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CS 591: Data Systems Architectures

Systems & Research Project

Prof. Manos Athanassoulis

http://manos.athanassoulis.net/classes/CS591

data systems

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

[The Forbes, 2016]

complex analytics

simple queries

access data

store, maintain, update

data systems

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complex analytics

simple queries

access data

store, maintain, update

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

amazon DynamoDB

APACHE HBASE

Google BigTable

AsterixDB

Cassandra

RocksDB

Couchbase

mongoDB

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?

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

other problems?

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

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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***"

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index: { **yob**, { **student_id1, student_id2, …** } }

how to use a key-value store?

basic interface

put(k,v)

more

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

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

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

deletes: delete(k)

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

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

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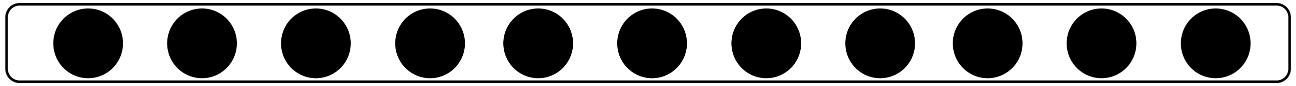
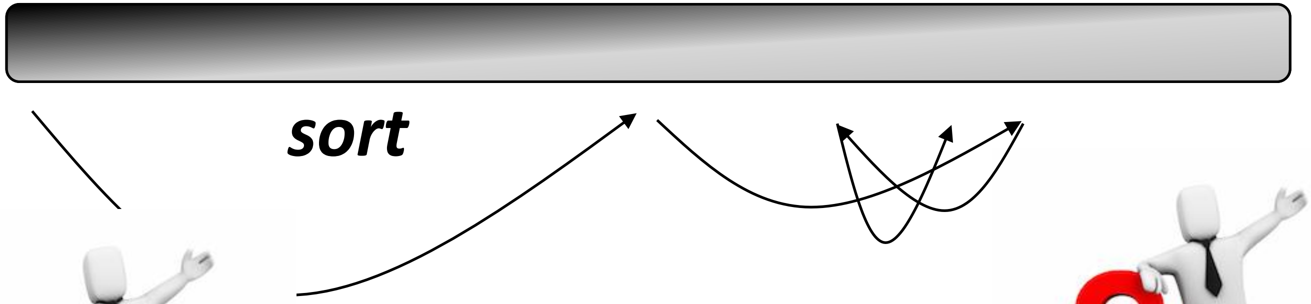
how to build a key-value store?

append

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



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



sort

and then?

what about full scan?

range queries?

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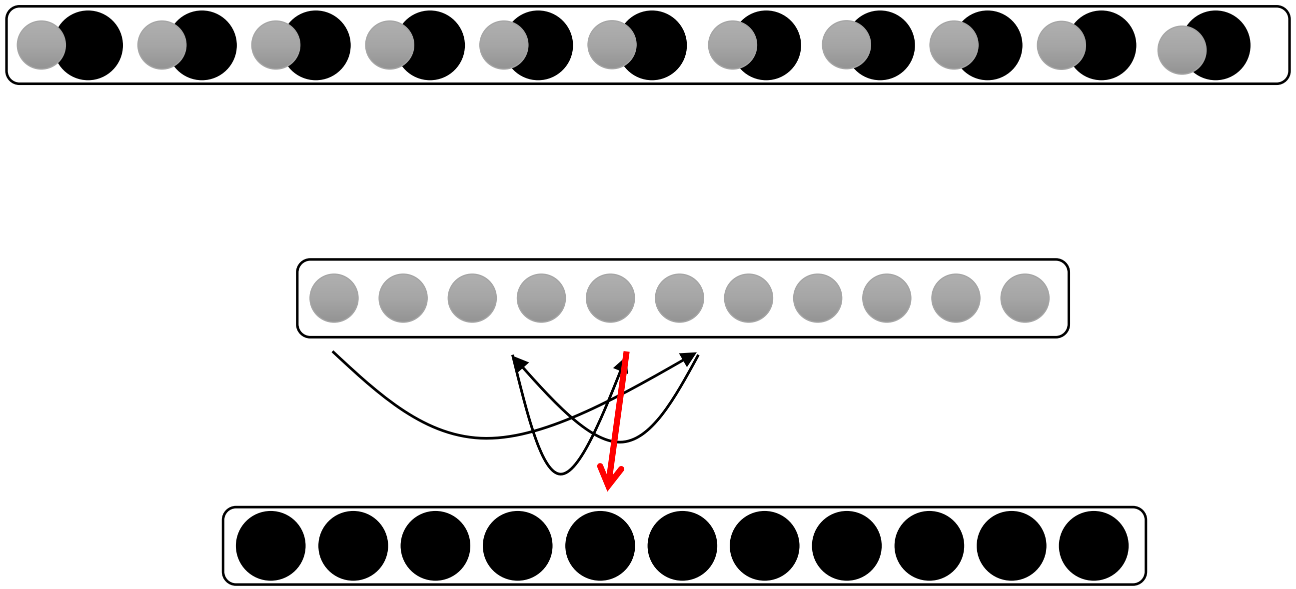
can we separate keys and values?



at what price?

locality? code?

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read queries

(point or range)

inserts

(or updates)

sort data

simply append

amortize sorting cost

avoid resorting after every update

how to bridge?

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LSM-tree
Key-Value Stores

What are they really?

