BOSTON UNIVERSITY

CS 561: Data Systems Architectures

class 4

Systems & Research Project

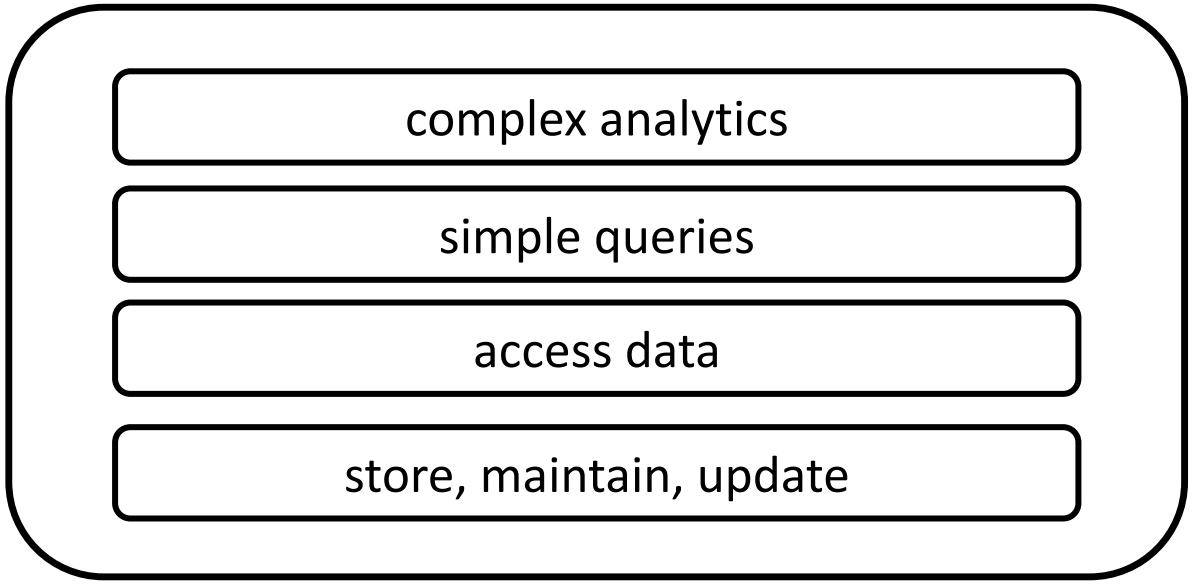
Prof. Manos Athanassoulis

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

data systems

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

[The Forbes, 2016]



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data systems

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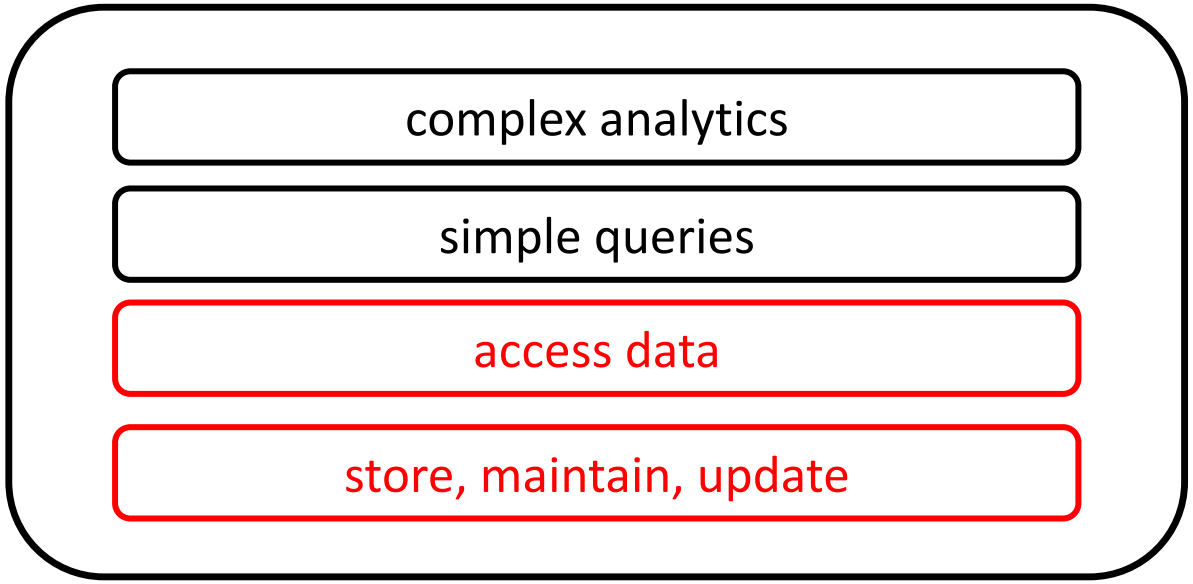


access methods*

***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

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})

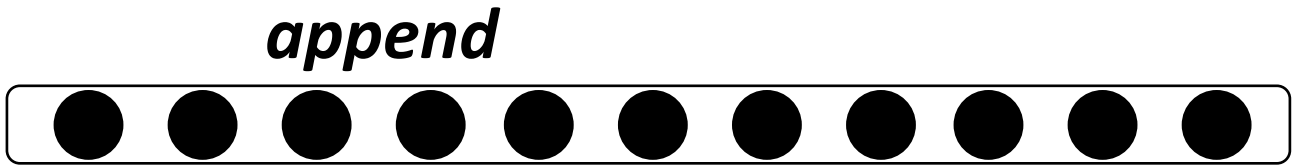
deletes: delete(k)

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

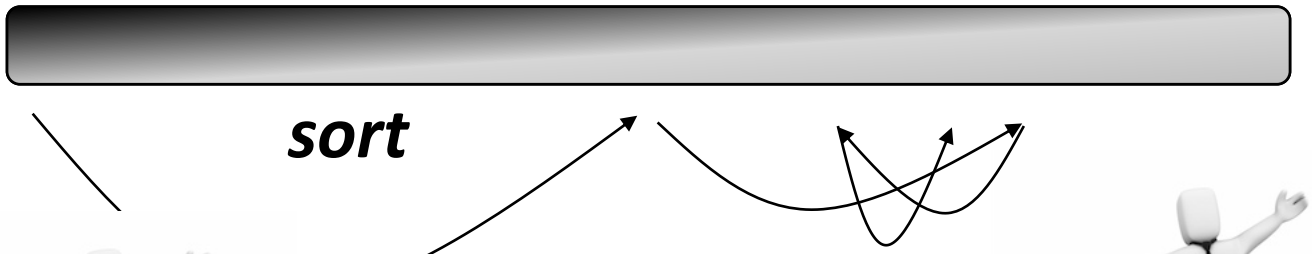
get set: {v_1, v_2, …} = get_set(k_1, k_2, …)

how to build a key-value store?

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



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

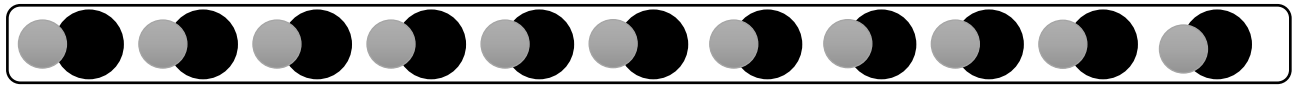


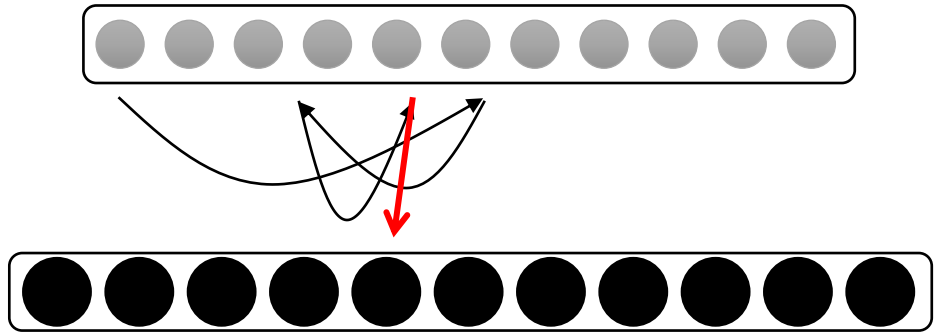
what about full scan?

