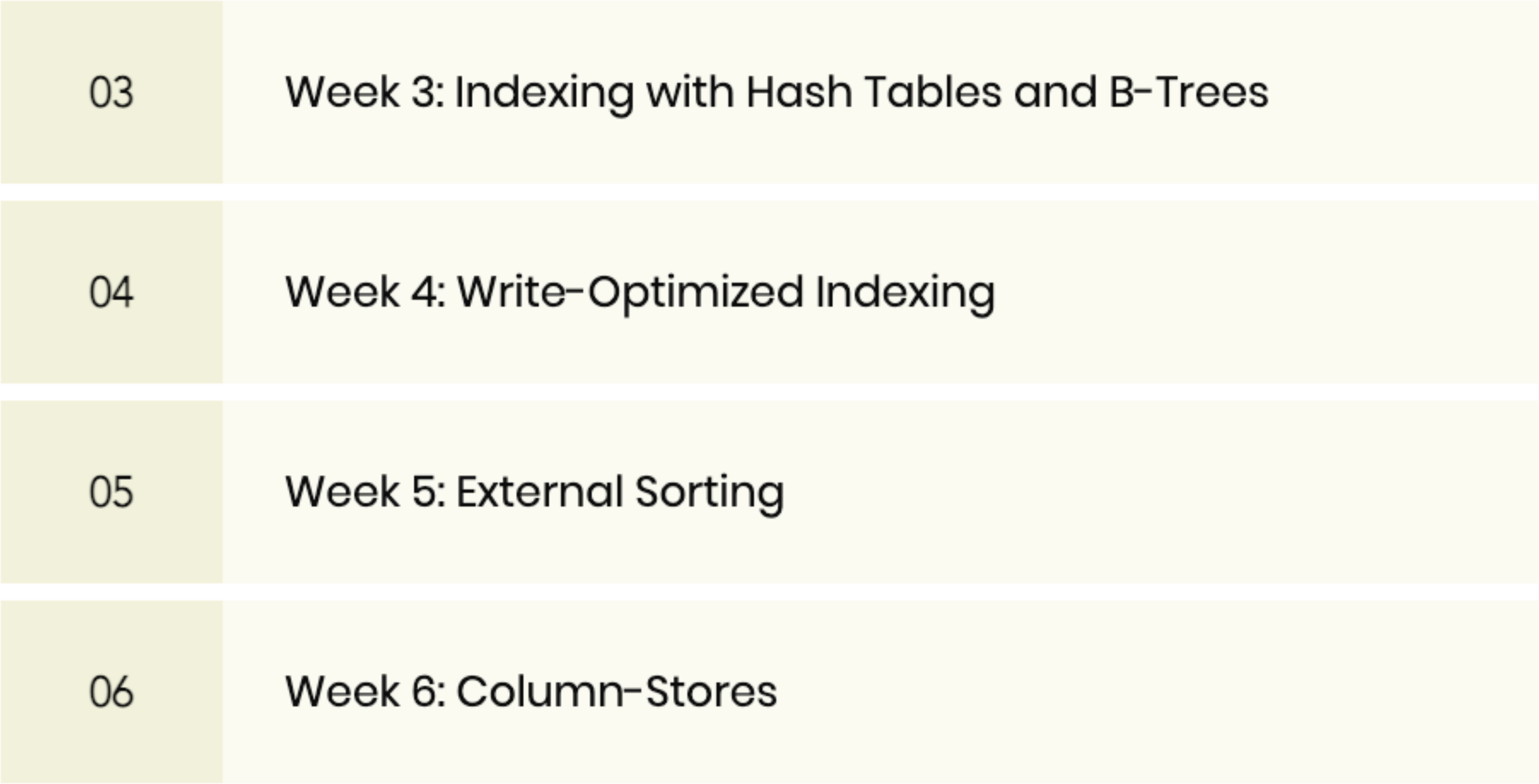
We’ll start with a summary of RAID

Then cover table & buffer management

We will start at 2:10 pm

Changes in schedule to better fit project



03	Week 3: Indexing with Hash Tables and B-Trees
04	Week 4: Write-Optimized Indexing
05	Week 5: External Sorting
06	Week 6: Column-Stores

Send me whichever groups have formed

Mail nivdayan@gmail.com

11 groups contacted me already

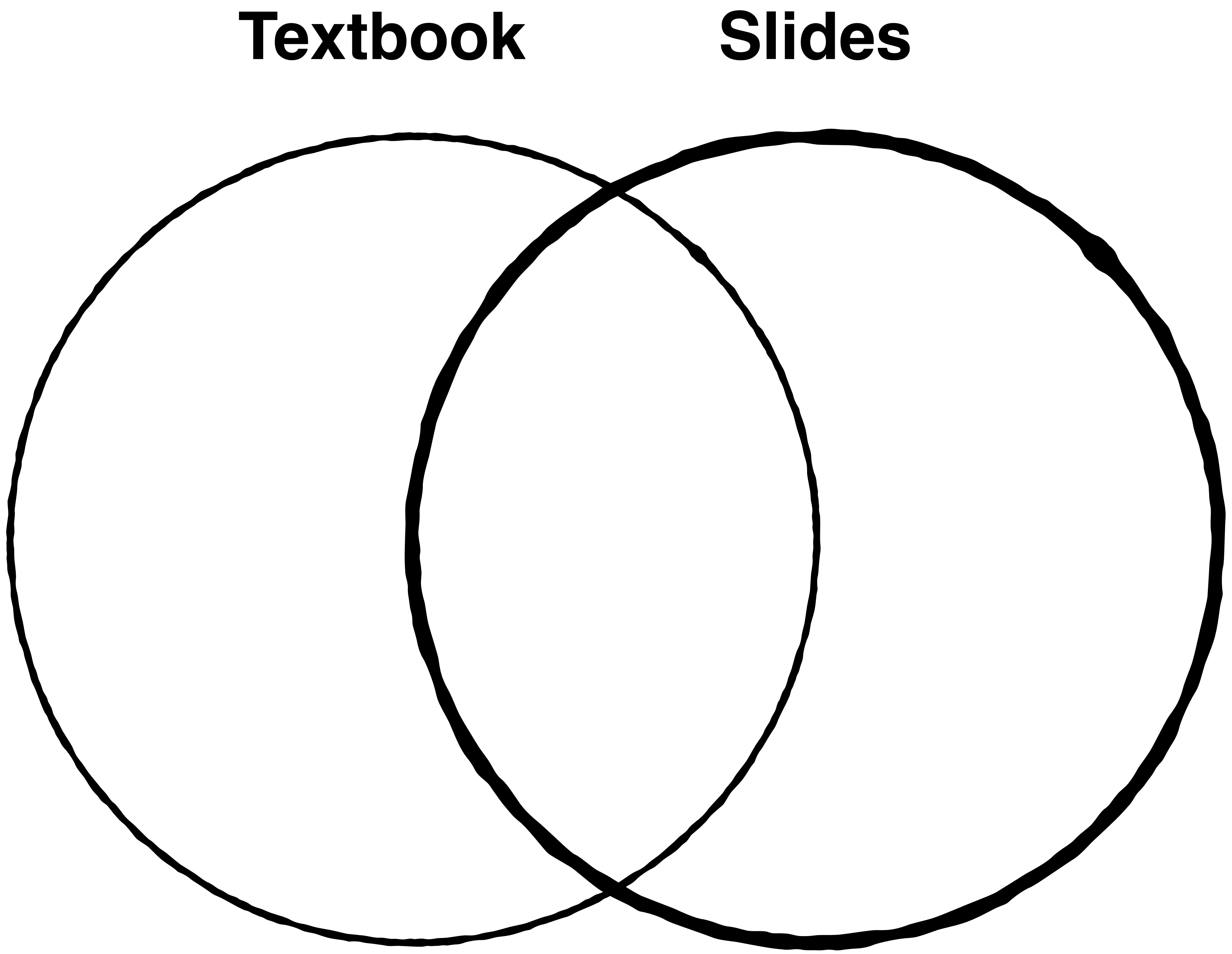
My cs.toronto.edu email does not seem to be receiving all emails

This week’s tutorial

Exercise session

Relevant for midterm/final

There to solidify your understanding and get a historical perspective.



Textbook

Slides

Only material in the slides will appear in the midterm/exam

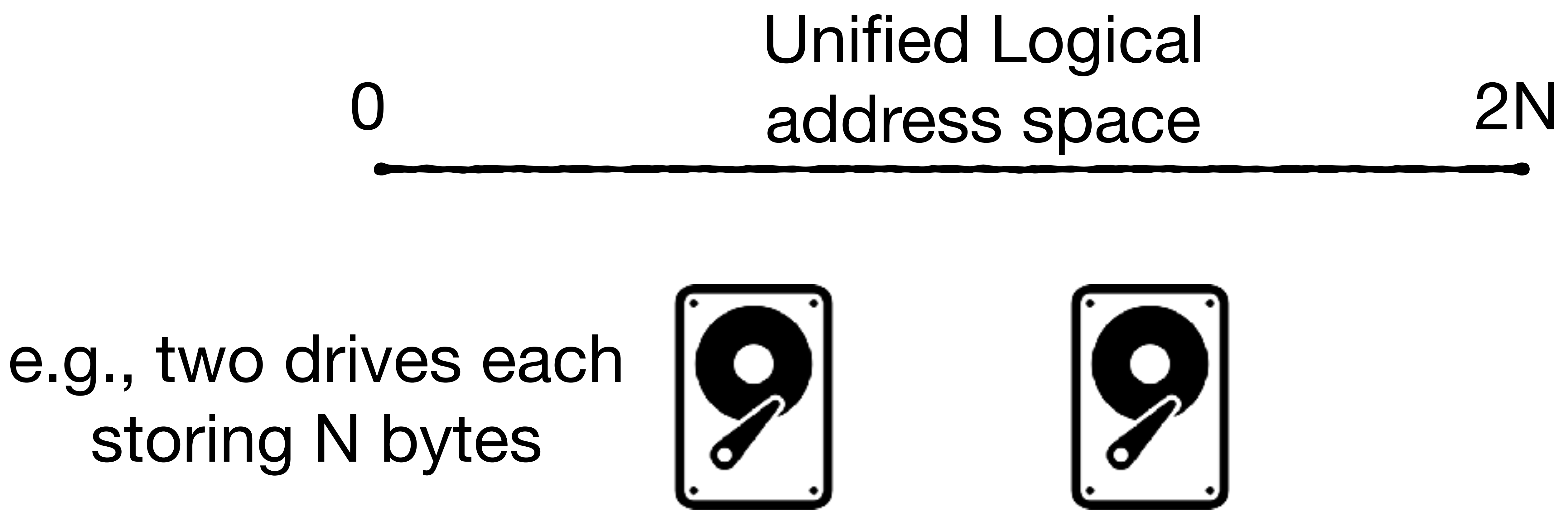
RAID Addresses Three Problems

Our database size exceeds one drive and we need more storage

A drive fails, and we need to recover its data

We want to overcome the limits of one storage device speed

Expose a larger logical address space to OS



Unified Logical address space

0

2N

e.g., two drives each storing N bytes

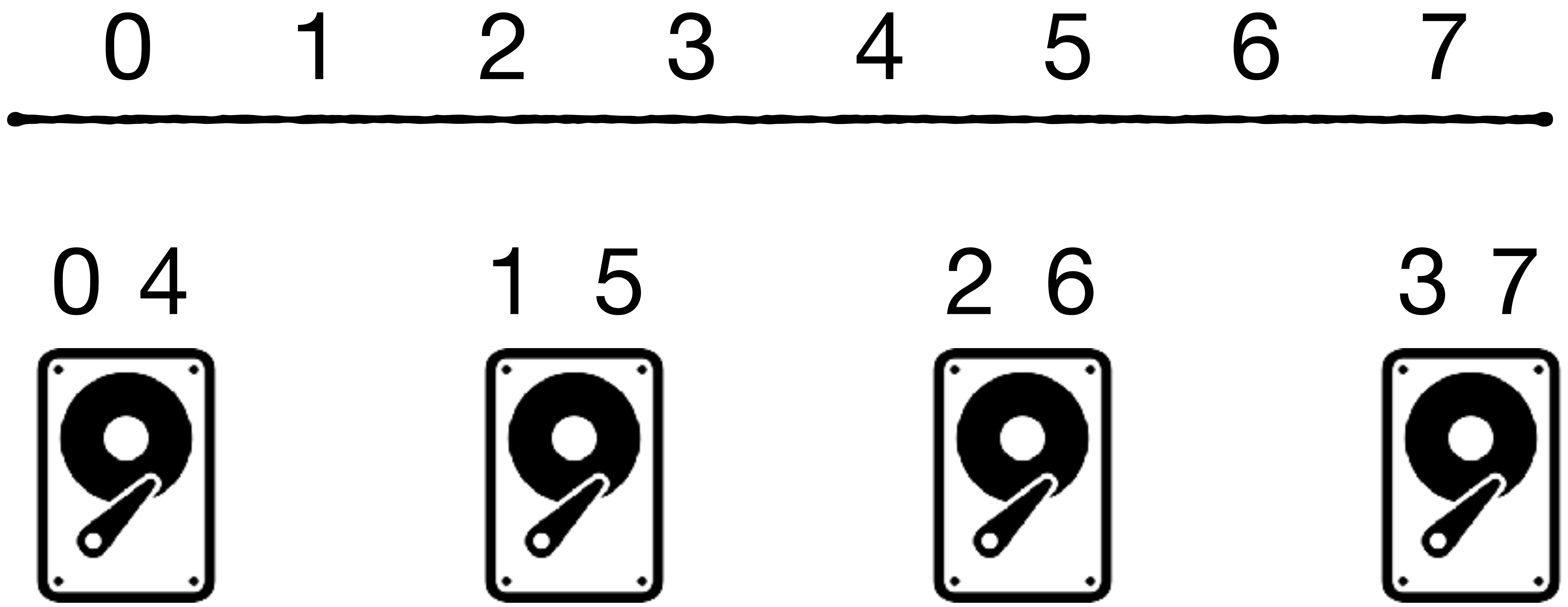
Looks to the OS like one drive, though consists of many

The spectrum of RAID designs

RAID 0 **RAID 1** **RAID 0+1** RAID 4 RAID 5 RAID 6

RAID 0 - Pure striping

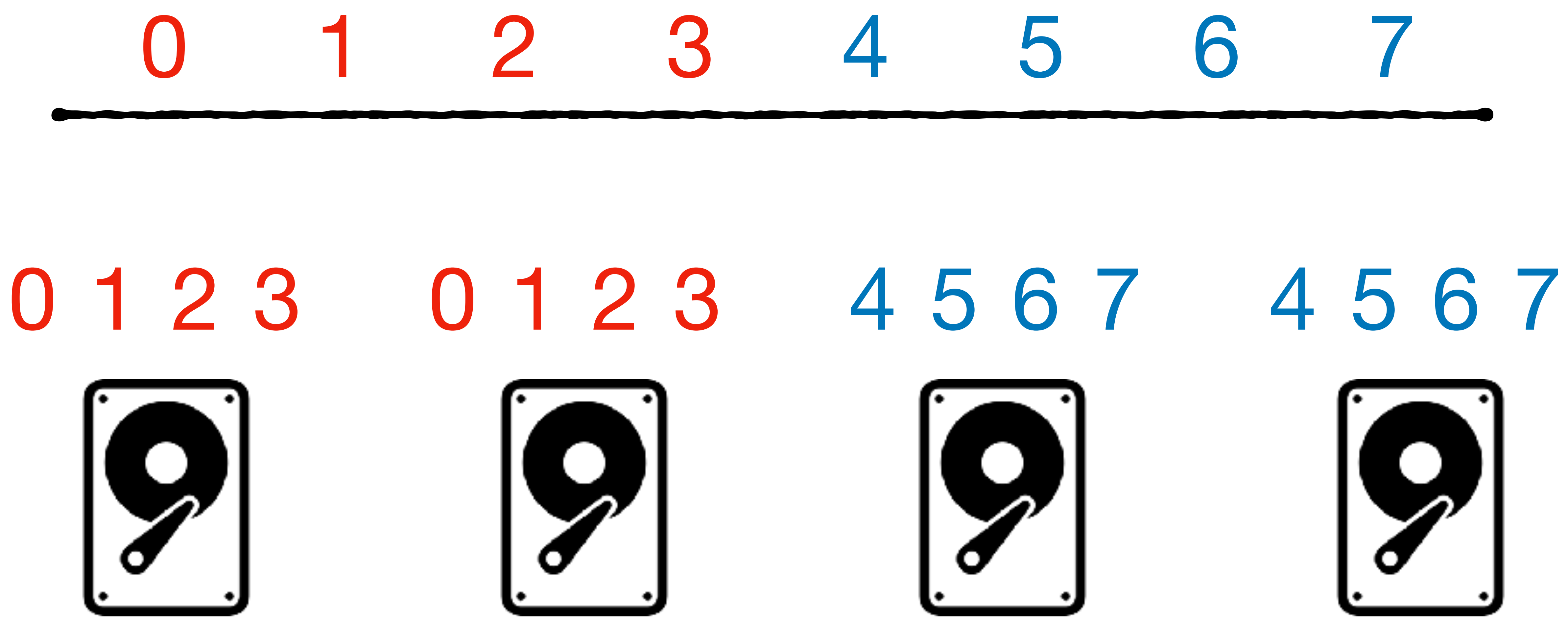
Stripe data in the logical address



1. Much faster sequential writes and reads
2. Also improvement for random writes and reads due to load balancing
3. No redundancy. If one disk fails, we lose data.

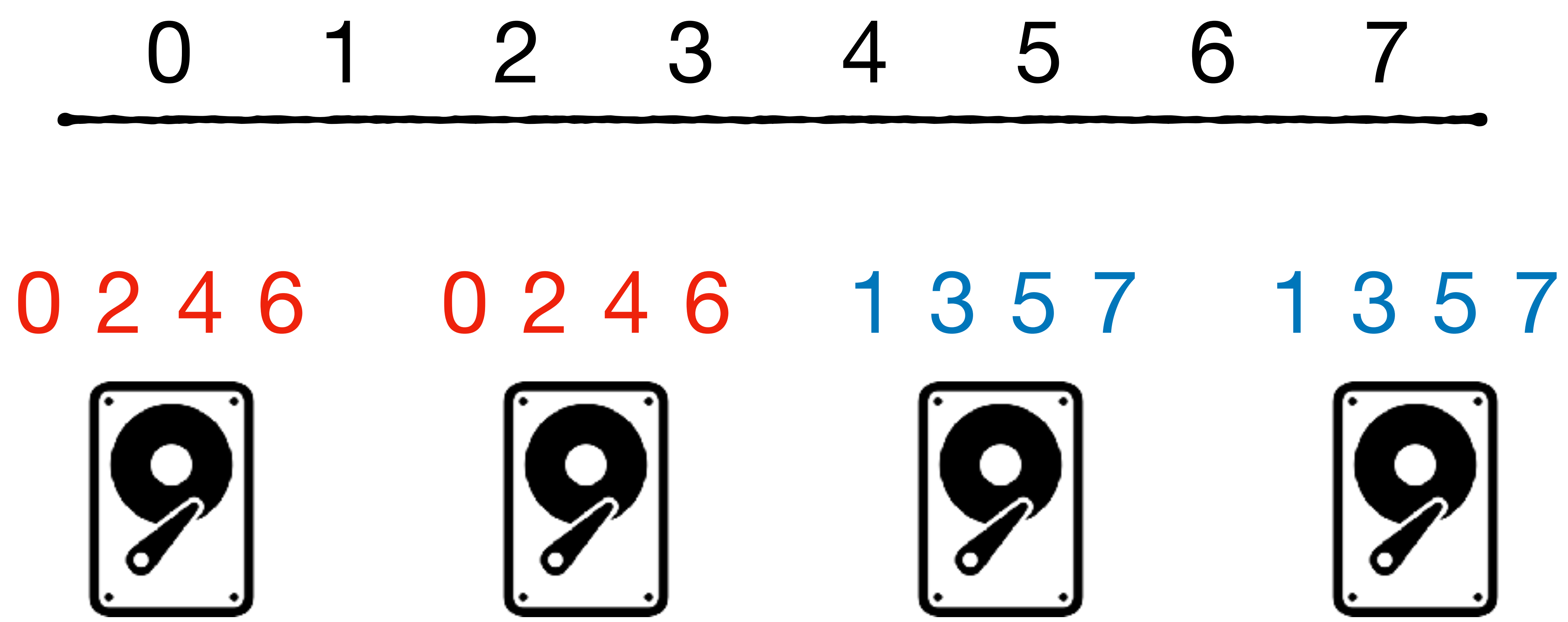
RAID 1 - Mirroring

Each drive has one mirror

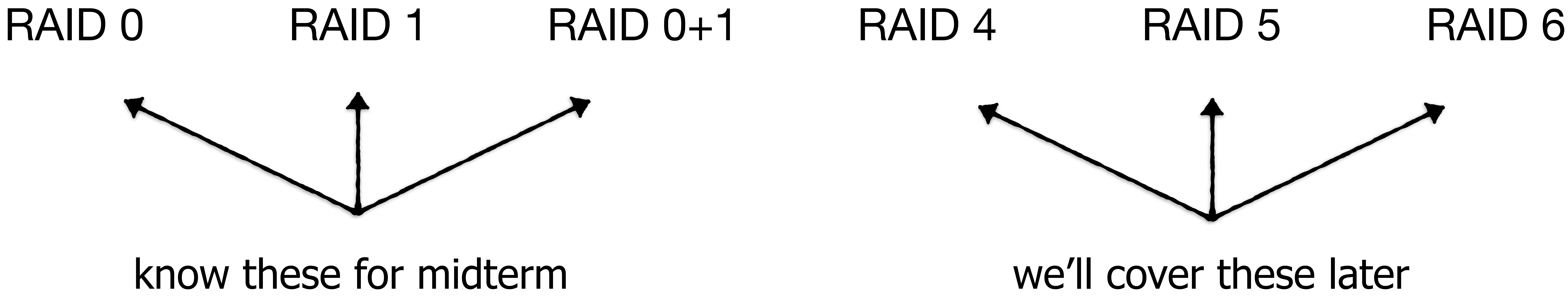


1. Slower writes as they must make 2 copies
2. Faster reads as we have a choice to read from a non-busy drive
3. Allows recovery of a disk but costs 50% of storage capacity

RAID 0+1 - Striping and Mirroring



1. Faster sequential reads and writes as they are more distributed
2. Writes still require making two copies, and reads still have flexibility
3. Still requires 50% of storage capacity



RAID 0

RAID 1

RAID 0+1

know these for midterm

RAID 4

RAID 5

RAID 6

we’ll cover these later

Storage

Tables

Buffering

Indexes

Sorting

Operators

Query Optimization

Transactions

Recovery

Tables Management

Database System Technology - Lecture 3, Chapter 9

Niv Dayan

Database Tables

A database consists of multiple tables

Customers

ID	Name	email	Addr

Orders

ID	Customer ID	Product ID	Date

Database Tables

A database consists of multiple tables

How do we store them in storage efficiently?