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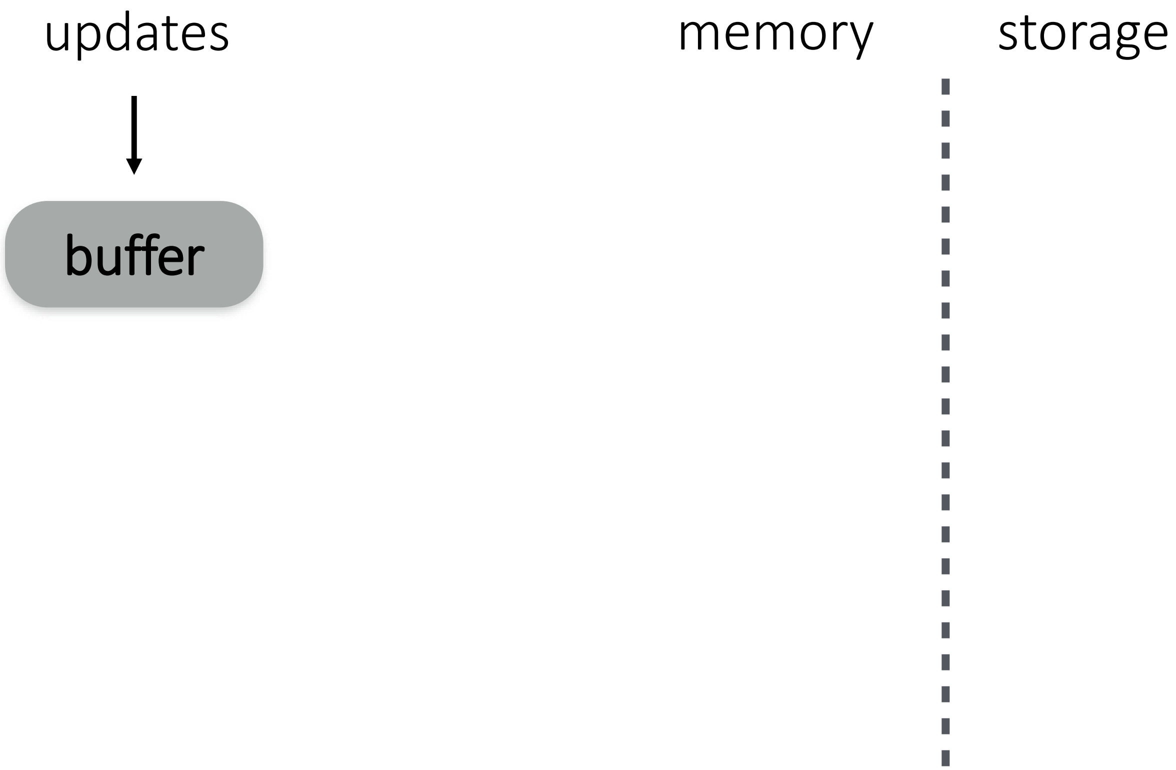
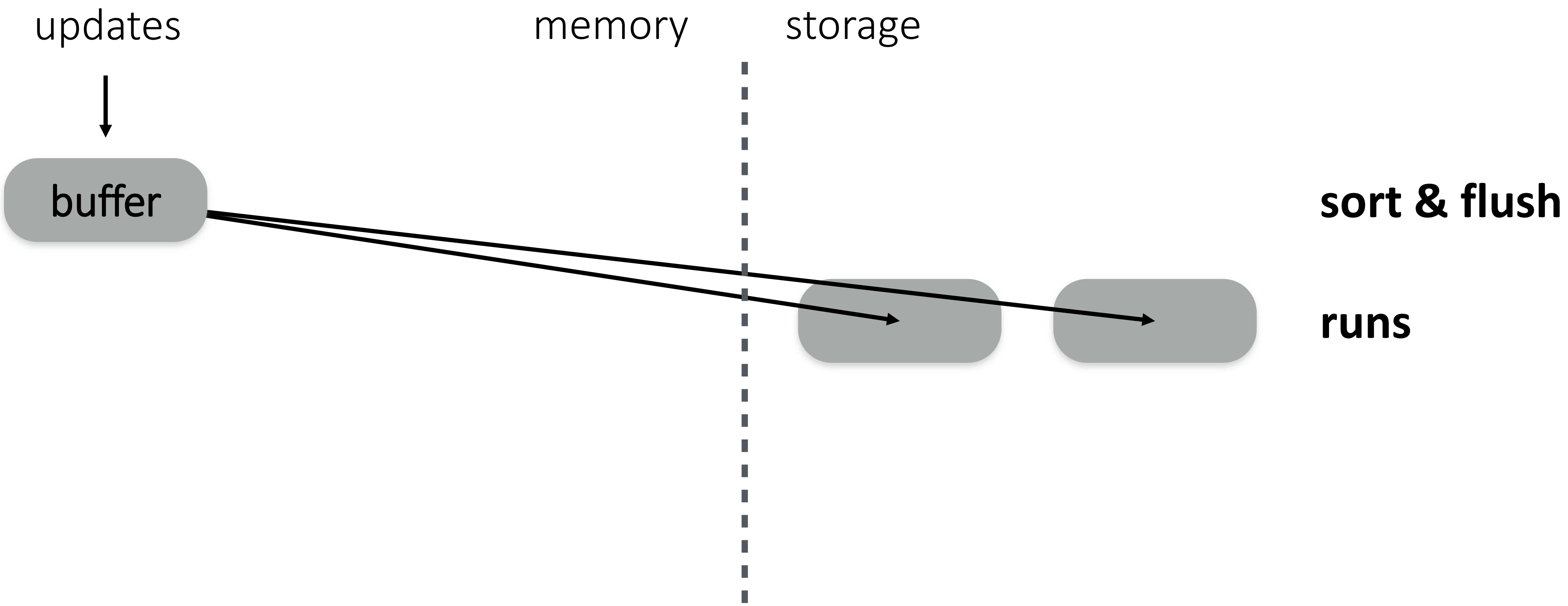
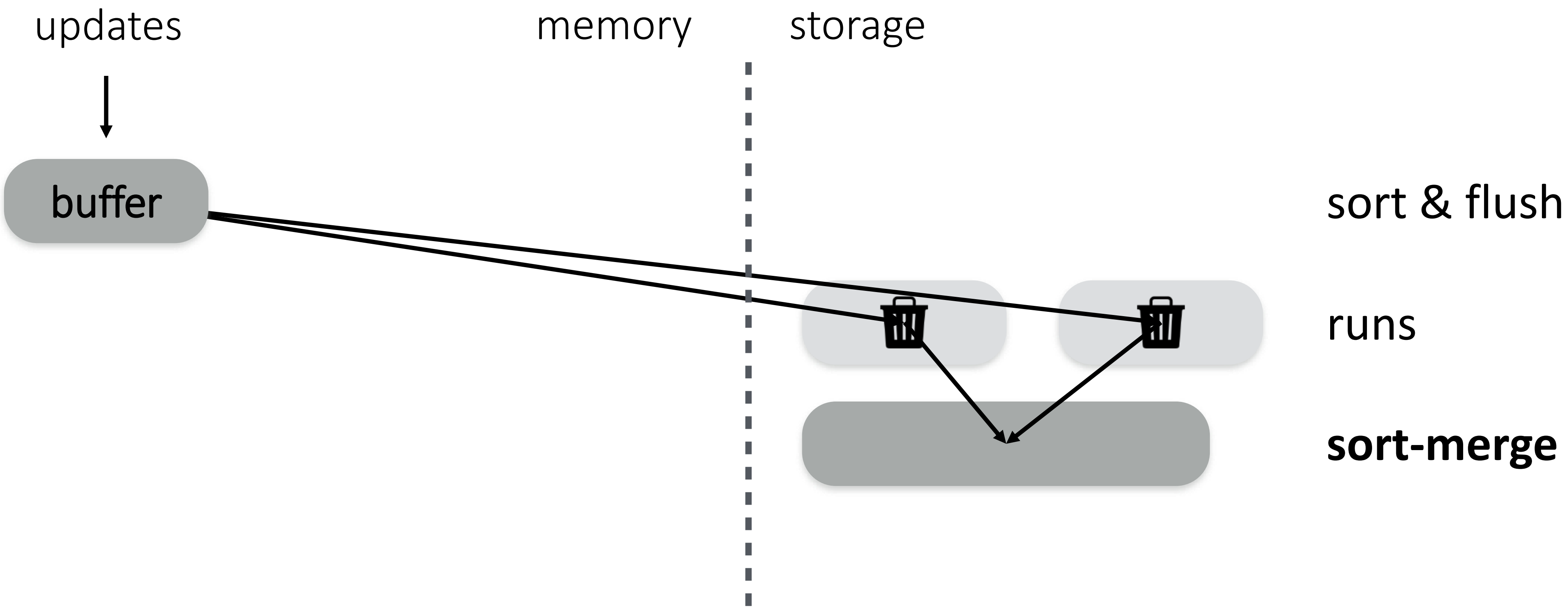