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

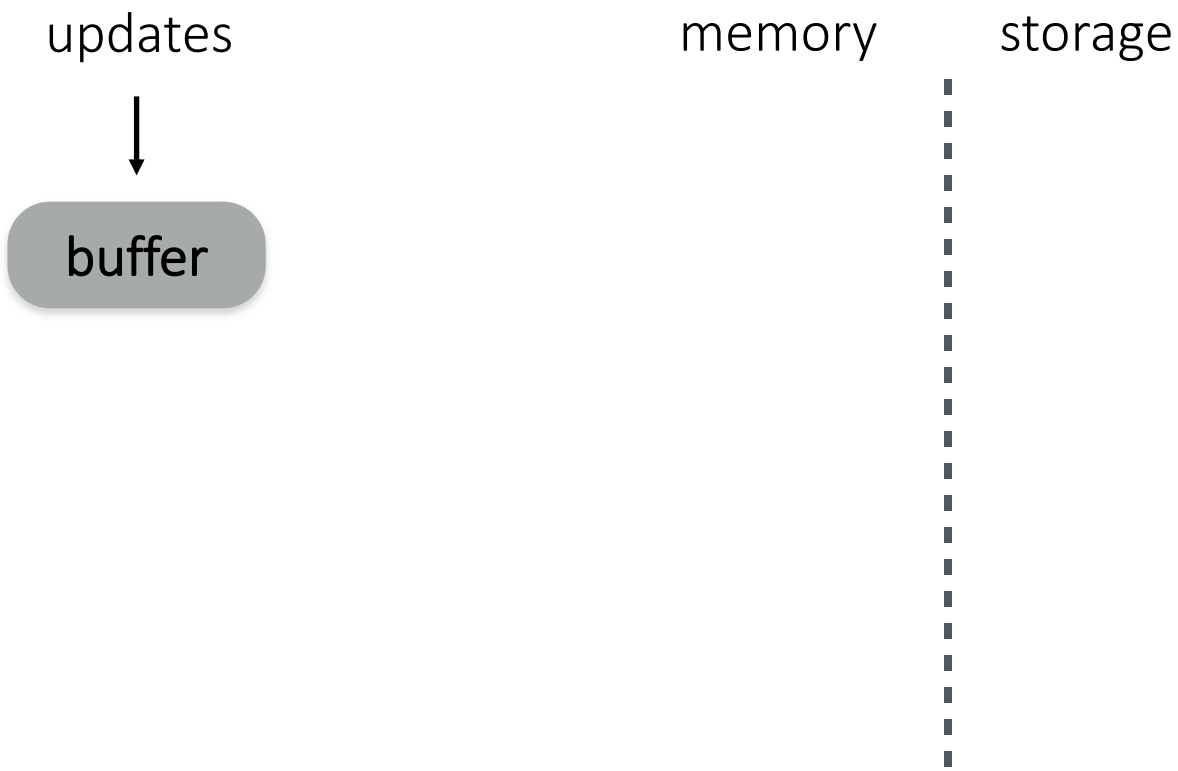
amortize sorting cost

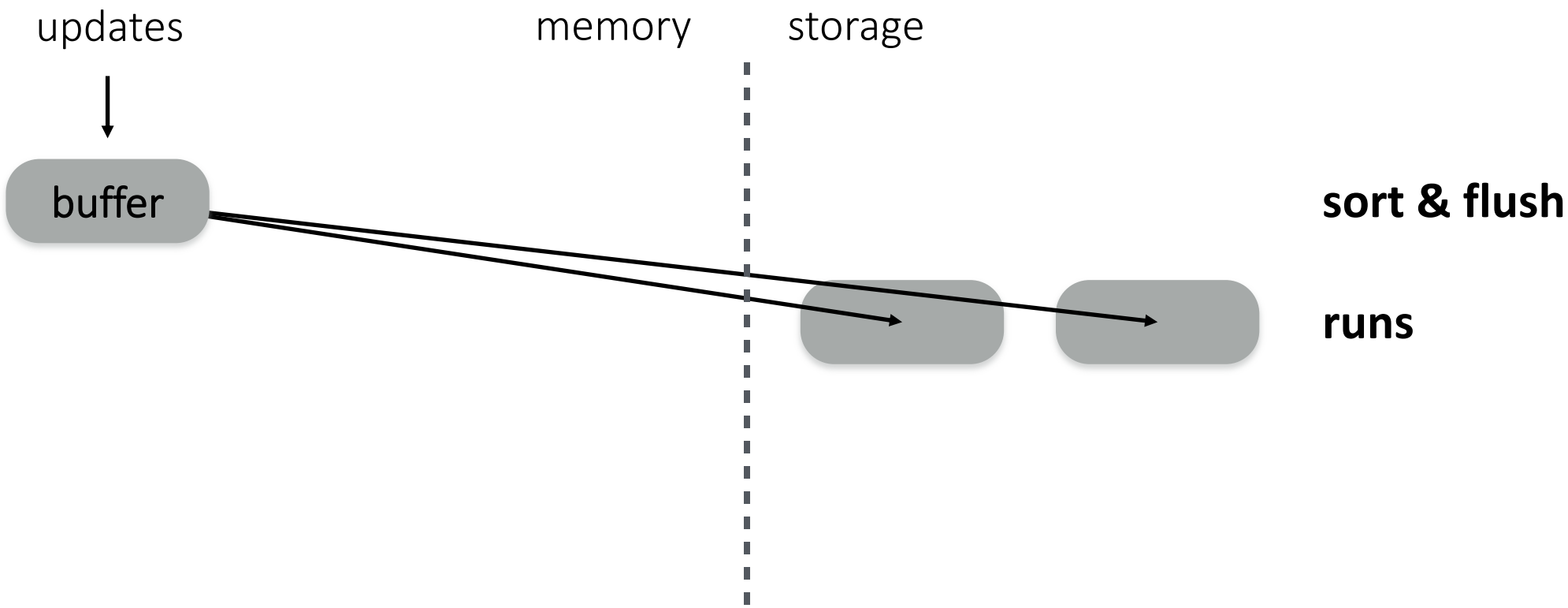
avoid resorting after every update

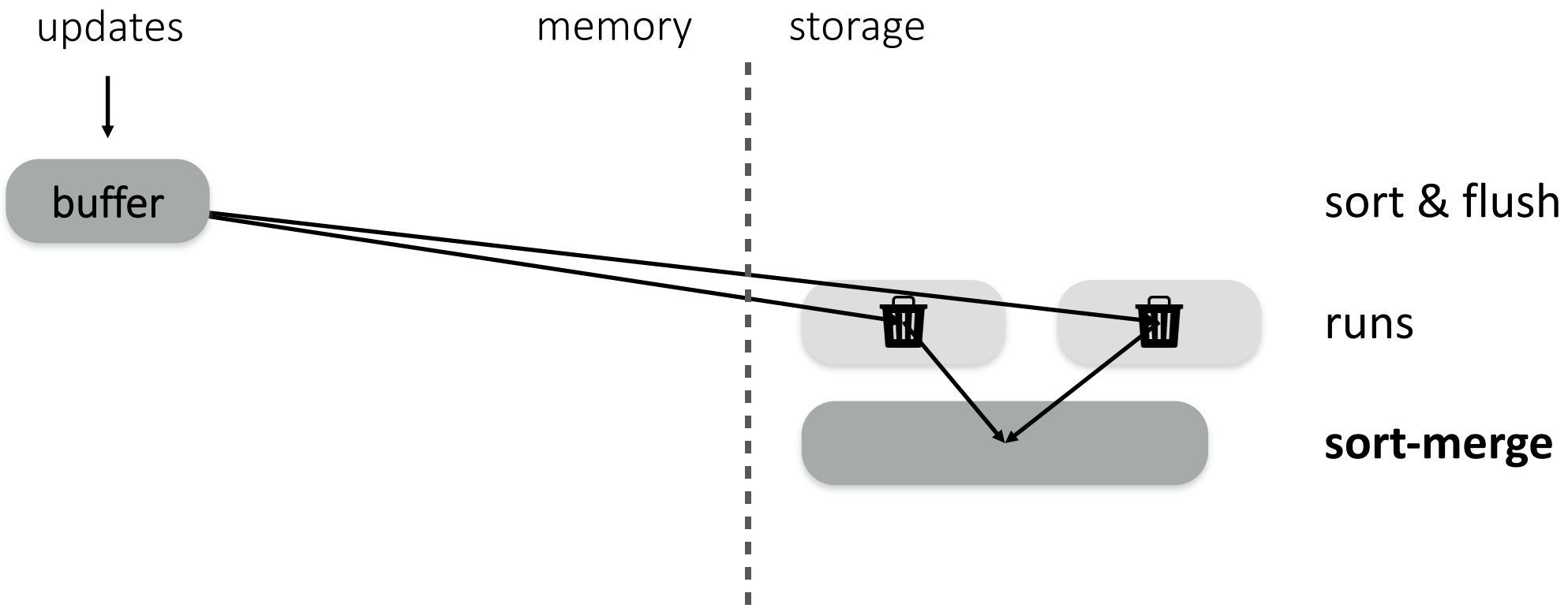
how to bridge?