Customers

ID	Name	email	Addr

Orders

ID	Customer ID	Product ID	Date

SSD

Operations to Efficiently Support

1. Scans e.g., select * from Customers
2. Deletes e.g., delete from Customers where name = “…”
3. Updates e.g., update Customers set email = “…” where name = “”
4. Insertions e.g., Insert into Customers (, , ,)

Customers

ID	Name	email	Addr

Optimizing for Data Movement

In previous courses on algorithms & data structures, you learned to optimize CPU cycles for an algorithm.

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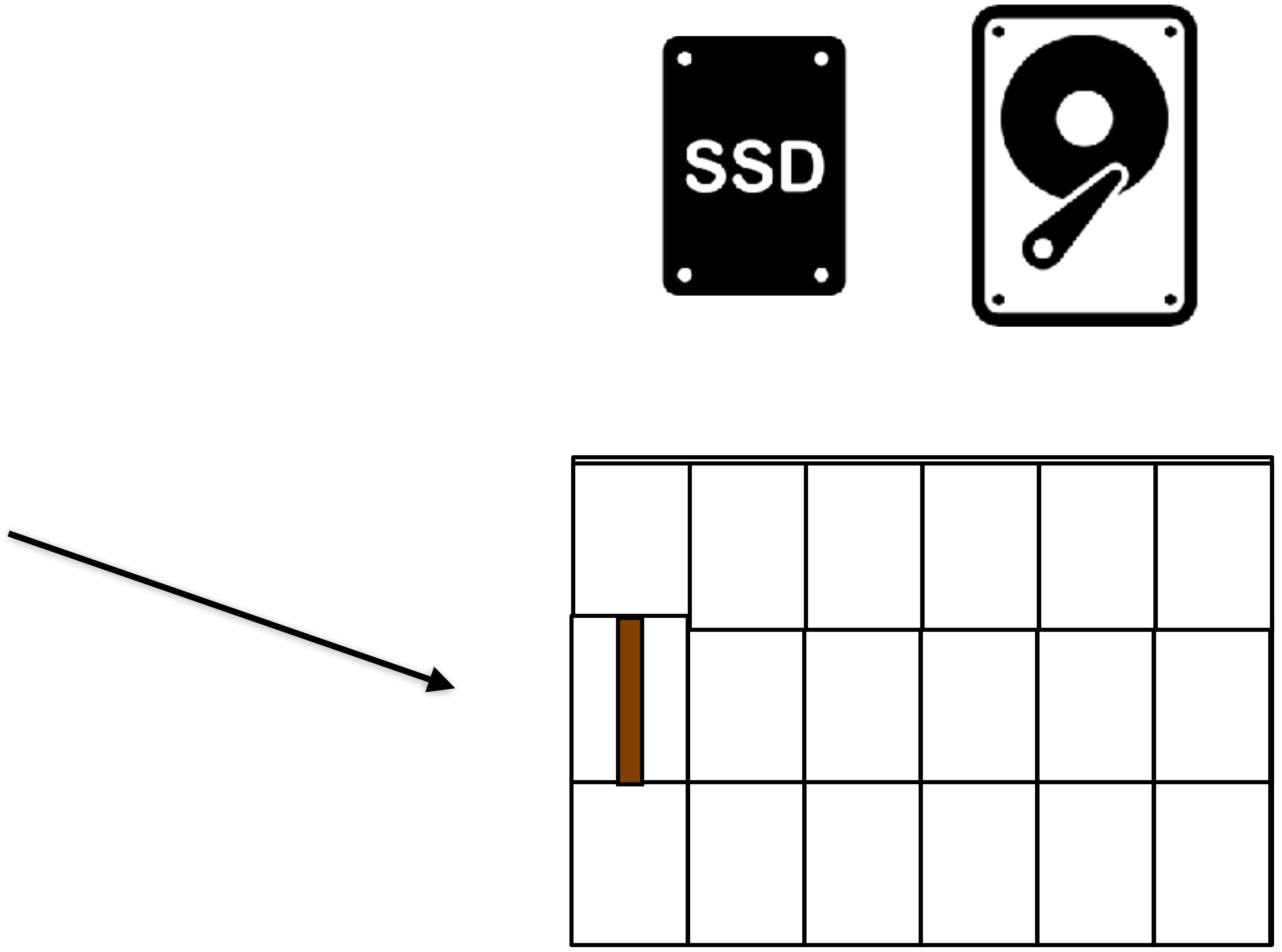
As storage devices are far slower, in this course we focus on optimizing data movement.

First Insight: Database Pages

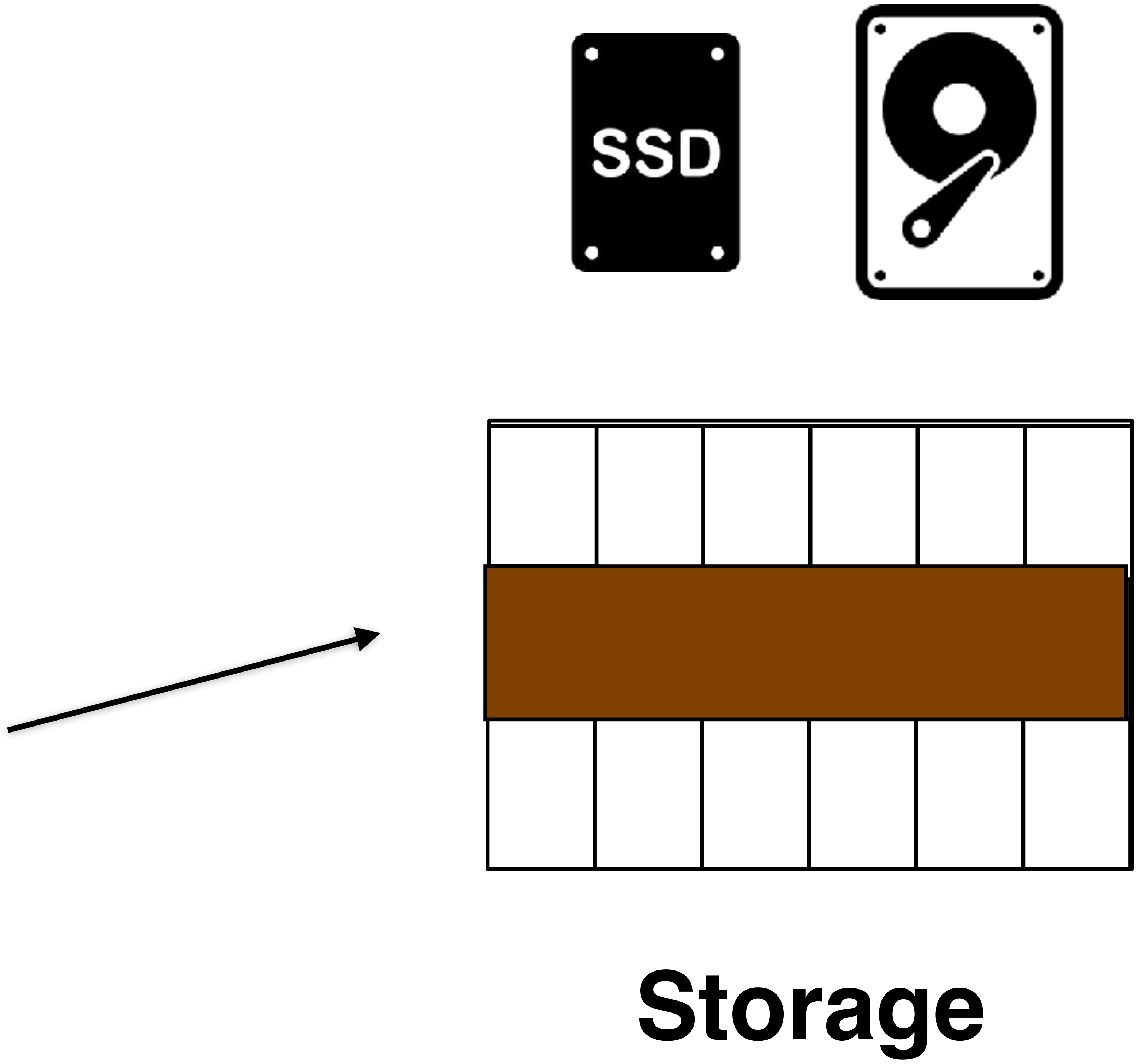
Reading/writing from storage at units of less than ≈4KB does not pay off.



First Insight: Database Pages

Reading/writing from storage at units of less than ≈4KB does not pay off.

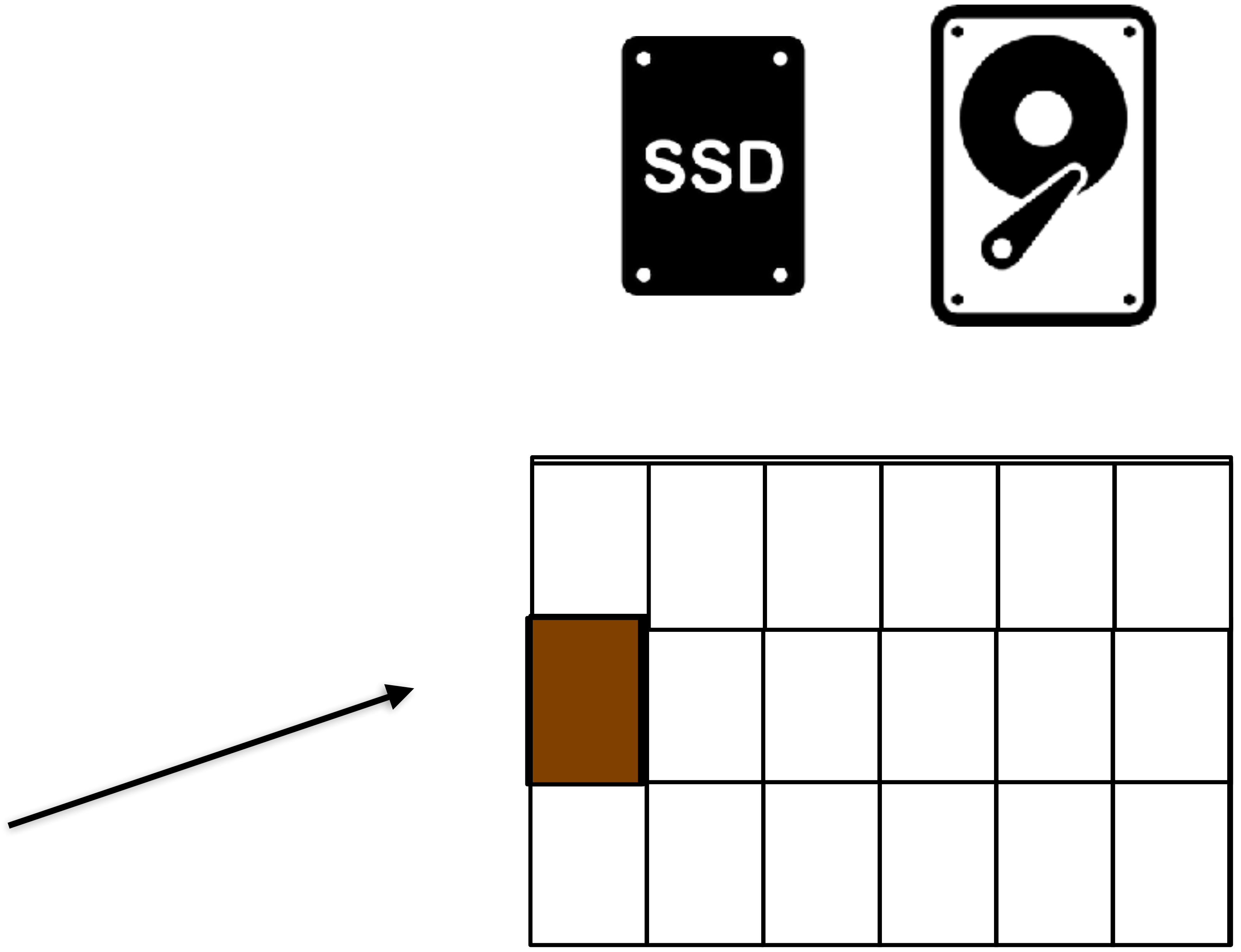
Reading/writing at very large units consumes memory and is less flexible for applications



Database Pages

To balance, DBs use ≈4KB as the read/write unit. This is known as a database page.

An I/O (input/output) is one read or write request of one database page.



Storage

The Disk Access Model (The DAM Model)

We will shortly propose algorithms to support scans/delete/updates/inserts

To reason about such algorithms, we need a cost model

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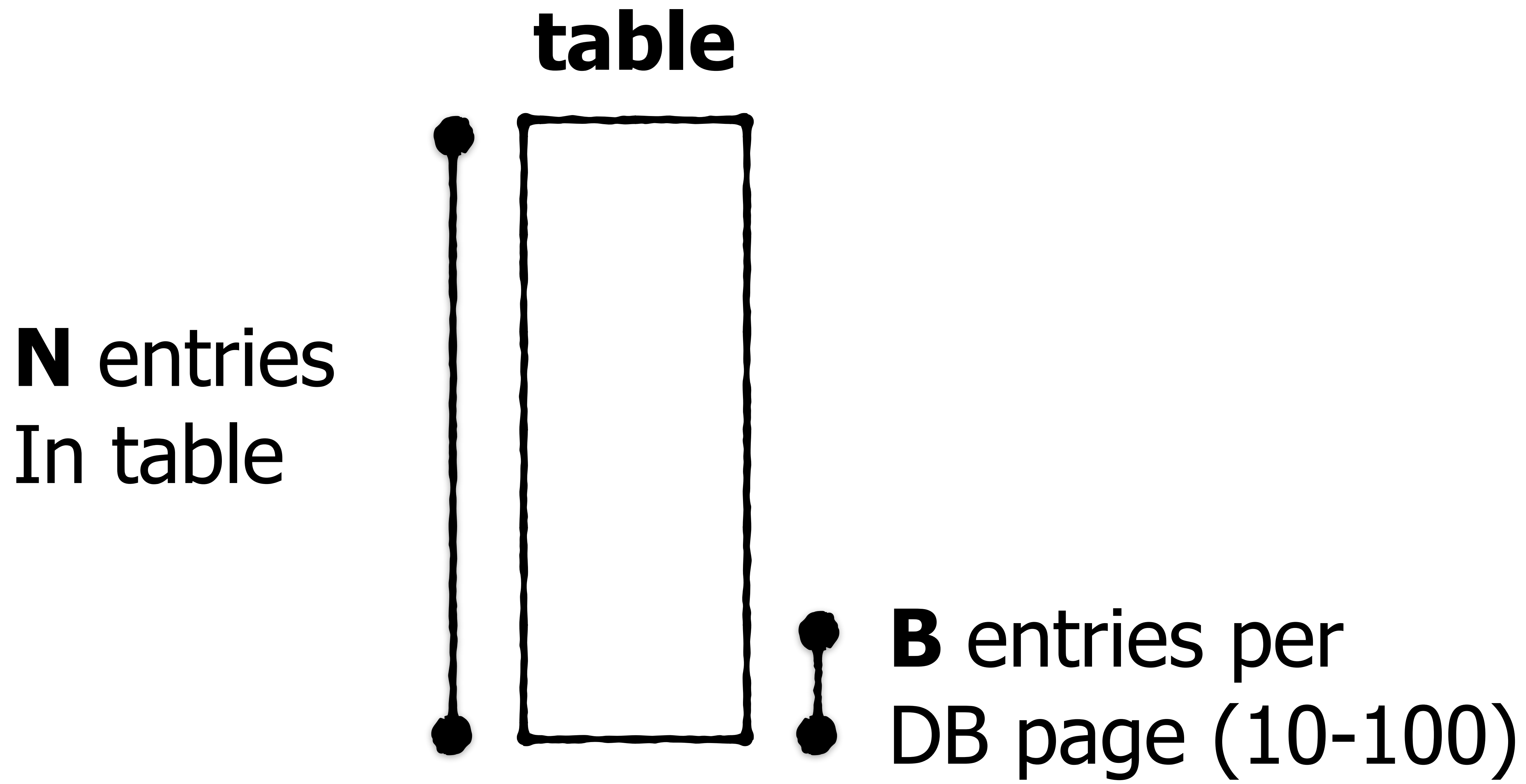


table

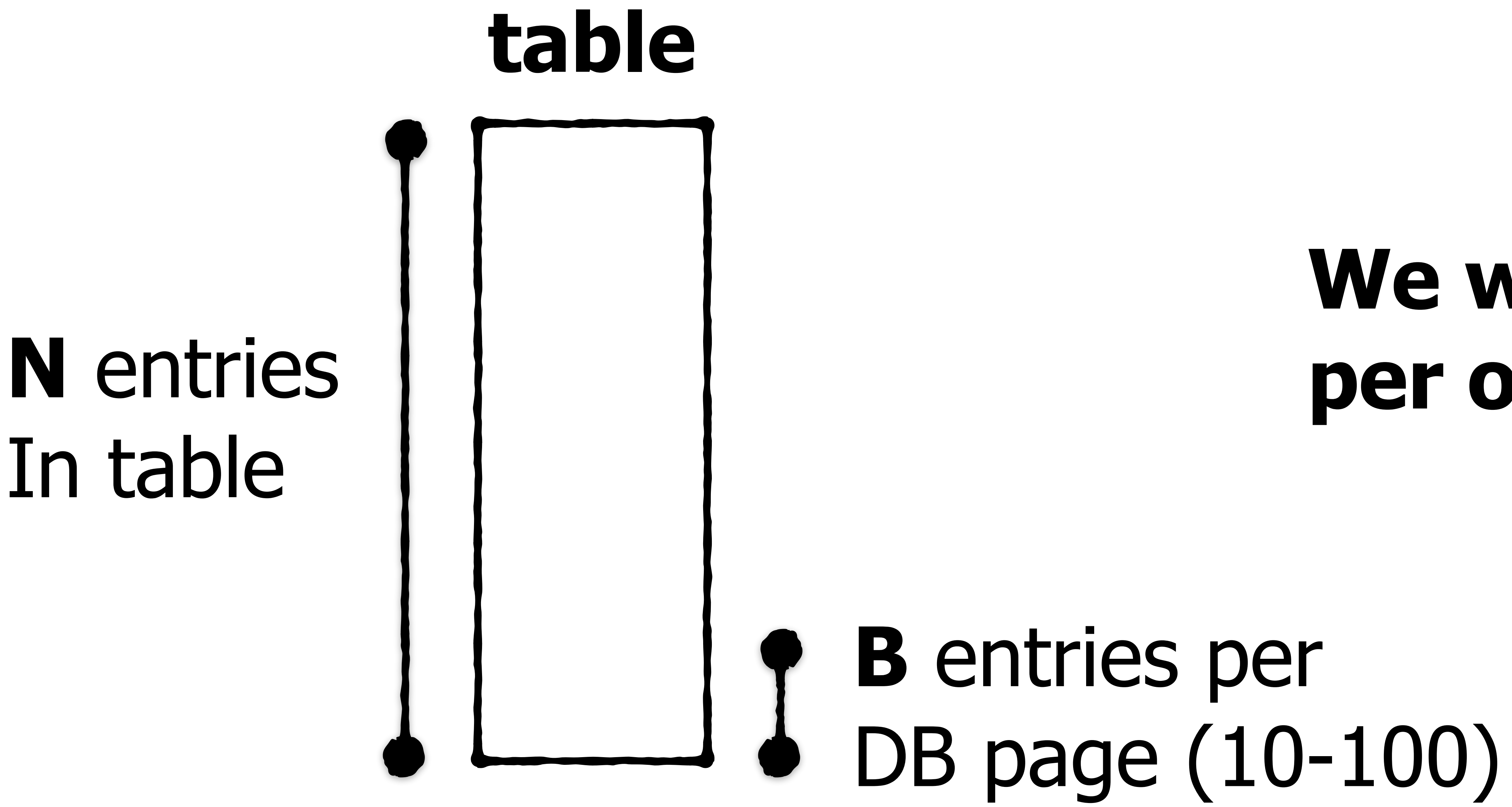
N entries
In table

B entries per
DB page (10-100)

The Disk Access Model (The DAM Model)

We will shortly propose algorithms to support scans/delete/updates/inserts

To reason about such algorithms, we need a cost model



We will count the worst-case number of I/Os per operations with respect to N and B

The Disk Access Model (The DAM Model)

This model is imperfect. It ignores many characteristics of storage.

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This model is imperfect. It ignores many characteristics of storage.

Ignores that sequential disk reads are more economical

Ignores that SSD asynchronous I/O are faster

Ignores SSD garbage-collection due to random writes

However, it’s useful due to its simplicity.