updates
buffer
memory
storage


updates
memory
storage
buffer
sort & flush
runs



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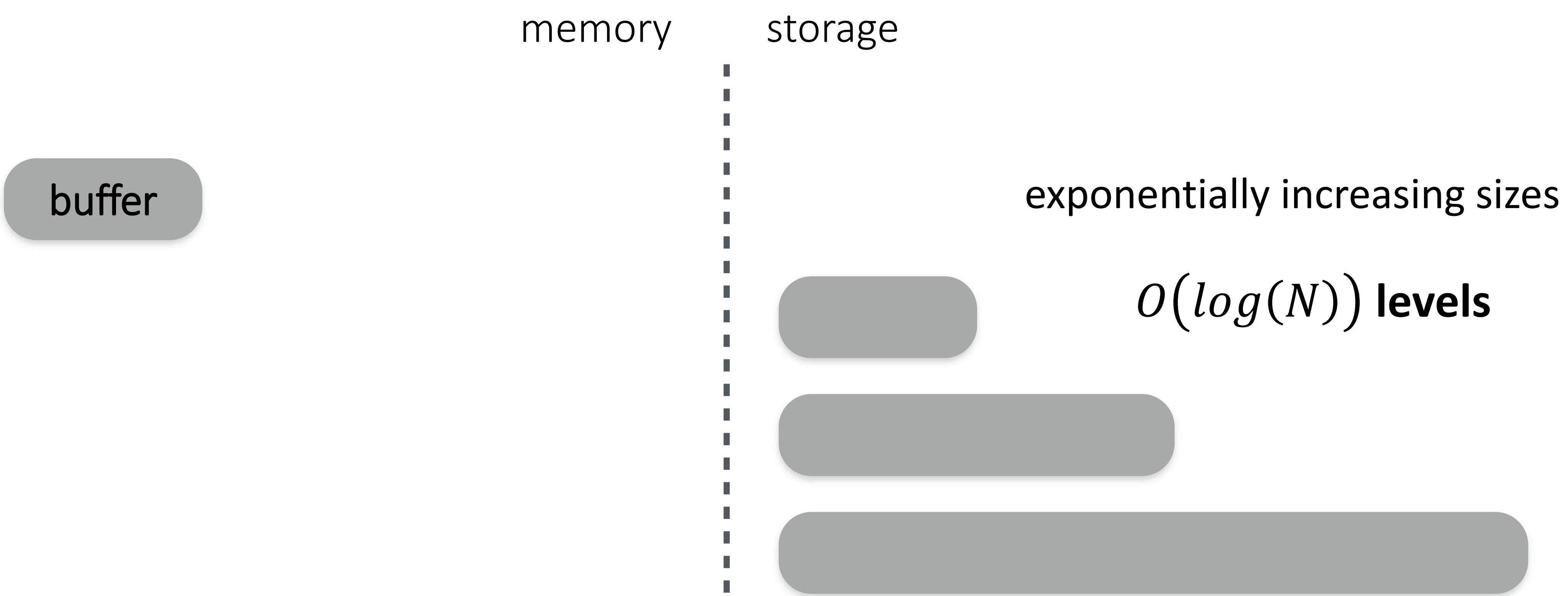
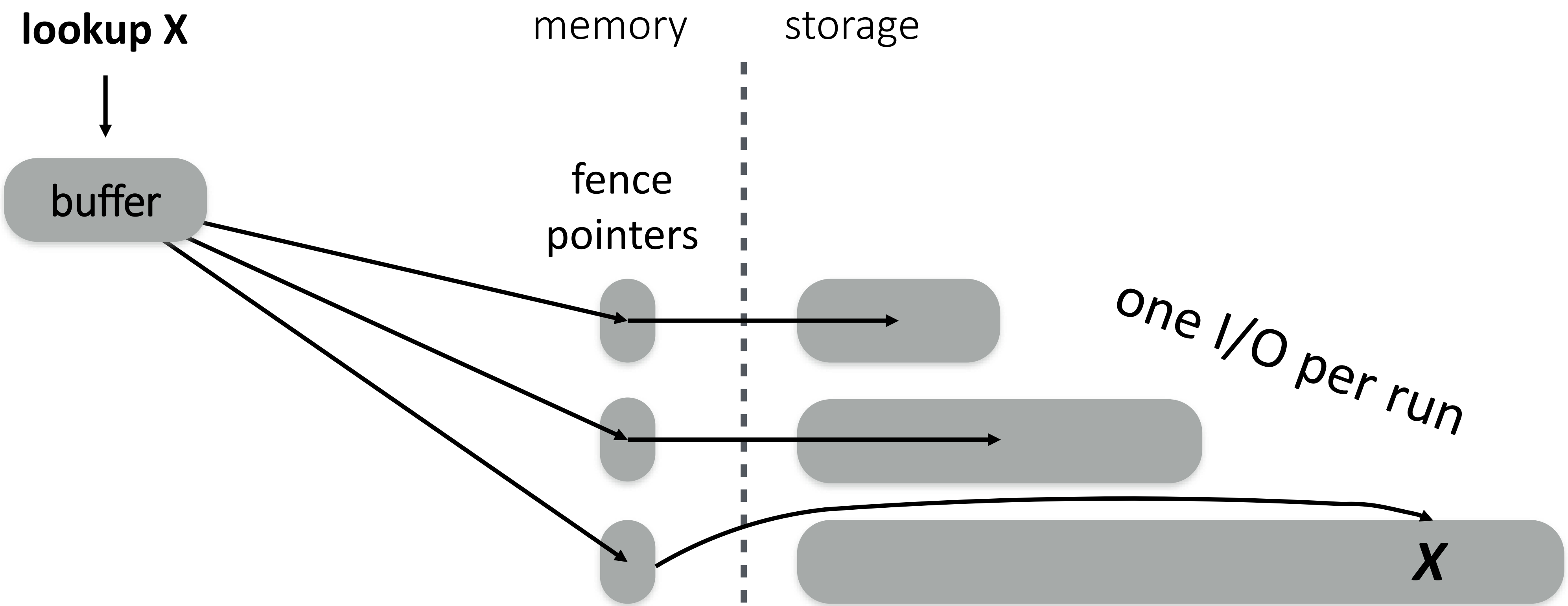

memory
storage
buffer
exponentially increasing sizes
$O(log(N))$ **levels**



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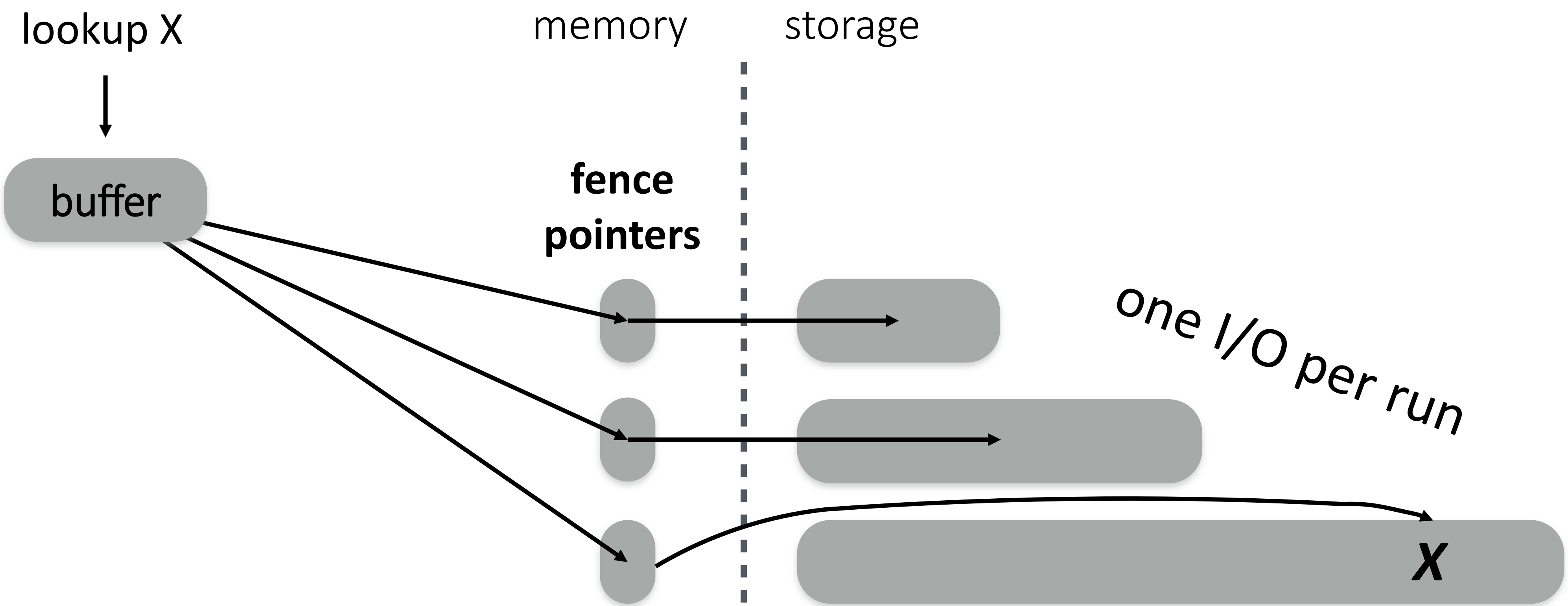