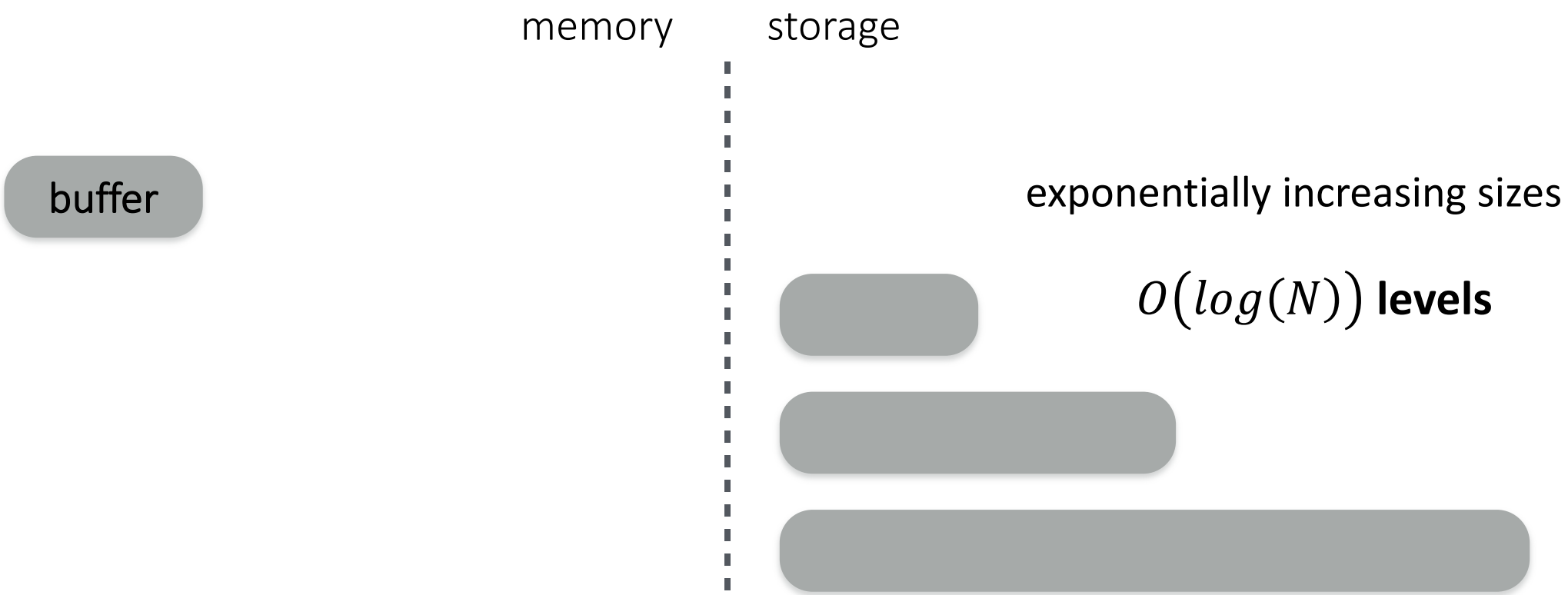
LSM-tree
Key-Value Stores

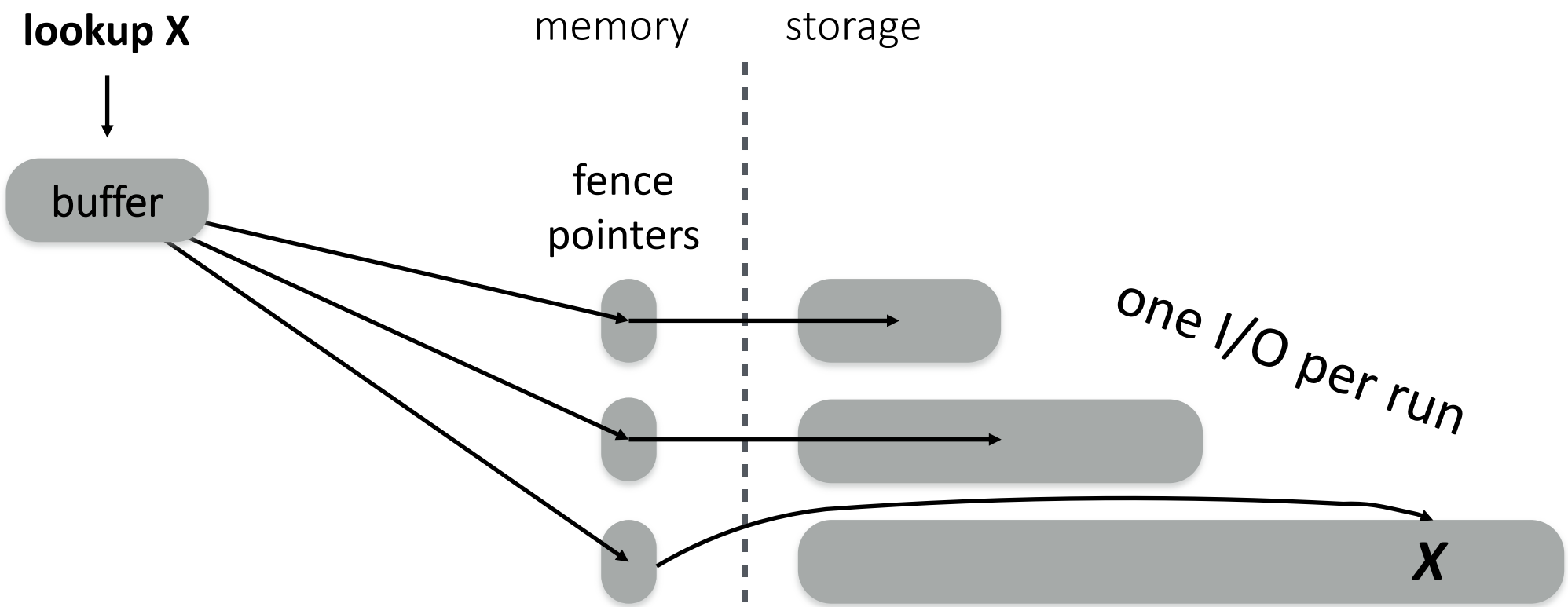
What are they really?

