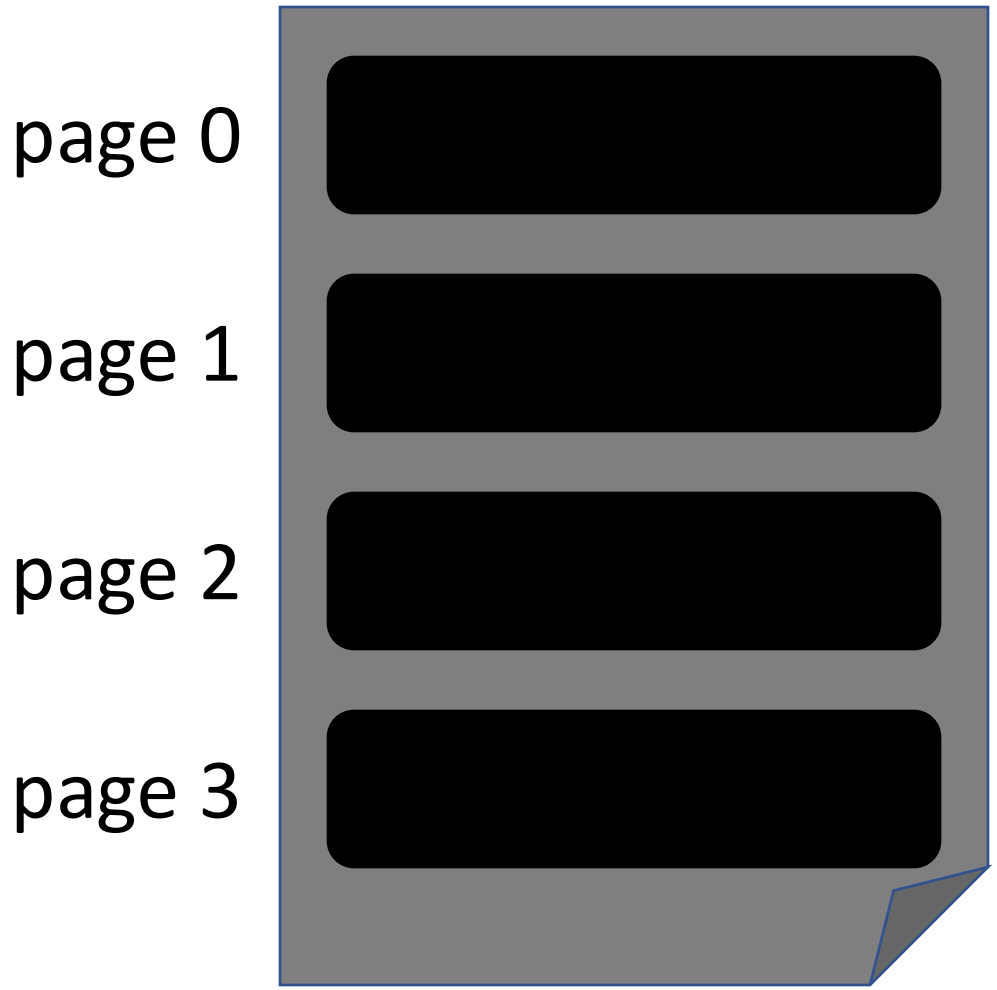
# Let’s revisit Zonemaps

- Light-weight auxiliary data structure (*“scan accelerator”*)

# Let’s revisit Zonemaps

zonemaps

file = collection of pages



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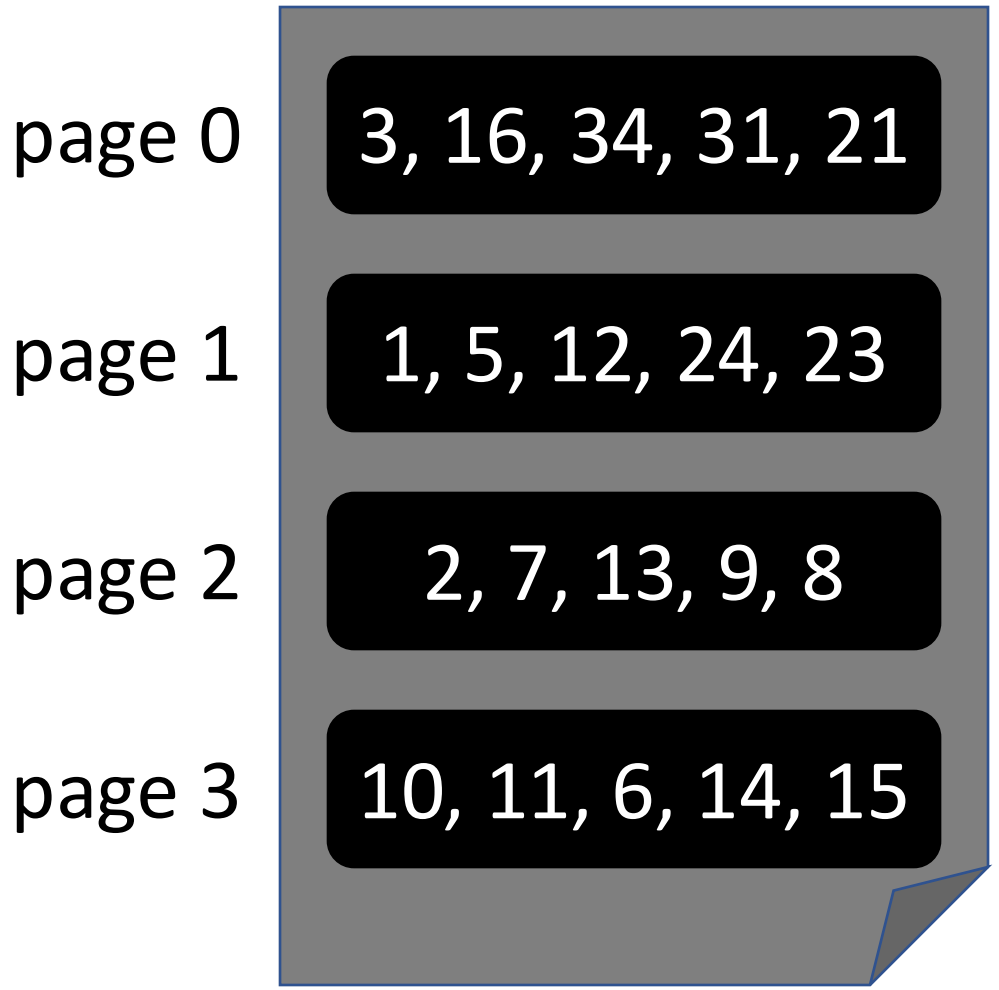

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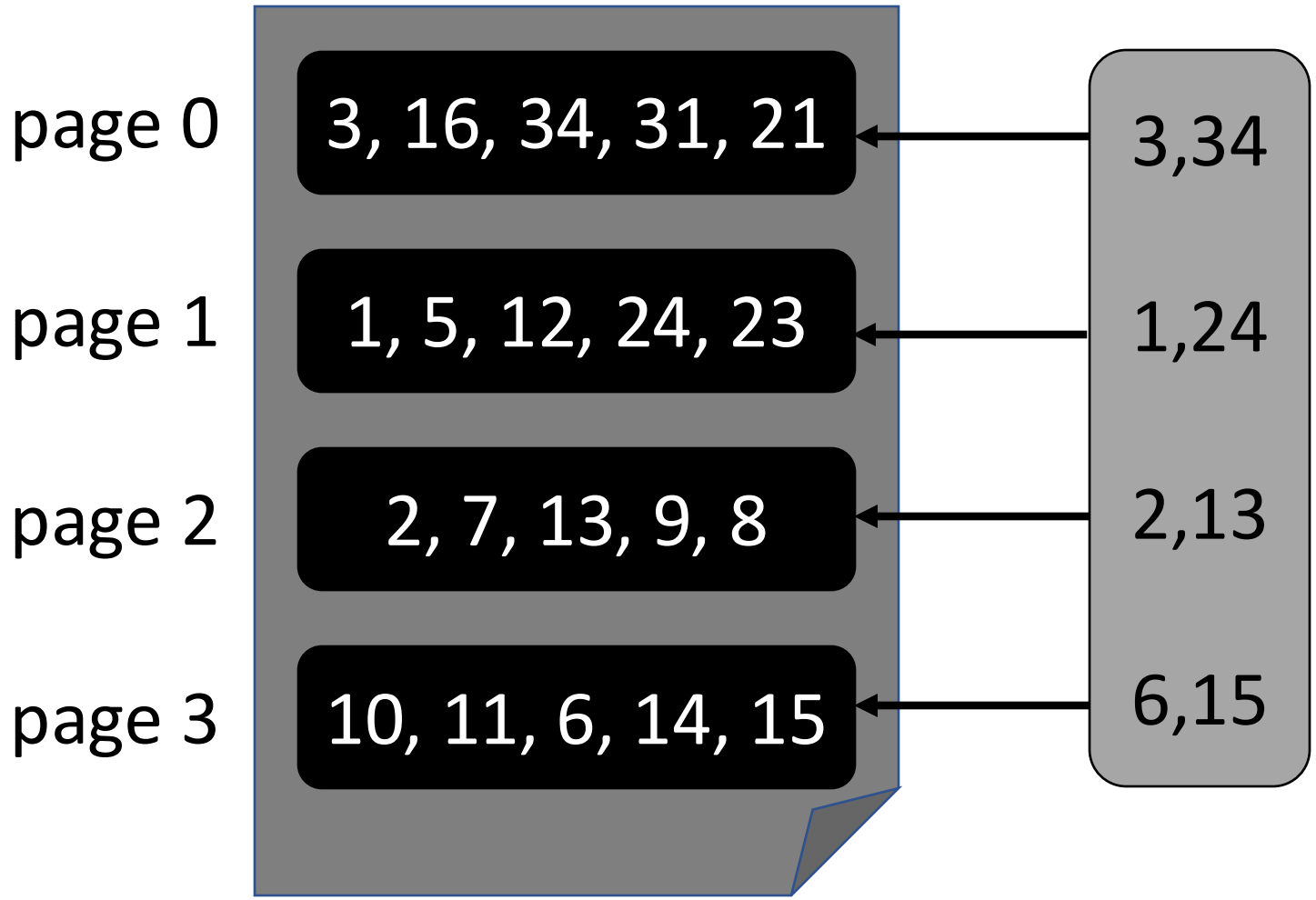


*light-weight*

*typically retained in memory*

But what if the data is sorted?