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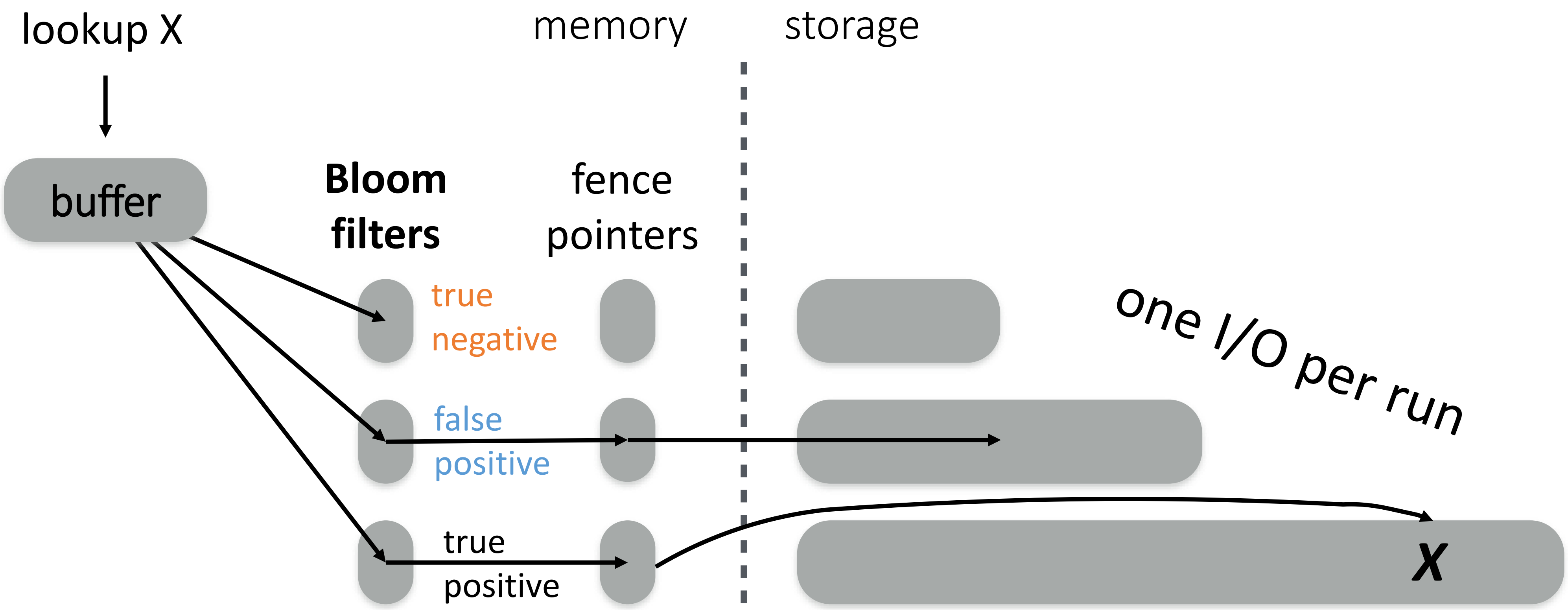
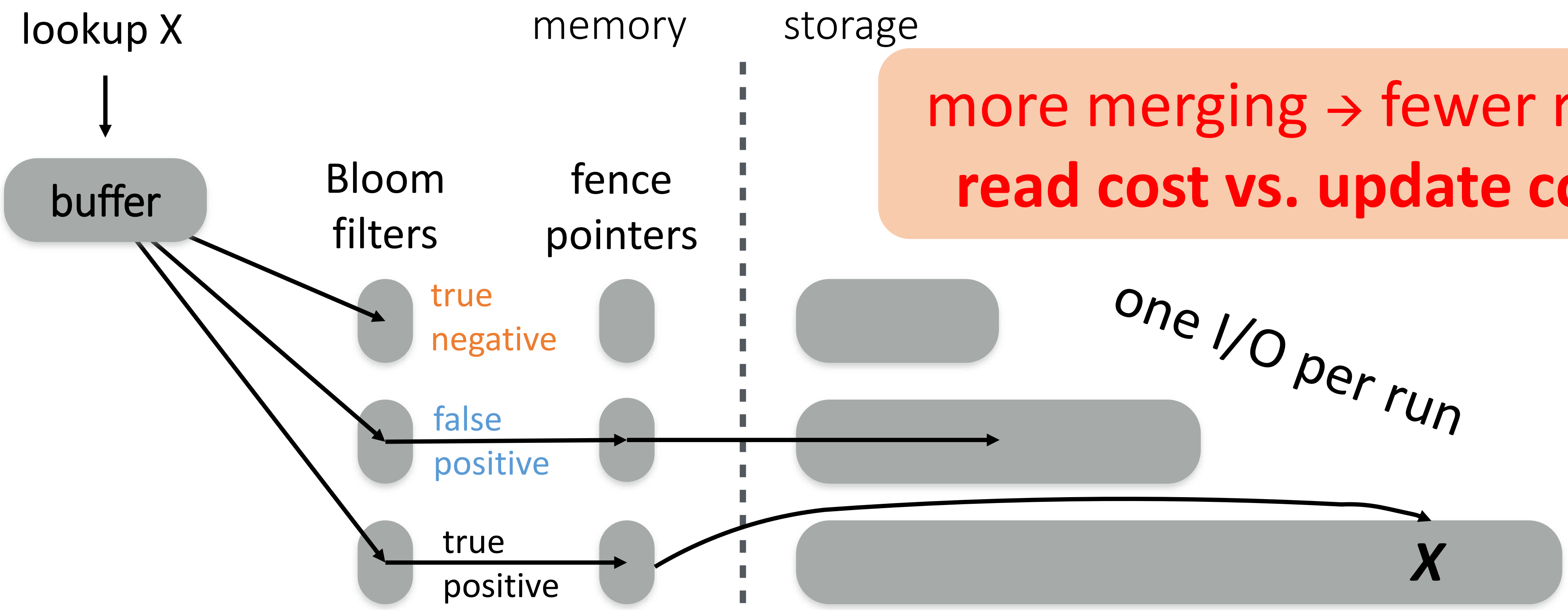

lookup X
memory
storage
buffer
Bloom filters
fence pointers
true negative
false positive
true positive
one I/O per run
X

performance & cost trade-offs



more merging → fewer runs

read cost vs. update cost

bigger filters → fewer false positives

memory space vs. read cost

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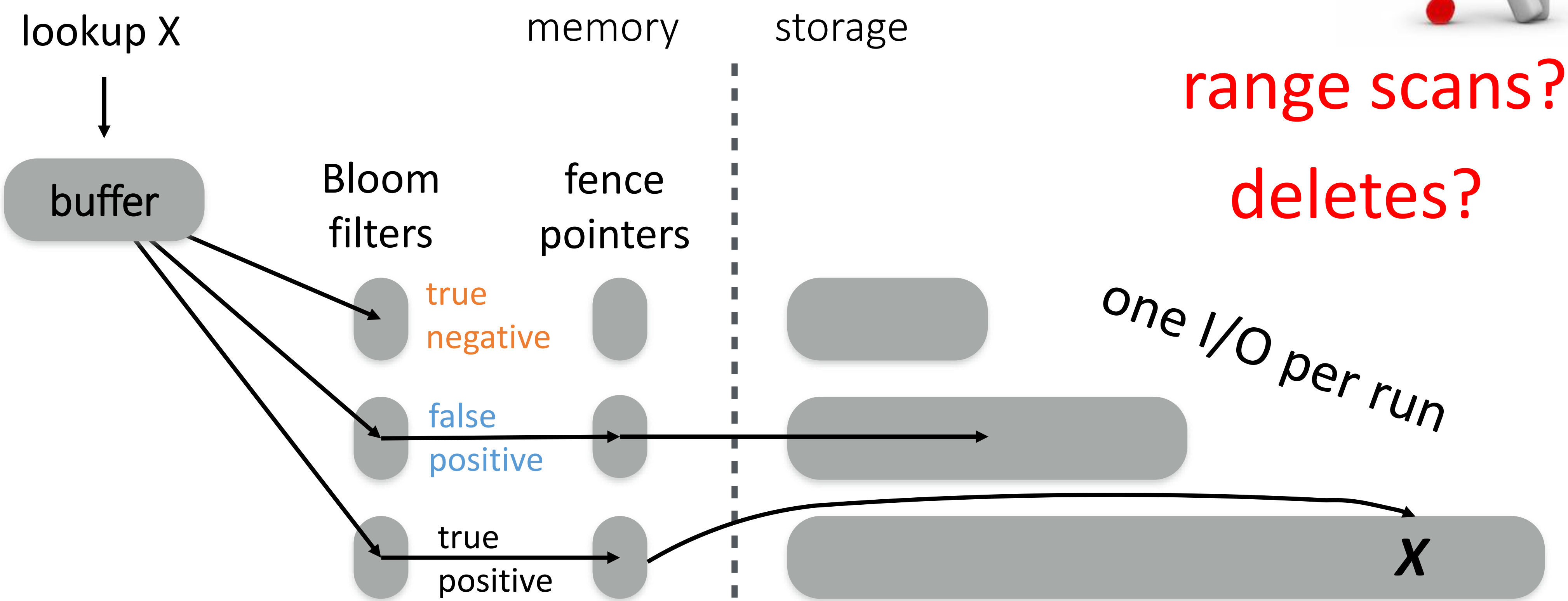
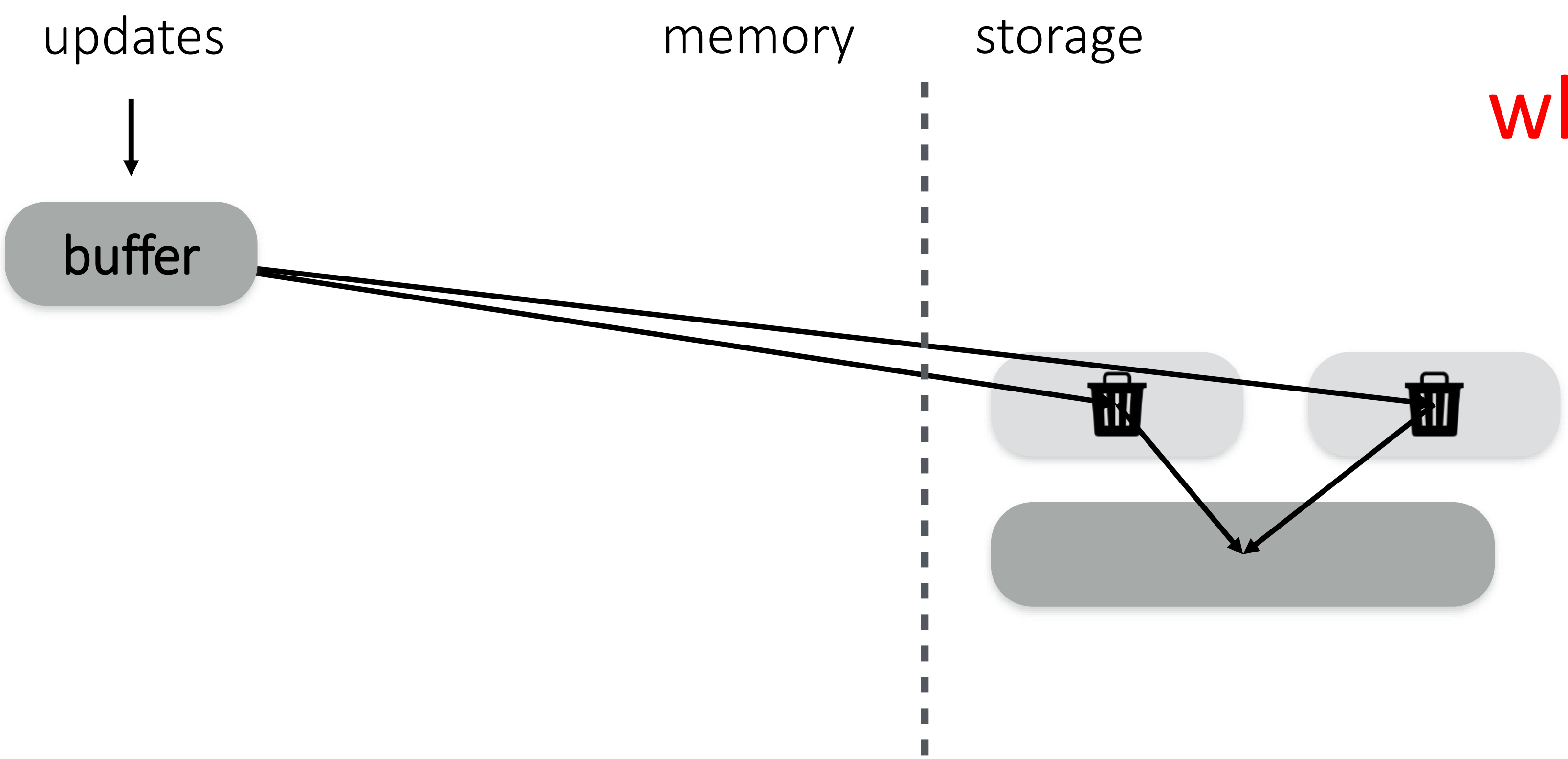
other operations