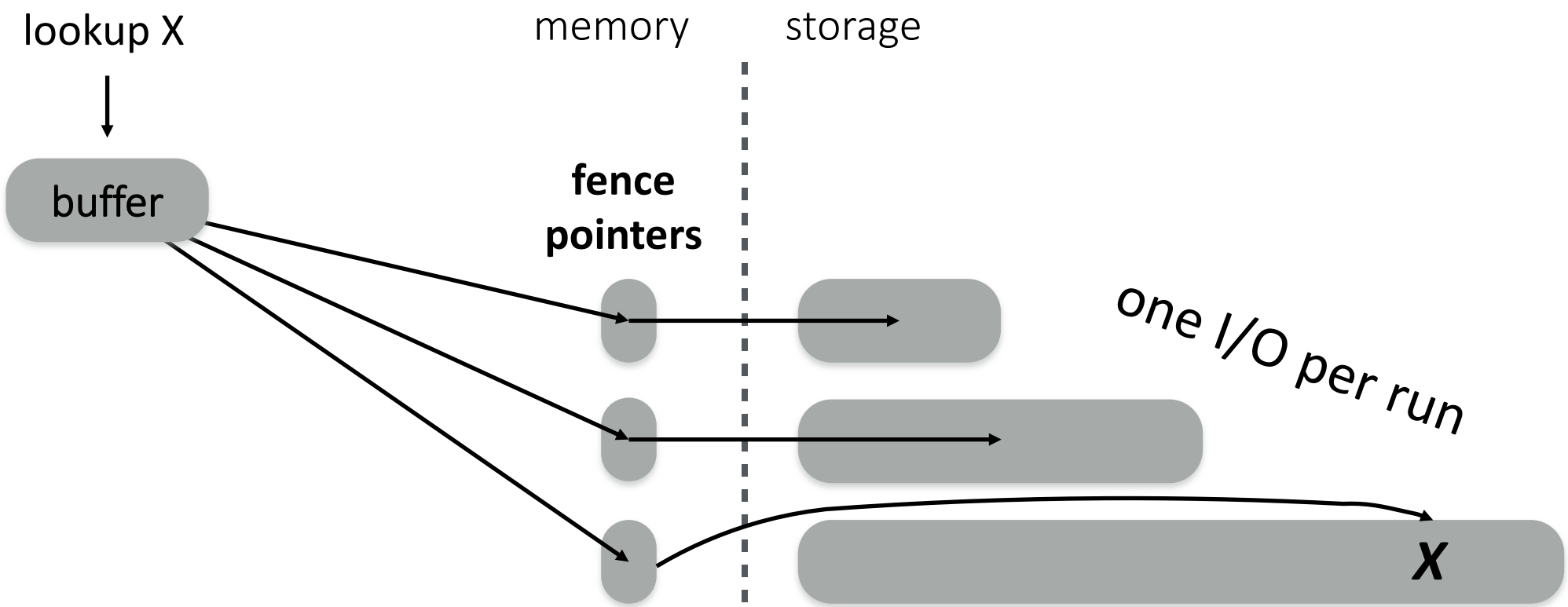


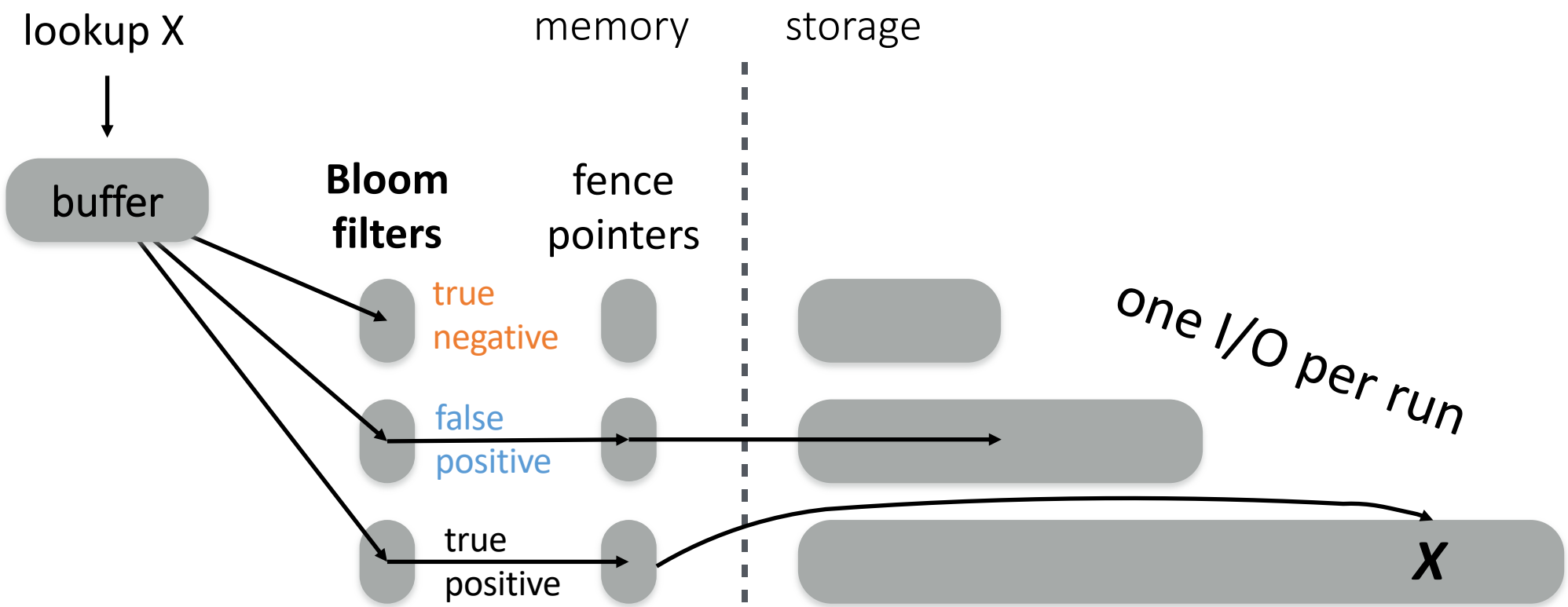




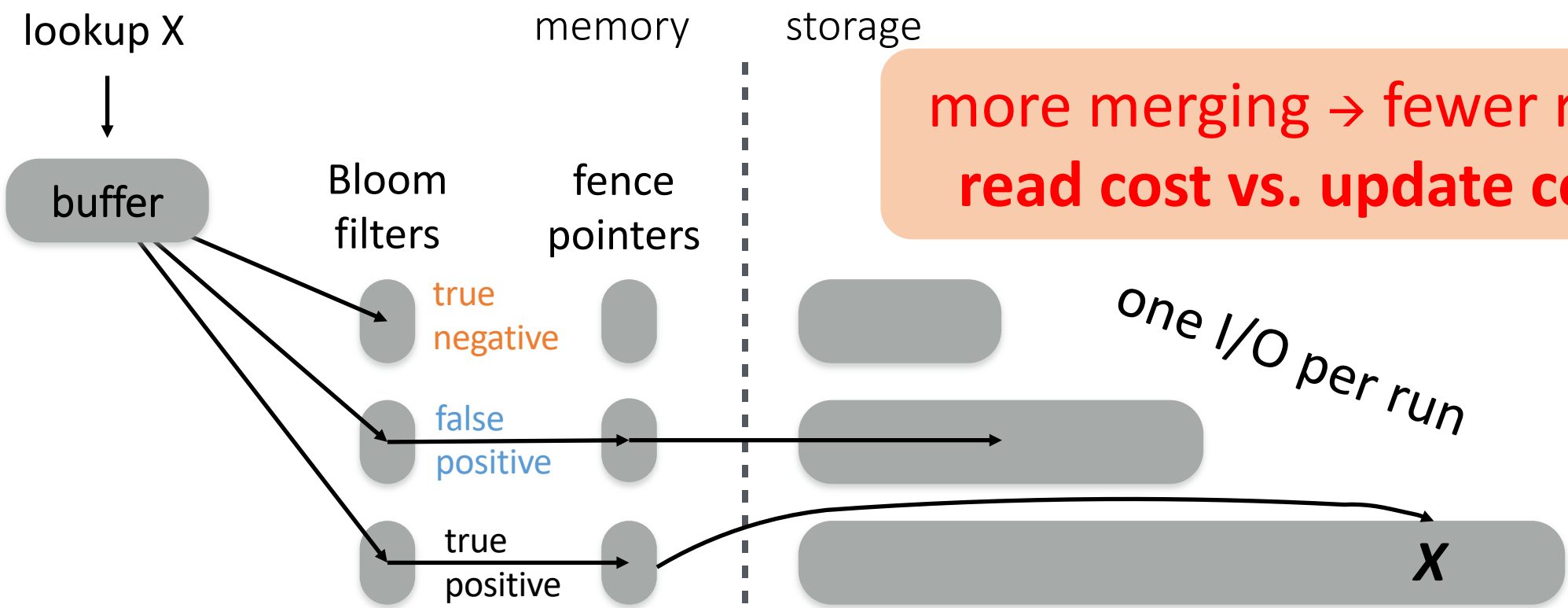








performance & cost trade-offs



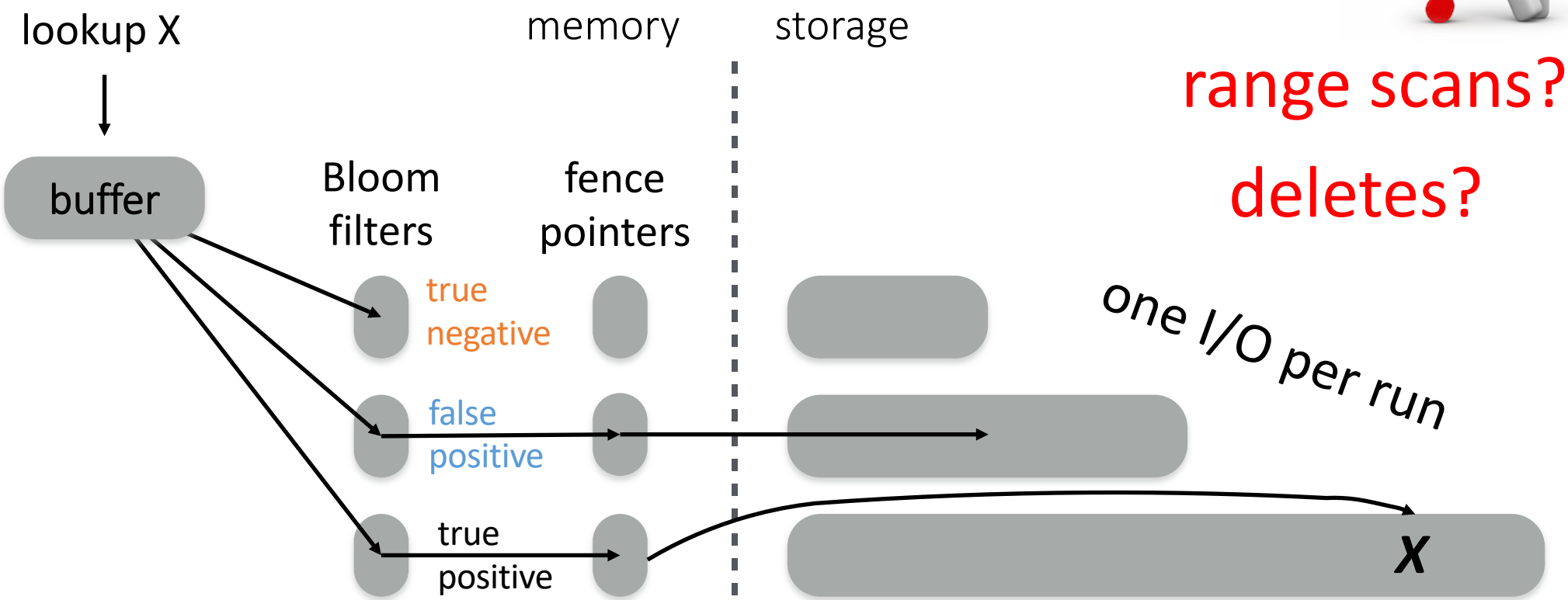
more merging → fewer runs

read cost vs. update cost

bigger filters → fewer false positives

memory space vs. read cost

other operations



range scans?