Operations

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Scans - How not to Support Them

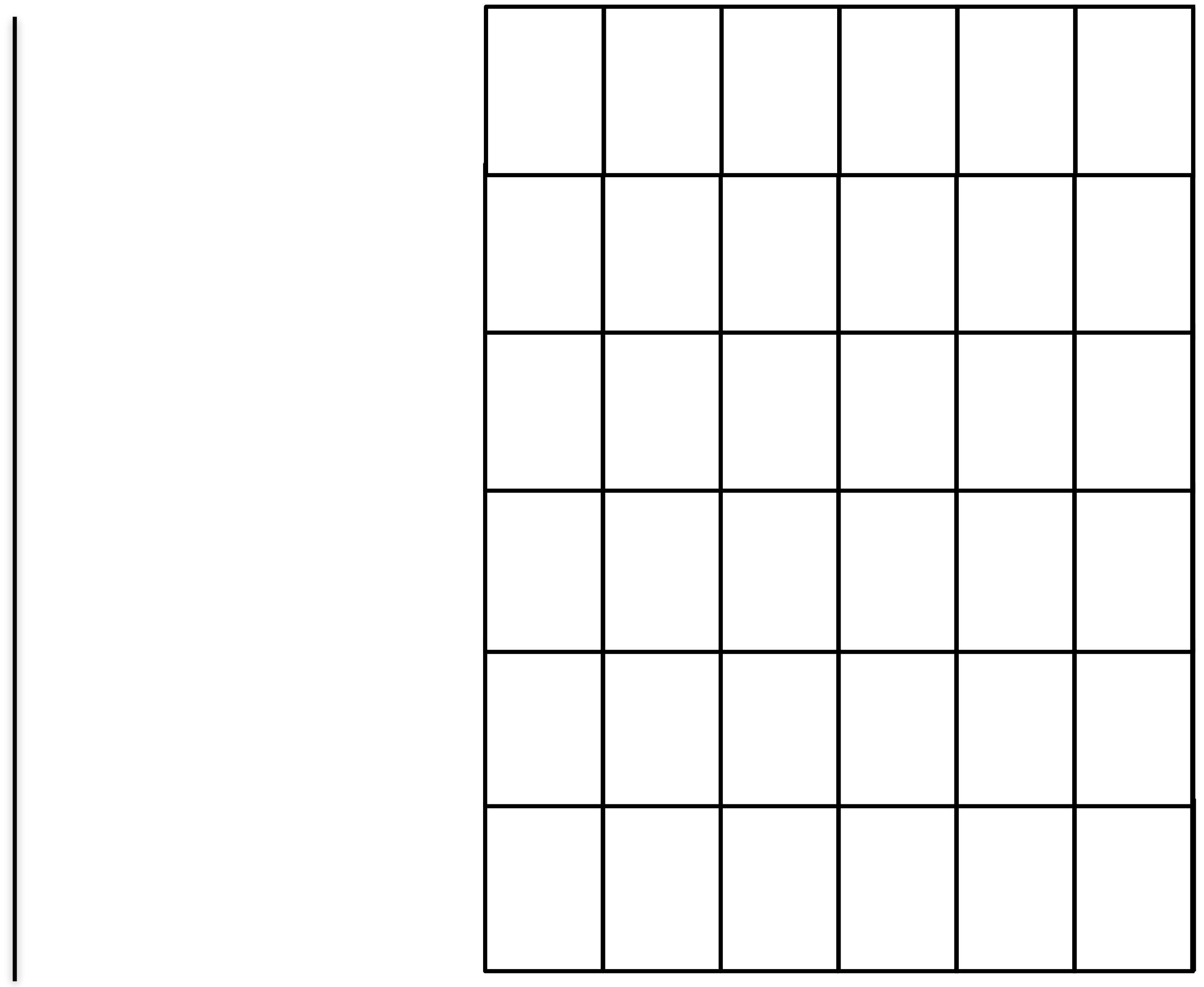
Customers

ID	Name	email	Addr

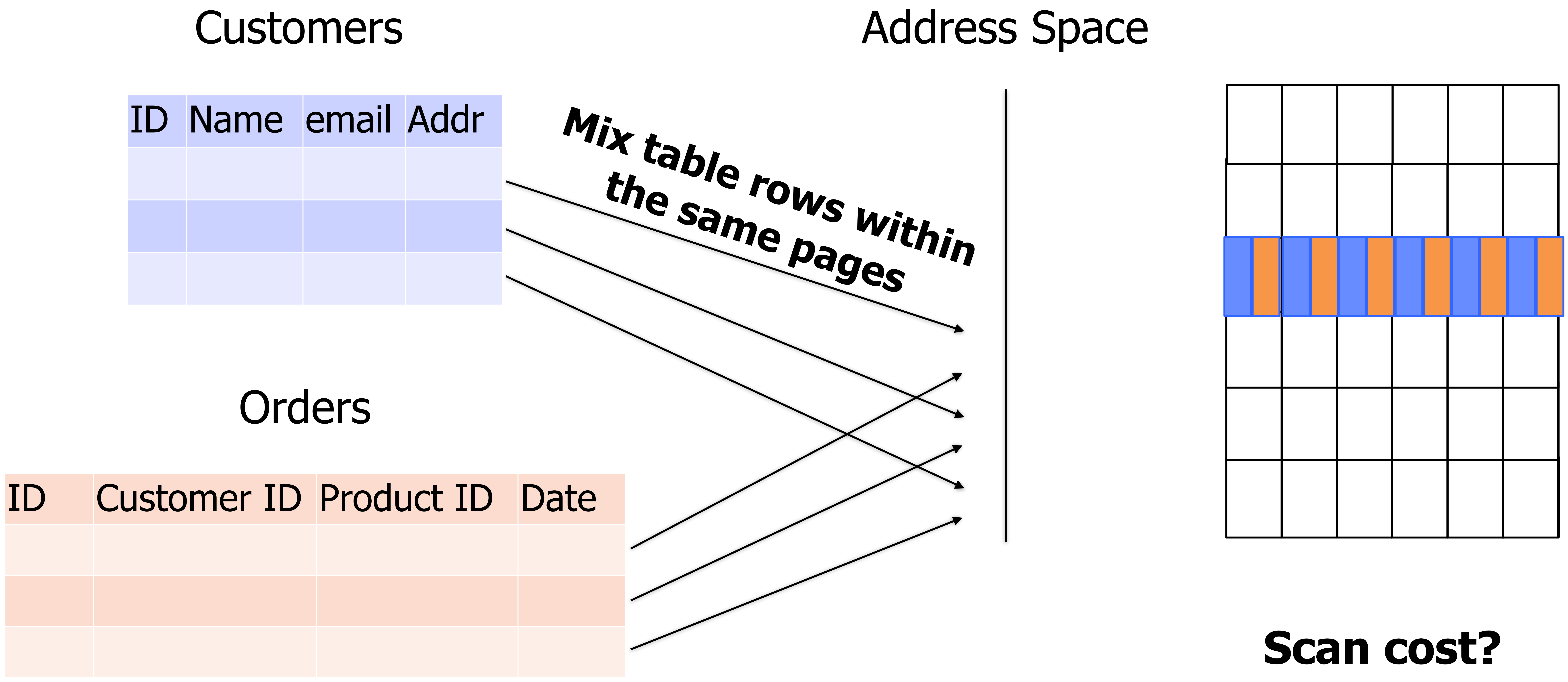
Orders

ID	Customer ID	Product ID	Date

Address Space



Scans - How not to Support Them



Customers

ID	Name	email	Addr

Orders

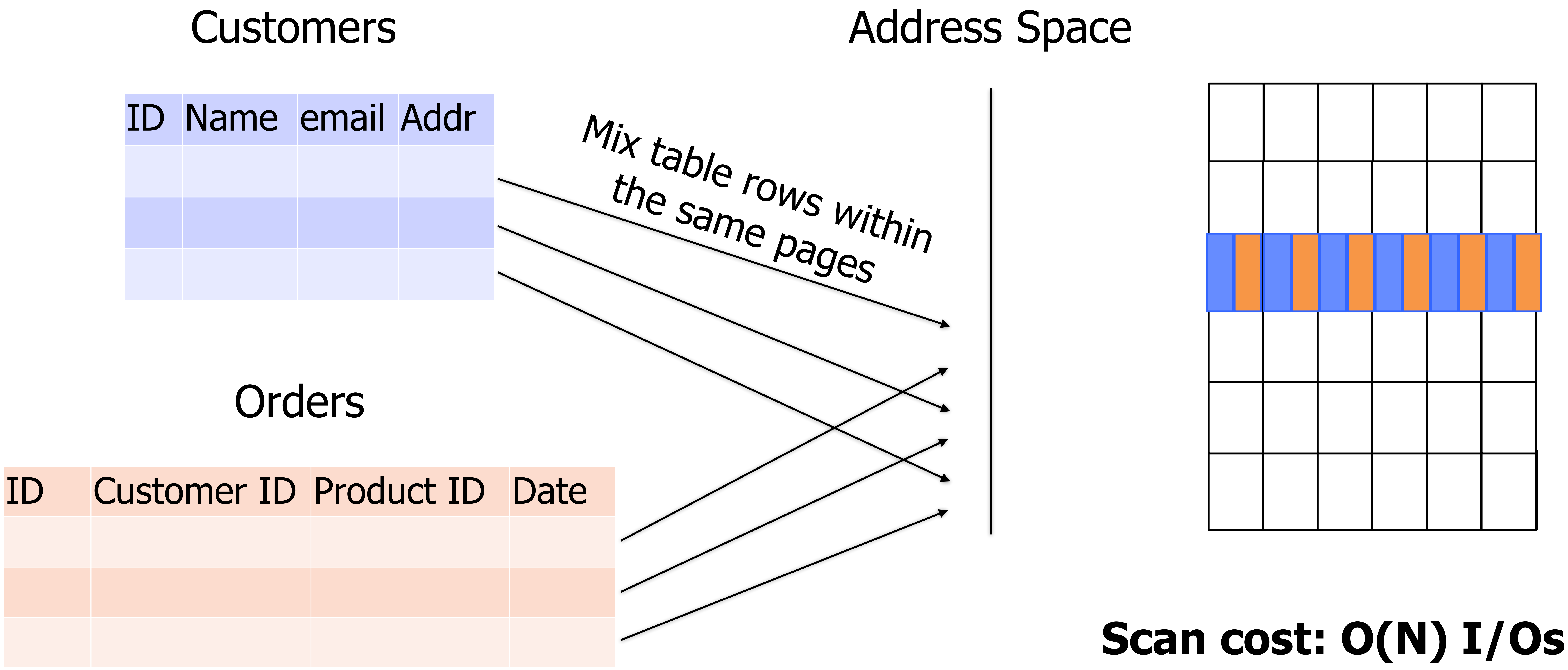
ID	Customer ID	Product ID	Date

Mix table rows within the same pages

Address Space

Scan cost?

Scans - How not to Support Them



Customers

ID	Name	email	Addr

Orders

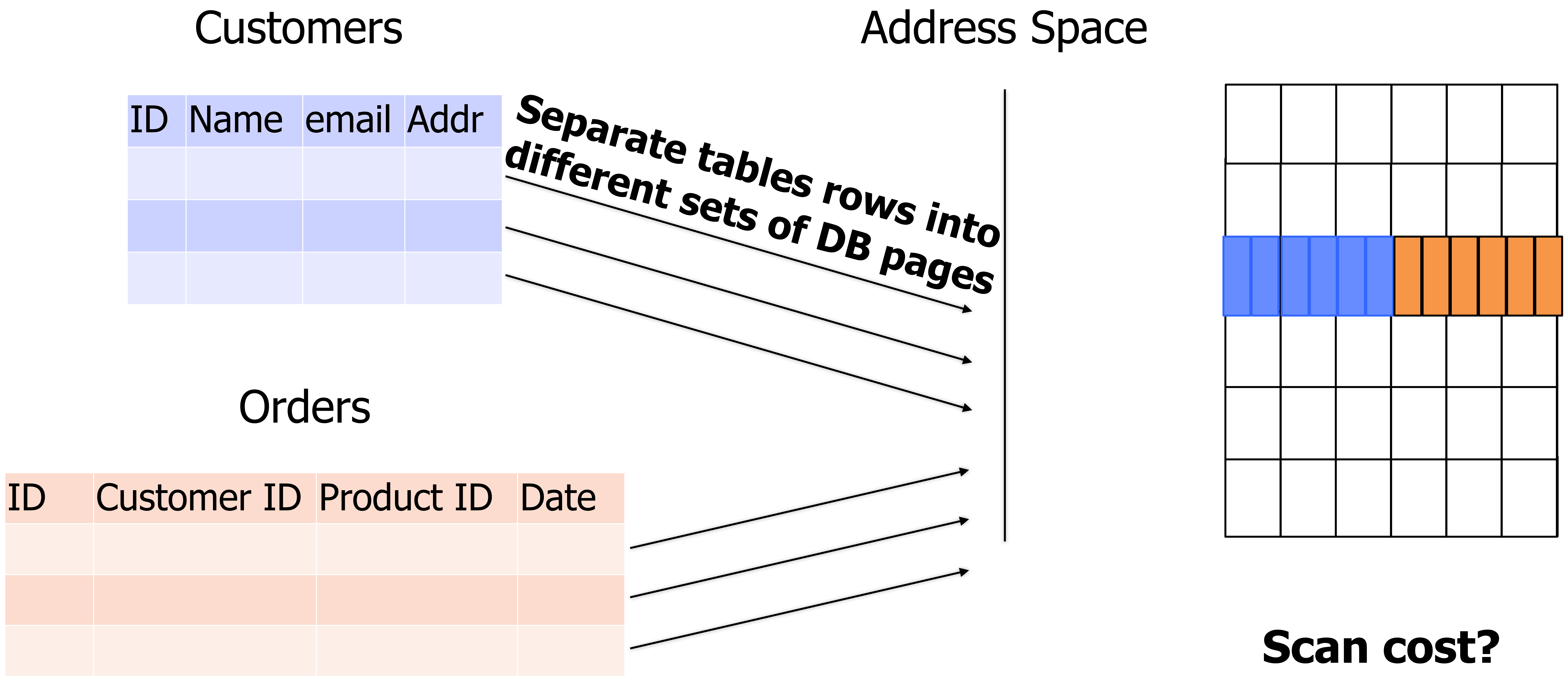
ID	Customer ID	Product ID	Date

Address Space

Mix table rows within the same pages

Scan cost: O(N) I/Os

Efficient Scans



Customers

ID	Name	email	Addr

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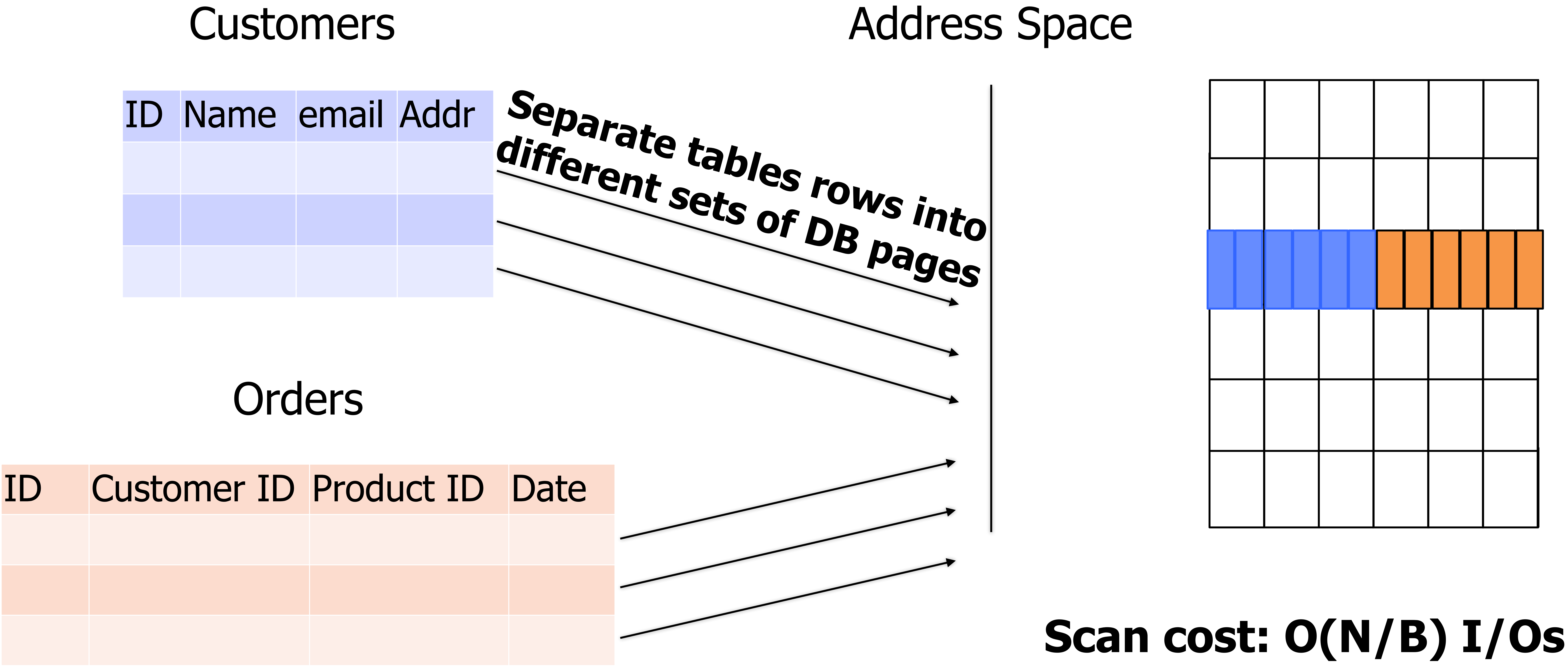
Address Space

Separate tables rows into different sets of DB pages

Scan cost?

Efficient Scans



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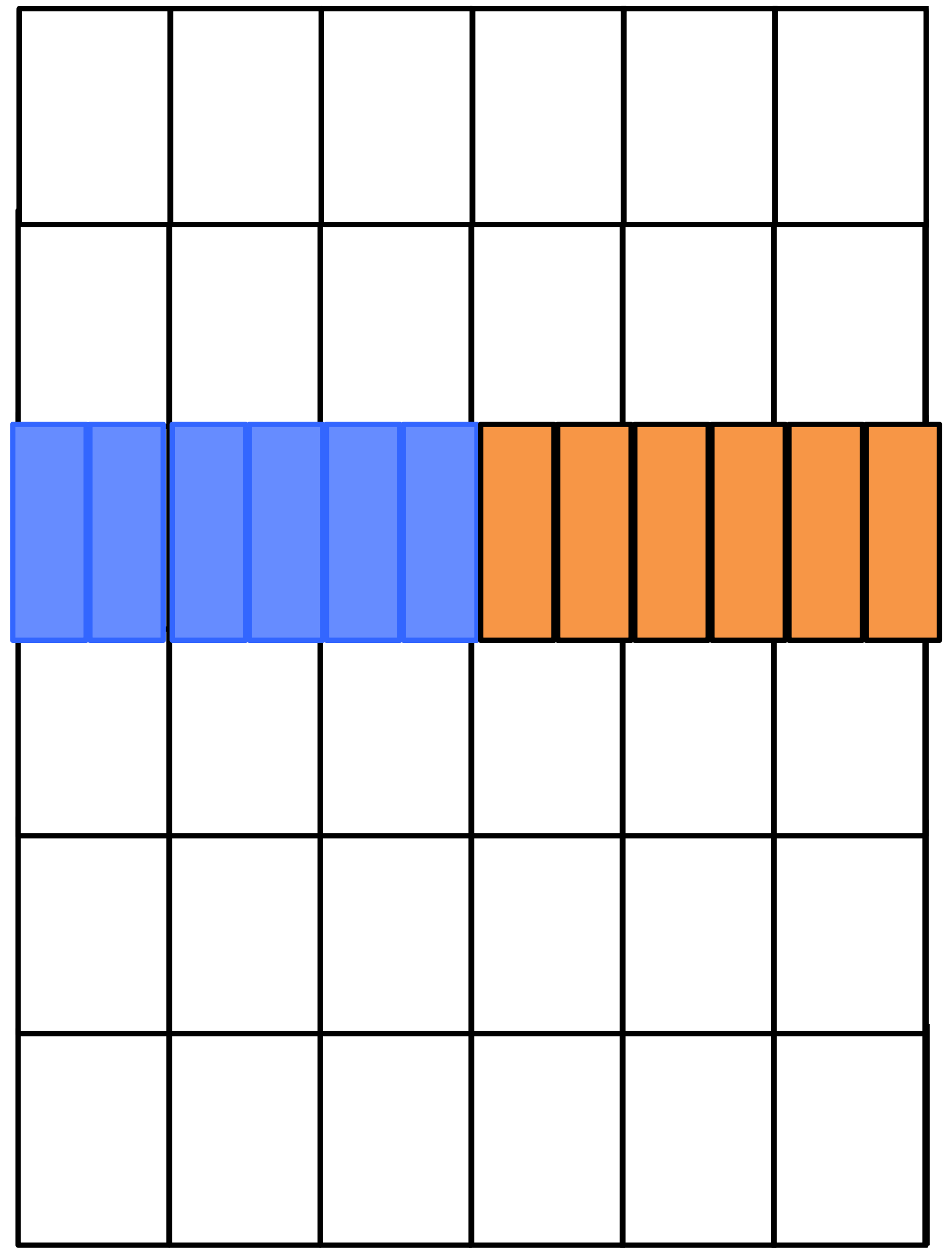
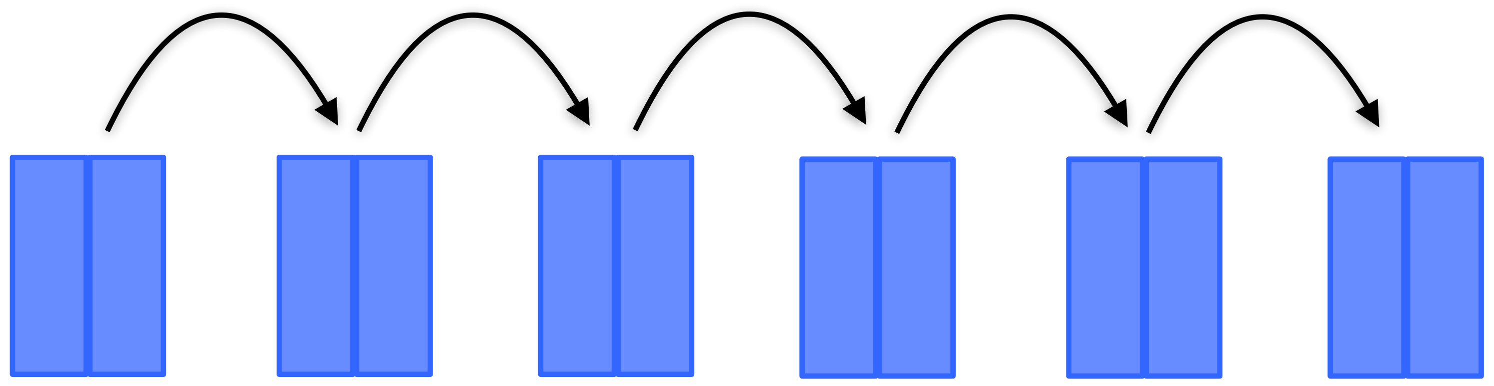
Which pages belong to which table?



Efficient Scans

Which pages belong to which table?