range scans?

deletes?

remember merging?



what strategies?

sort & flush

runs

sort-merge

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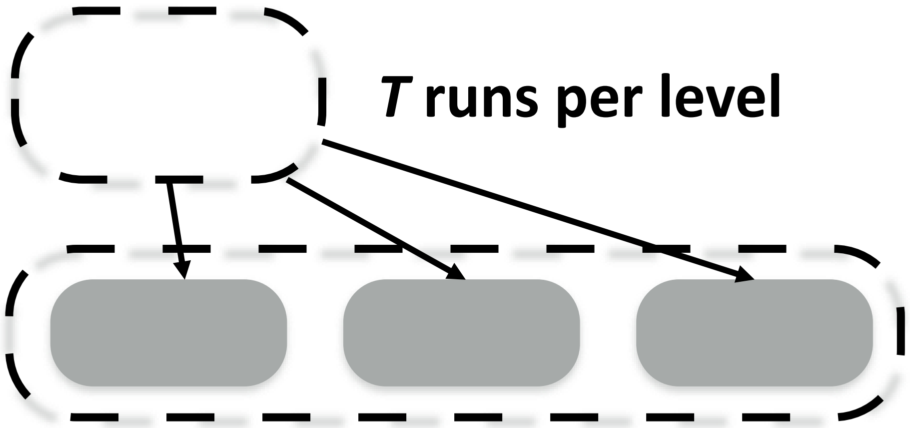
Merge Policies