# zonemaps

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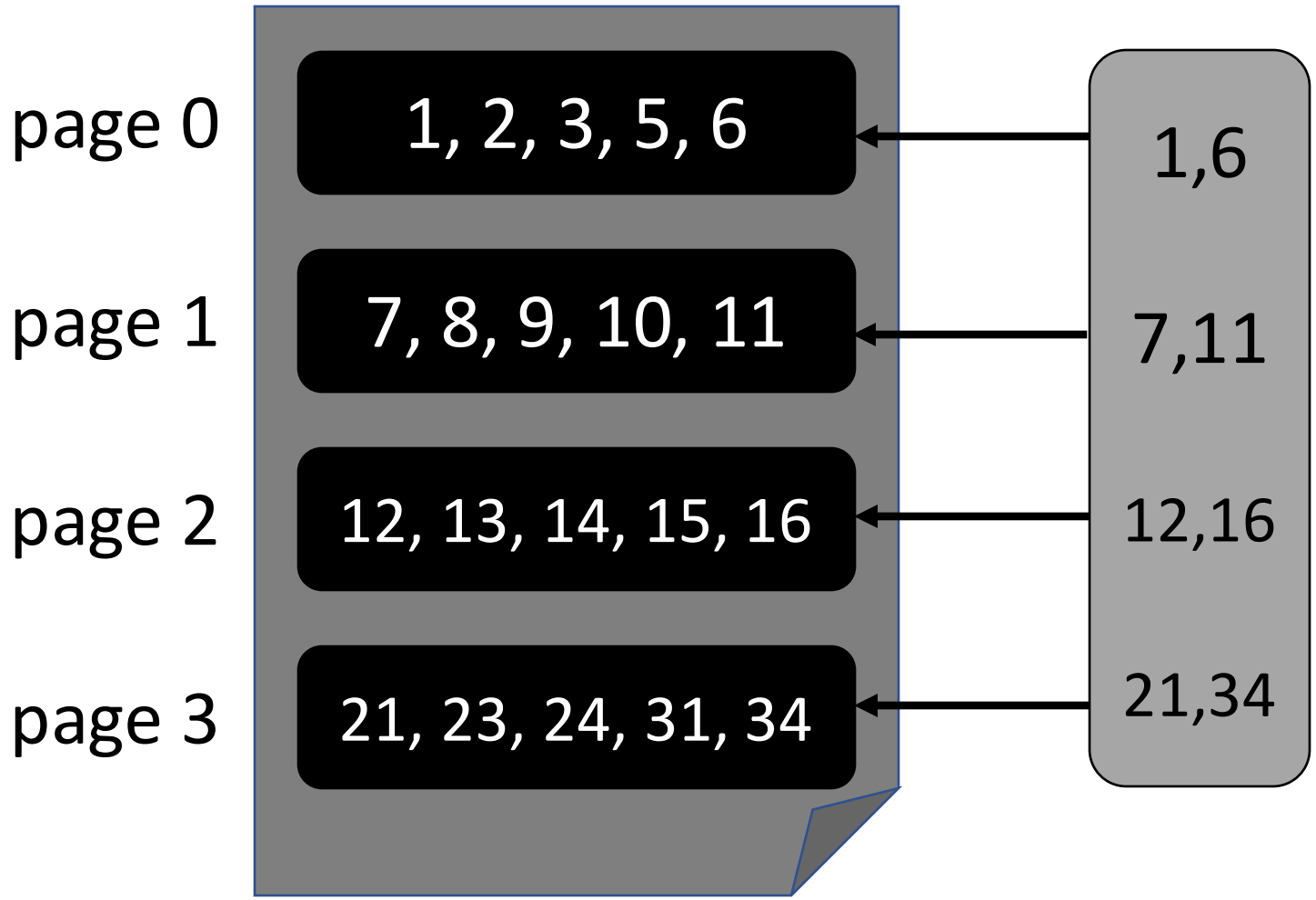


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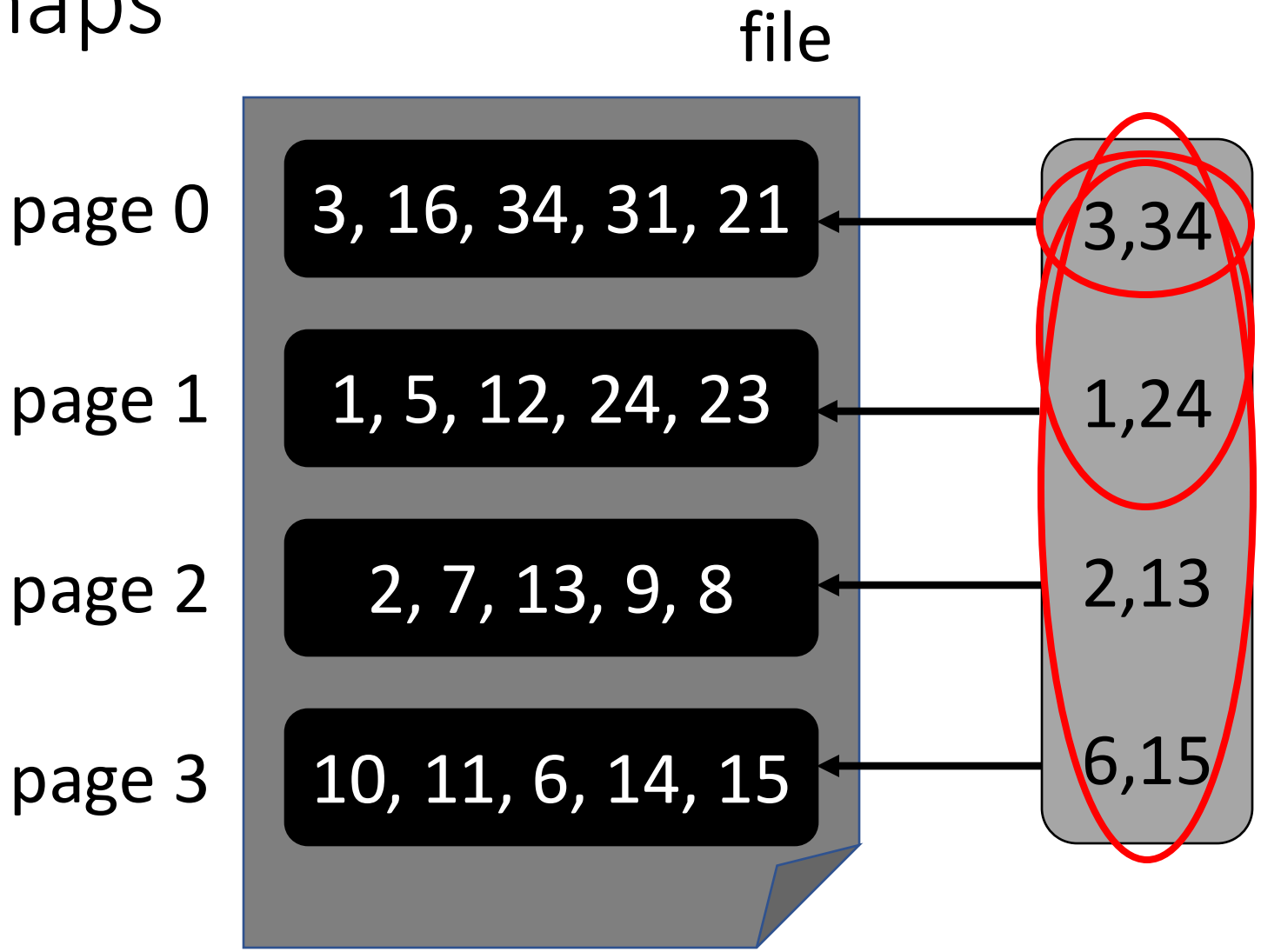
# zonemaps




Range Queries

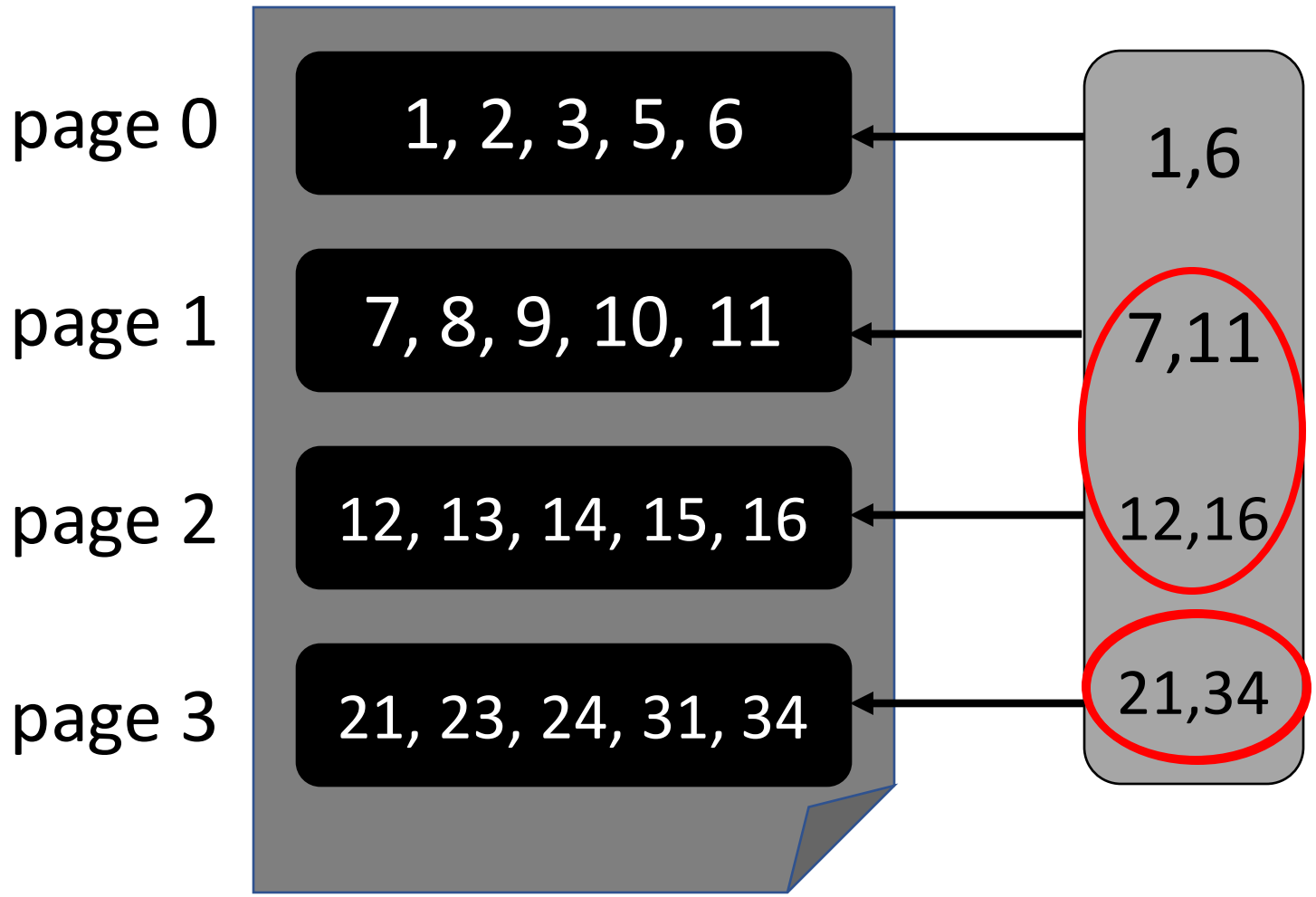
[25, 100] 1 page

[20, 25] 2 pages

[10, 13] 4 pages

# zonemaps

But what if the data is sorted?




Range Queries

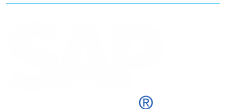
[25, 100] 1 page

[20, 25] 1 page

[10, 13] 2 pages

Zonemaps efficiency depends on data & queries!