Simplest Solution: Linked List



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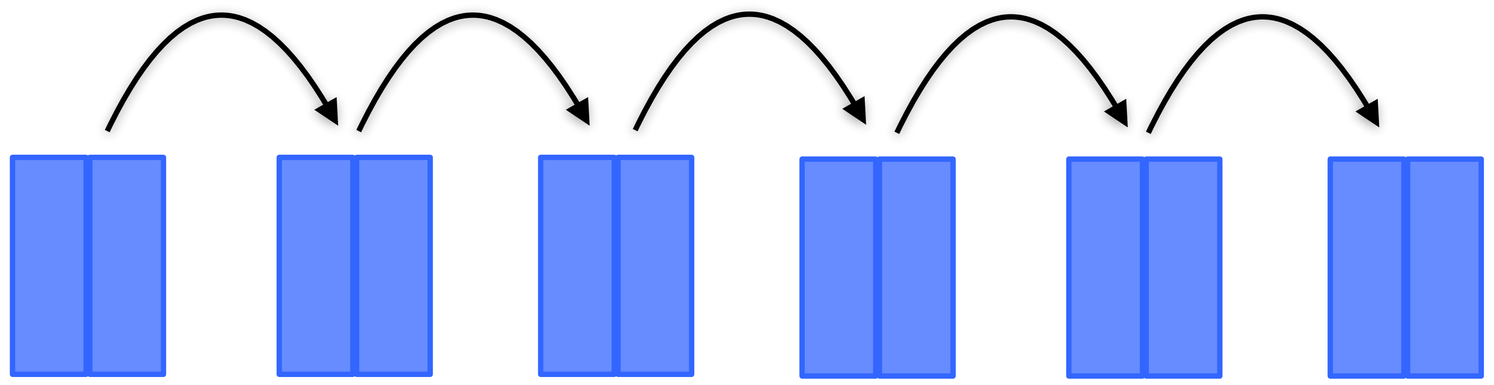
Problem:



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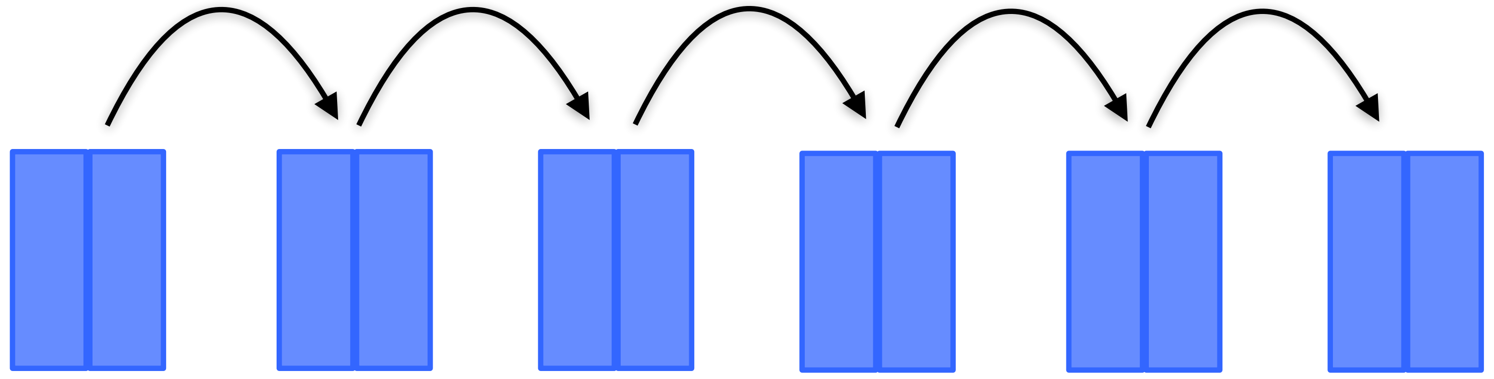
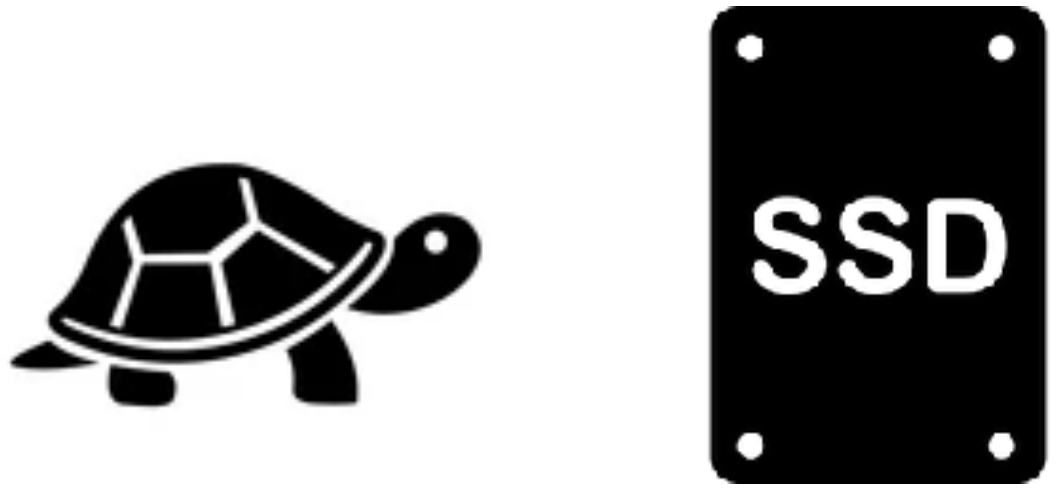


Problem: **entails synchronous I/Os, which do not exploit SSD parallelism**

Solution:



Efficient Scans

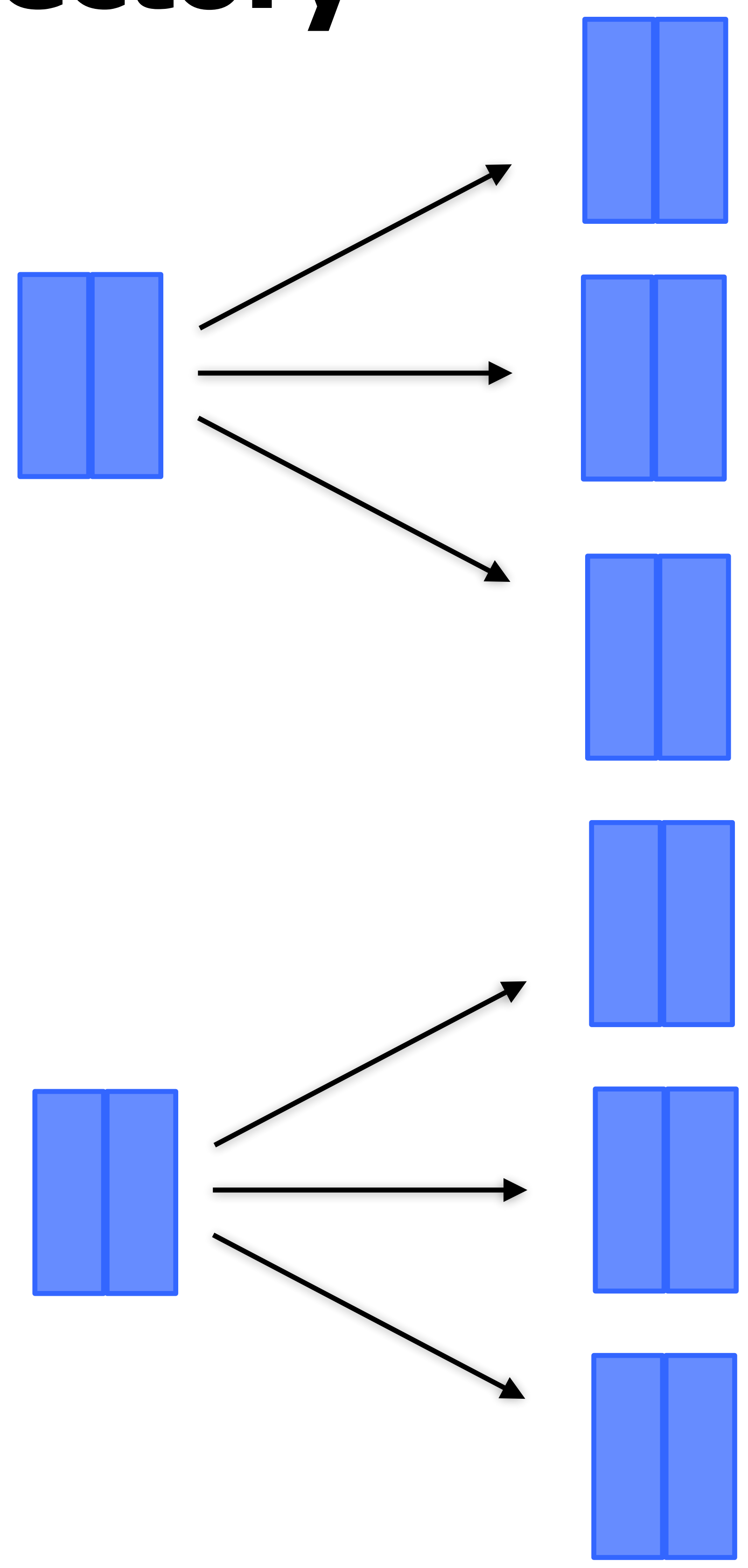
Which pages belong to which table?

Simplest Solution: Linked List

Problem: entails synchronous I/Os,
which do not exploit SSD parallelism

Solution: **Employ directory to allow reading many pages asynchronously**

Directory

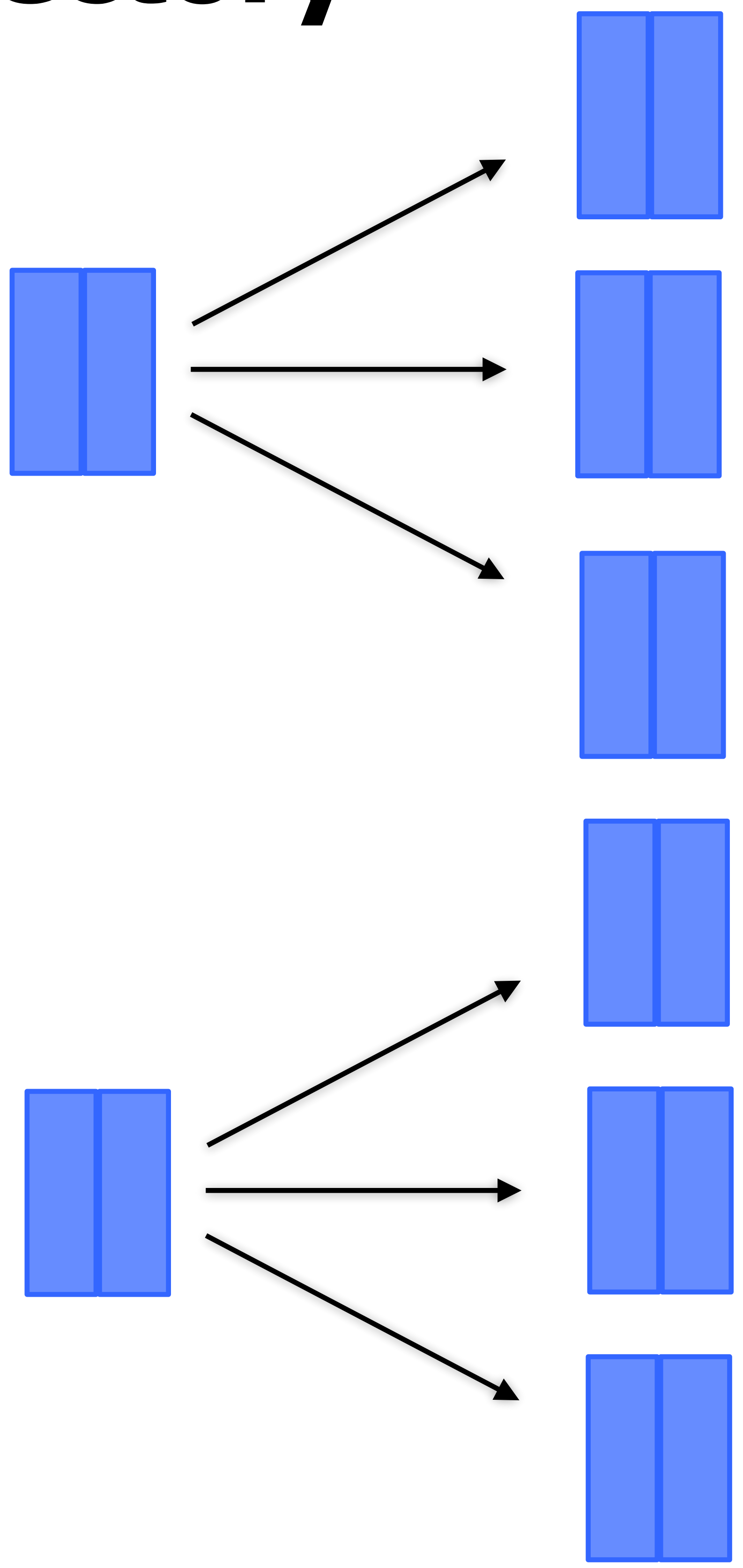


Efficient Scans

Which pages belong to which table?

Problem: small I/Os, which do not saturate a disks's sequential bandwidth

Directory



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Which pages belong to which table?

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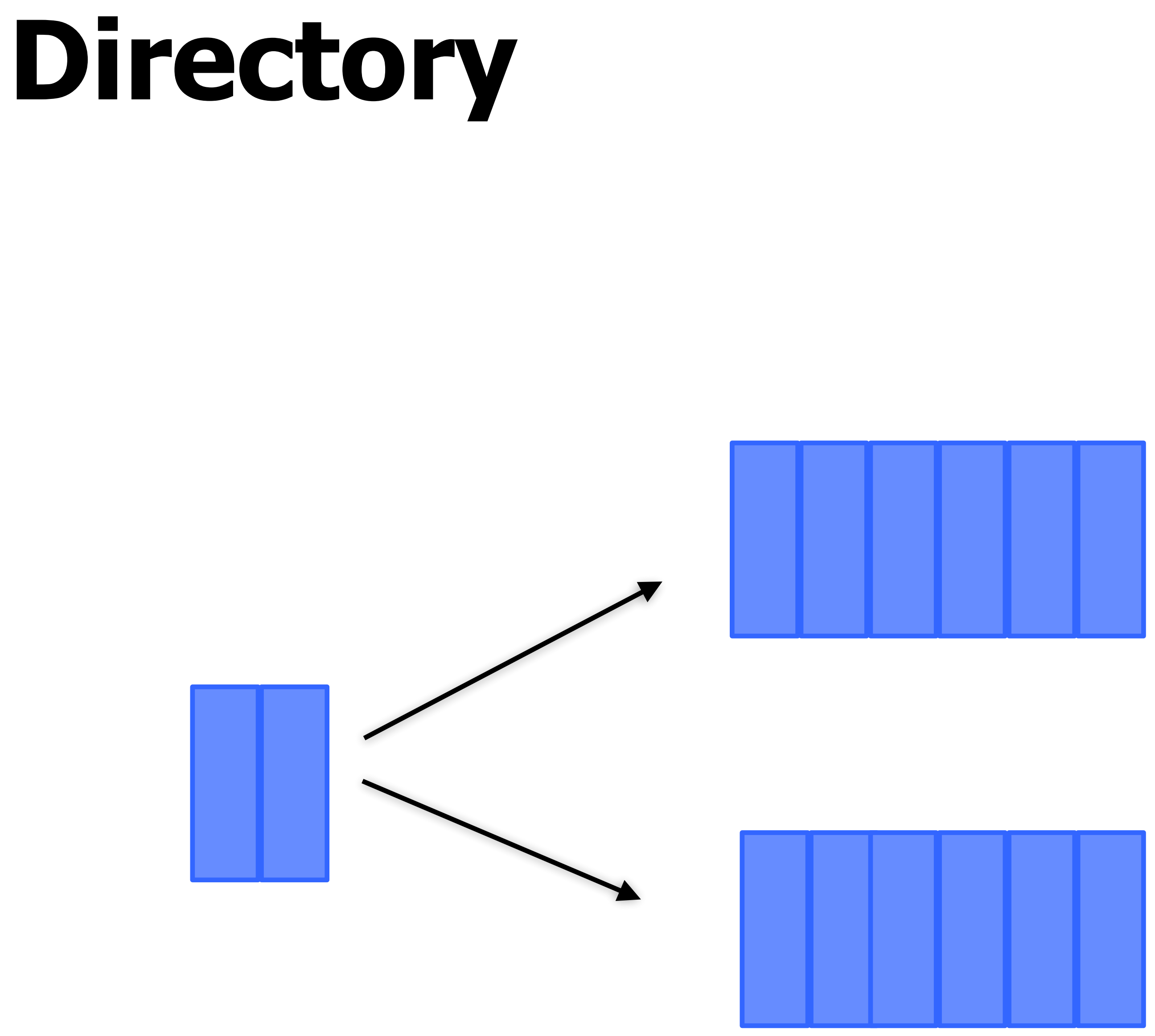
Solution: **Store multiple database pages contiguously along "extents"** (8-64 pages)



Efficient Scans

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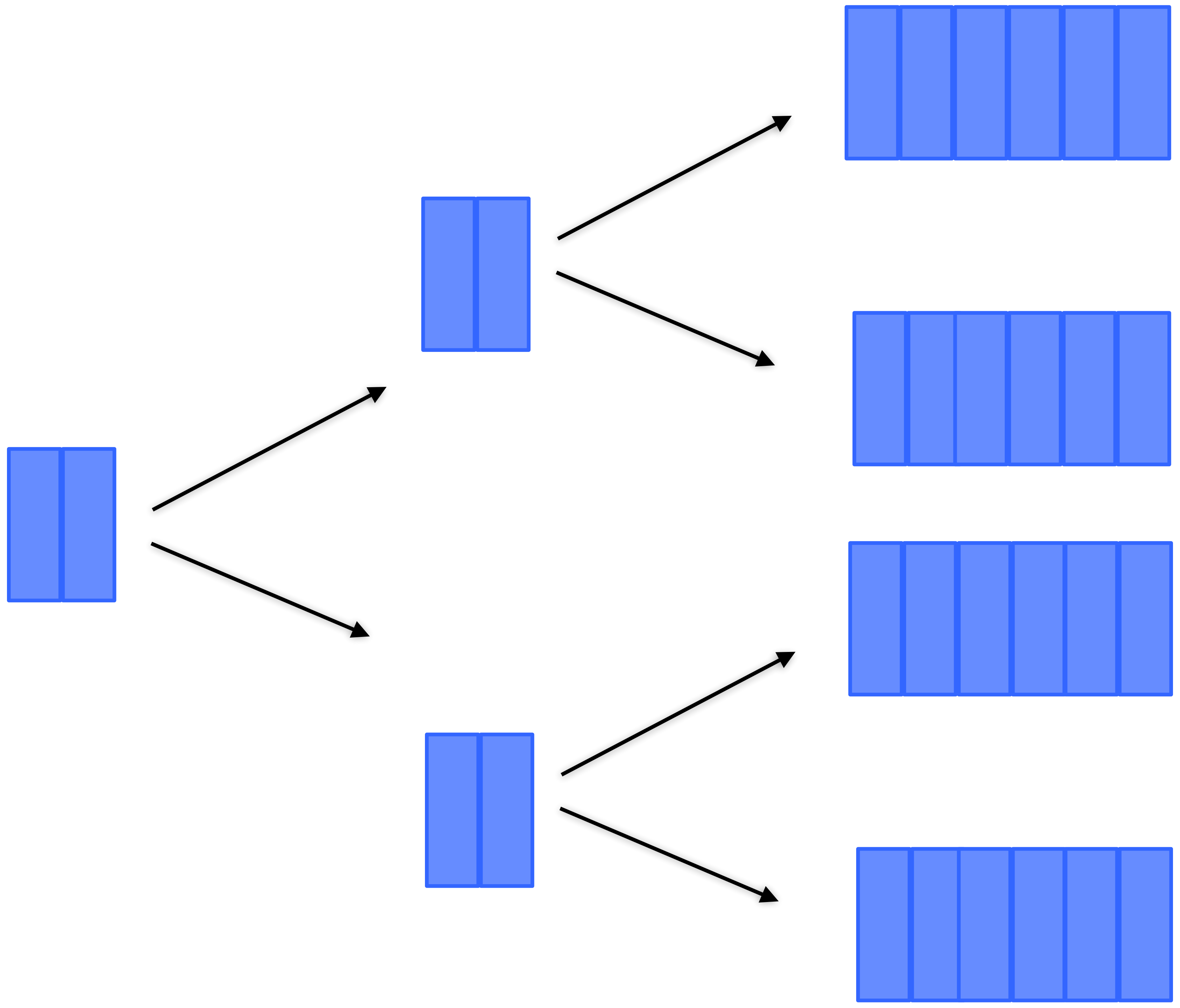
Bonus: Saves some metadata

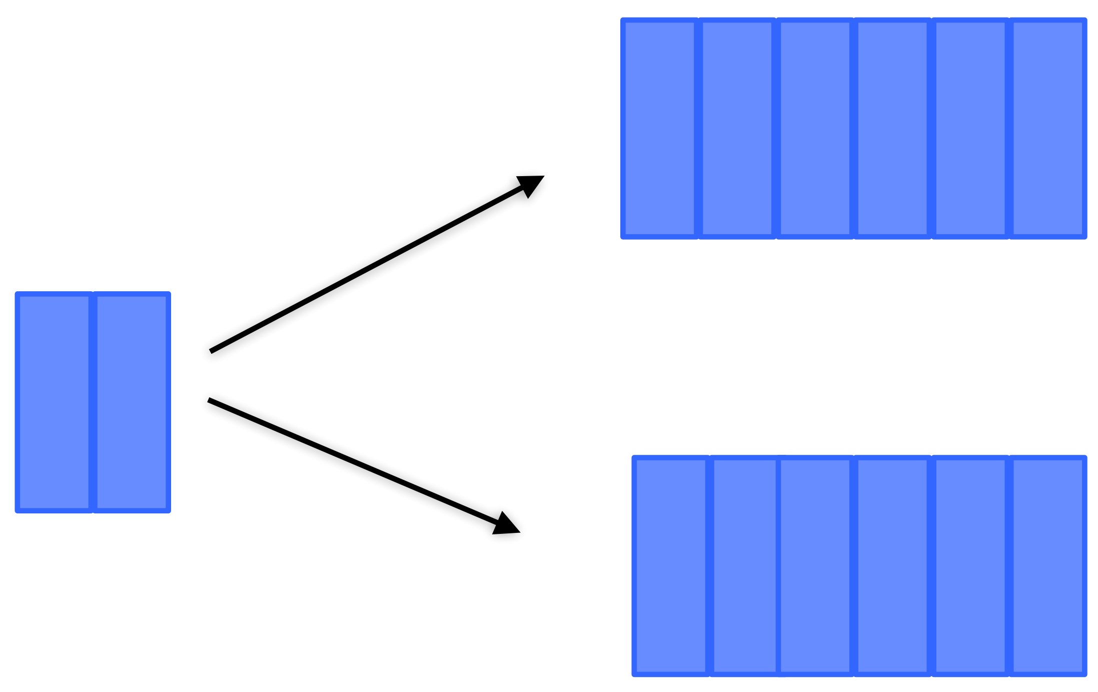
File can grow as a tree if it gets large

Directory



Efficient Scans

How to keep track of directories of all files?