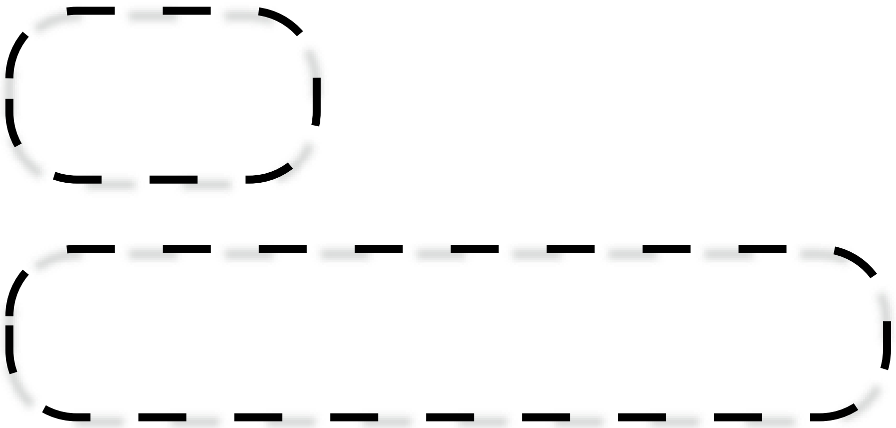
Tiering
write-optimized

Leveling
read-optimized

Tiering
write-optimized

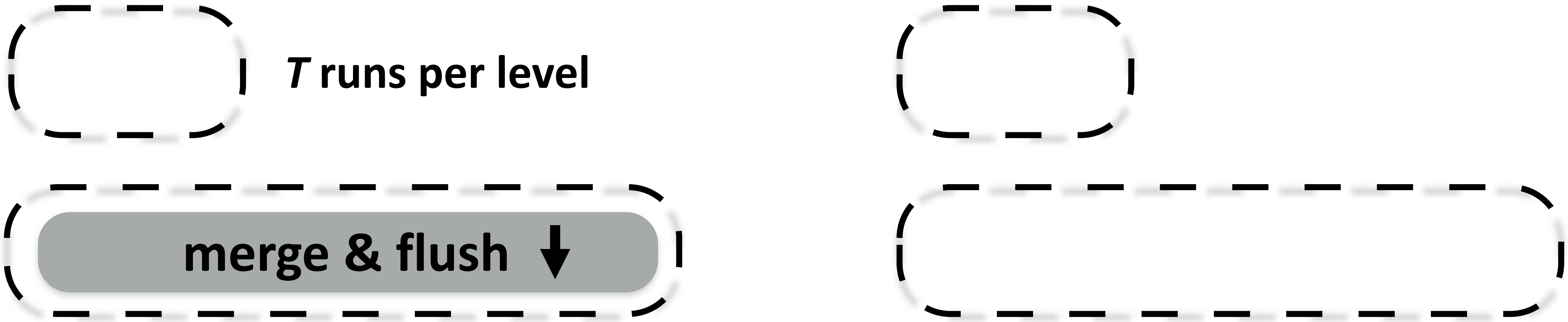


Leveling
read-optimized

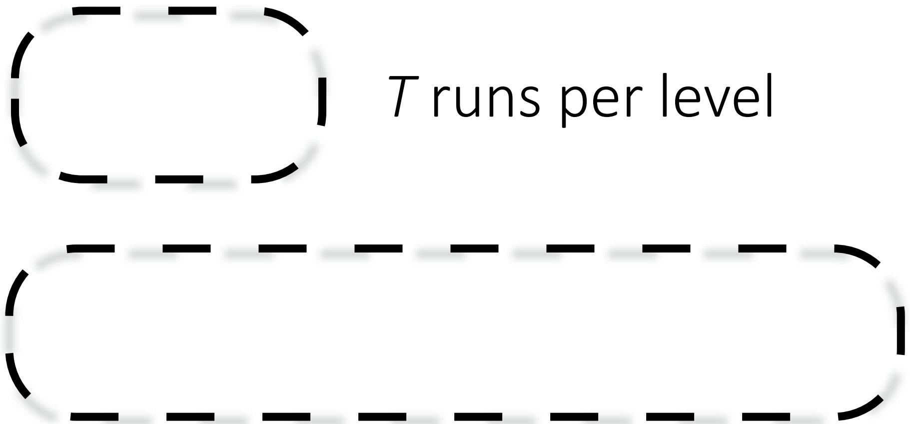


Tiering
write-optimized

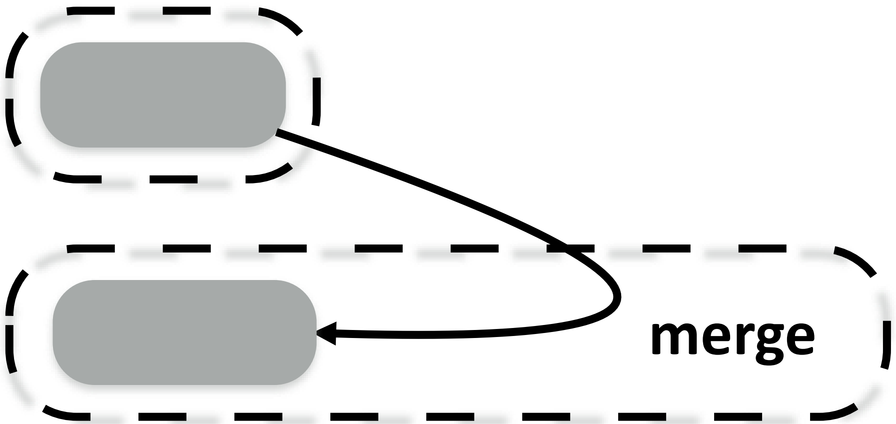
Leveling
read-optimized



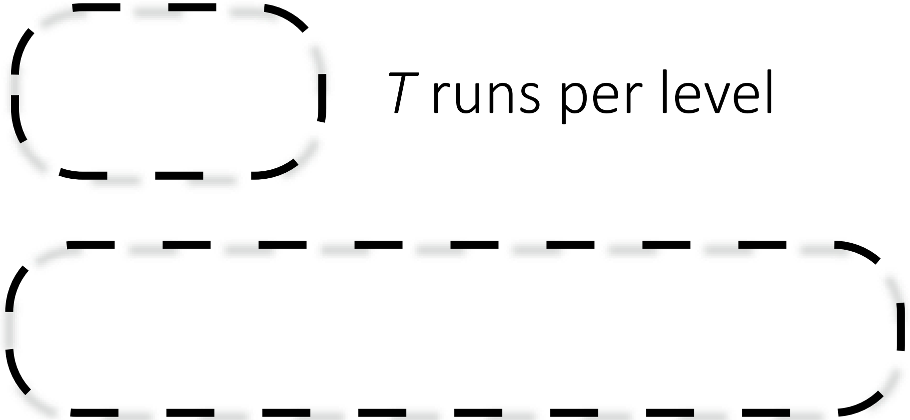
Tiering
write-optimized



Leveling
read-optimized

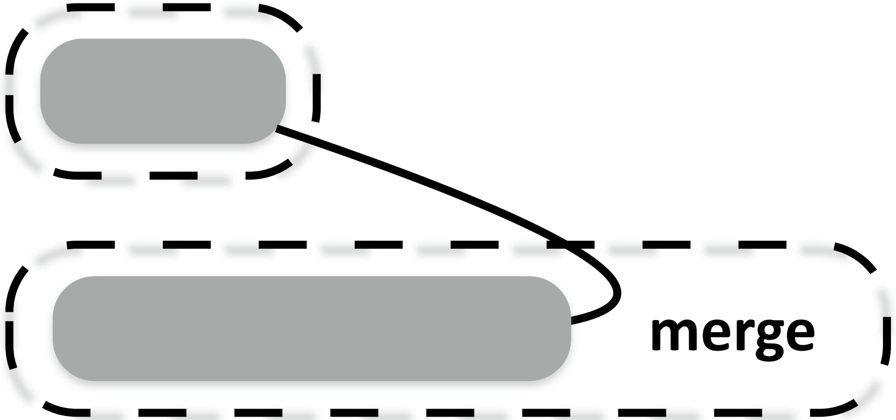


Tiering
write-optimized

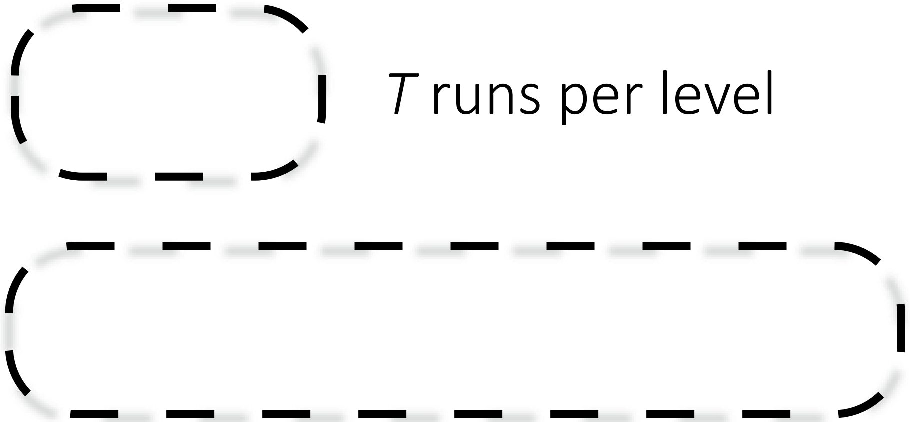


T runs per level

Leveling
read-optimized

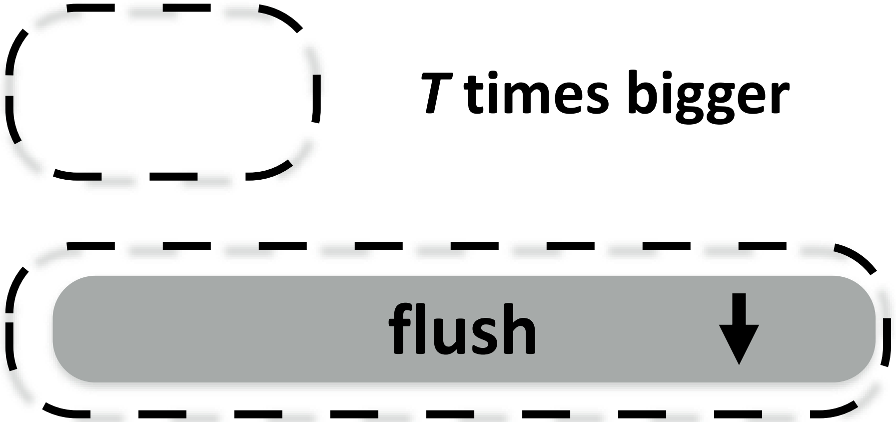


Tiering
write-optimized



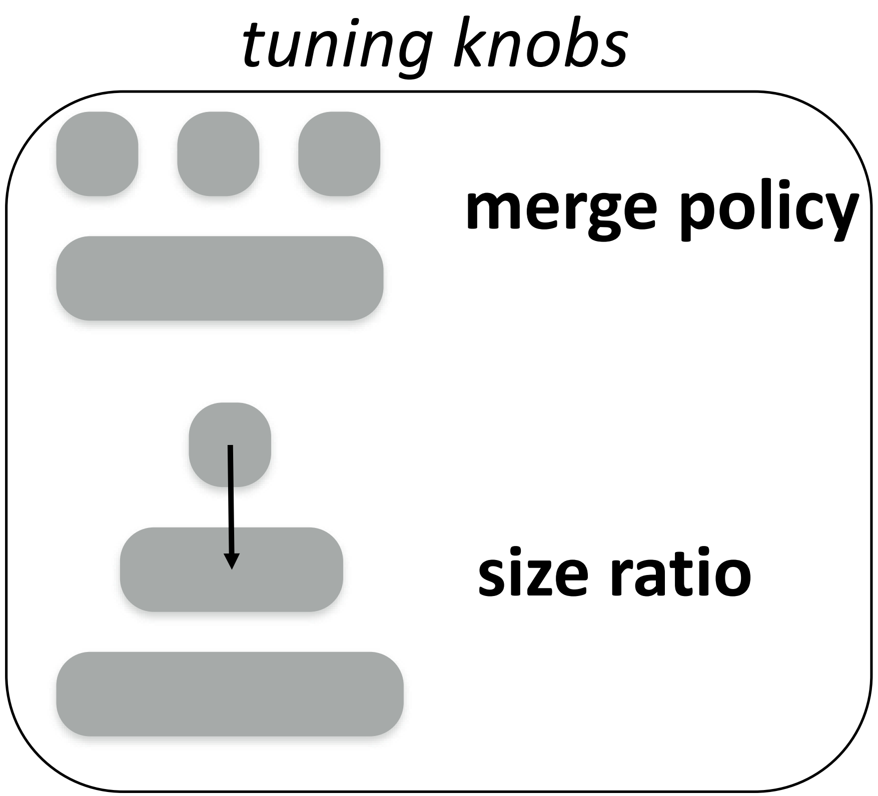
T runs per level

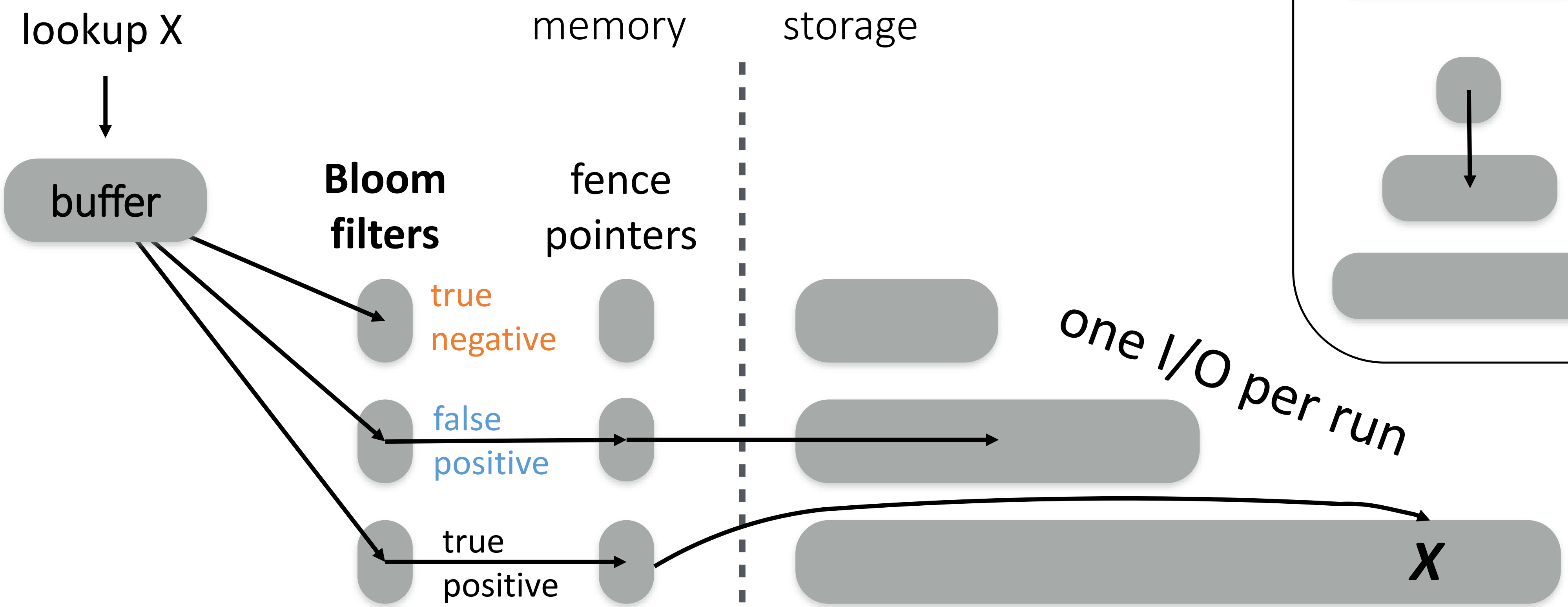
Leveling
read-optimized



***T* times bigger**

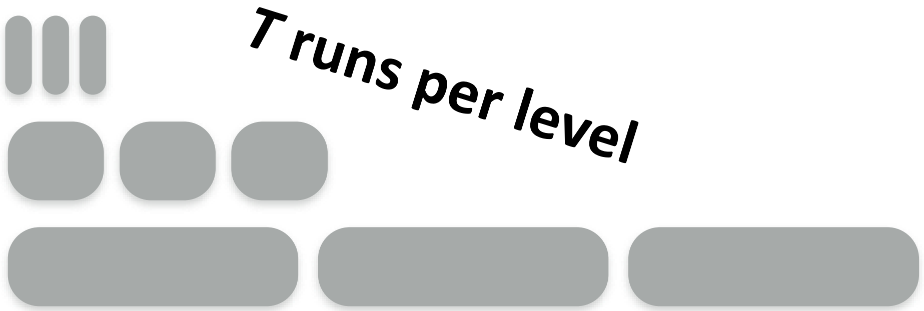