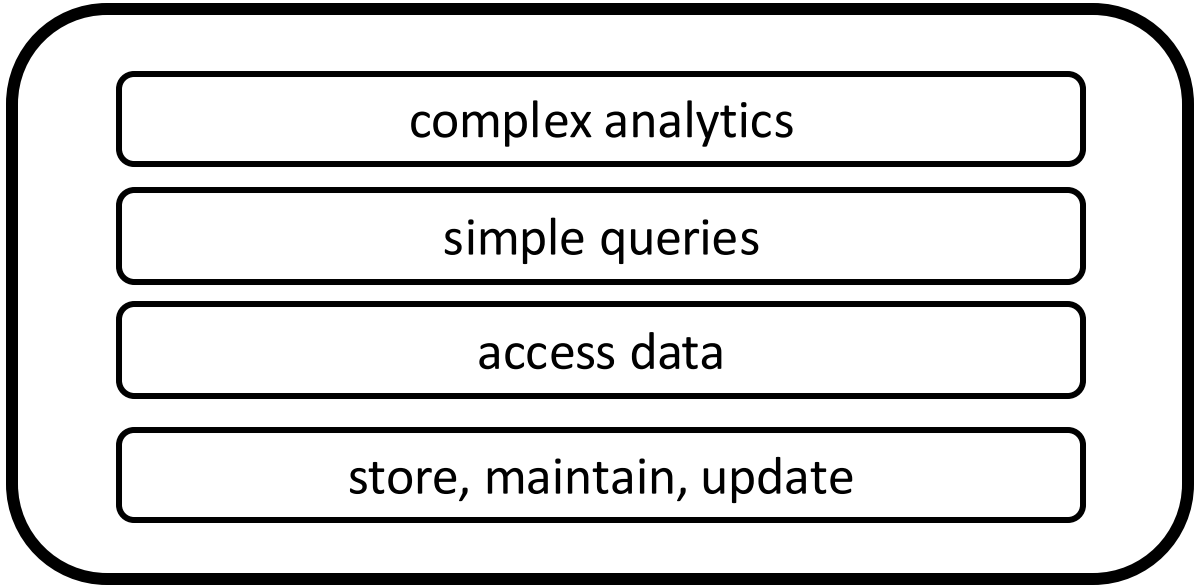
# data systems

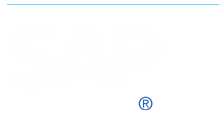








# data systems

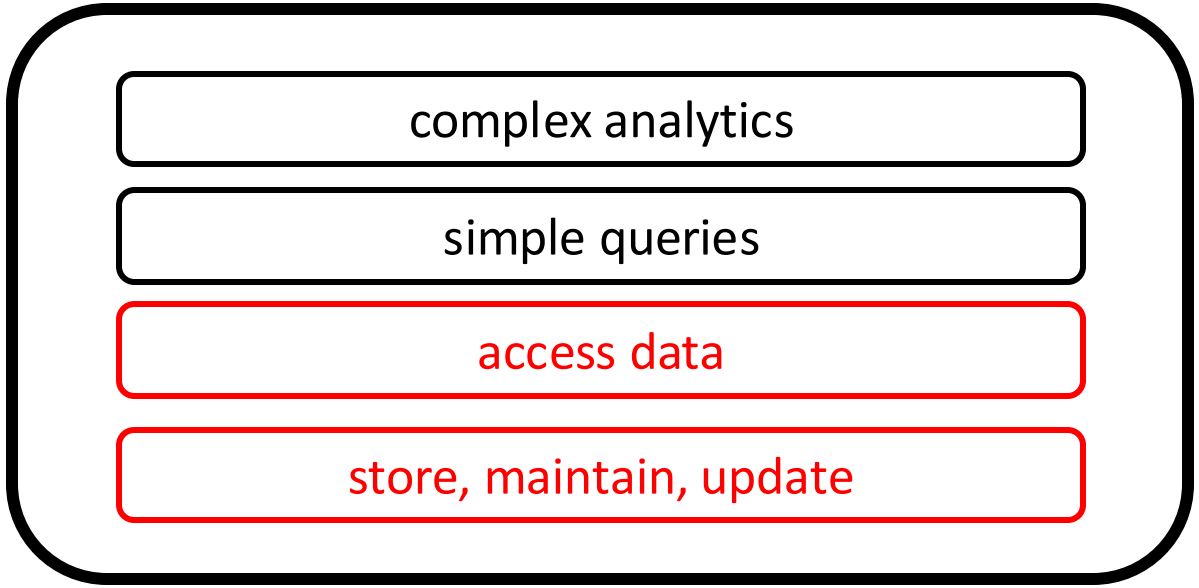






>$200B by 2020, growing at 11.7% every year

[The Forbes, 2016]




***access methods****

***algorithms** and **data structures** for organizing and accessing data

# data systems core: storage engines

## main decisions

how to ***store*** data?

how to ***access*** data?

how to ***update*** data?

# let's simplify: **key-value** storage engines

collection of keys-value pairs

query on the key, return both key and value

***remember***






Couchbase



***state-of-the-art*** design

# how general is a key value store?

can we store relational data?

yes! {<primary_key>,<rest_of_the_row>}

example: { **student_id**, { **name**, **login**, **yob**, **gpa** } }

what is the caveat?

**how to index these attributes?**

other problems?

index: { **name**, { **student_id** } }

index: { **yob**, { **student_id$_1$**, **student_id$_2$**, **…** } }

# how general is a key value store?

can we store relational data?

yes! {<primary_key>,<rest_of_the_row>}

how to efficiently code if we do not know the structure of the "***value***"

index: { **yob**, { **student_id$_1$, student_id$_2$, …** } }

# how to use a key-value store?

***basic interface***

put(k,v)

{v} = get(k)  {$v_1$, $v_2$, …} = get(k)

{$v_1$, $v_2$, …} = get_range($k_{min}$, $k_{max}$)  {$v_1$, $v_2$, …} = full_scan()

c = count($k_{min}$, $k_{max}$)

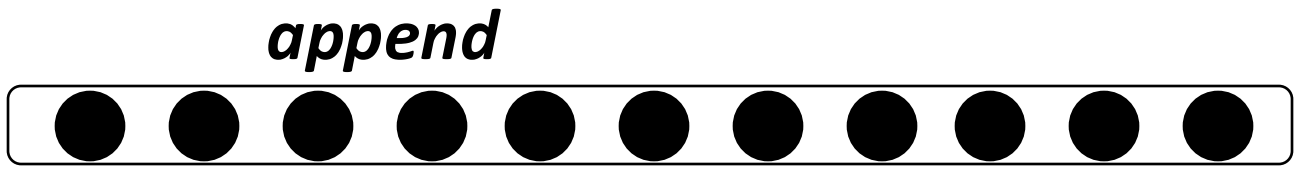
*deletes: delete(k)*

*updates: update(k,v)* is it different than put?

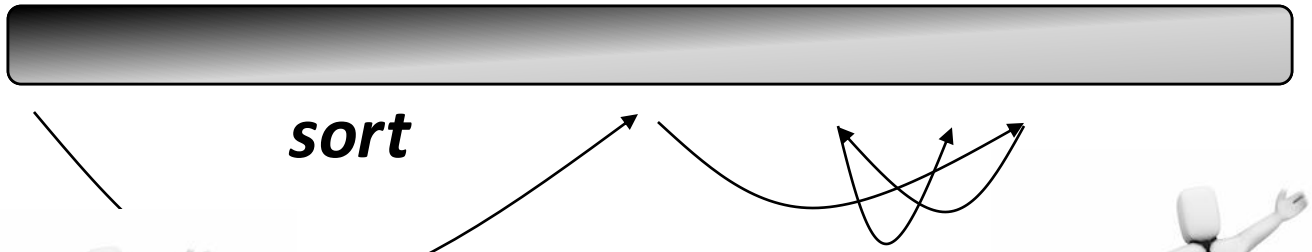
get set: {$v_1$, $v_2$, …} = get_set($k_1$, $k_2$, …)

# how to build a key-value store?

if we have only ***put*** operations




if we mostly have ***get*** operations

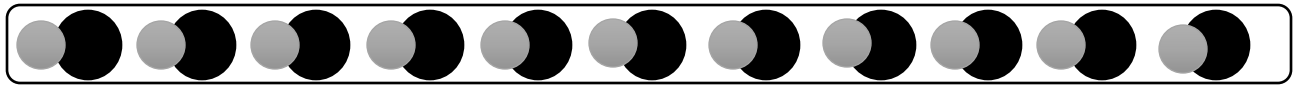


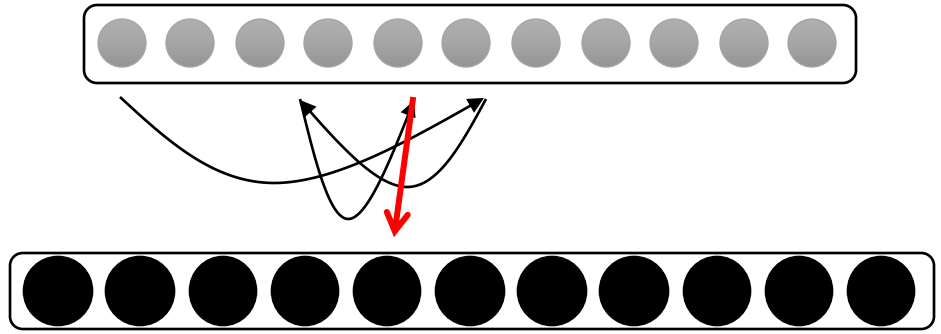

what about full scan?

and then

range queries?

# can we separate keys and values?





at what price?

locality? code?

read queries
(point or range)

inserts
(or updates)