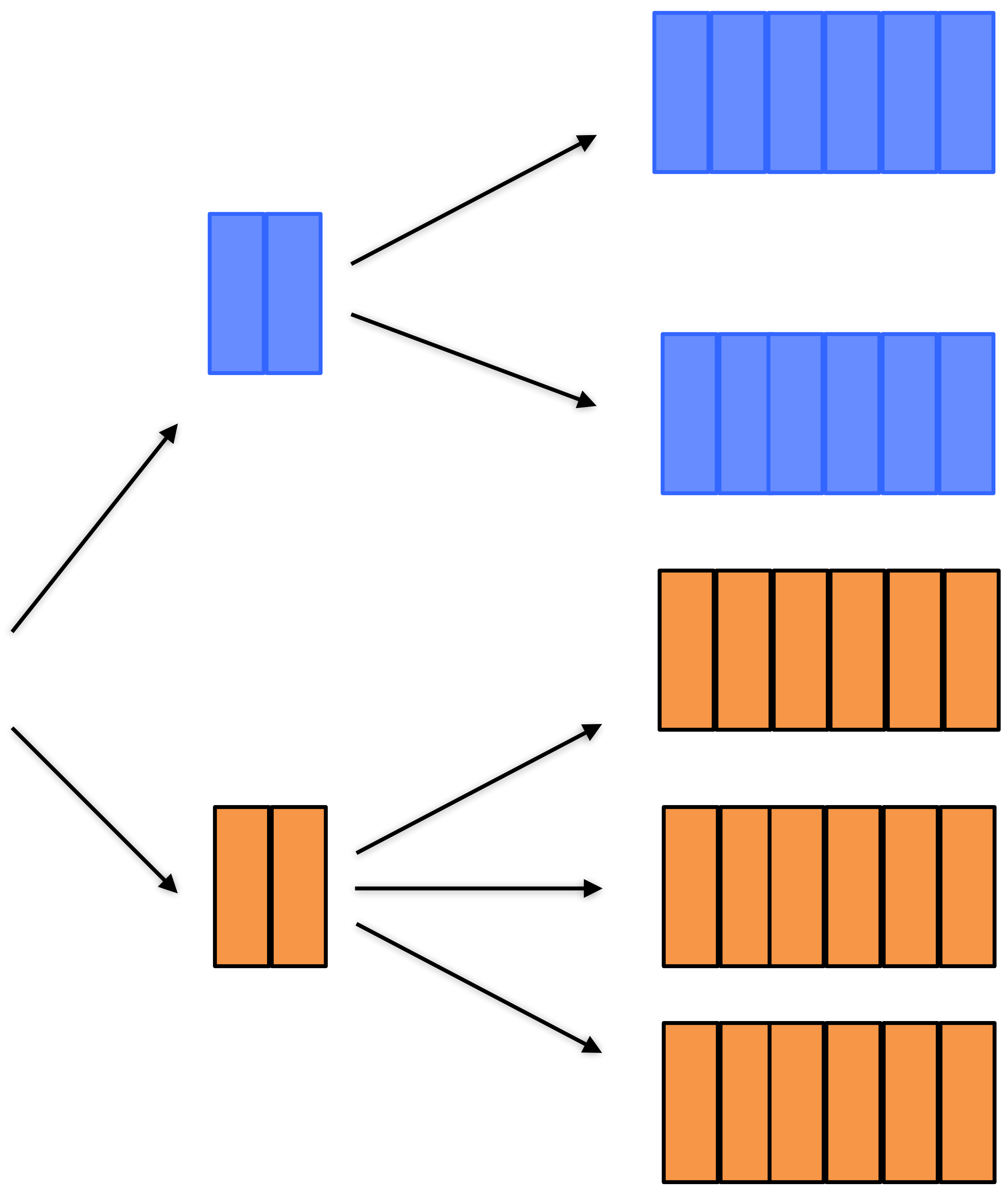


Efficient Scans

How to keep track of directories of all files?

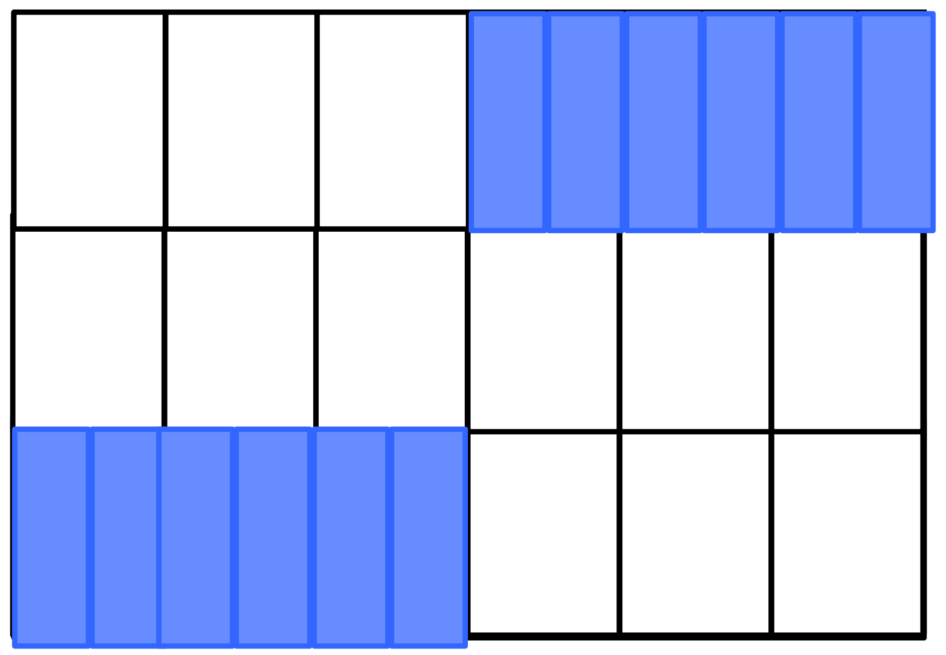
Catalog

Name	Data type	Size (Bytes)	Start
Customers			
Orders			



Efficient Scans

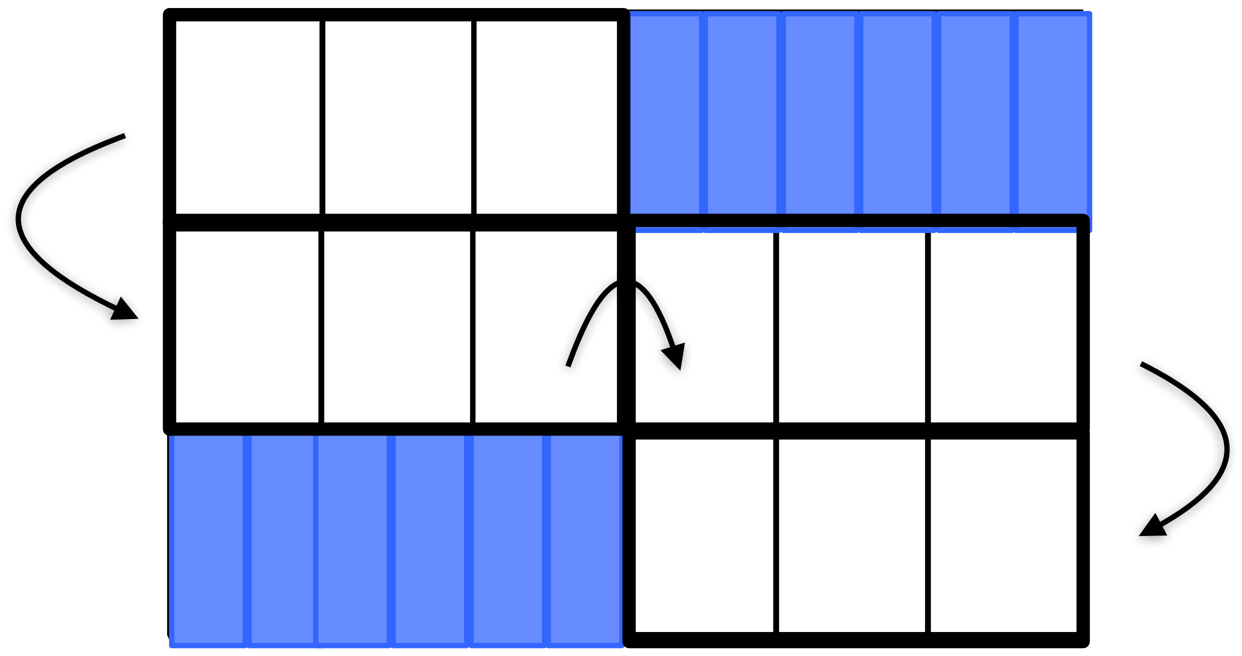
How to keep track of free pages/extents?



Efficient Scans

How to keep track of free pages/extents?

Solution 1: linked list (slower)

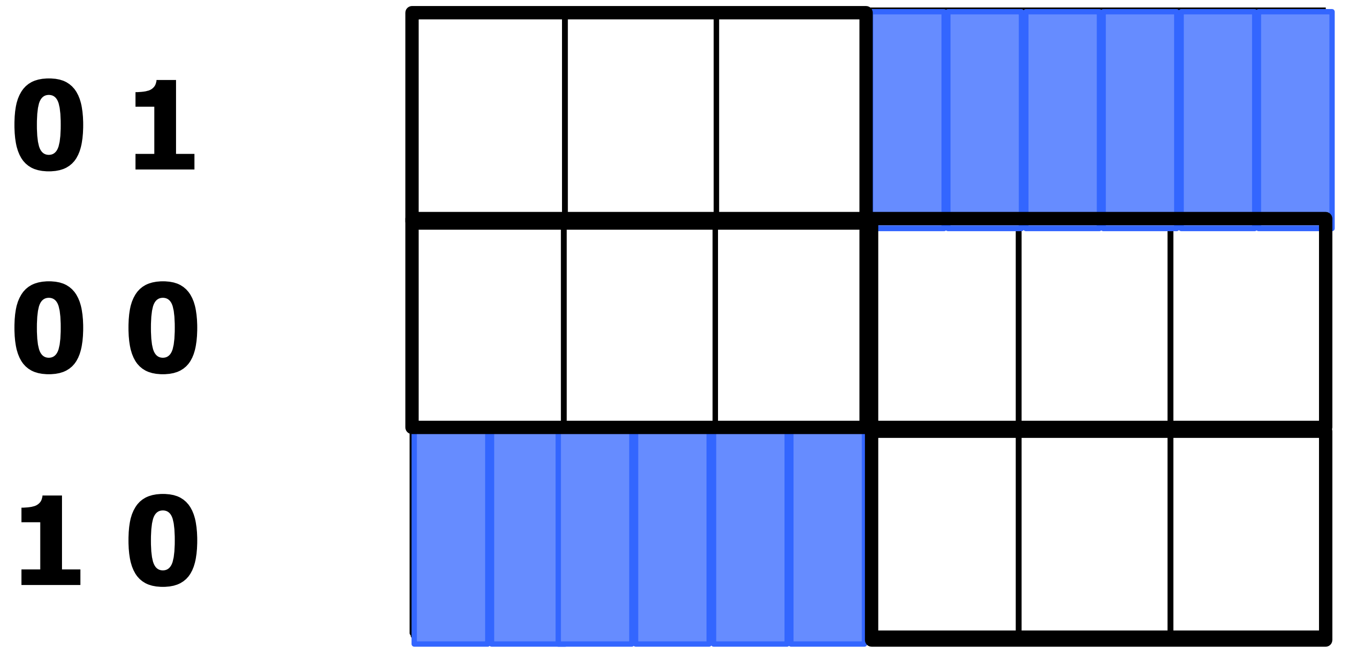


Efficient Scans

How to keep track of free pages/extents?

Solution 1: linked list (slower)

Solution 2: bitmap (takes space)



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4. Insertions e.g., Insert into Customers (, , ,)

Supporting Deletes

e.g., delete from Customers where name = "…"

Simplest solution?

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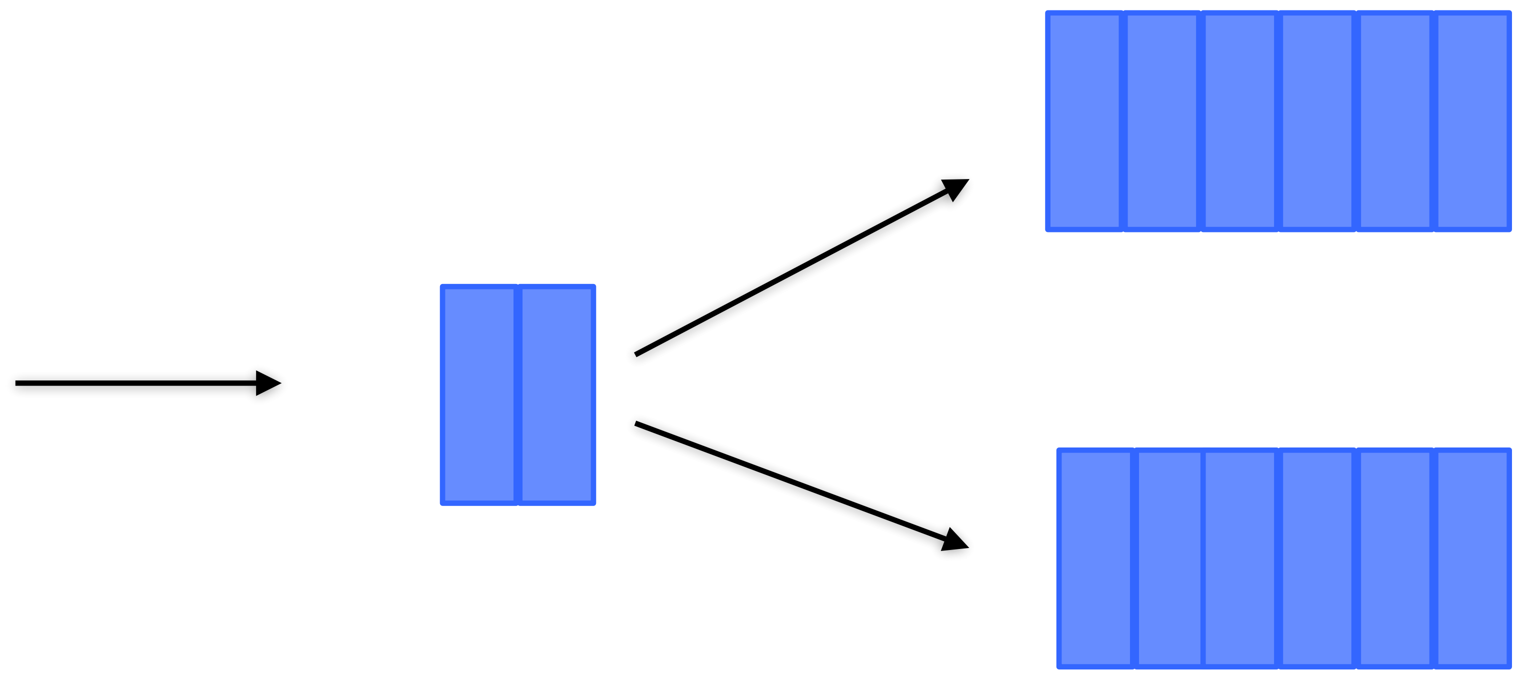
Orders			



Supporting Deletes

e.g., delete from Customers where name = "…"

Simplest solution? **Scan of the table. Creates "holes".**

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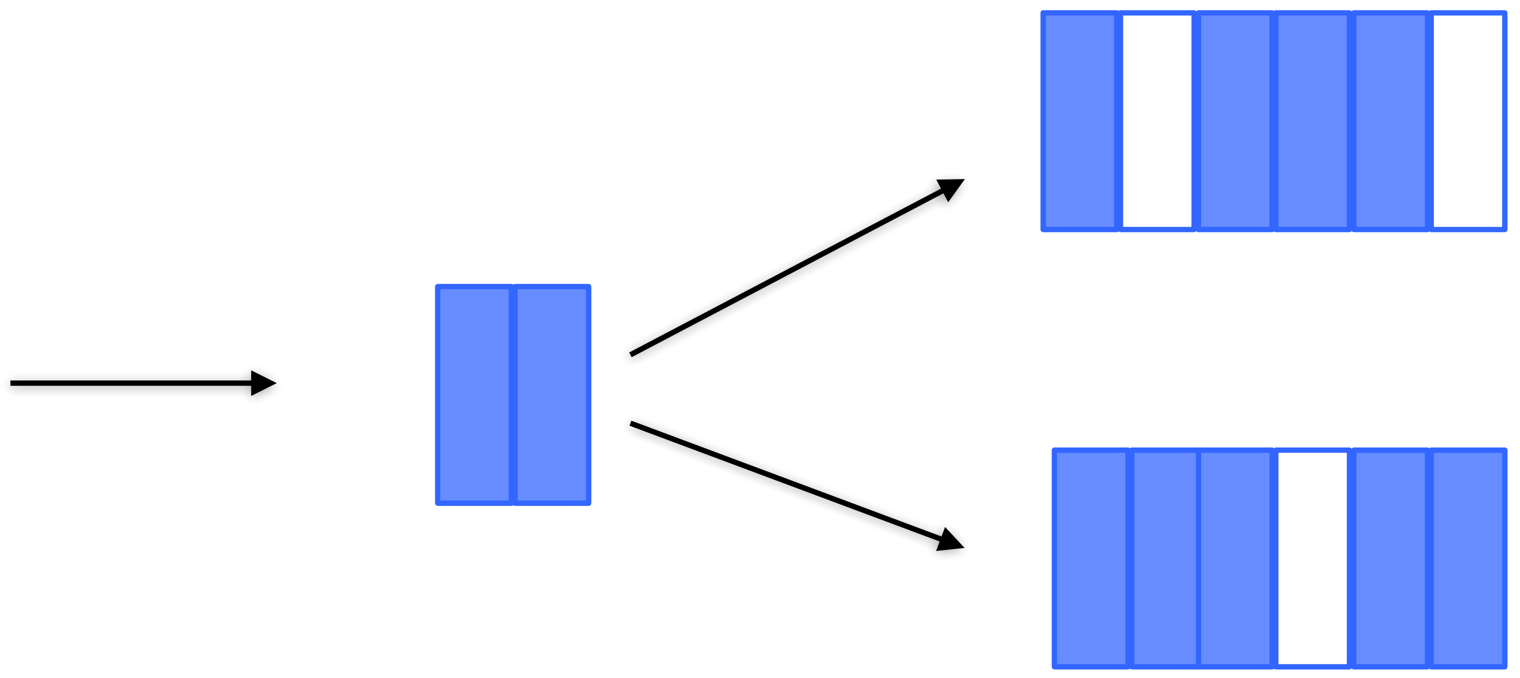

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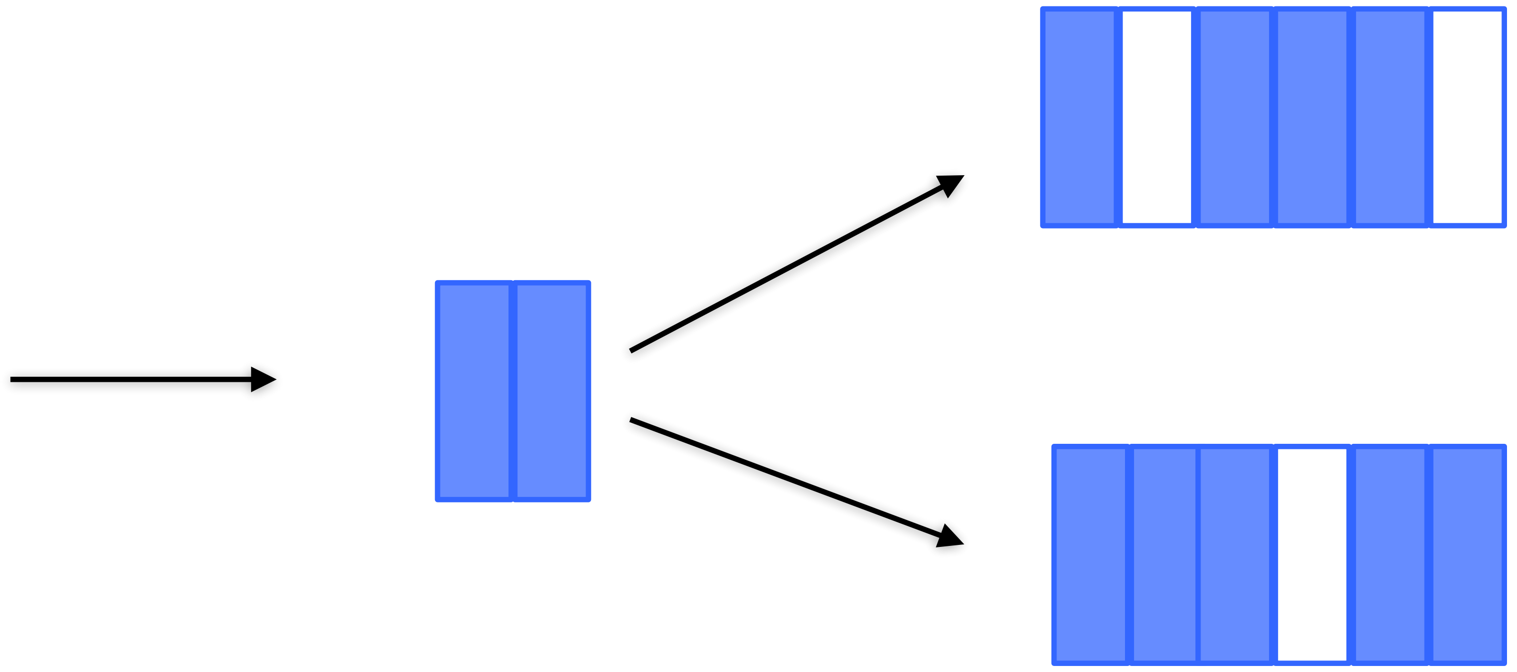

Cost: O(1) write and O(N/B) reads.

Operations

1. Scans
2. Deletes
3. **Updates**
4. Insertions

Supporting Updates

e.g., update Customers set email = “…” where name = “”

Scan and update.