Systems Project: LSM-Trees





more on LSM-Tree performance

Tiering
write-optimized



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

runs per level

levels

false positive rate

Leveling
read-optimized

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

levels

false positive rate

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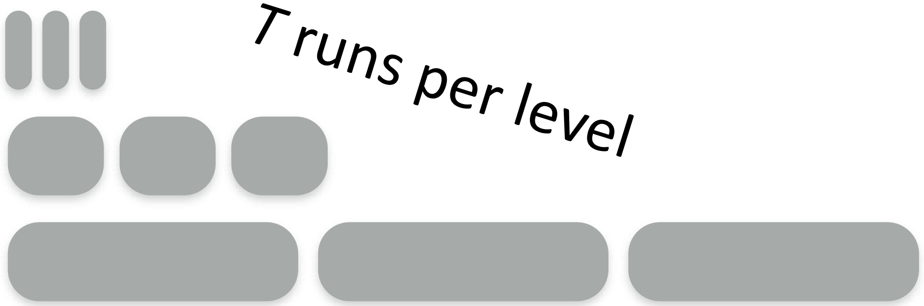
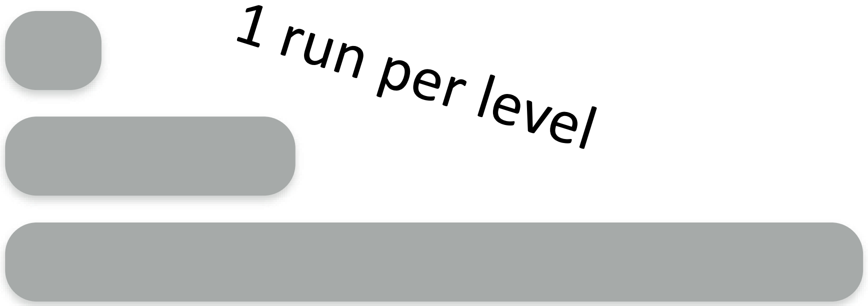
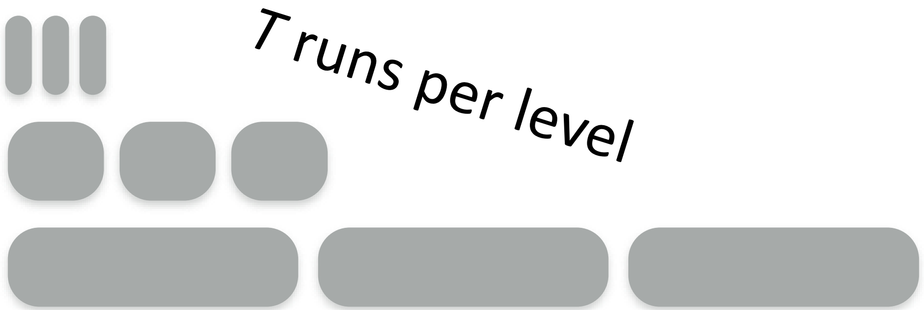
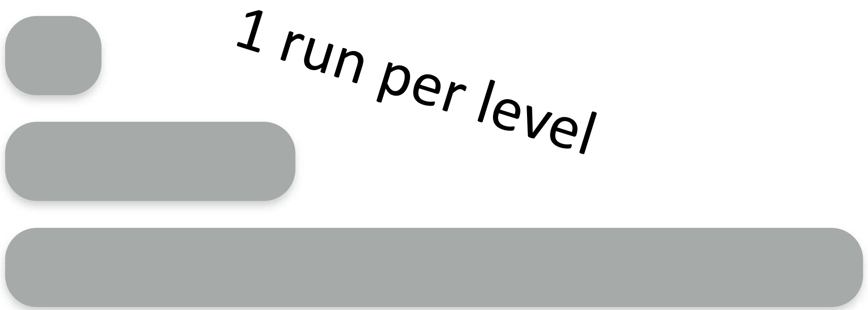
	Tiering write-optimized	Leveling read-optimized
		
lookup cost:	$O\left(T \cdot log_T(N) \cdot e^{-M/N}\right)$	$O\left(log_T(N) \cdot e^{-M/N}\right)$
update cost:	$\boldsymbol{O\left(log_T(N)\right)}$	$\boldsymbol{O\left(T \cdot log_T(N)\right)}$
	levels	merges per level levels