*sort data*

*simply append*

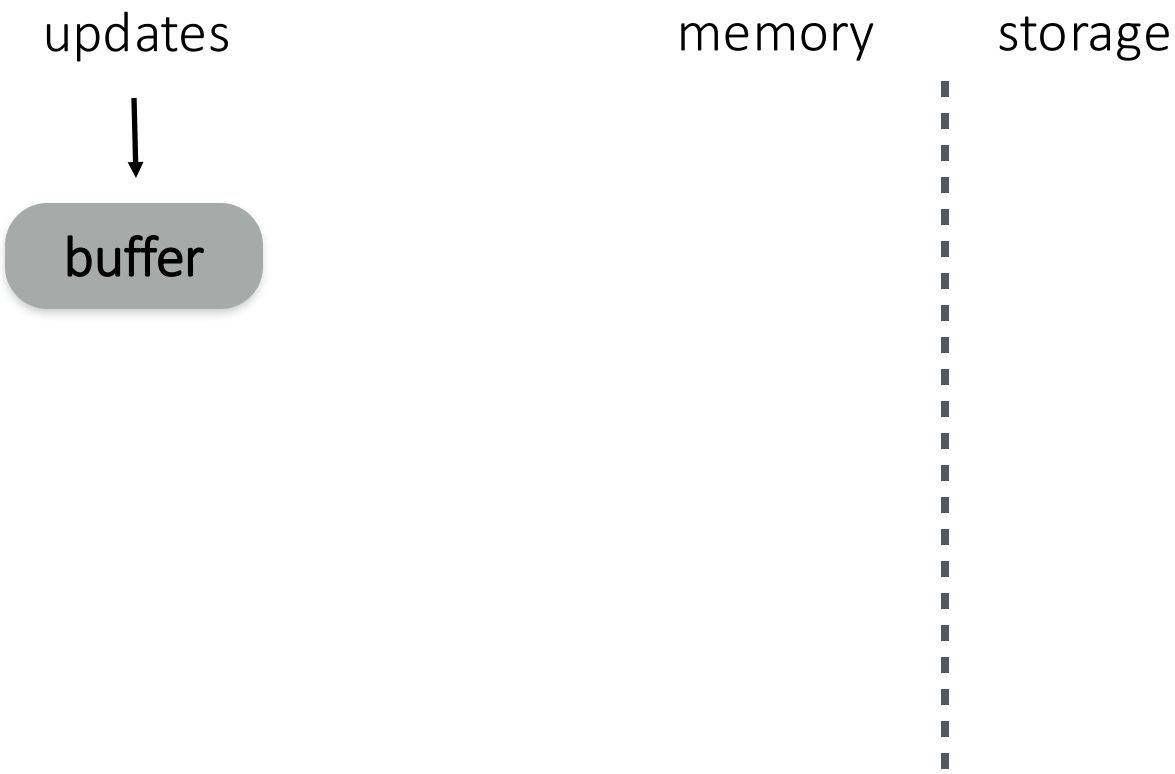
*amortize sorting cost*

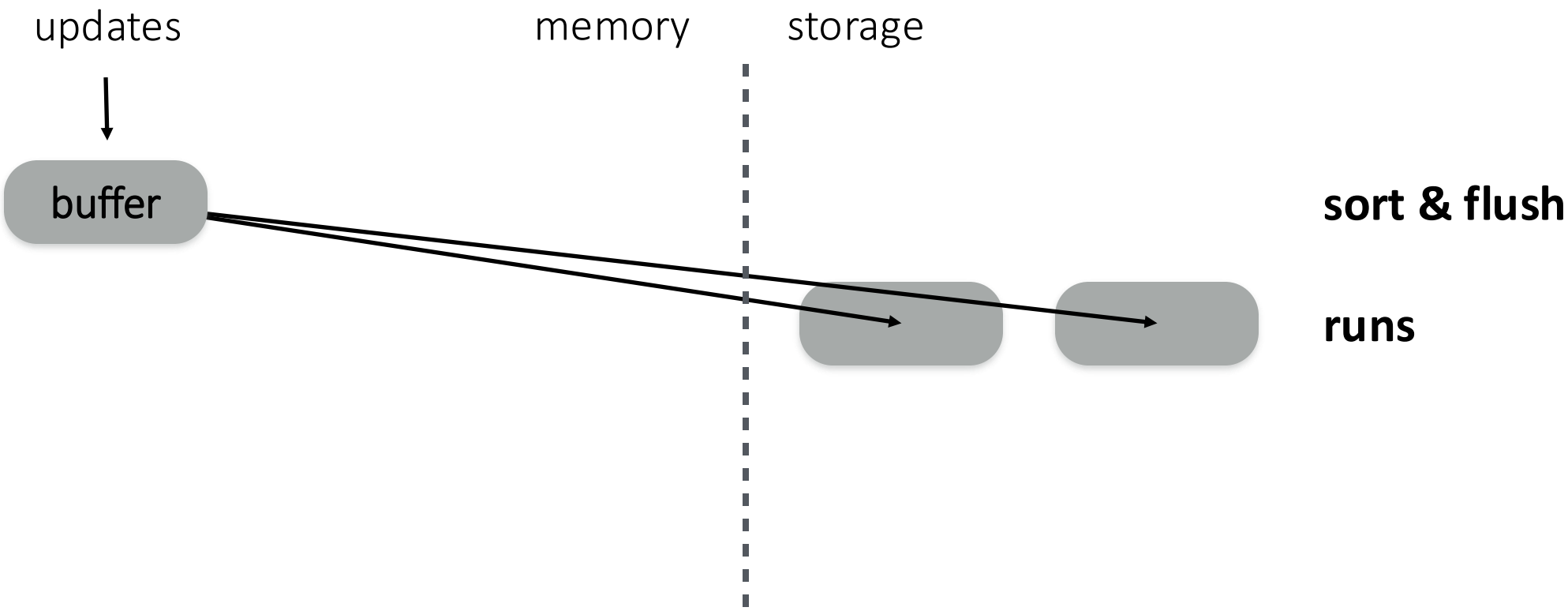
*avoid resorting after every update*

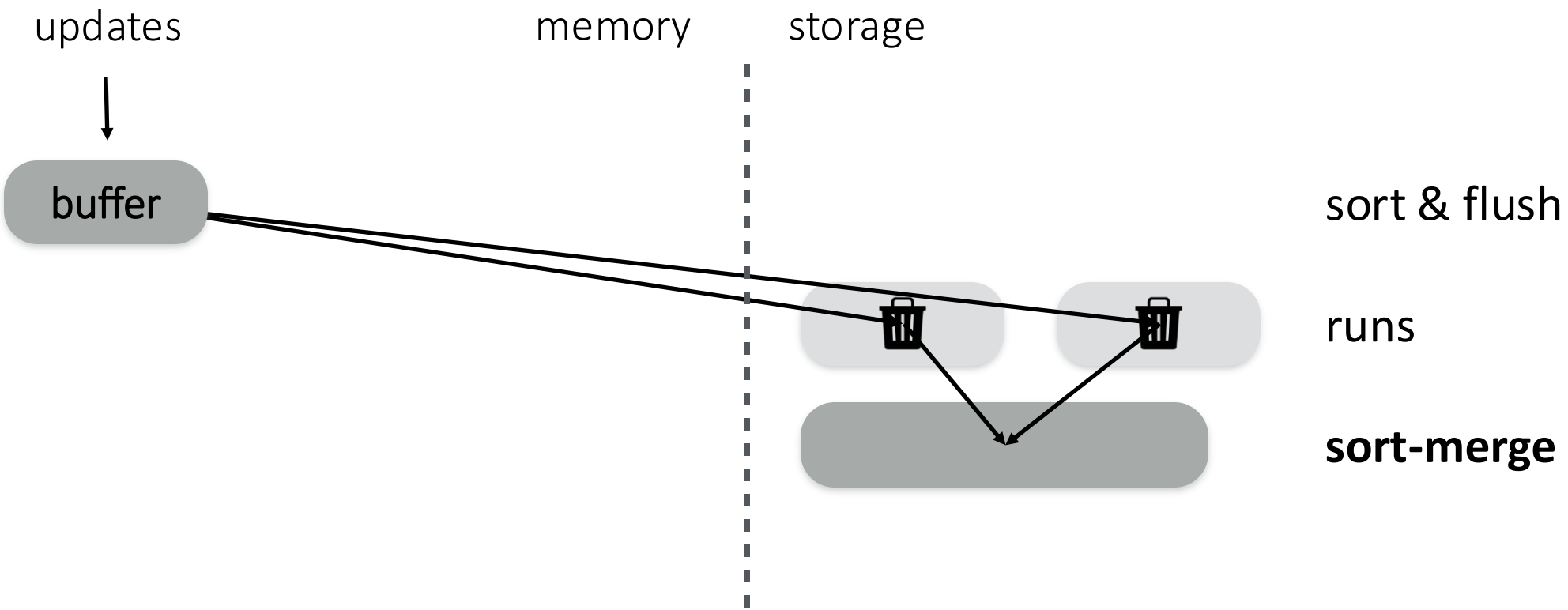
how to bridge?

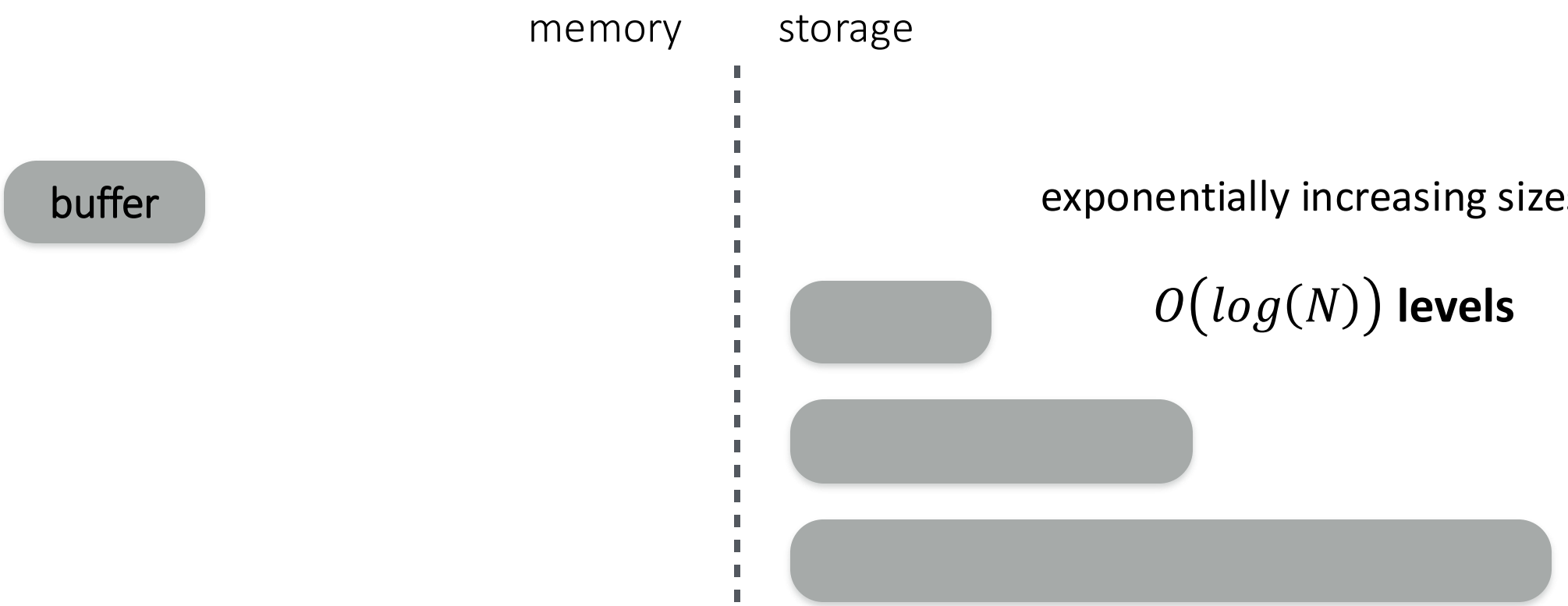
# LSM-tree
# Key-Value Stores

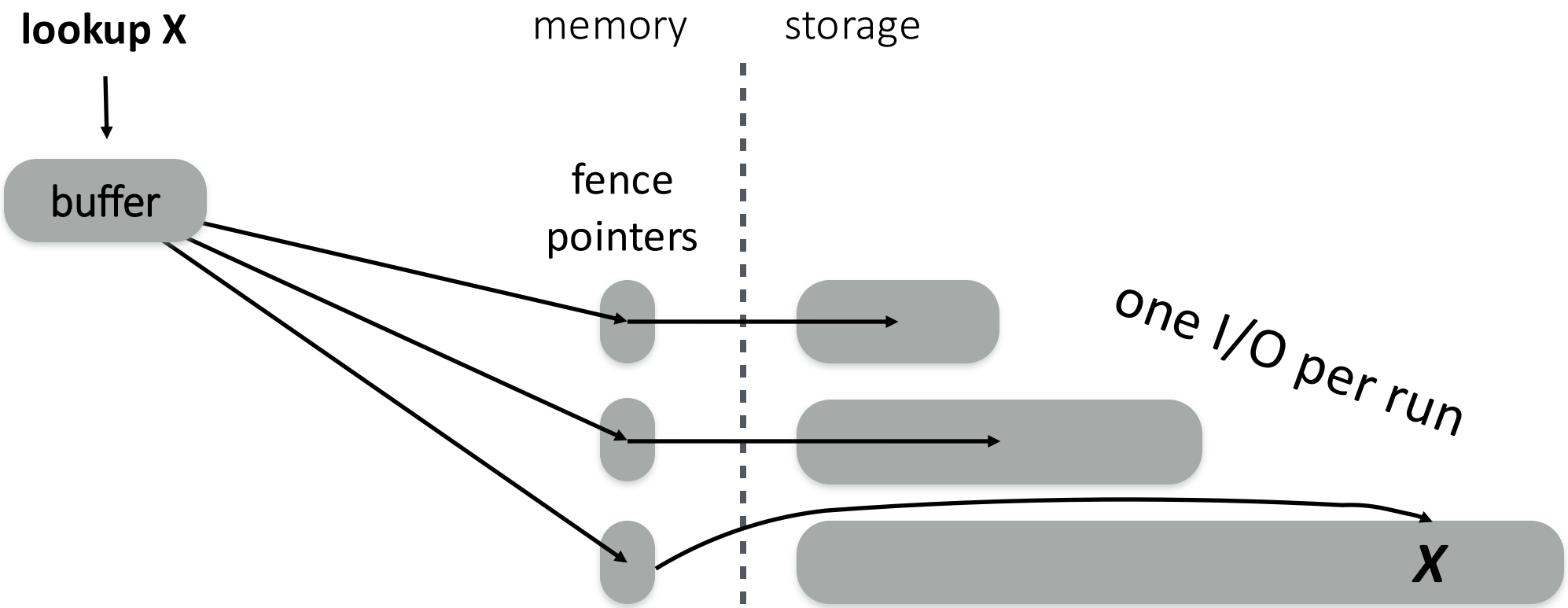
What are they really?