Catalog

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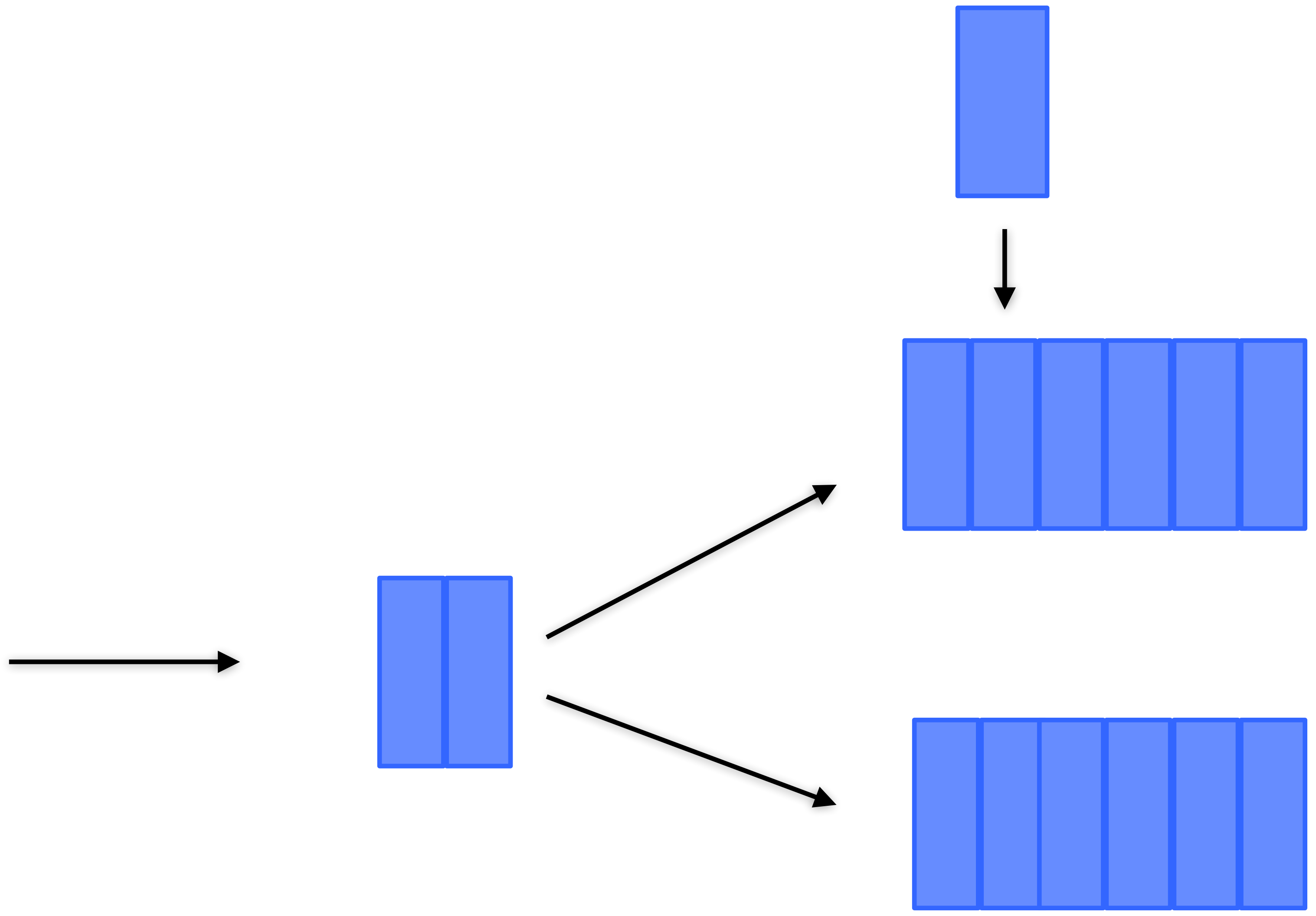
Orders			



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Scan and update. If newer version is too large, delete & reinsert

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Customers			
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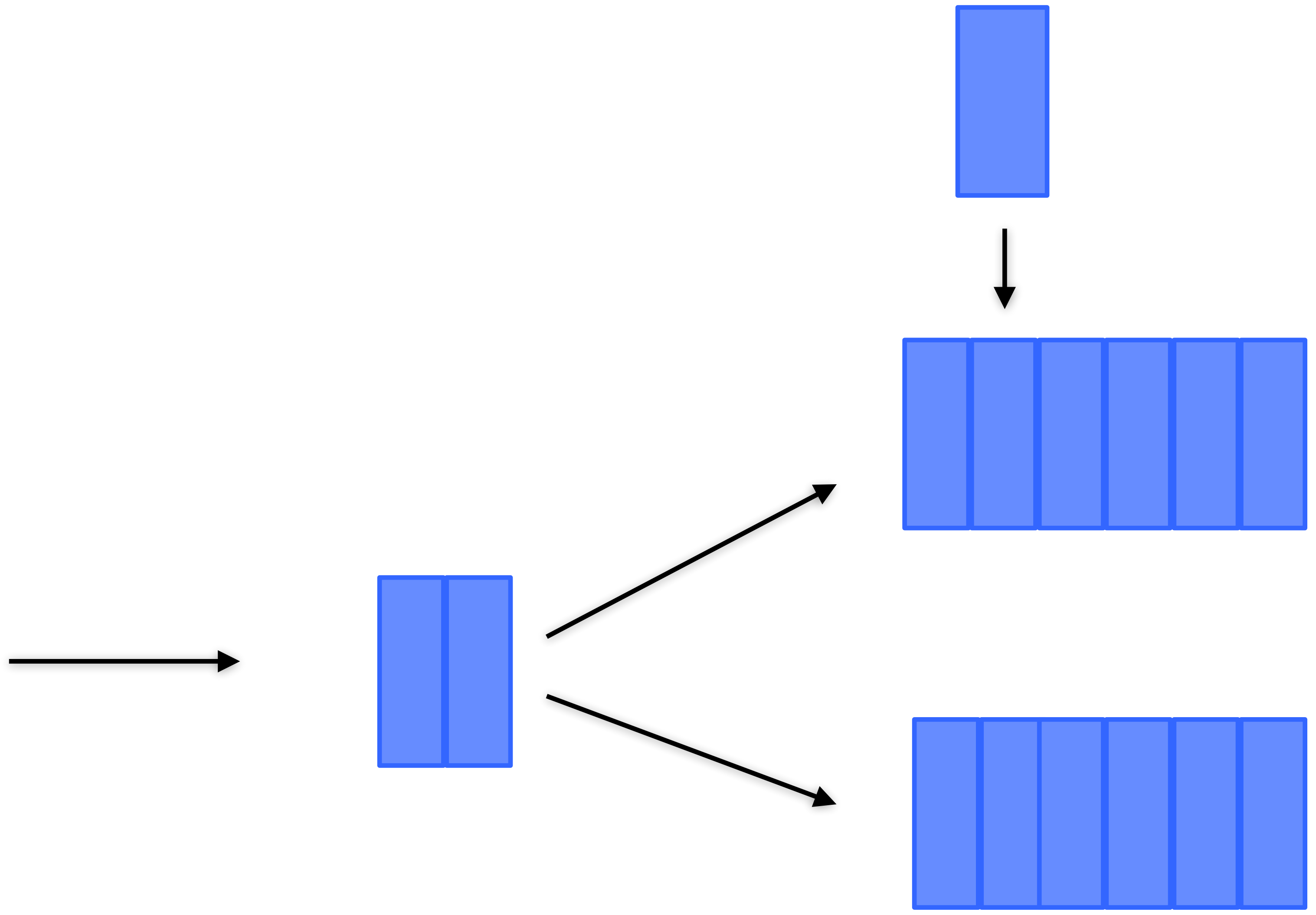

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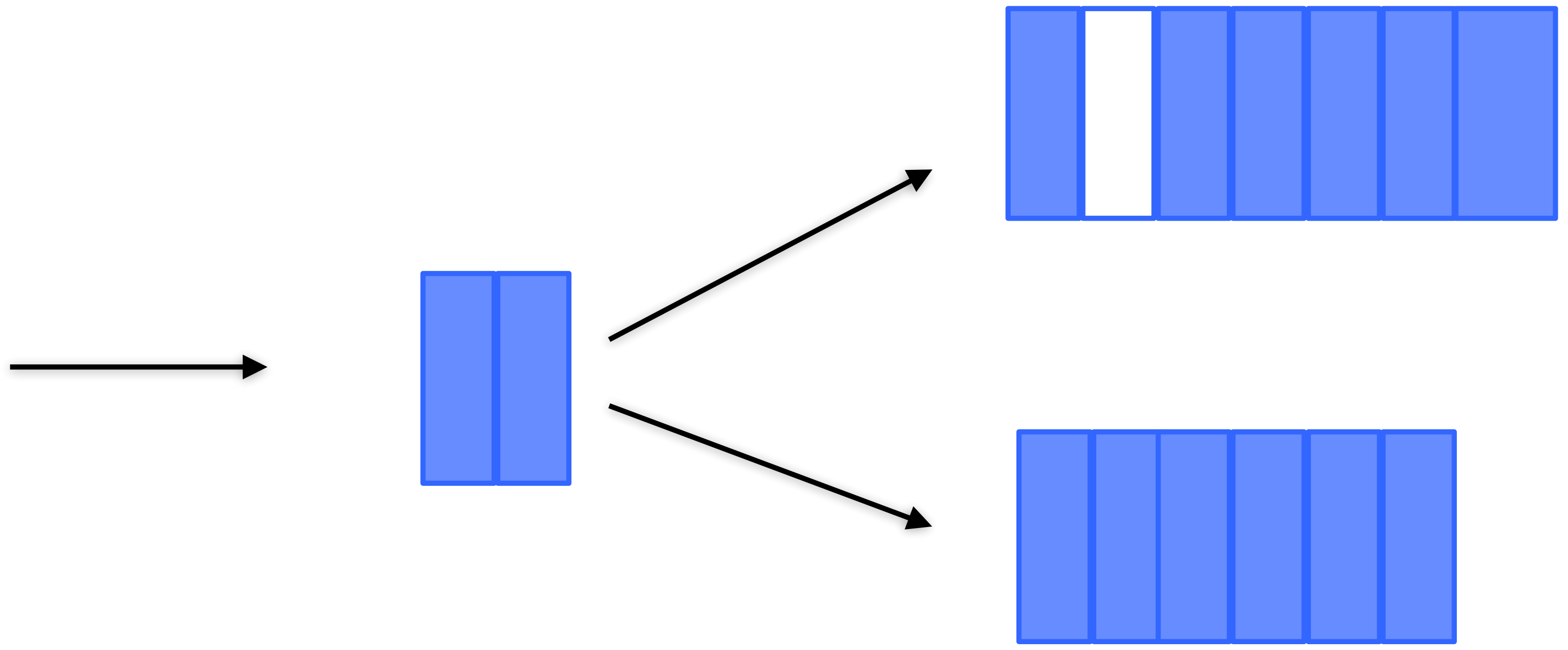

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Operations

1. Scans
2. Deletes
3. Updates
4. **Insertions**

Supporting Insertions

e.g., Insert into Customers (, , ,)

Solutions?

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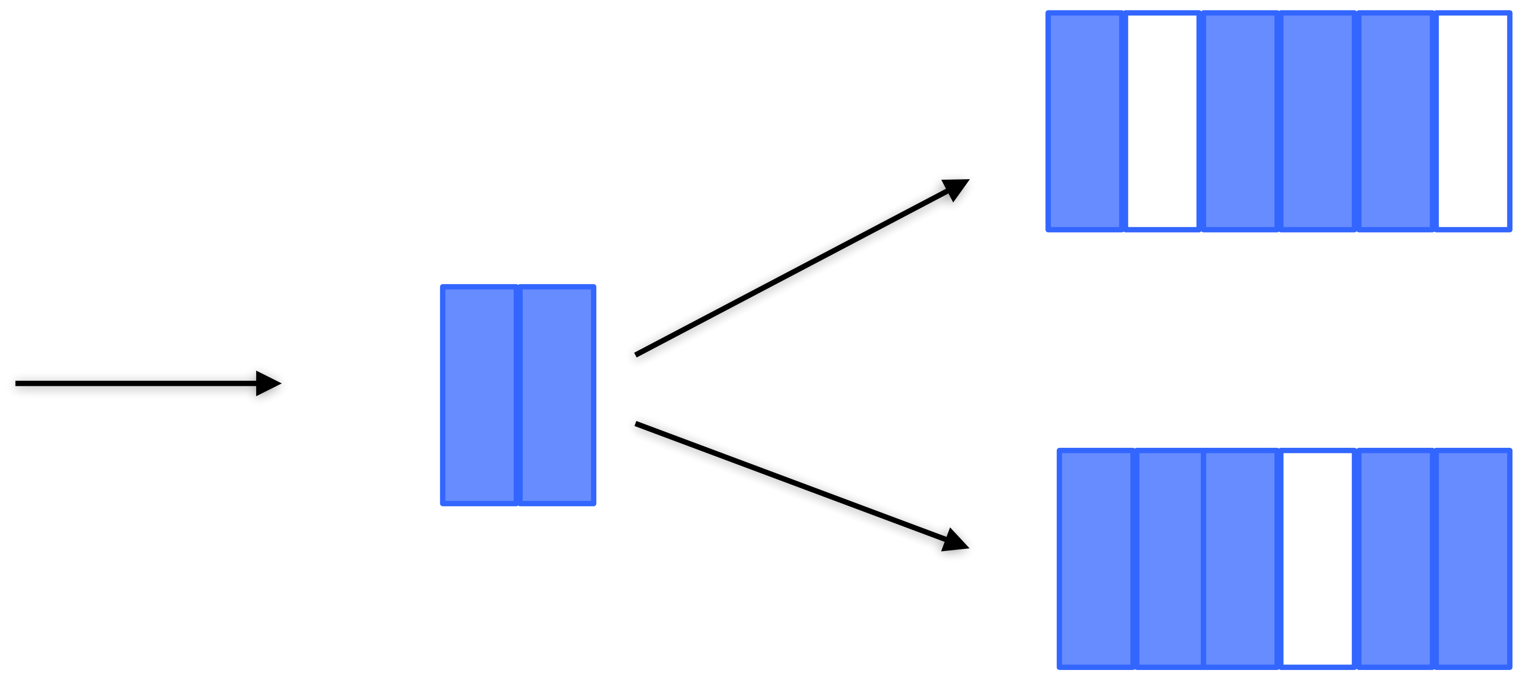

Supporting Insertions

(1) Scan & find space. Cost: O(N/B) reads and O(1) write.

Catalog

Name	Data type	Size (Bytes)	Start
Customers			
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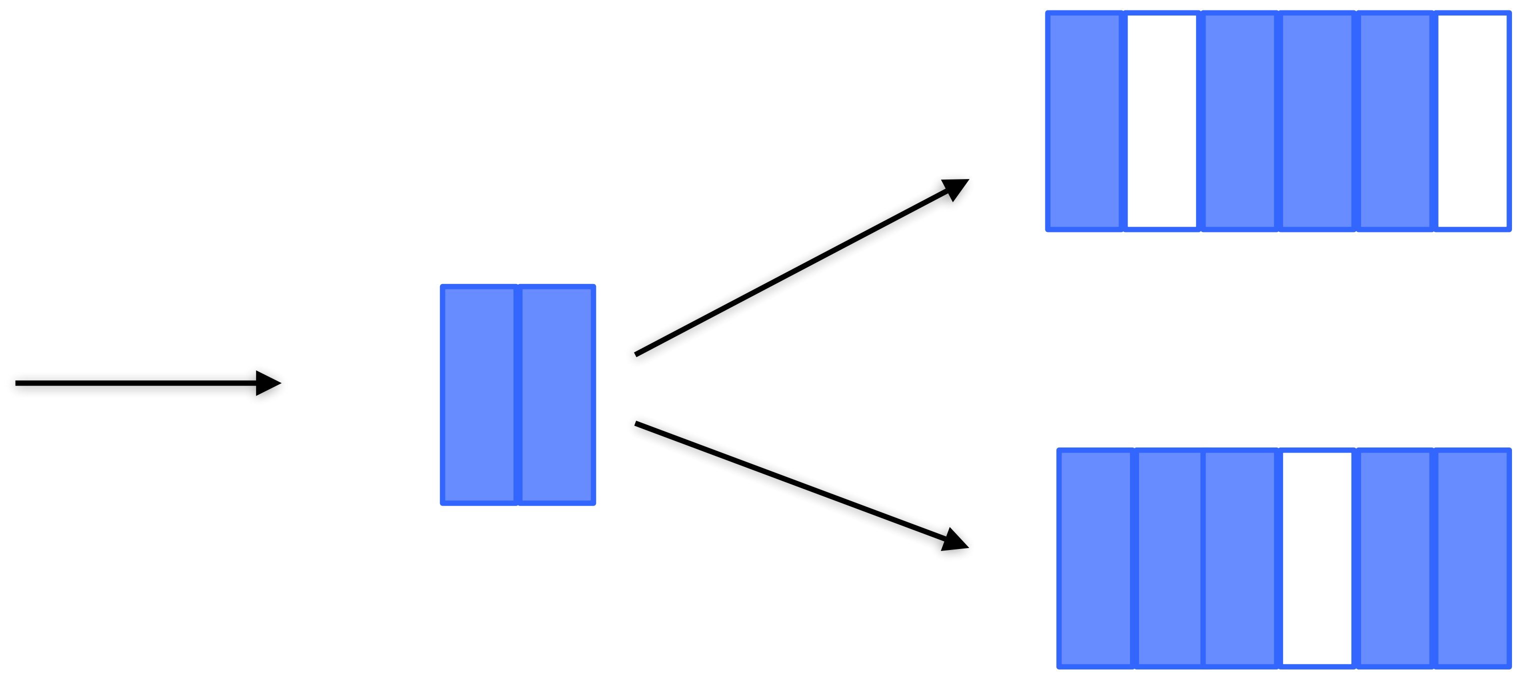


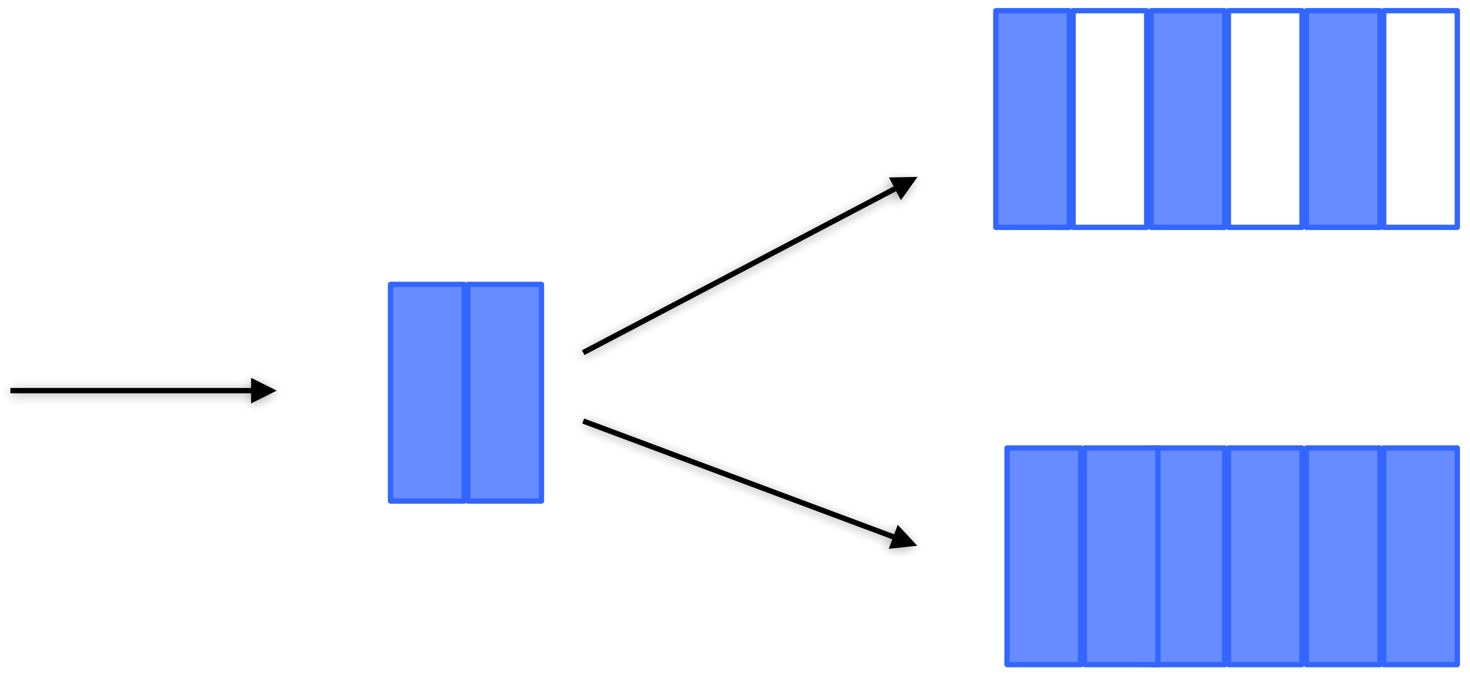
Supporting Insertions

(1) Scan & find space. Cost: O(N/B) reads and O(1) write.

(2) Separate Linked list of pages with free space.

Catalog

Name	Data type	Size (Bytes)	Start
Customers			
Orders			



Supporting Insertions

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Cost: O(1) reads & O(1) write for fixed-sized entries

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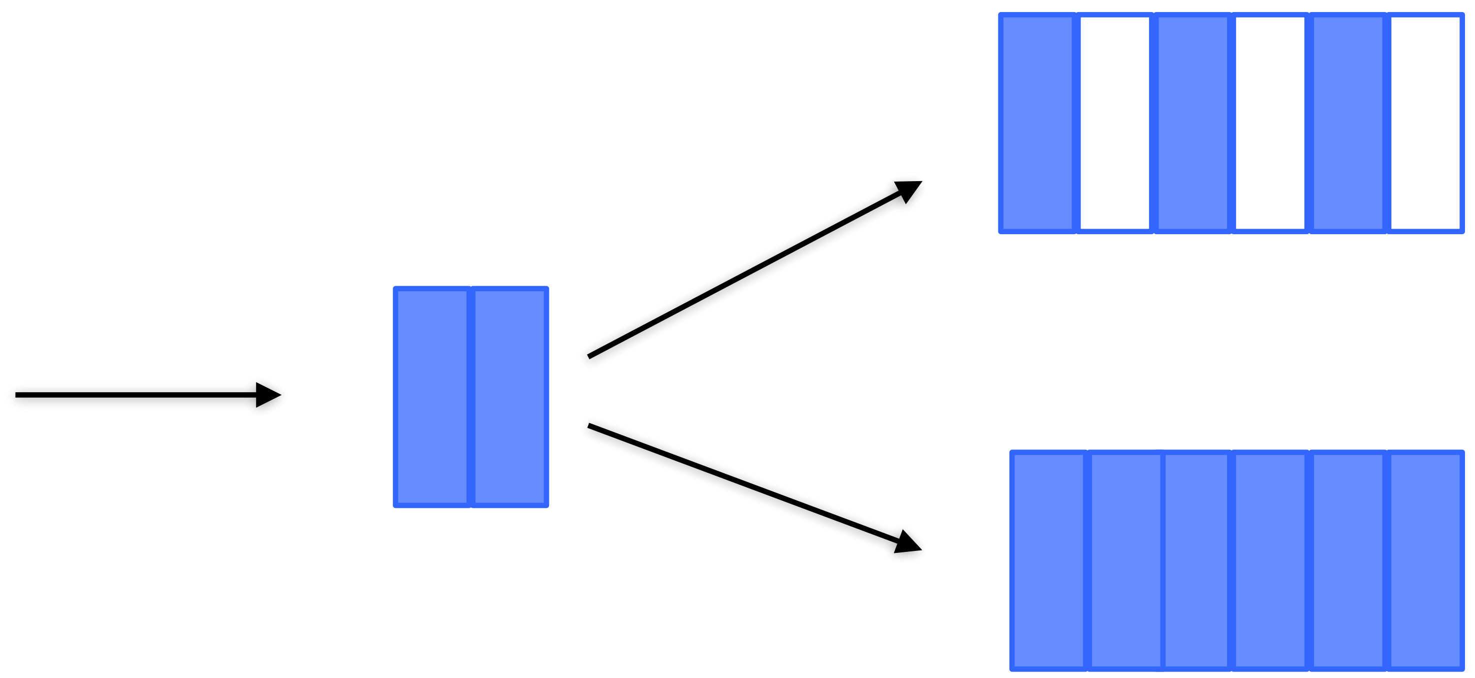