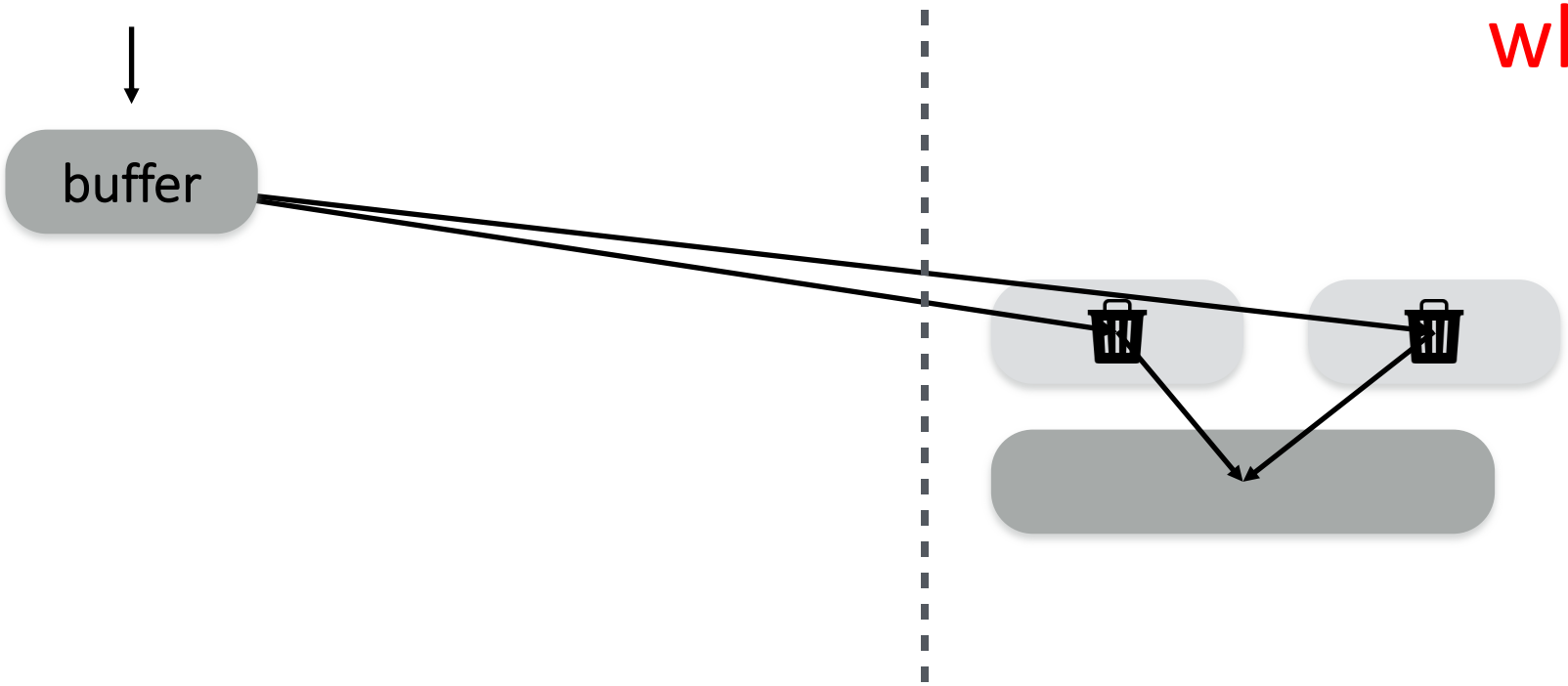
deletes?

remember merging?

updates

memory

storage



what strategies?

sort & flush

runs

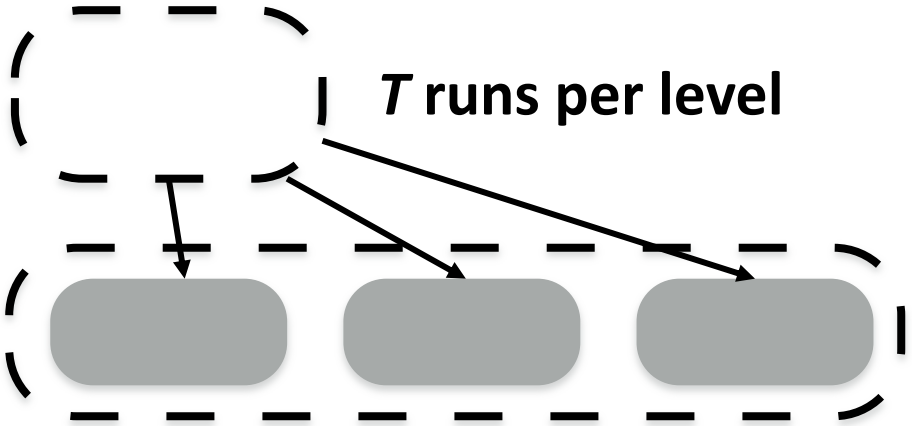
sort-merge

Merge Policies

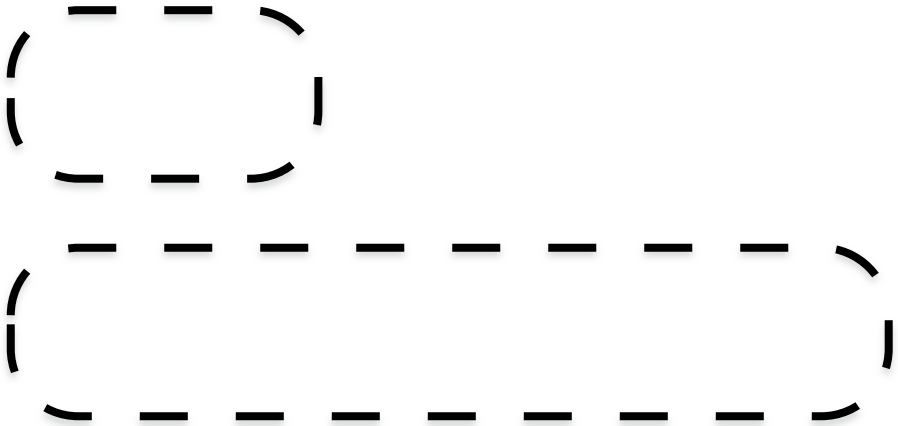
Tiering
write-optimized

Leveling
read-optimized

Tiering
write-optimized



Leveling
read-optimized



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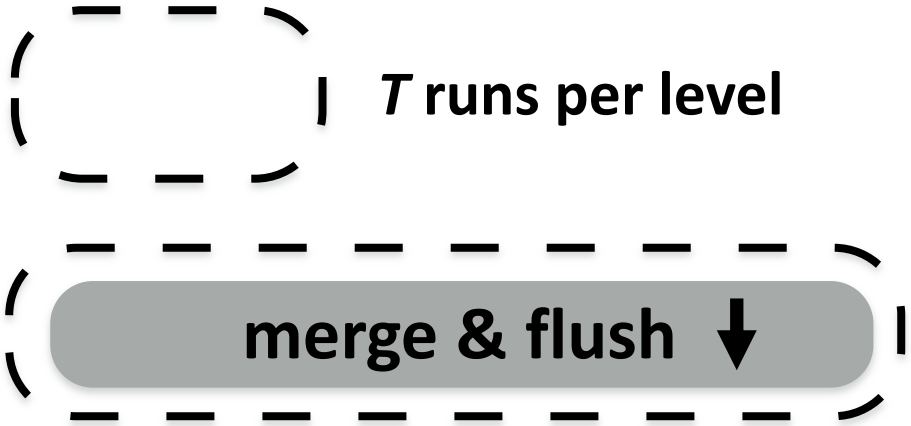

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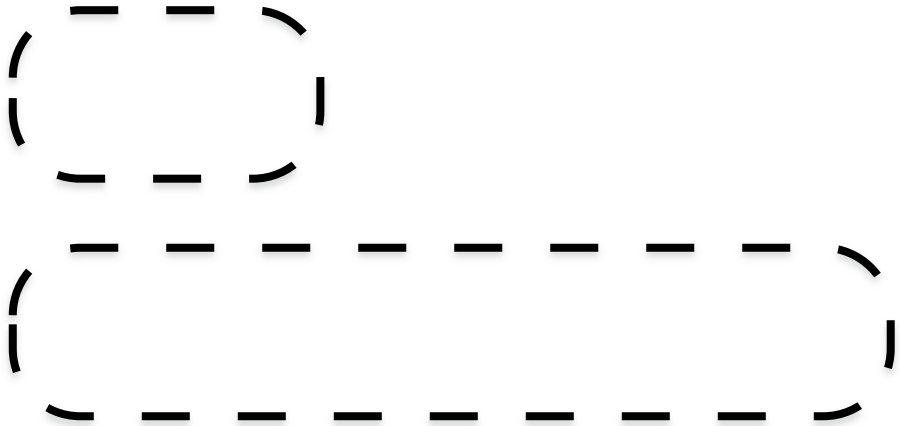