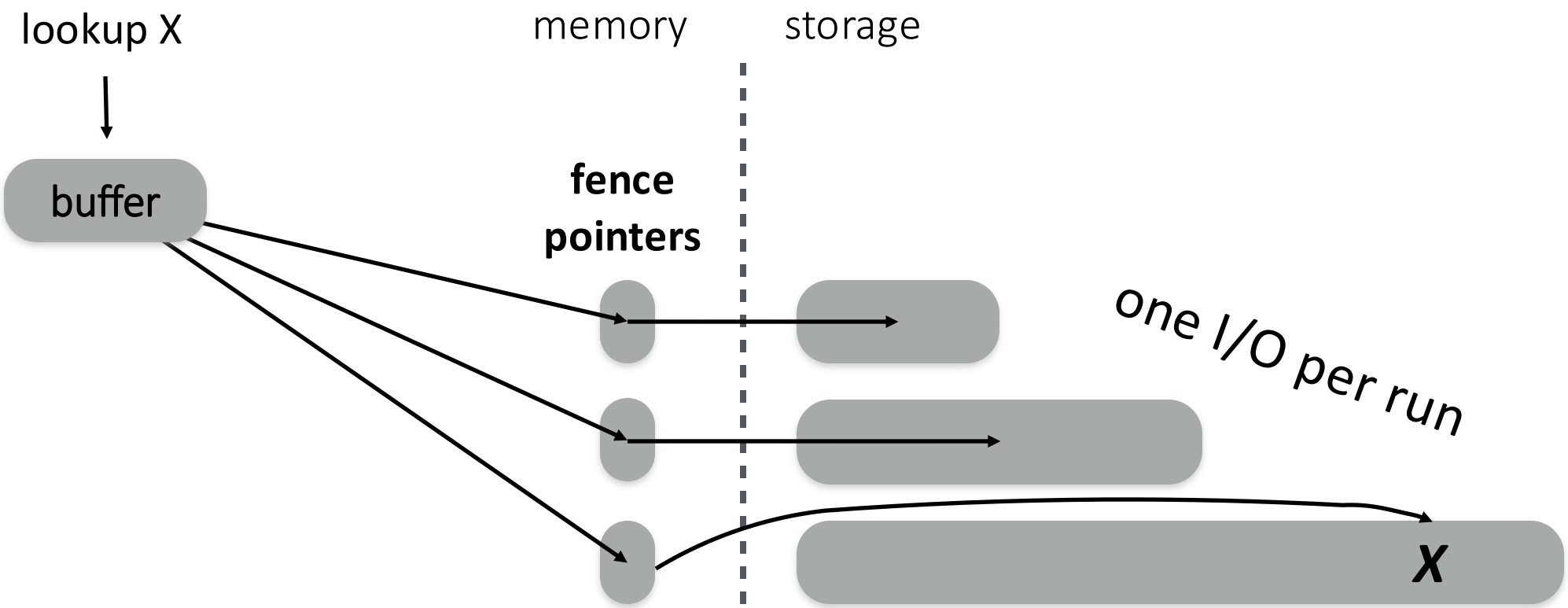


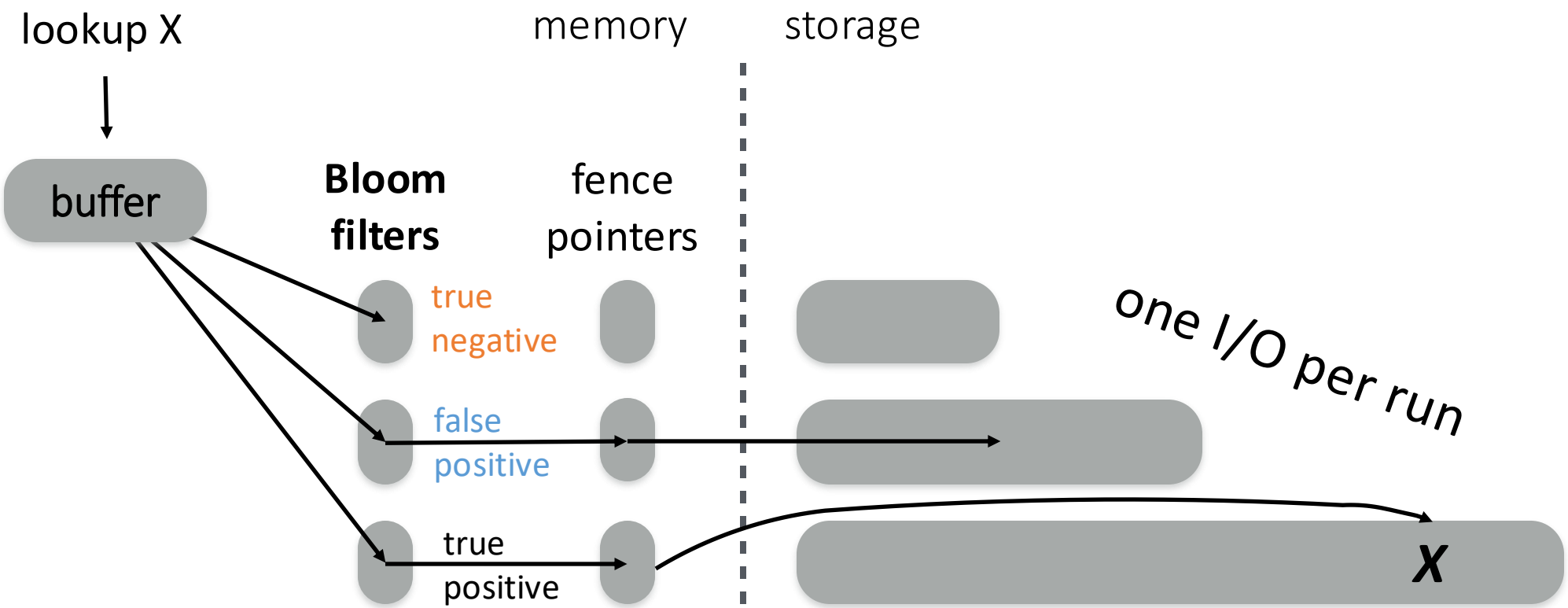




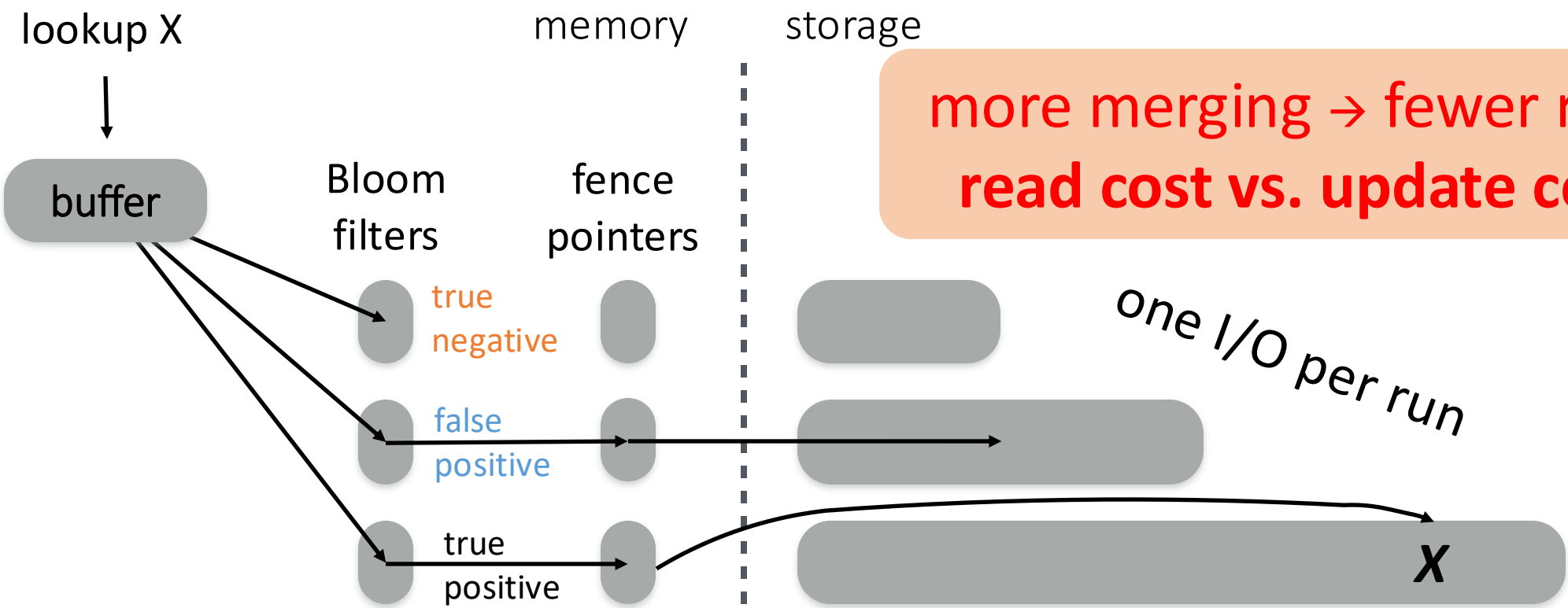








# performance & cost trade-offs




more merging → fewer runs

**read cost vs. update cost**

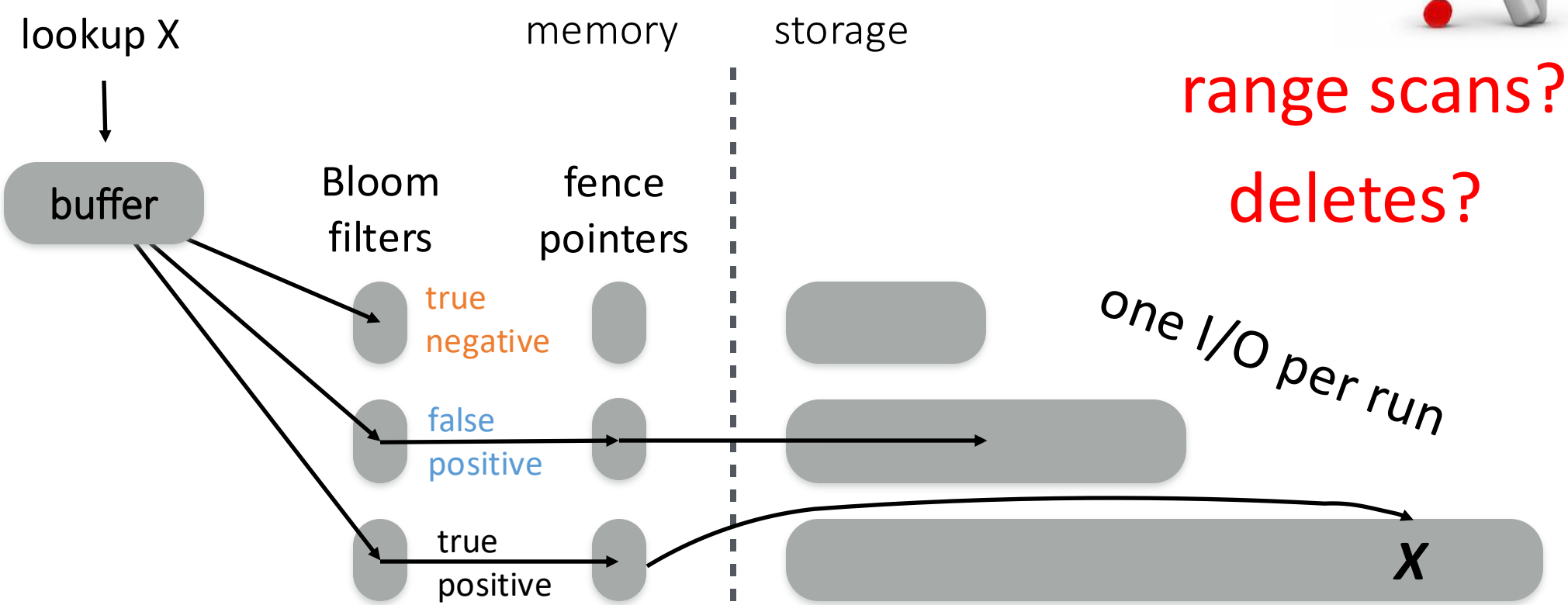
bigger filters → fewer false positives

**memory space vs. read cost**

# other operations

range scans?

deletes?