Supporting Insertions

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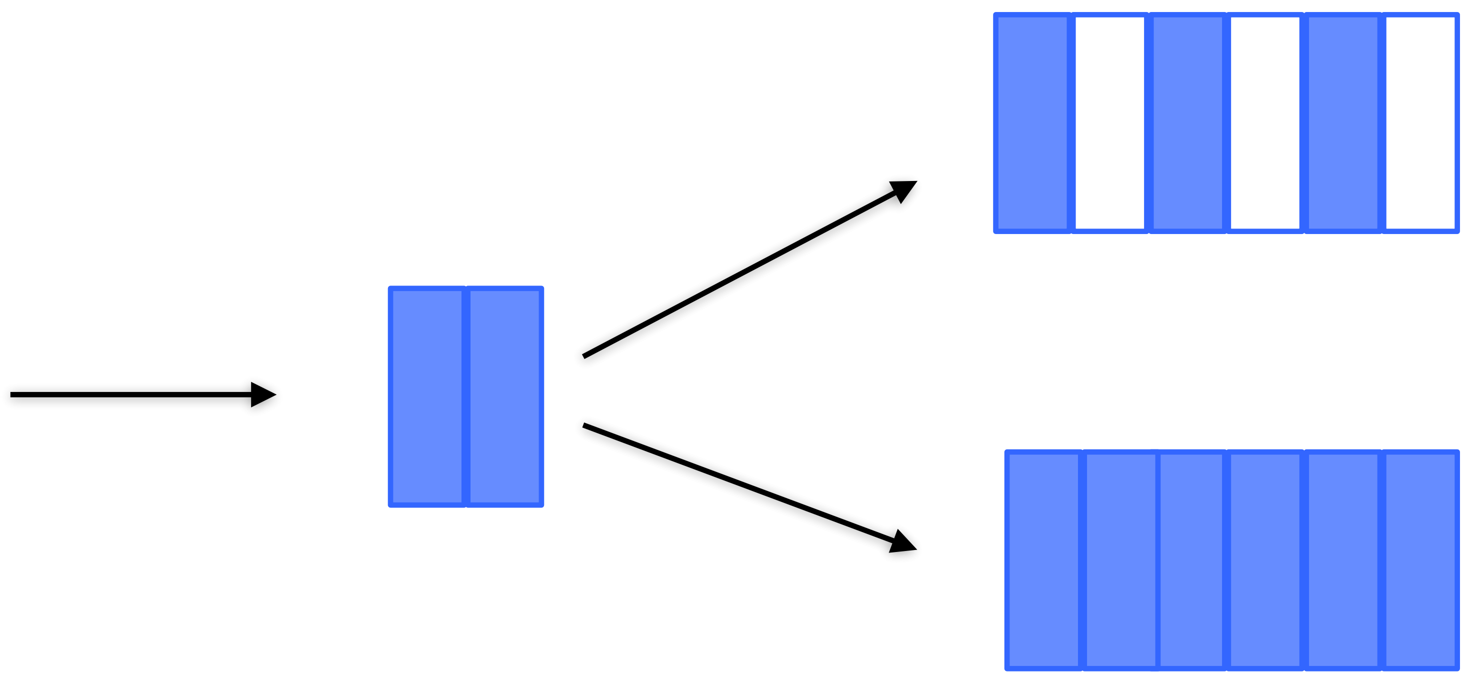
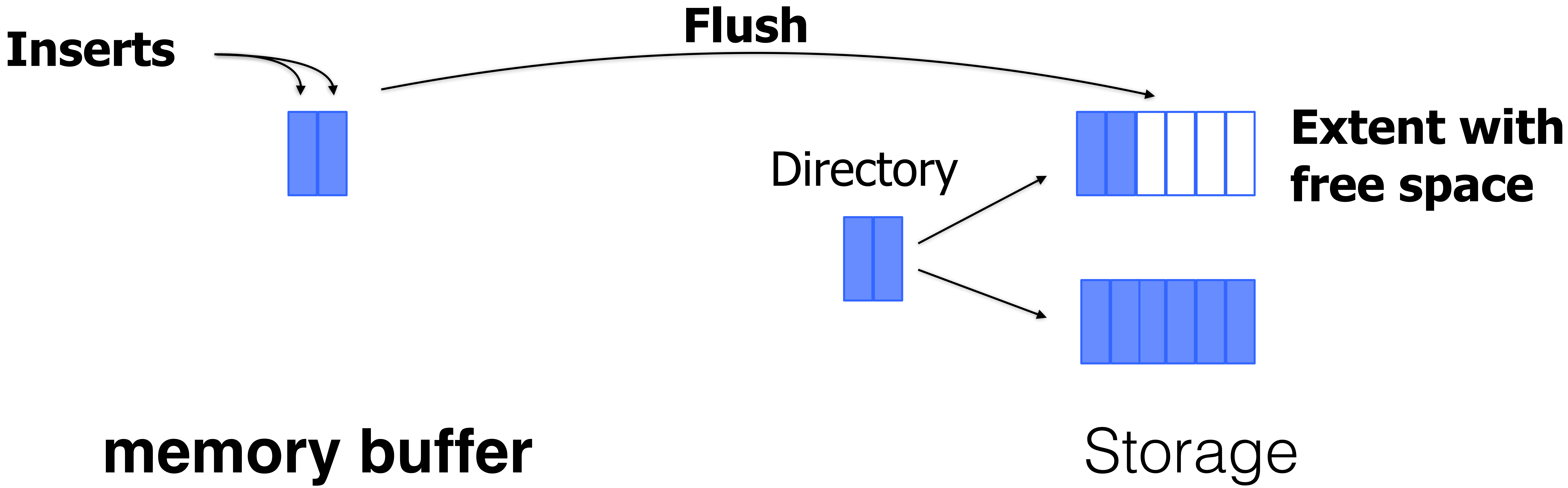


Supporting Insertions

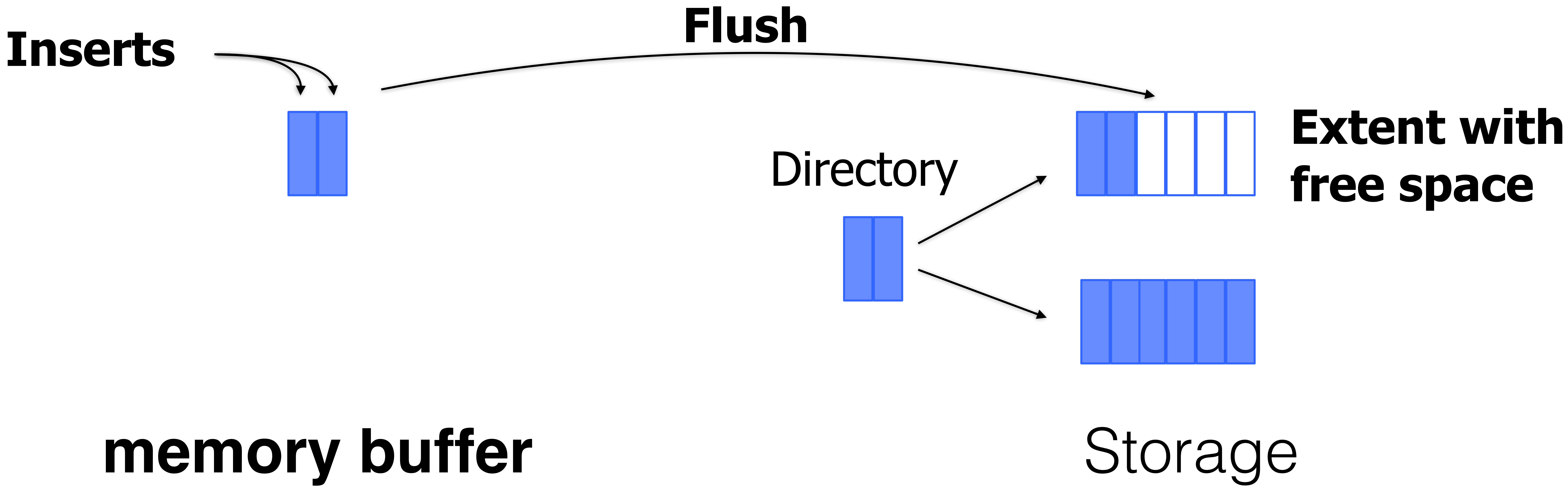
(3) buffer insertions in memory until a page fills up & append to extent



Supporting Insertions

(3) buffer insertions in memory until a page fills up & append to extent

Cost: No reads and O(1/B) of a write



Supporting Insertions

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(2) Separate Linked list of pages with free space.

Cost: O(1) reads & O(1) write for fixed-sized entries

Cost: O(N/B) reads & O(1) write for variable-sized entries

(3) buffer insertions in memory until a page fills up & append to extent

Cost: No reads and O(1/B) of a write

Internal Page Organization

Recall each page is 4-8 KB

Suppose rows are fixed-sized

How to organize rows within a slot?

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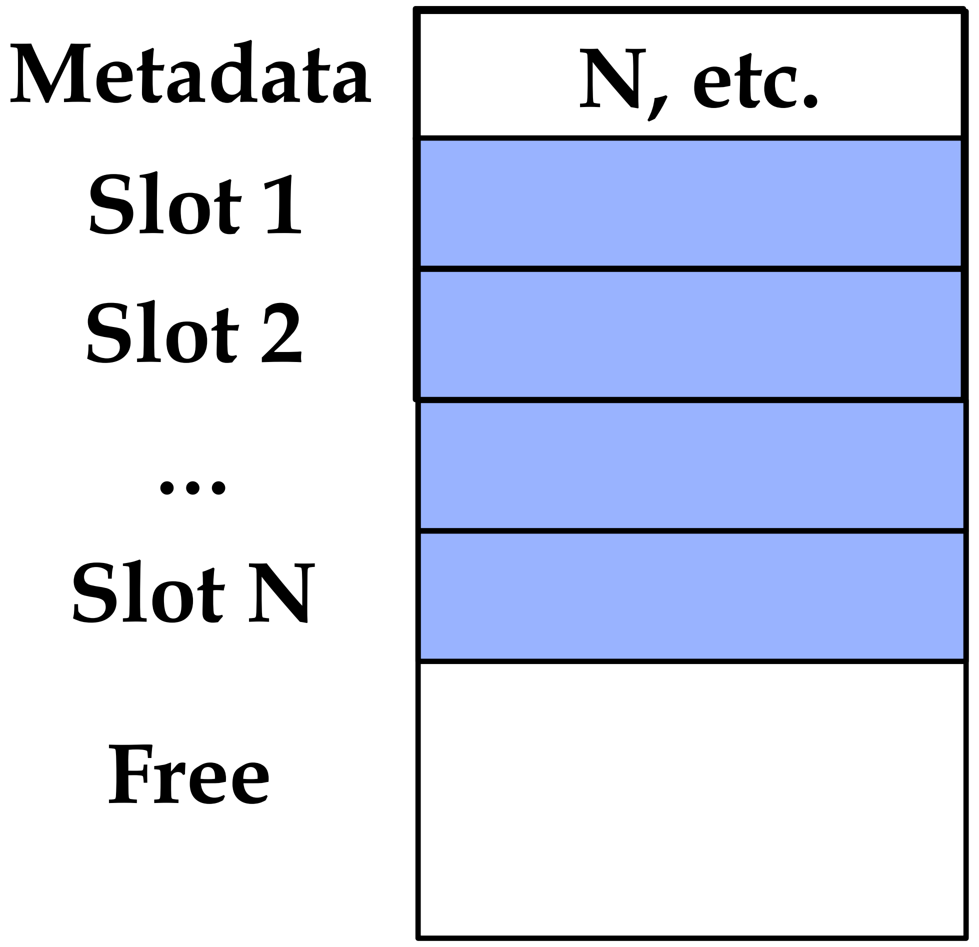

Internal Page Organization

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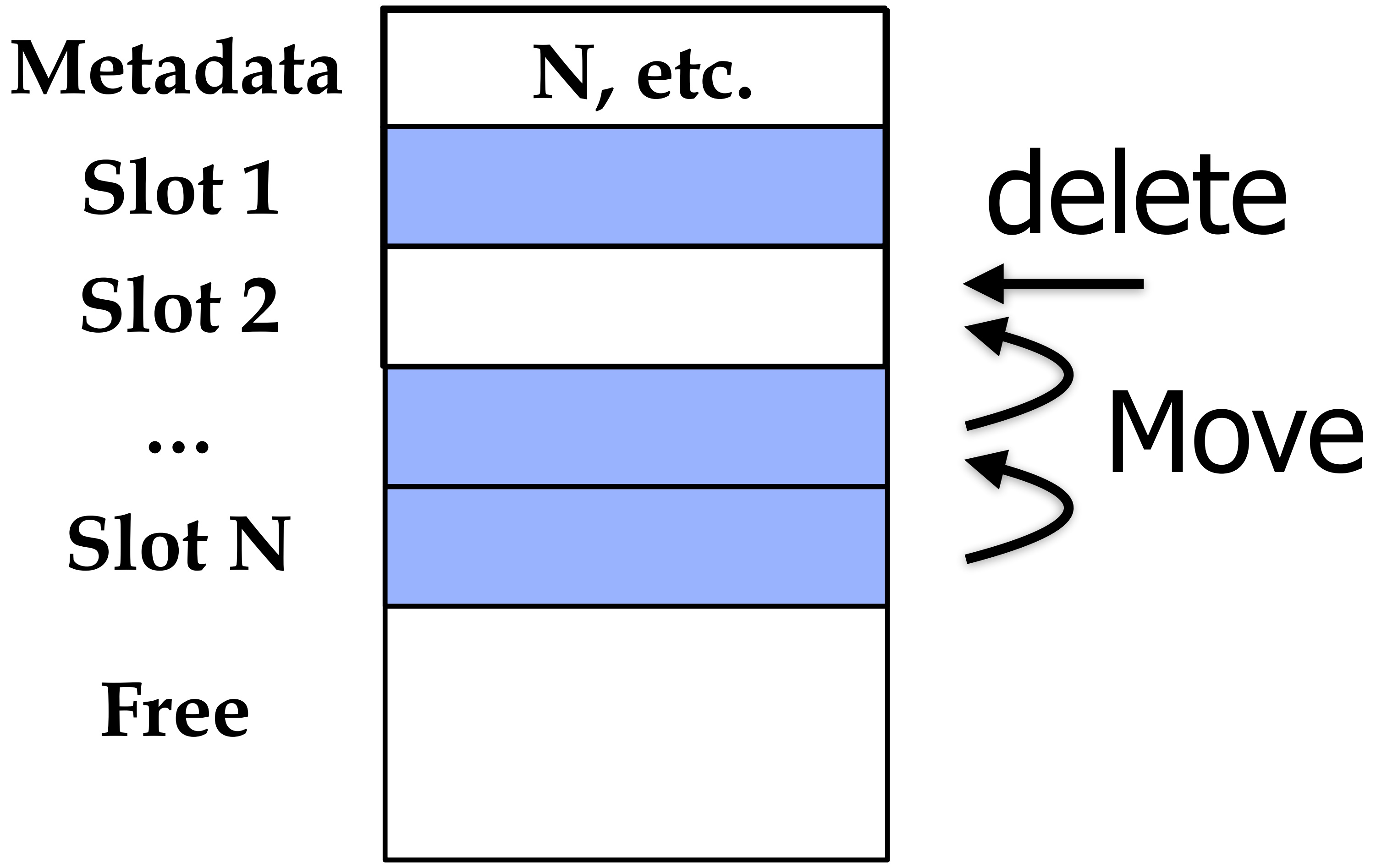
Suppose rows are fixed-sized

How to organize rows within a slot?



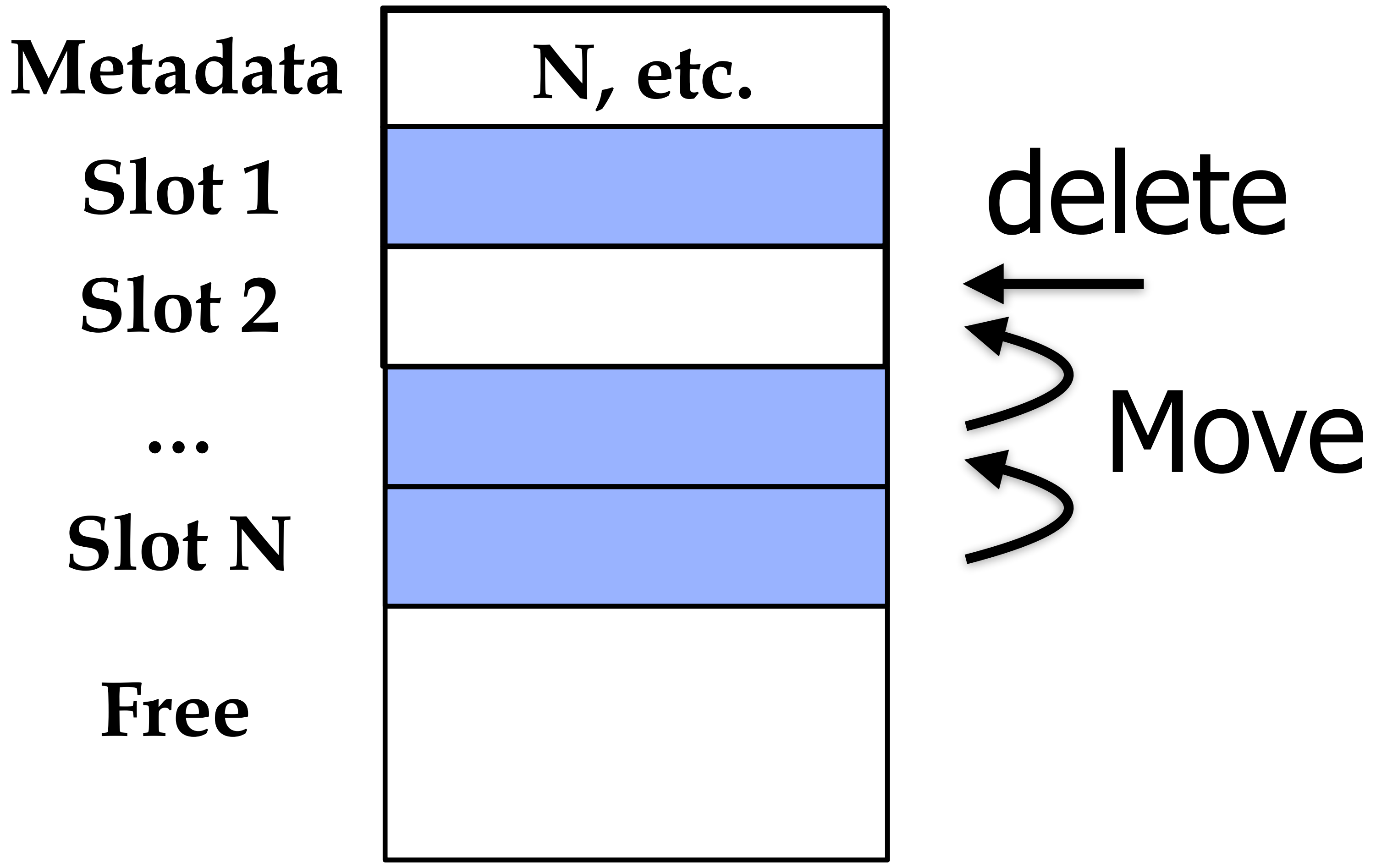
Need to reorganize due to deletes

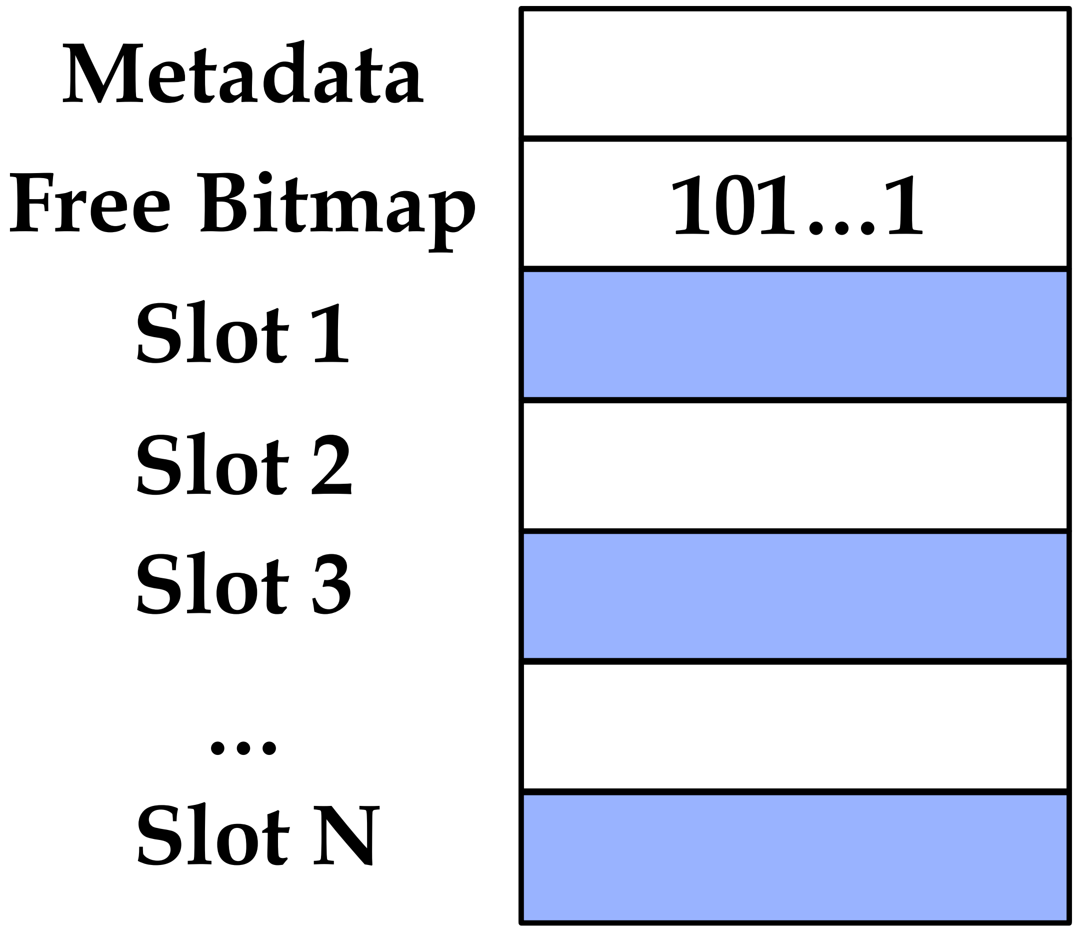
Internal Page Organization

Recall each page is 4-8 KB

Suppose rows are fixed-sized

How to organize rows within a slot?