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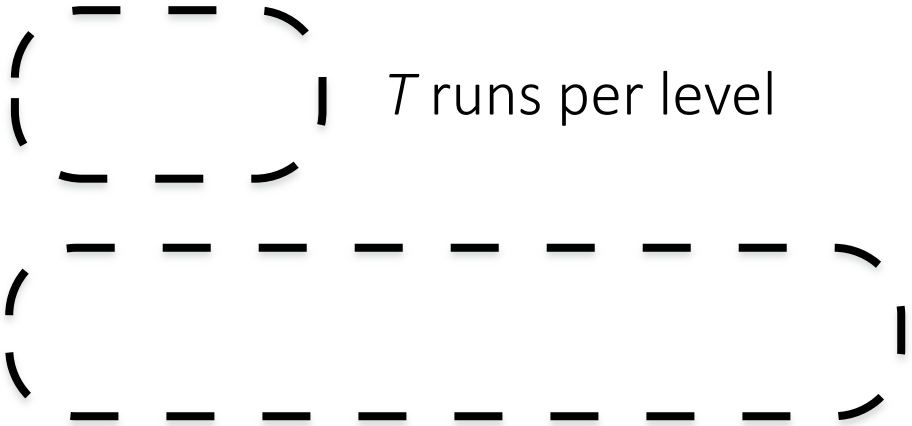

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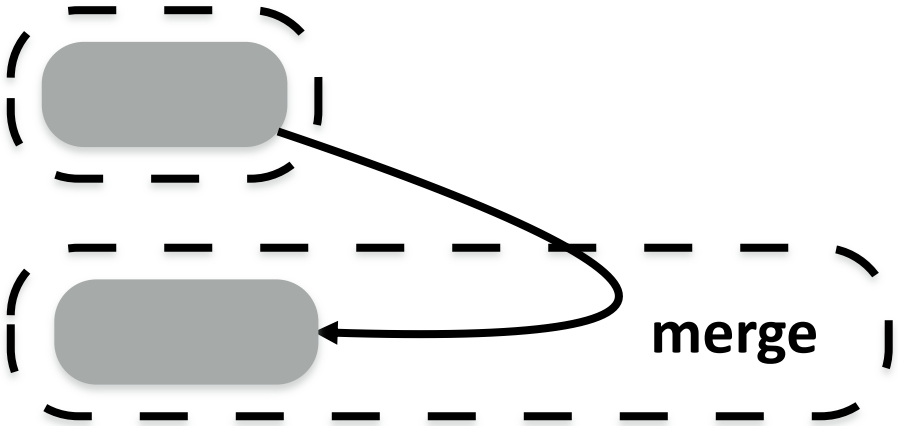
read-optimized



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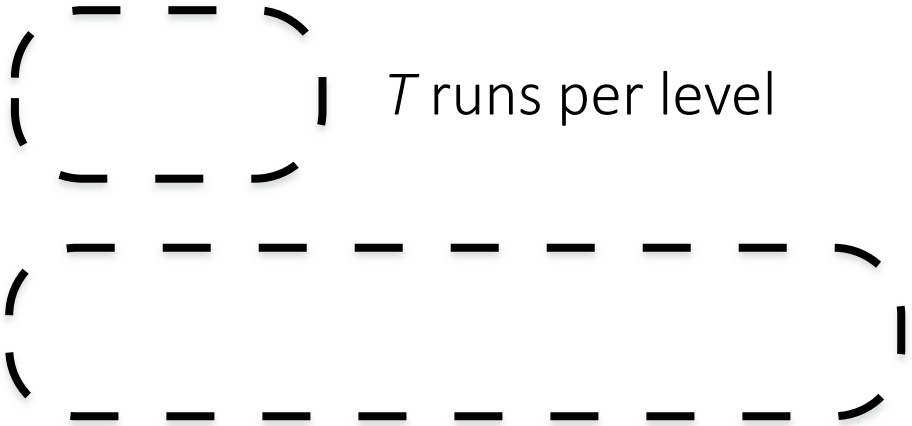

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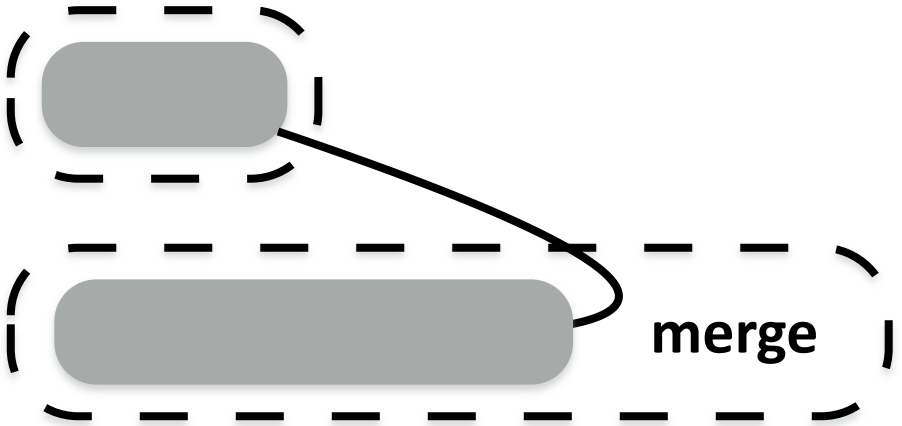

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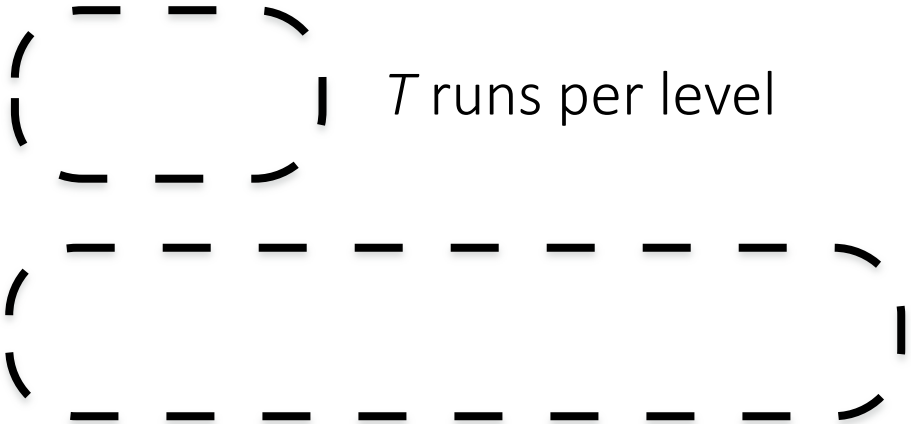

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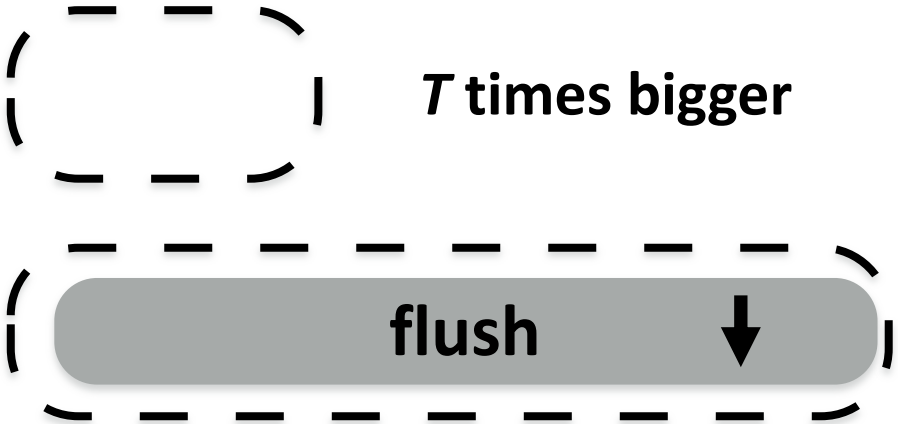