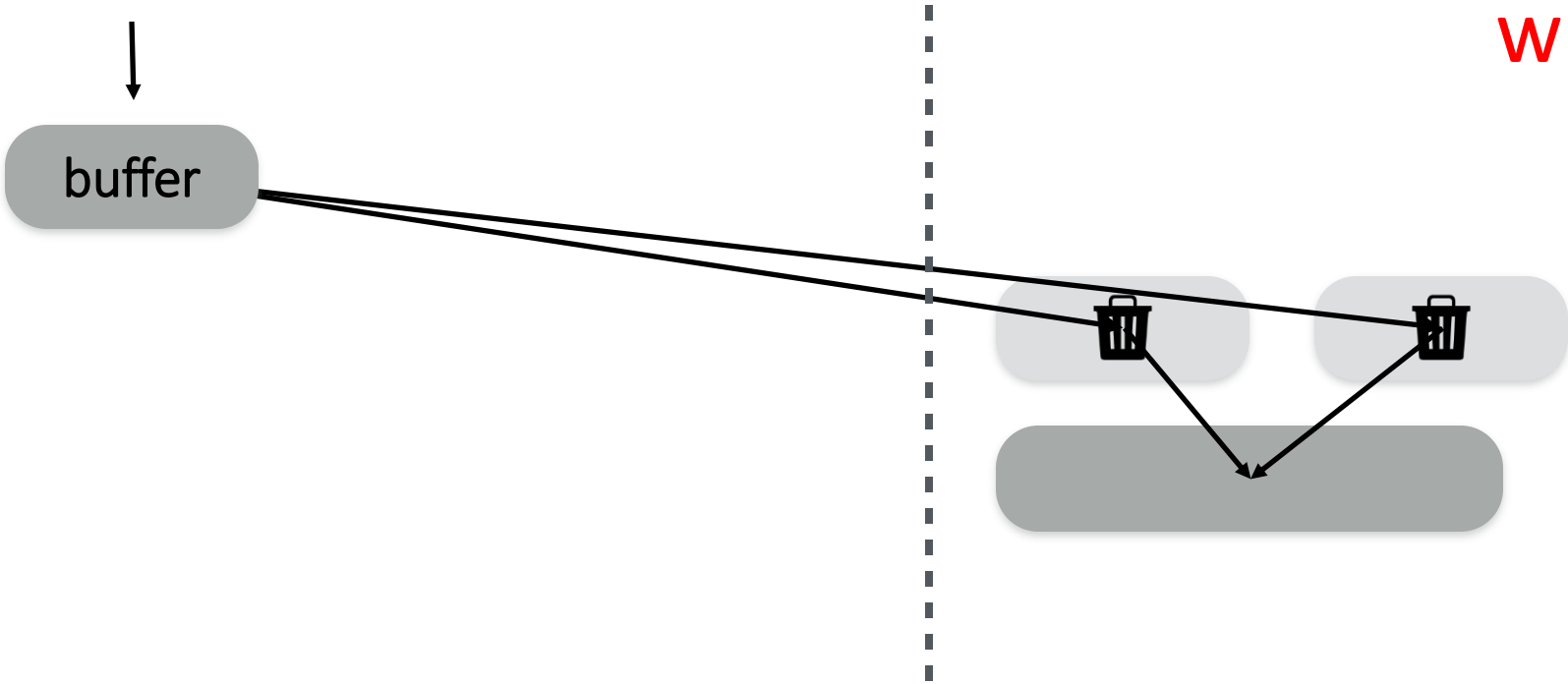
# remember merging?

updates

memory

storage

buffer



## what strategies?

sort & flush

runs

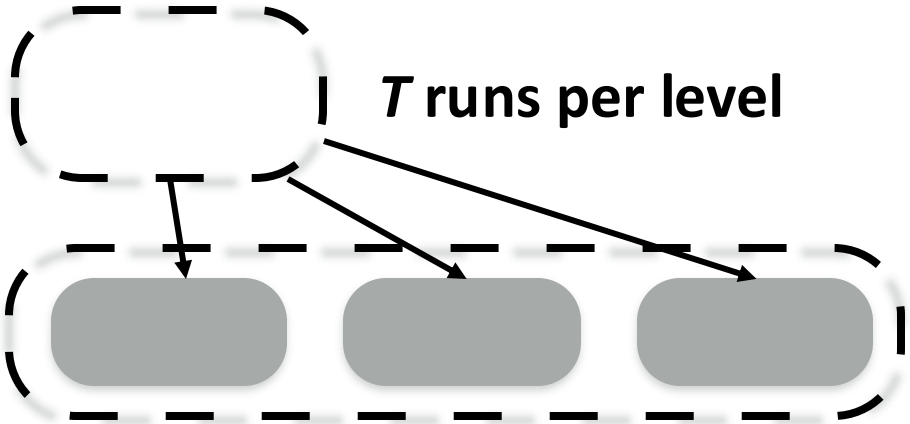
**sort-merge**

# Merge Policies

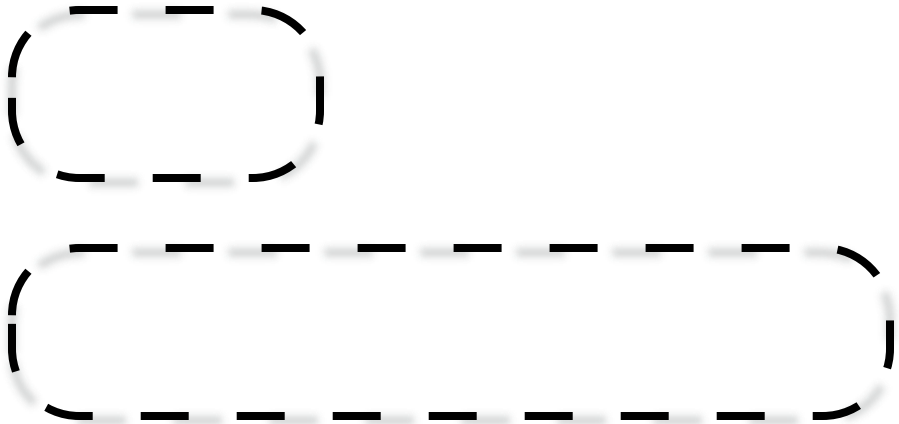
**Tiering**
write-optimized

**Leveling**
read-optimized

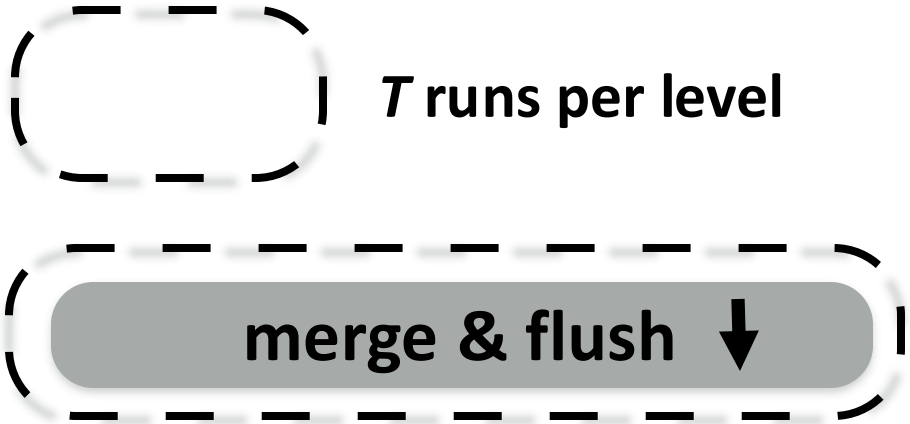
Tiering
write-optimized




Leveling
read-optimized



## Tiering
## write-optimized

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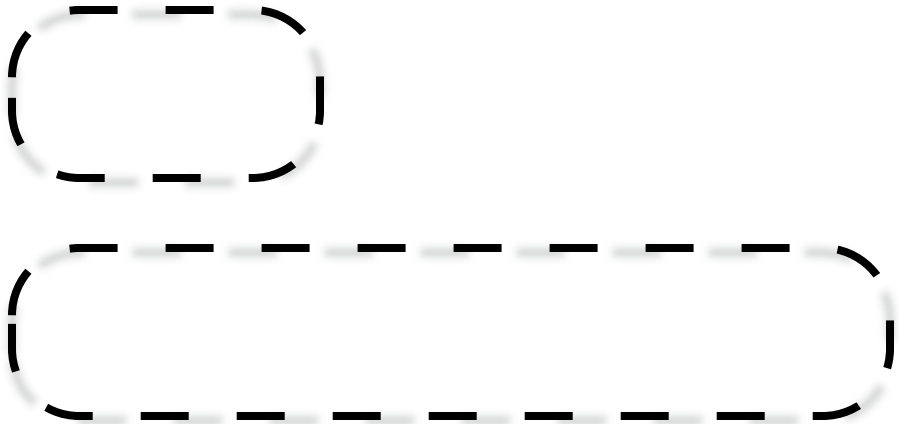

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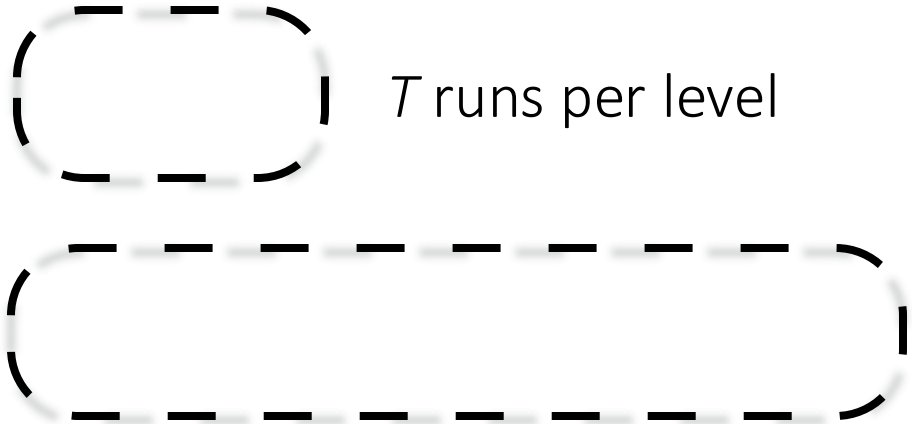


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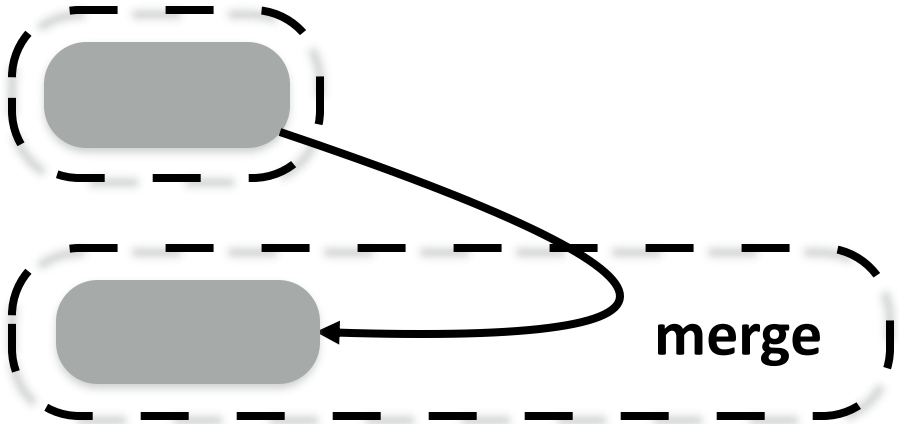

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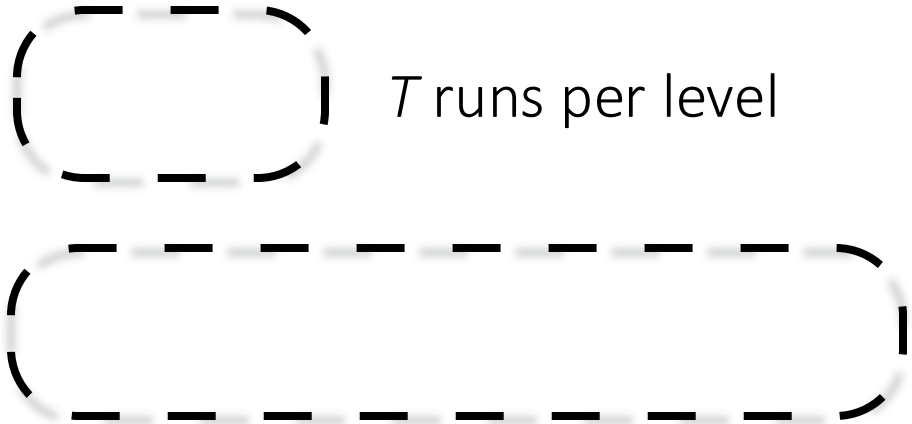


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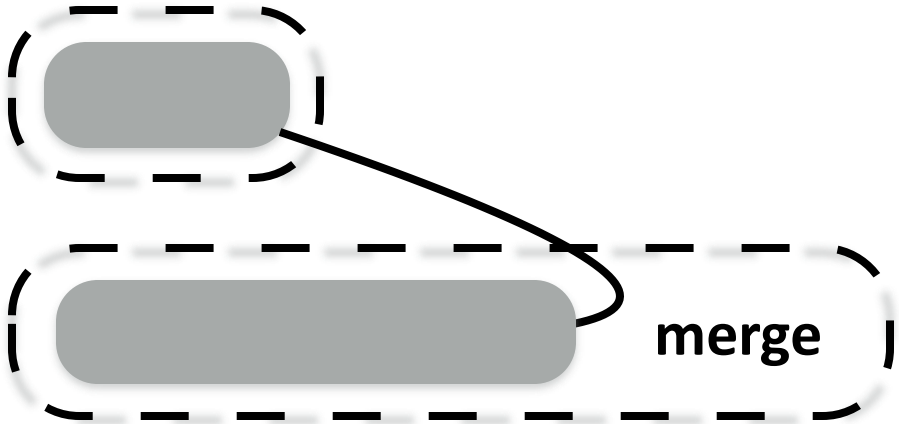