Need to reorganize due to deletes

No reorganization, requires more space

Internal Page Organization

Recall each page is 4-8 KB

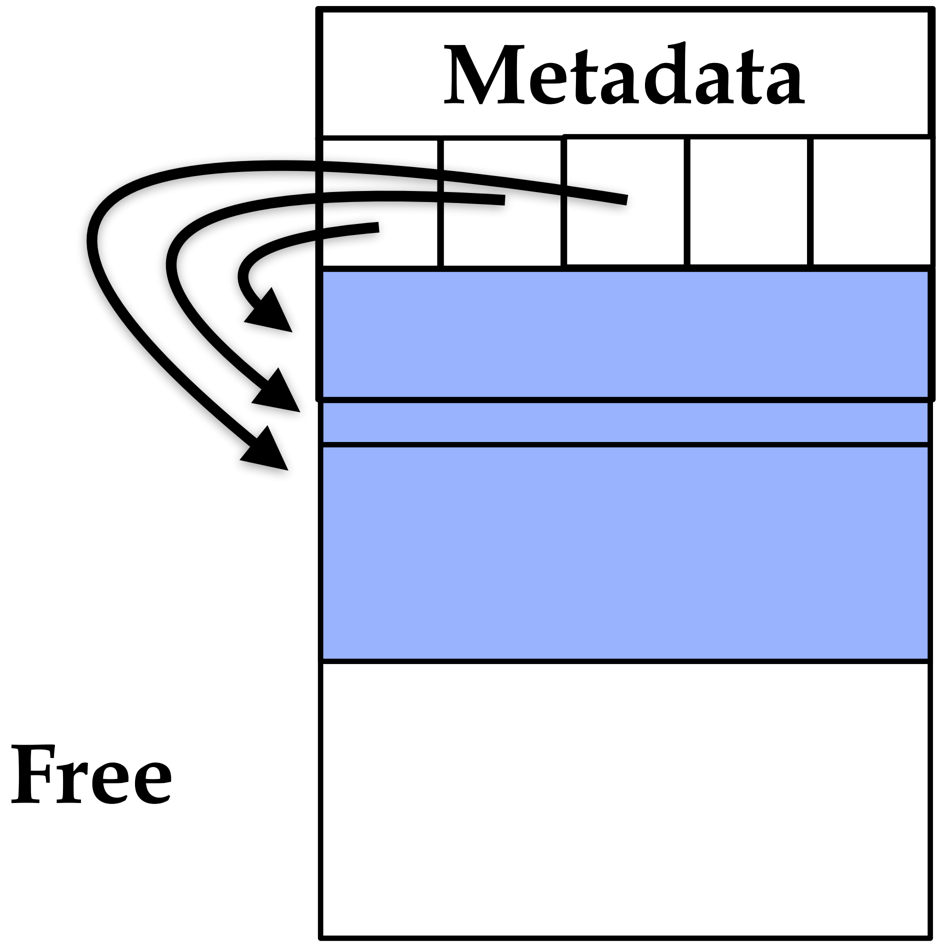
Suppose rows are **variable-length**

Solutions?

Internal Page Organization

Recall each page is 4-8 KB

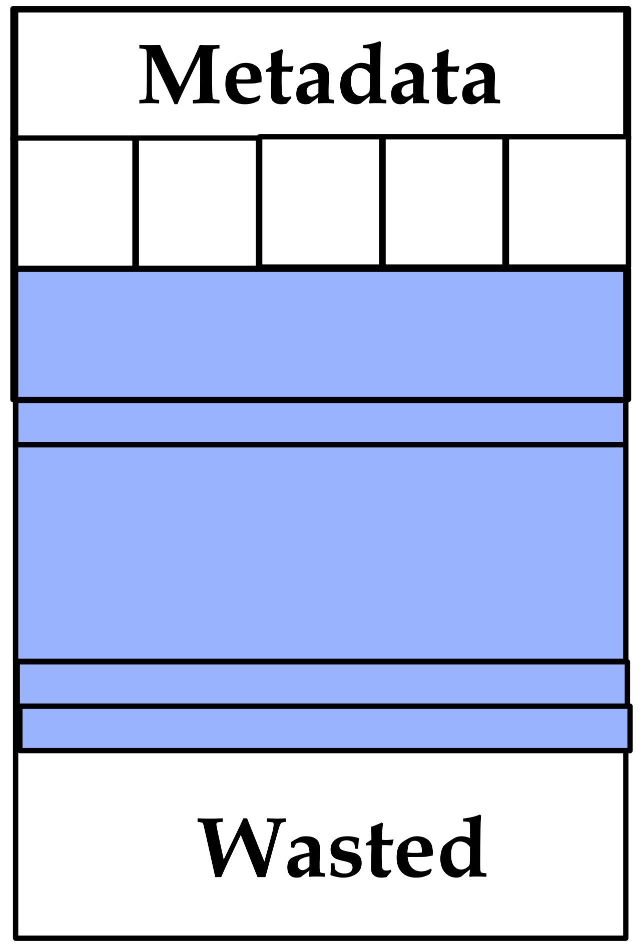
Suppose rows are **variable-length**



Internal Page Organization

Recall each page is 4-8 KB

Suppose rows are **variable-length**

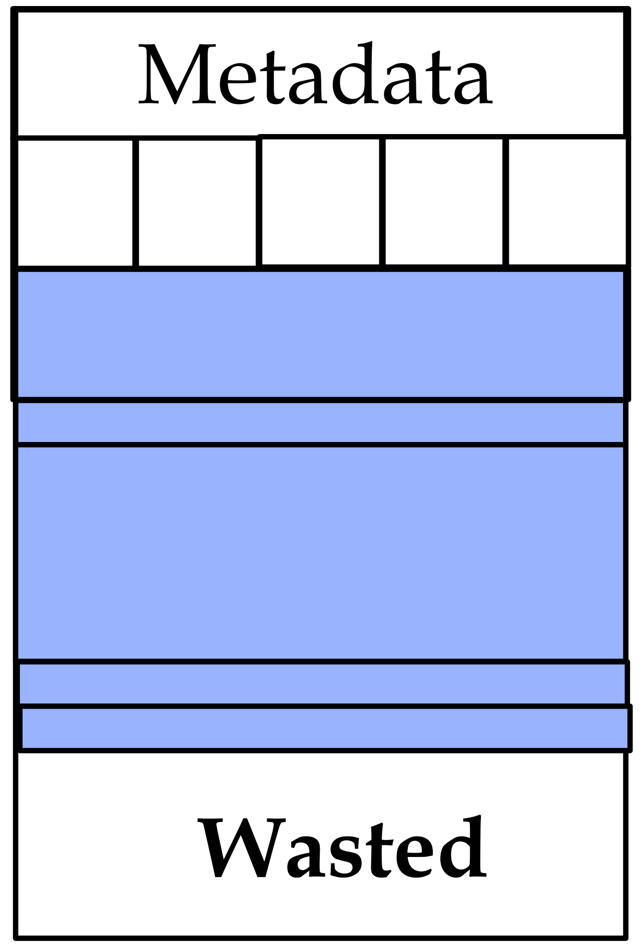


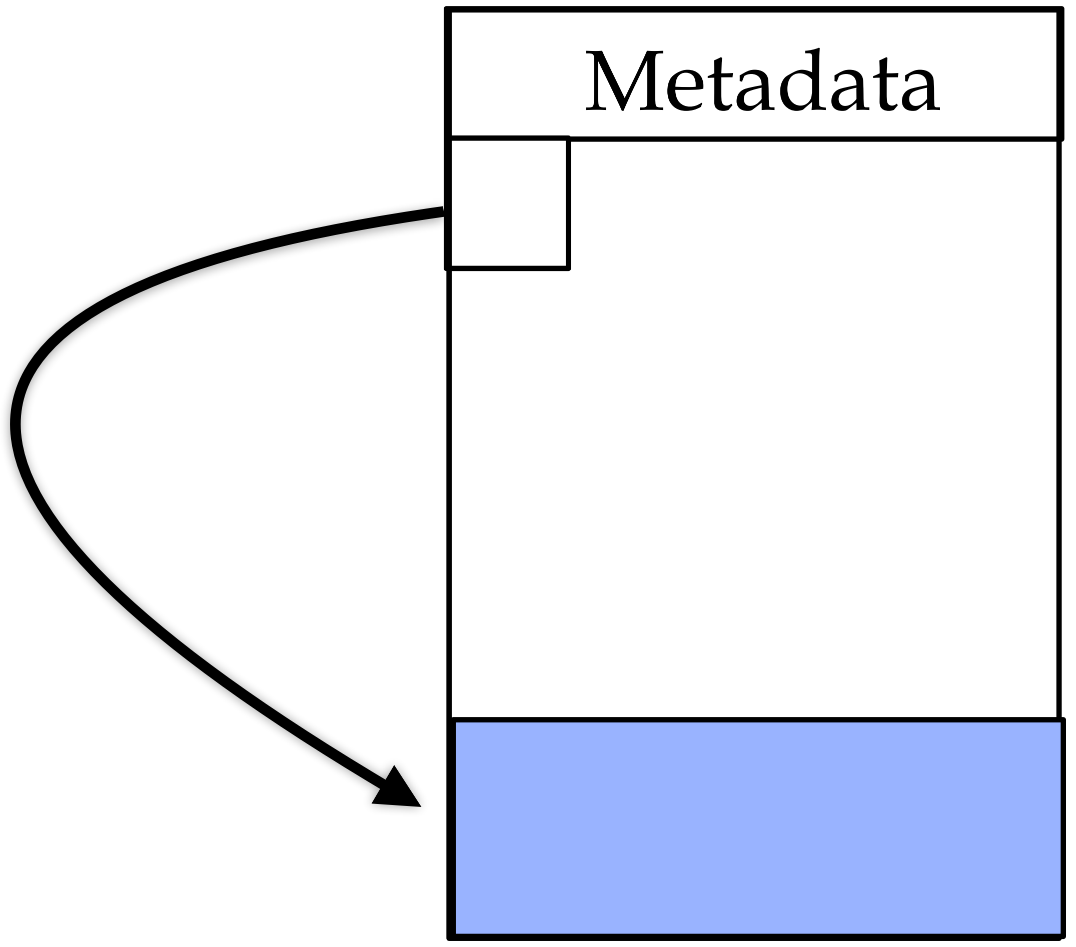
If entries are small, we waste space at the end, or we must push all content up to clear space

Internal Page Organization

Recall each page is 4-8 KB

Suppose rows are **variable-length**



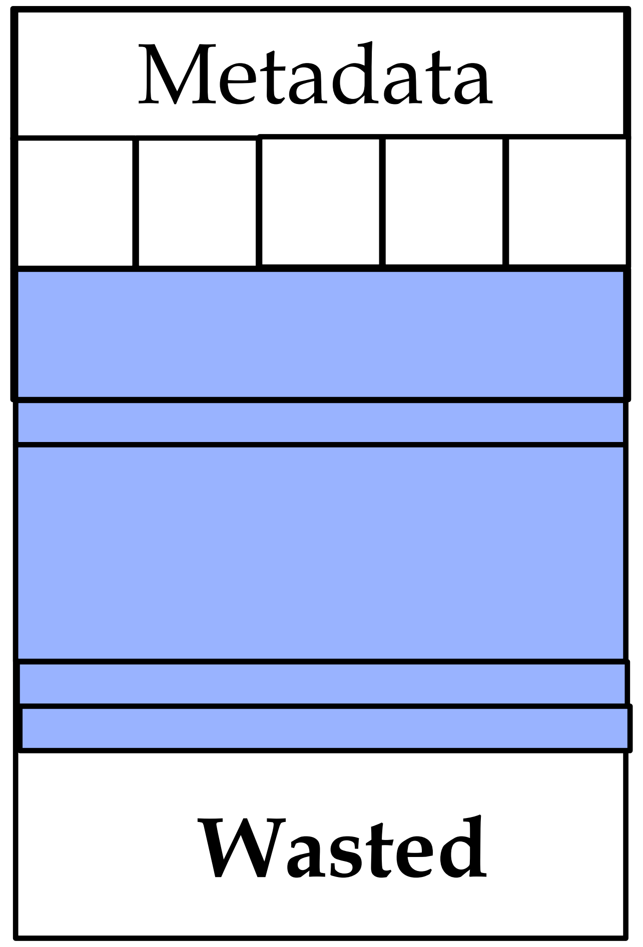


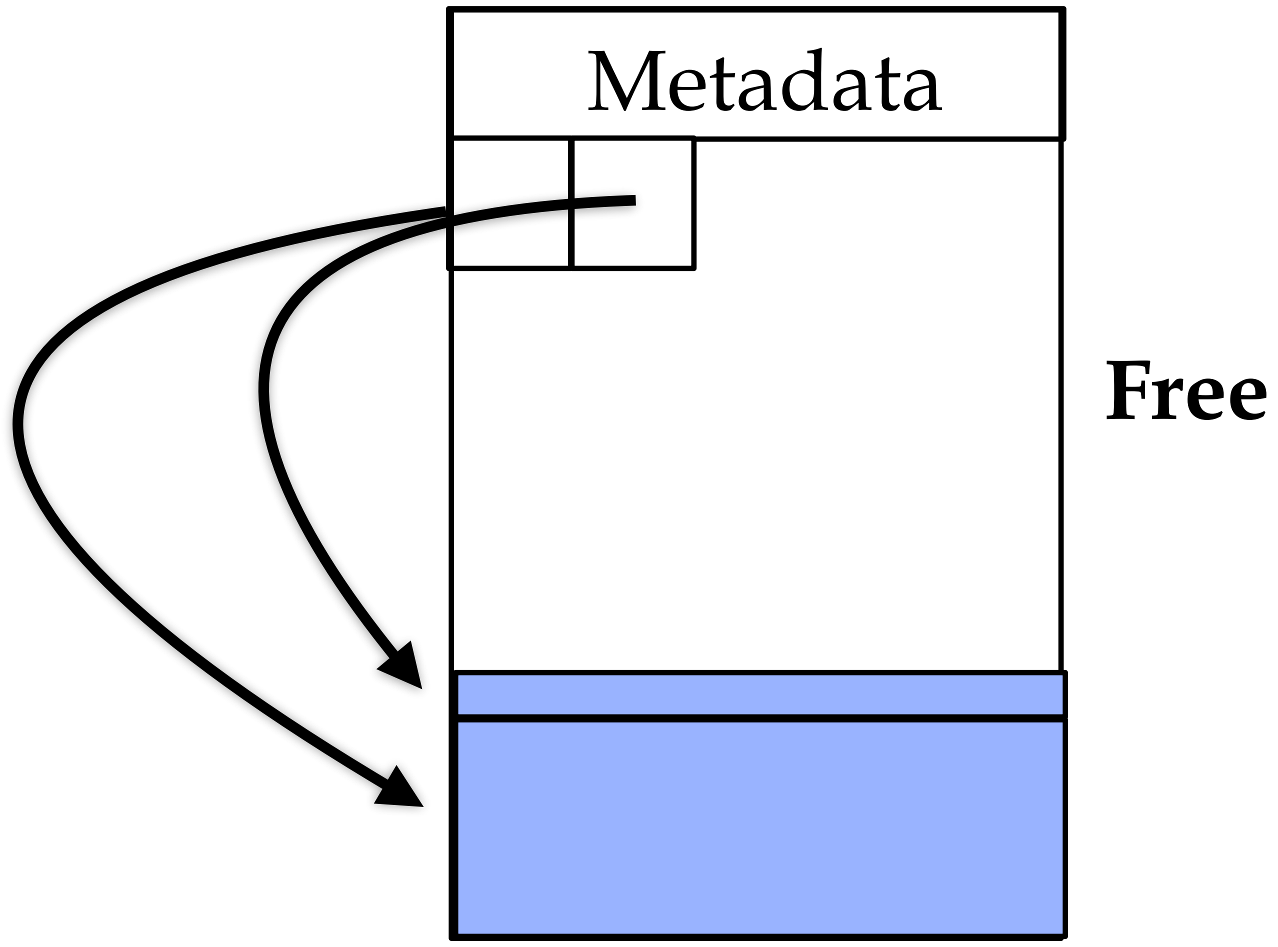
Store data from end of page

Internal Page Organization

Recall each page is 4-8 KB

Suppose rows are **variable-length**

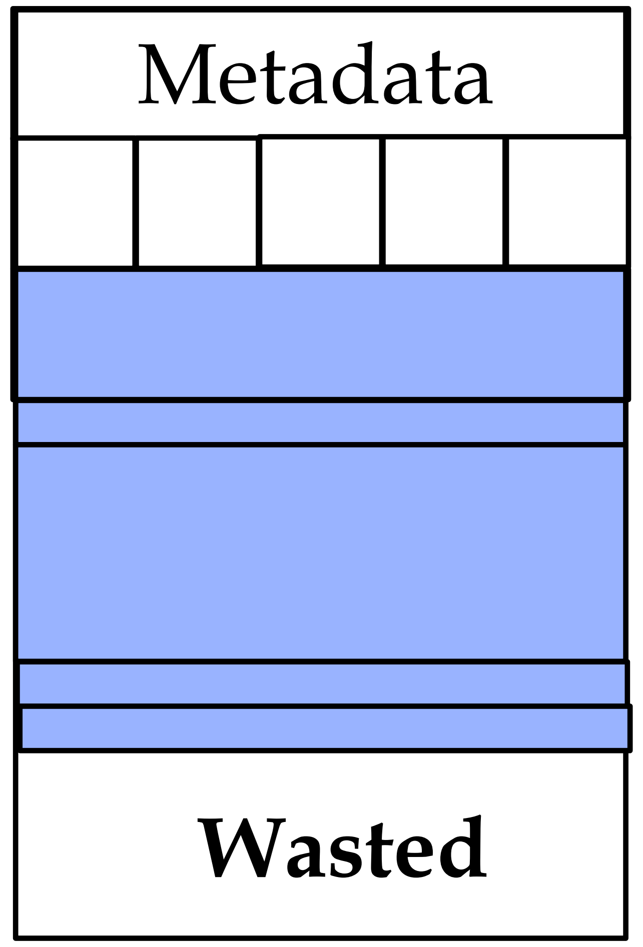


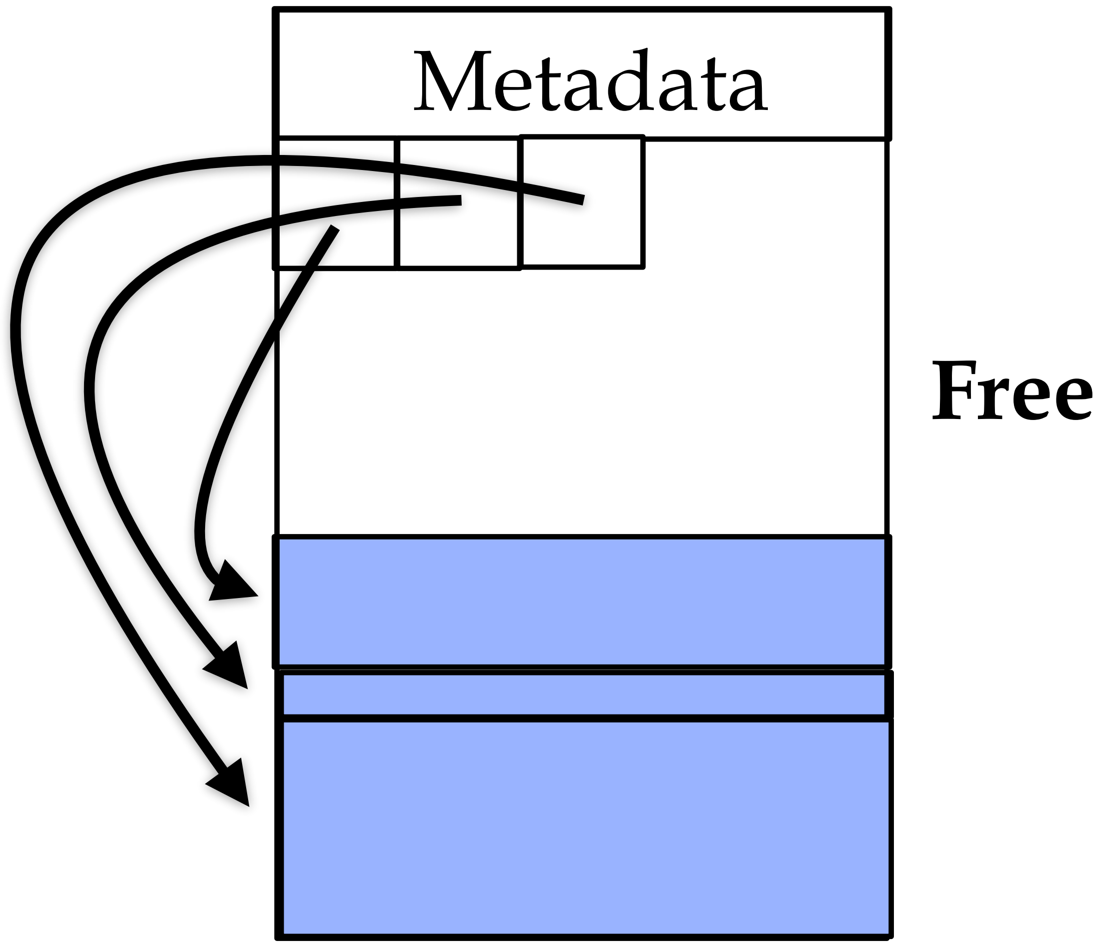


Internal Page Organization

Recall each page is 4-8 KB

Suppose rows are **variable-length**

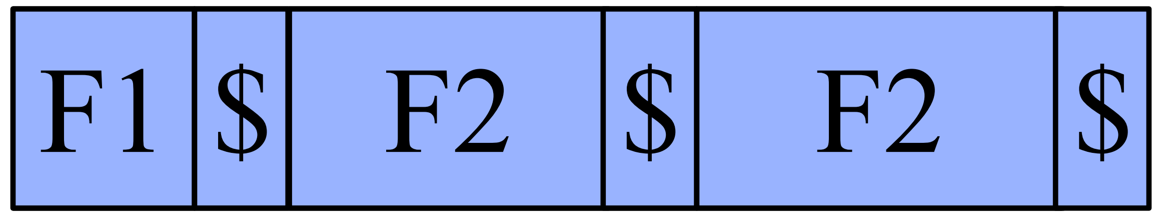




Minimal space wastage,
and no need to move data

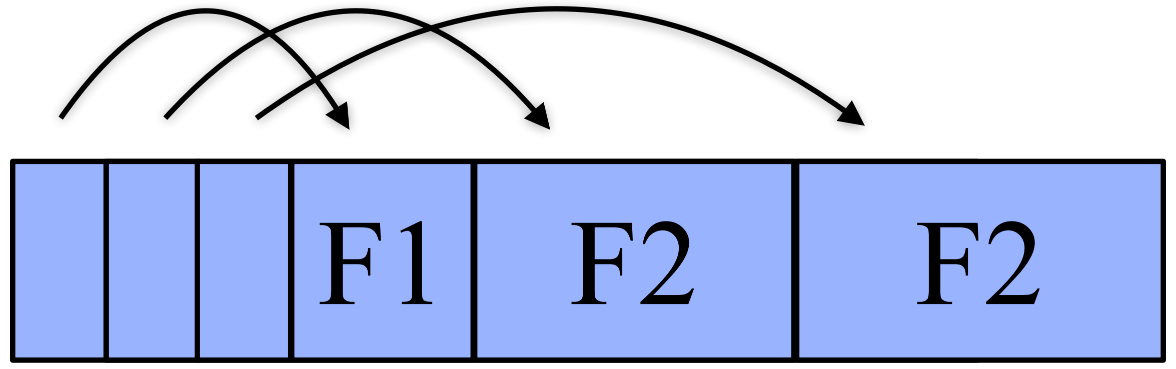
Variable-Sized Record Organization

Delimiters



Smaller
No random access

Pointers



More space
Random access (faster)

Break

Then let’s now move to buffer management