Systems Project: LSM-Trees

tuning knobs

merge policy

size ratio

lookup X

memory

storage

buffer

Bloom filters

fence pointers

true negative

false positive

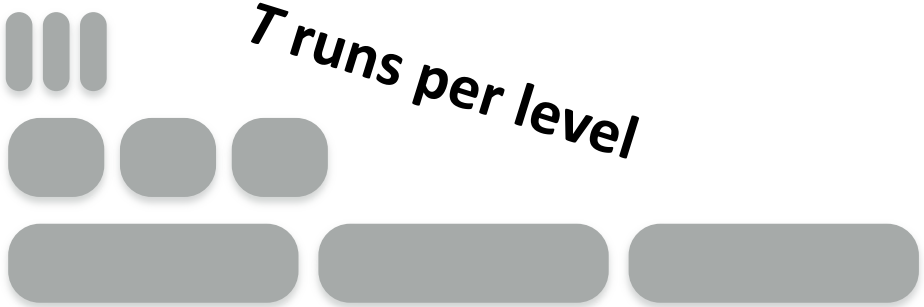
true positive

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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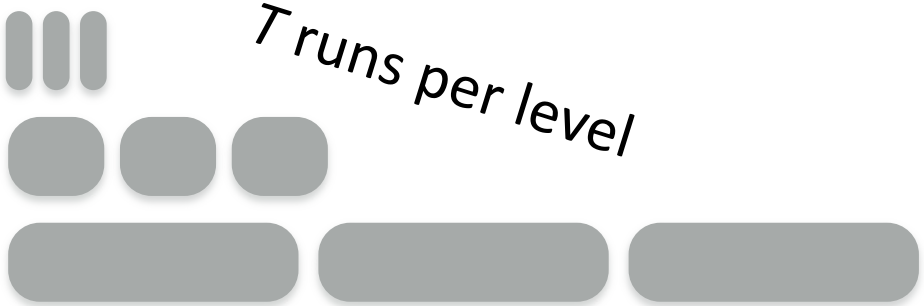
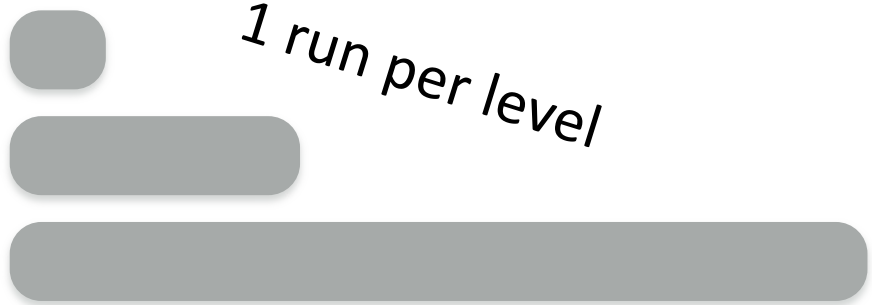
Tiering
write-optimized



Leveling
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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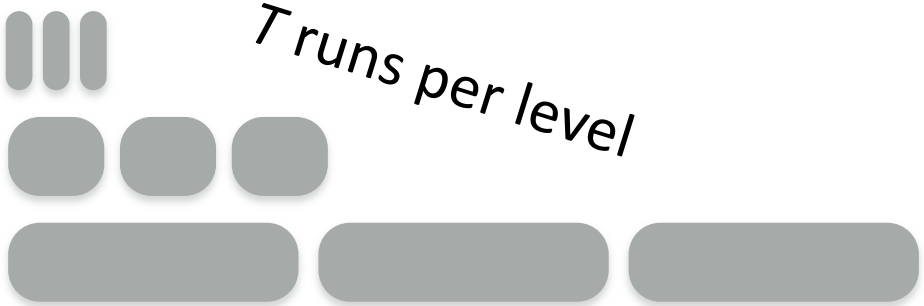
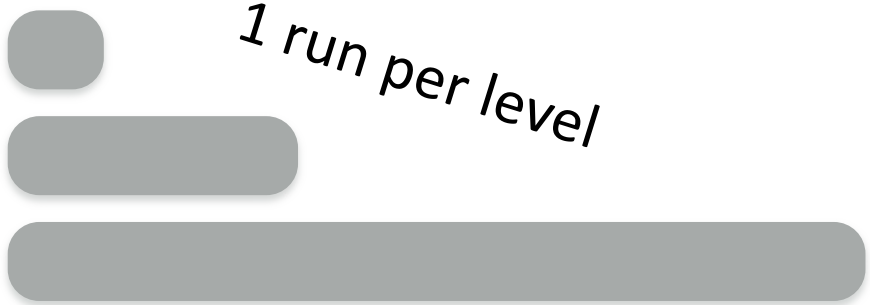
Tiering
write-optimized



Leveling
read-optimized

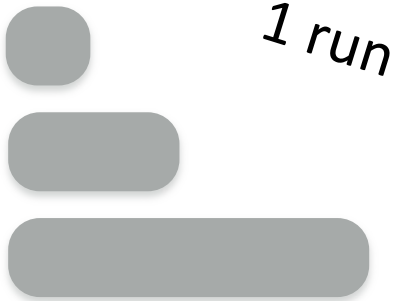


lookup cost: $O\left(T \cdot log_T(N) \cdot e^{-M/N}\right)$ $O\left(log_T(N) \cdot e^{-M/N}\right)$

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

for size ratio T ⌄⌄

Tiering
write-optimized



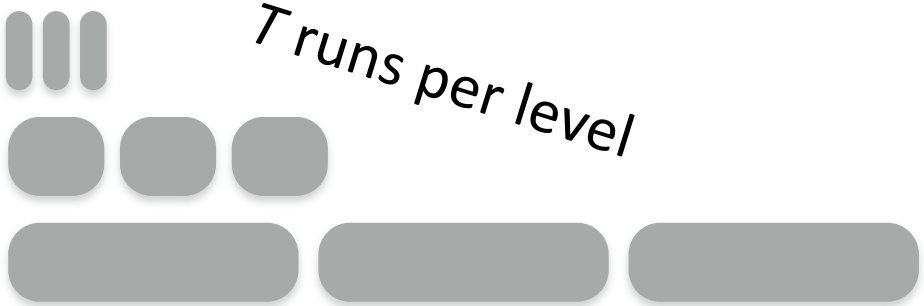
Leveling
read-optimized

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

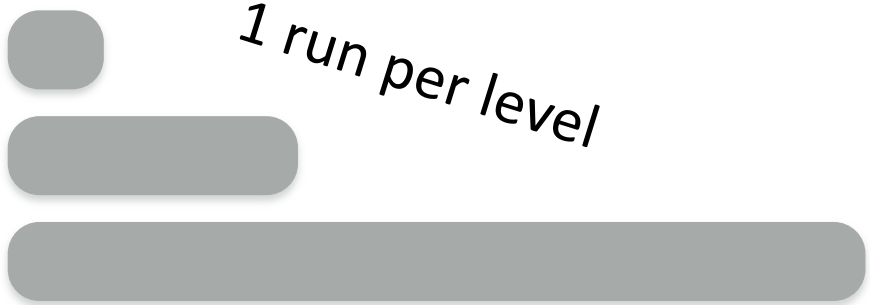
update cost: $O\left(log_T(N)\right) = O\left(log_T(N)\right)$