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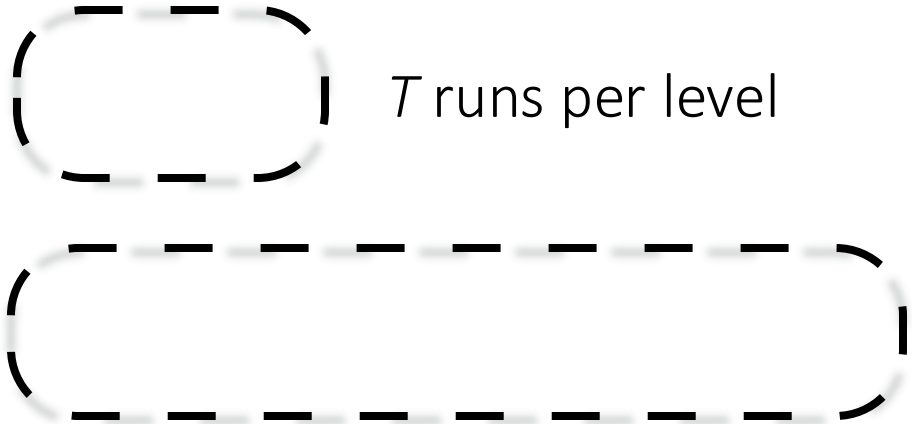


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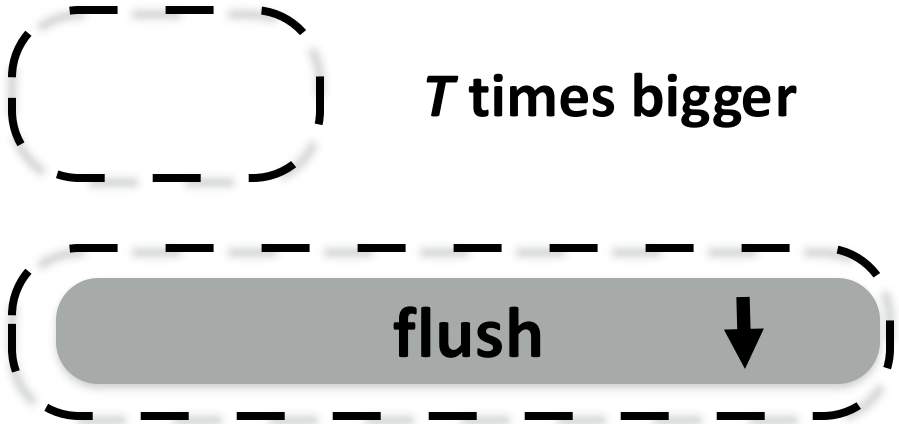


# Systems Project: LSM-Trees

*tuning knobs*

**merge policy**

**size ratio**

lookup X

memory

storage

buffer

**Bloom filters**

fence pointers

true negative

false positive

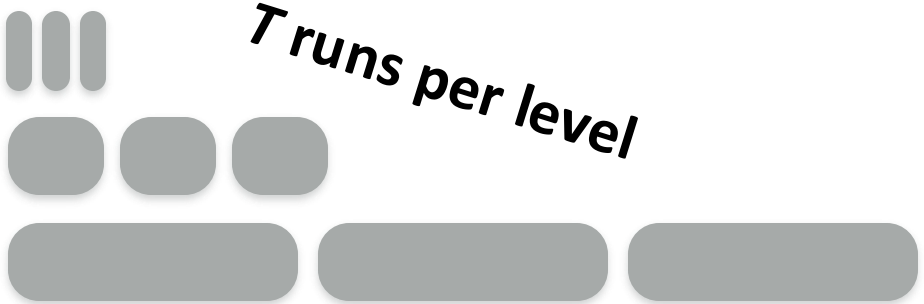
true positive

one I/O per run

***X***

# more on LSM-Tree performance

## Tiering
## write-optimized




## Leveling
## read-optimized


**lookup cost:**

$$O\left(T \cdot log_T(N) \cdot e^{-M/N}\right)$$

runs per level — levels — false positive rate

$$O\left(log_T(N) \cdot e^{-M/N}\right)$$

levels — false positive rate

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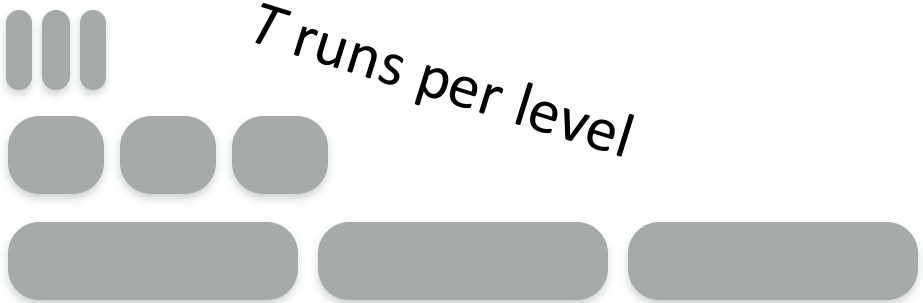
## Tiering
## write-optimized

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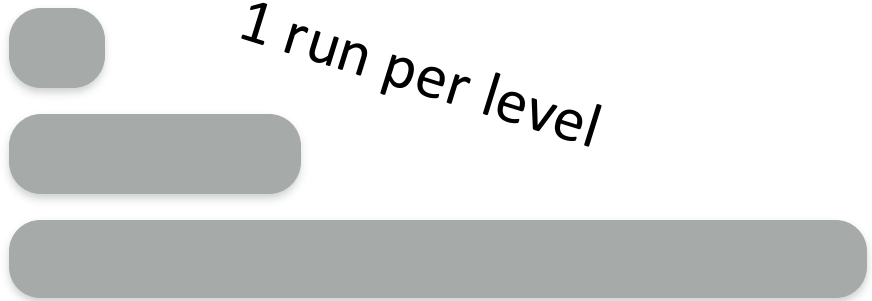
## read-optimized




lookup cost: $O\left(T \cdot log_T(N) \cdot e^{-M/N}\right)$

**update cost:** $\boldsymbol{O\left(log_T(N)\right)}$

levels

$O\left(log_T(N) \cdot e^{-M/N}\right)$

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

merges per level

levels

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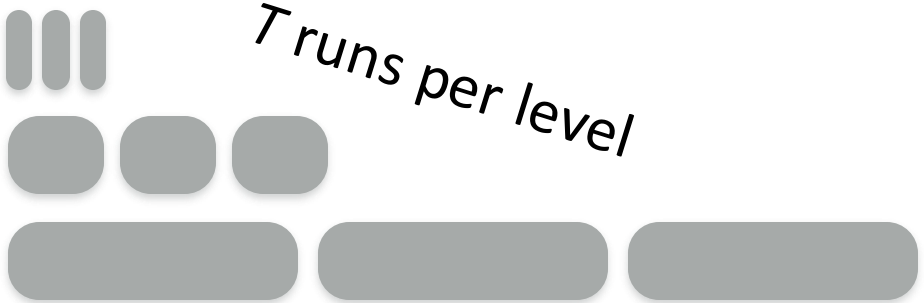
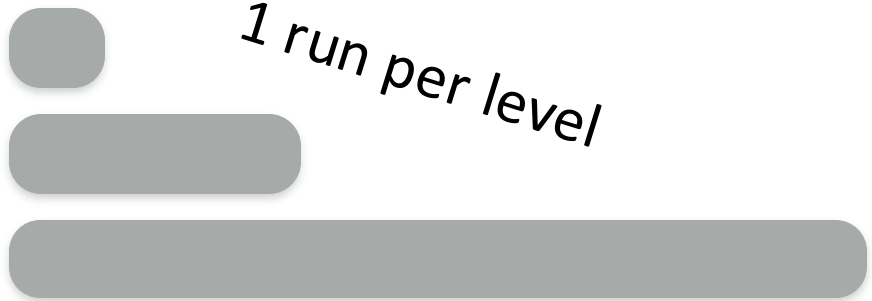
## Tiering
## write-optimized




## Leveling
## read-optimized

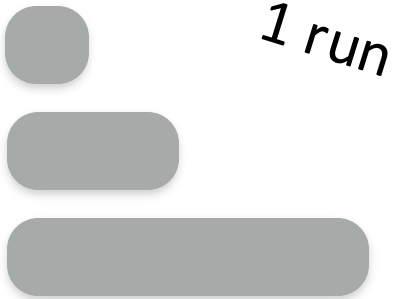



lookup cost: $O\left(T \cdot log_T(N) \cdot e^{-M/N}\right)$ $O\left(log_T(N) \cdot e^{-M/N}\right)$

update cost: $O\left(log_T(N)\right)$ $O\left(T \cdot log_T(N)\right)$

**for size ratio T** ⌄⌄

## Tiering
## write-optimized



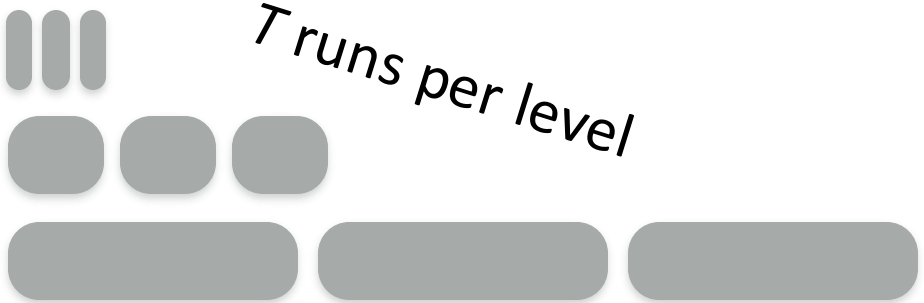

## Leveling
## read-optimized


lookup cost: $O\left(log_T(N) \cdot e^{-M/N}\right) = O\left(log_T(N) \cdot e^{-M/N}\right)$

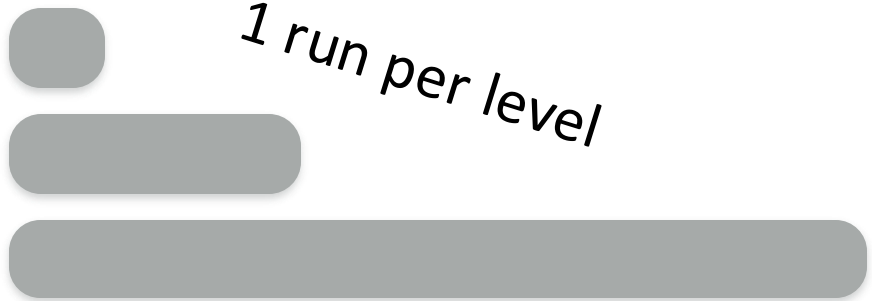
update cost: $O\left(log_T(N)\right) = O\left(log_T(N)\right)$

**for size ratio T** ⌄⌄

## Tiering
## write-optimized




## Leveling
## read-optimized




lookup cost: $O\left(T \cdot log_T(N) \cdot e^{-M/N}\right)$ $O\left(log_T(N) \cdot e^{-M/N}\right)$

update cost: $O\left(log_T(N)\right)$ $O\left(T \cdot log_T(N)\right)$

**for size ratio T** ⌃⌃

Tiering
write-optimized

$O(N)$ runs per level

**log**

Leveling
read-optimized

1 run per level

**sorted array**

lookup cost: $O\left(T \cdot log_T(N) \cdot e^{-M/N}\right)$ $O\left(log_T(N) \cdot e^{-M/N}\right)$

update cost: $O\left(log_N(N)\right) = \boldsymbol{O(1)}$ $O\left(N \cdot log_N(N)\right) = \boldsymbol{O(N)}$