Tiering
write-optimized



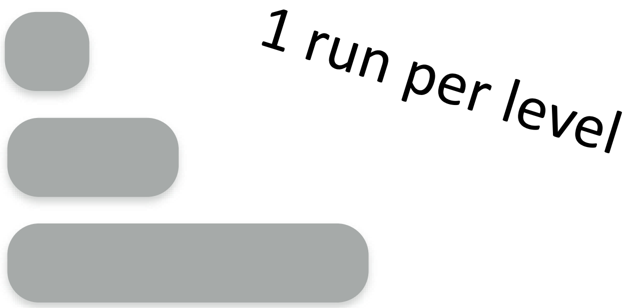
Leveling
read-optimized



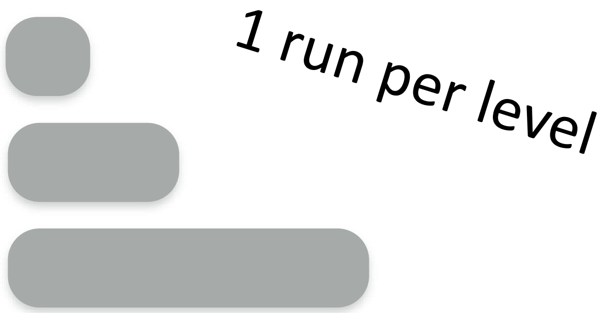
	Tiering	Leveling
lookup cost:	$O\left(T \cdot log_T(N) \cdot e^{-M/N}\right)$	$O\left(log_T(N) \cdot e^{-M/N}\right)$
update cost:	$O\left(log_T(N)\right)$	$O\left(T \cdot log_T(N)\right)$

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

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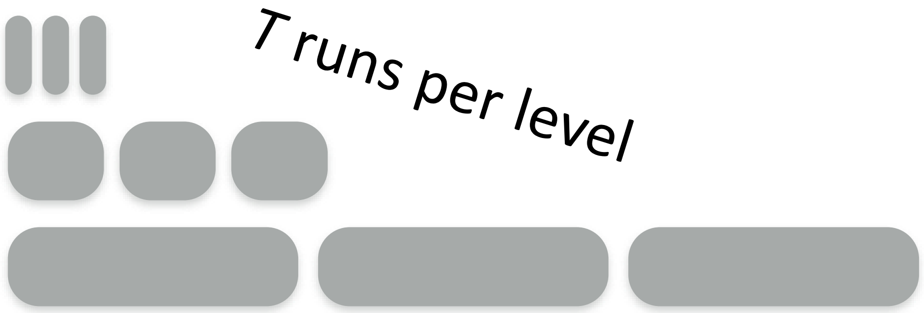
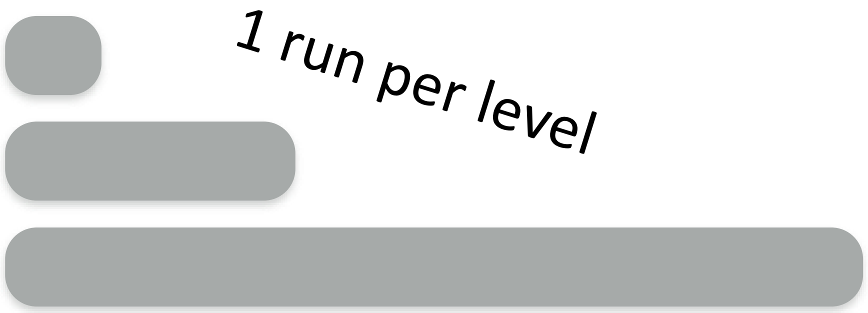
Tiering
write-optimized

Leveling
read-optimized





	Tiering	Leveling
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

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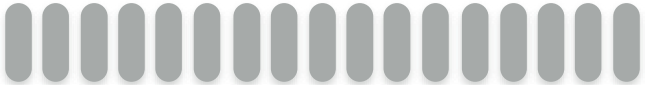
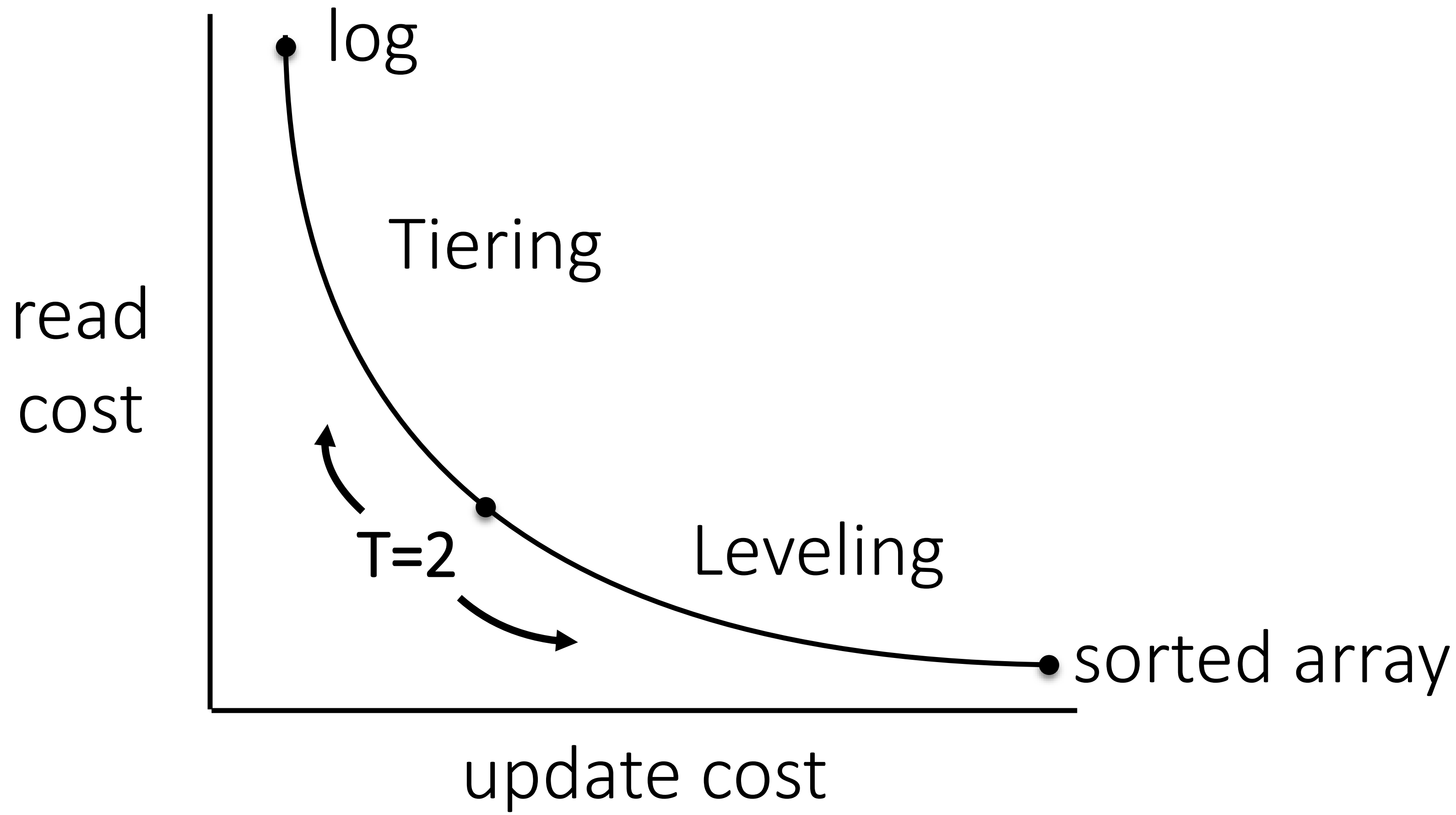
Tiering	Leveling
write-optimized	read-optimized
$O(N)$ runs per level	1 run per level
	
log	**sorted array**

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

for size ratio T $\overset{\mathbf{N}}{\Uparrow}$



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 if data items come ordered?

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

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

RocksDB

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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*

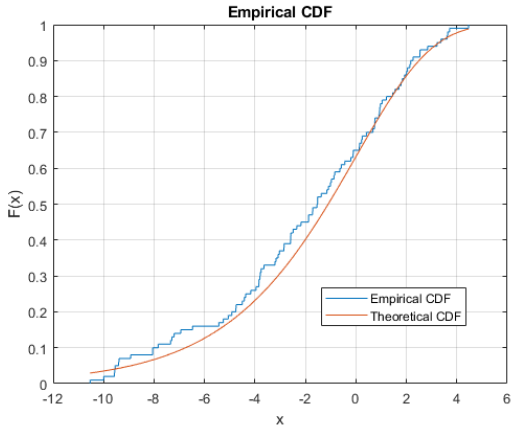
what if workload information is a bit wrong?

robust optimization (come and find me)

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?

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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
form groups of 3-4
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
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(speak to me in OH if you want to work on your own)

research project
form groups of 3-4
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 2-3 weeks (by Feb 22nd)
submit proposal on March 8th

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http://manos.athanassoulis.net/classes/CS591