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

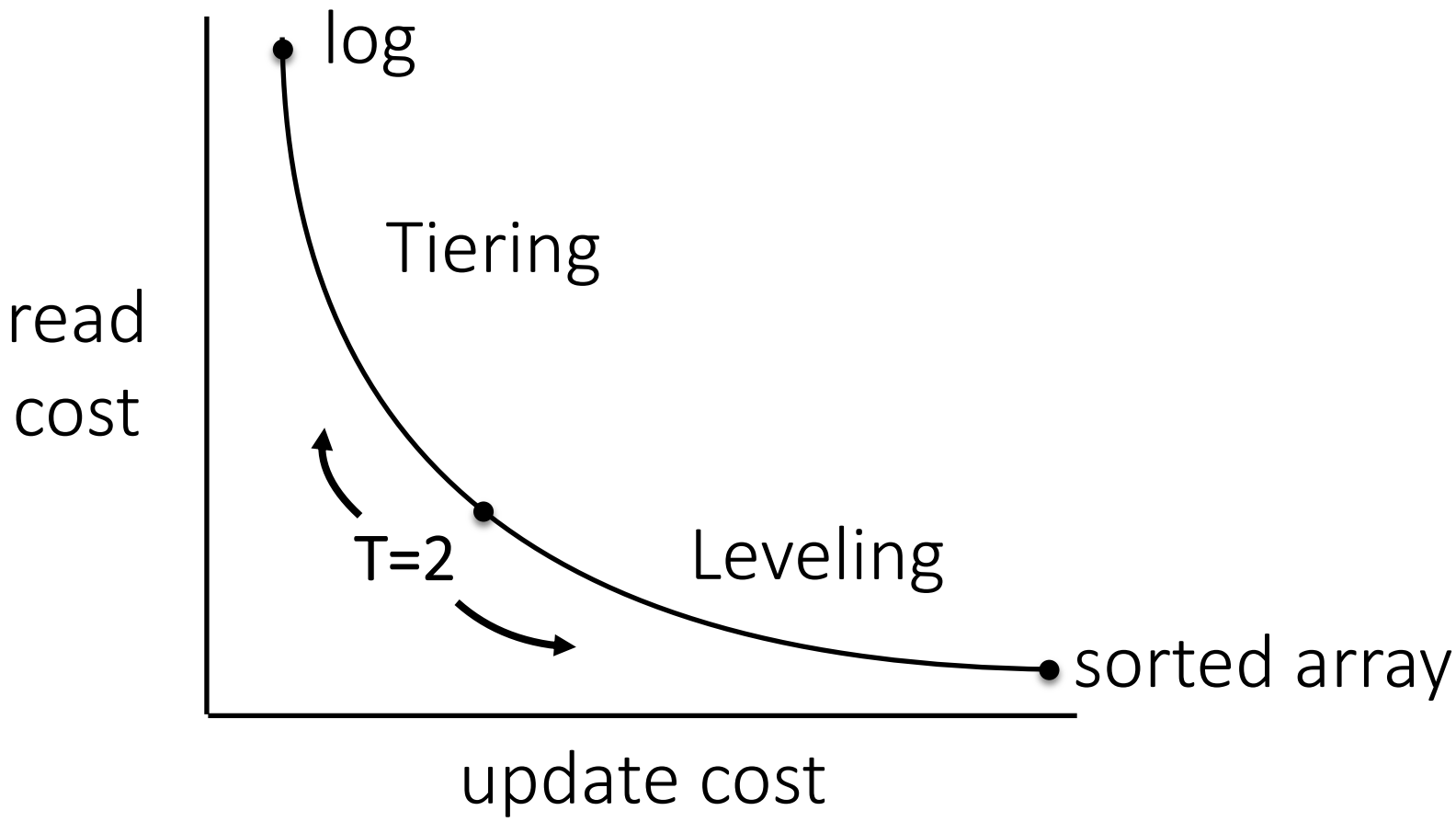
1 run per level

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** ≫



T : size ratio

Research Question on LSM-Trees

how to do range scans?

how to delete? how to delete ***quickly***?

how to allocate memory between buffer/Bloom filters/fence pointers?

what is the CPU overhead of Bloom filters?

what if data items come ordered?

what if data items come ***almost ordered***?

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

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RocksDB

What “almost ordered” even mean?

Research question on ***sortedness***

How to quantify it? Need a metric!

How does the sortedness of the data affect
the behavior of LSM-Trees, B-Trees, Zonemaps?

similar question to:
how does the order of the values in an array affect a sorting algorithm

How to tune our system?

if we know the workload …

LSM-Trees: memory (Buffer/BF/FP) – what about caching?

Back to column-stores: do we need to sort?

partition the data?

add ***empty slots*** in the column for future inserts?

Workload-based tuning

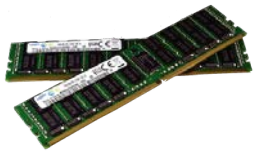
find *Tuning*, s.t.
min *cost*(*Workload, Data, Tuning)*
given *Workload* and *Data*

what if workload information is a bit wrong?

robust optimization (come and find me)

Asynchronous Bufferpool

what is the bufferpool?



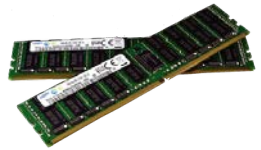
BP

Page Requests from Higher Levels

BUFFER POOL

disk page

free frame



choice of frame dictated by **replacement policy**

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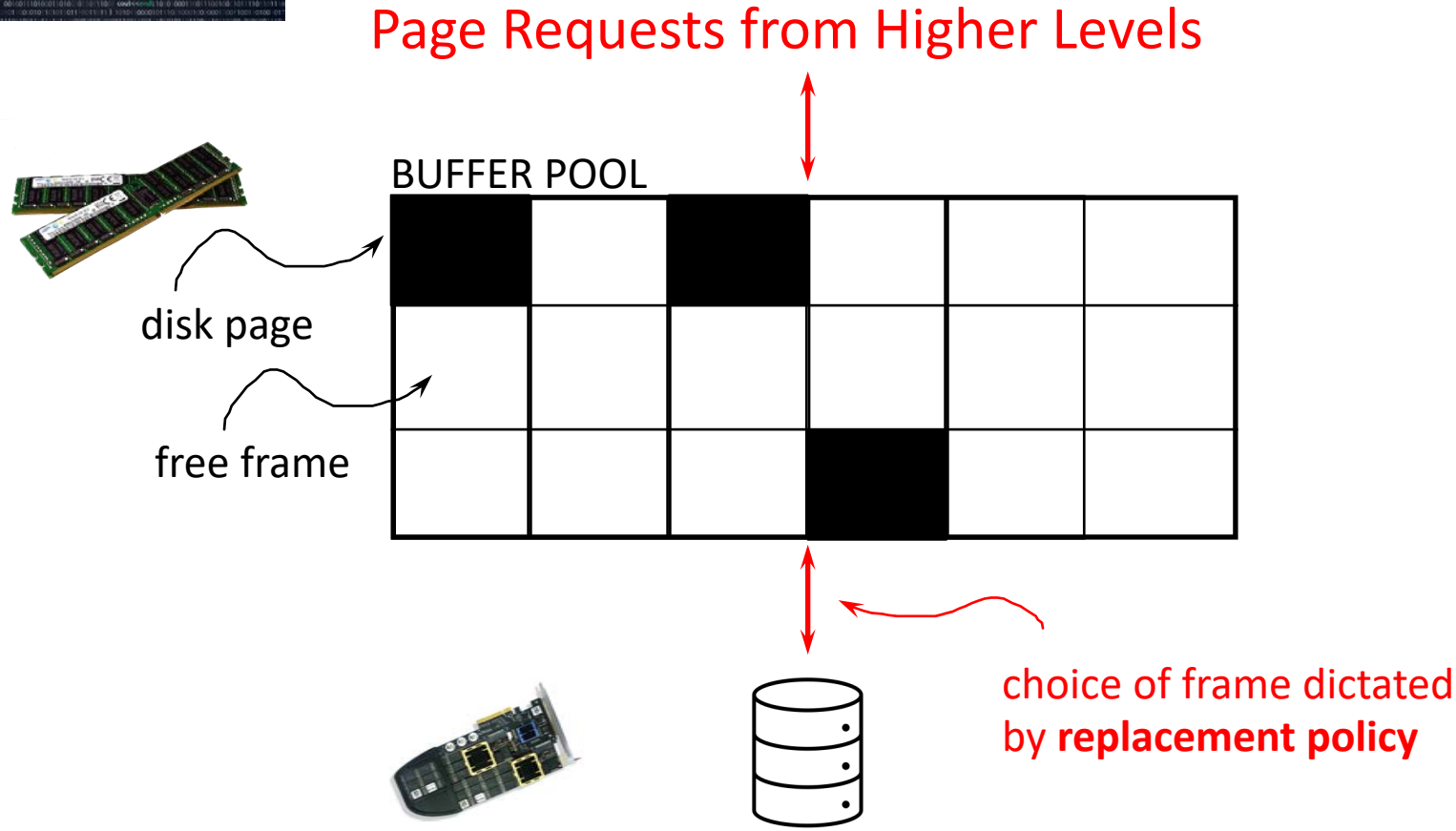
Systems Project: Bufferpool



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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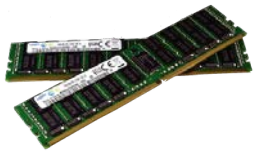
Asynchronous Bufferpool

what is the bufferpool?



BP

manages available memory
reads/writes from/to disk

what happens when full?

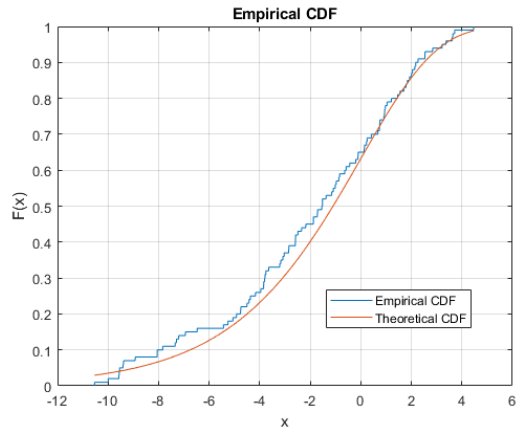
writes one page back and reads on page

is this optimal?

what is an index?

sorted data

1 1 1 2 3 5 10 11 12 13 18 19 20 50 54 58 62 98 101 102



$$postition(val) = CDF(val) \cdot array\_size$$

can you learn the CDF?
what is the best way to do so?
how to update that?

what to do now?

systems project

form groups of 1-2

(speak to me in OH if you want to work on your own)

research project

form groups of 2-3

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 1-2
(speak to me in OH if you want to work on your own)

research project
form groups of 2-3
pick one of the subjects & read background material
define the behavior you will study and address
sketch approach and success metric

come to OH
finalize your project in 1-2 weeks (by Feb 14th)
submit proposal on February 21st

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CS 561: Data Systems Architectures

class 04

Systems & Research Project

Prof. Manos Athanassoulis

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