**for size ratio T** **N** ≫

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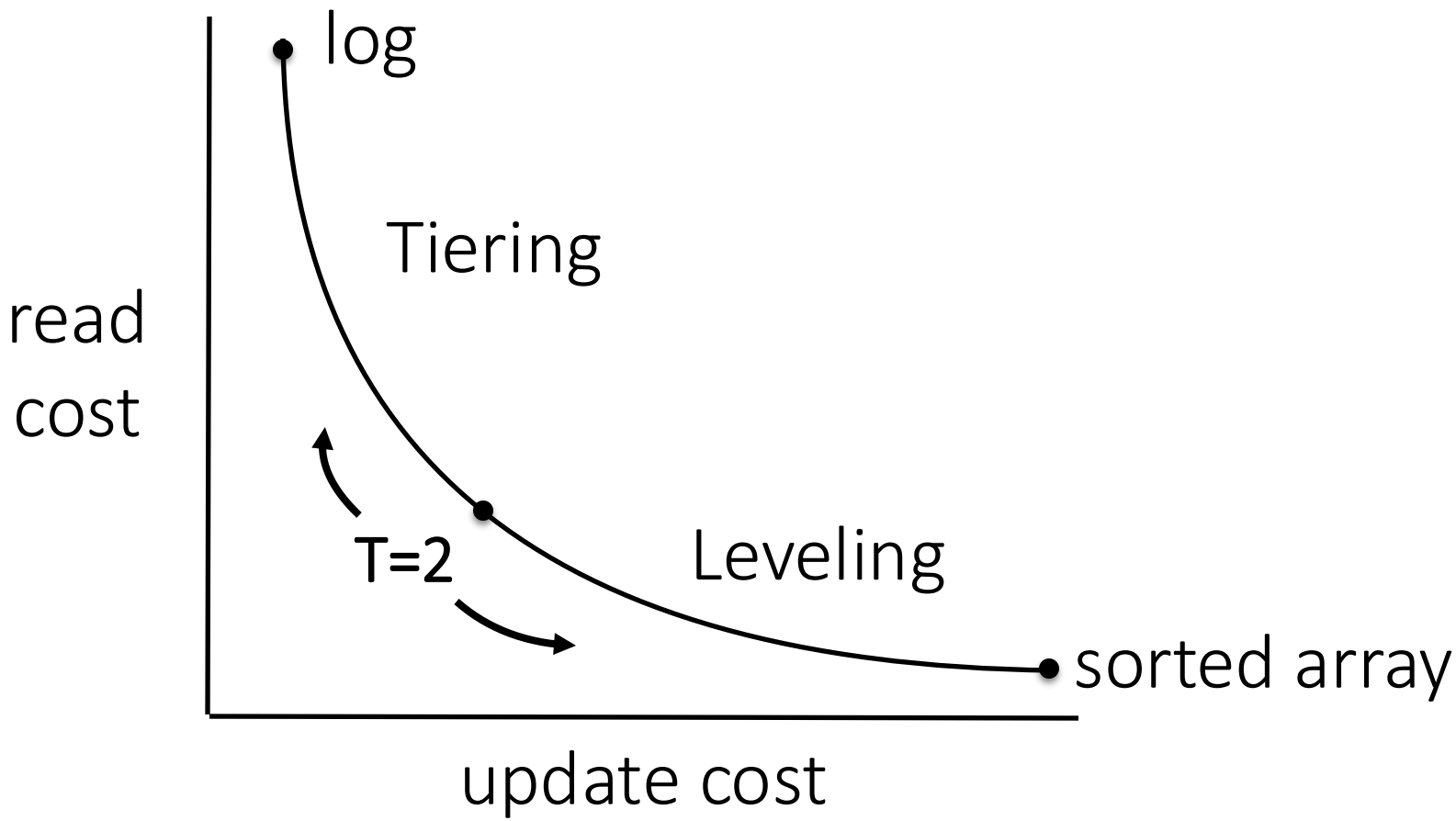


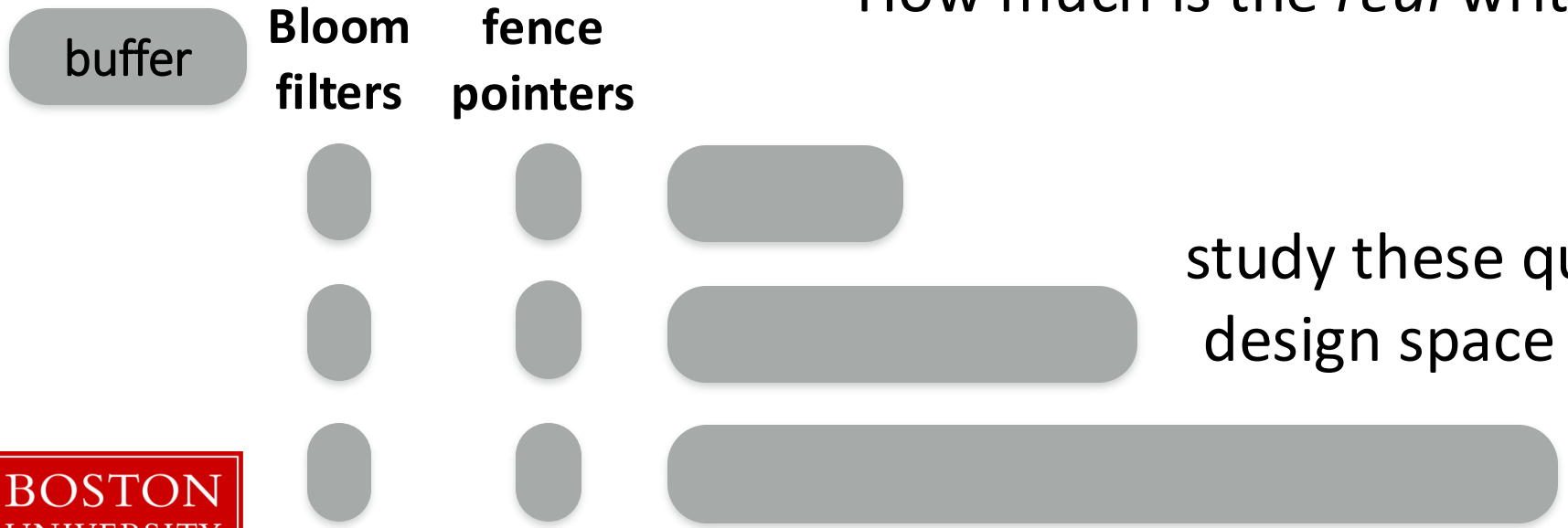

T : size ratio

# Research Question on LSM-Trees

how can we minimize the duplicate space during compaction?

how to ensure that we can tune without sharing workload details?

How much is the *real* write-amplification on SSDs?




study these questions and navigate LSM design space using Facebook's RocksDB

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RocksDB

# Research on PostgreSQL


***A state-of-the-art relational database***

How can we implement a skew-aware efficient join algorithm?

How much a noise in the existing cardinality estimation can impact the selected query plan, and the overall query performance

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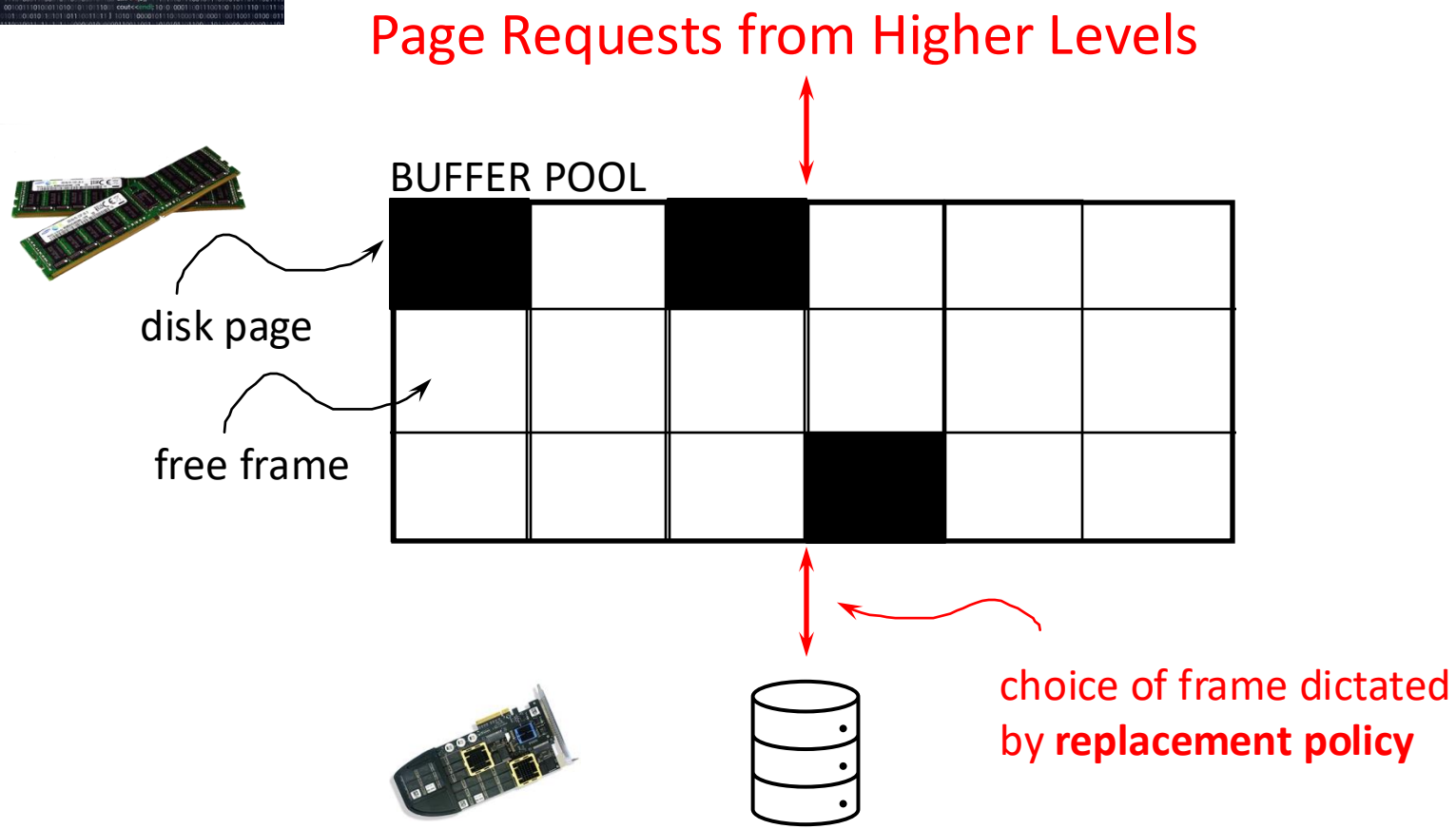
# Systems Project: Bufferpool




## *Implementation of a bufferpool*

- **Application requests** a page
  - If **in the bufferpool** return it
  - If **not in the bufferpool** fetch it from the disk
    - If bufferpool is full select page to **evict**

## *Core Idea: Eviction Policy*

- *Least Recently Used*
- *First In First Out*
- *more …*

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# Research Topics on Buffer Management & SSDs

How to deploy ACE buffer management on emulated SSDs?

How can we achieve storage parallelism in ZNS SSDs?

# Other Research Topics on Indexing and beyond

How to apply sortedness-aware concepts on Adaptive Radix Tree?

How to build cache-friendly sortedness-aware indexing?

How to design a sortedness-aware join algorithm?

# what to do now?

**systems project**

form groups of 3

(speak to me in OH if you want a different arrangement)

**research project**

form groups of 3

pick one of the subjects & read background material

define the behavior you will study and address

sketch approach and success metric

(if LSM-related get familiar with RocksDB)

# what to do now?

**systems project**
form groups of 2
(speak to me in OH if you want to work on your own)

**research project**

*come to OH/Labs*

submit project 0 this Friday on 1/31

start working on project 1 (due on 2/14)

submit semester project proposal on 2/23

BOSTON UNIVERSITY

# CS 561: Data Systems Architectures

## class 4

## Systems & Research Project

Zichen Zhu

https://bu-disc.github.io/CS561/