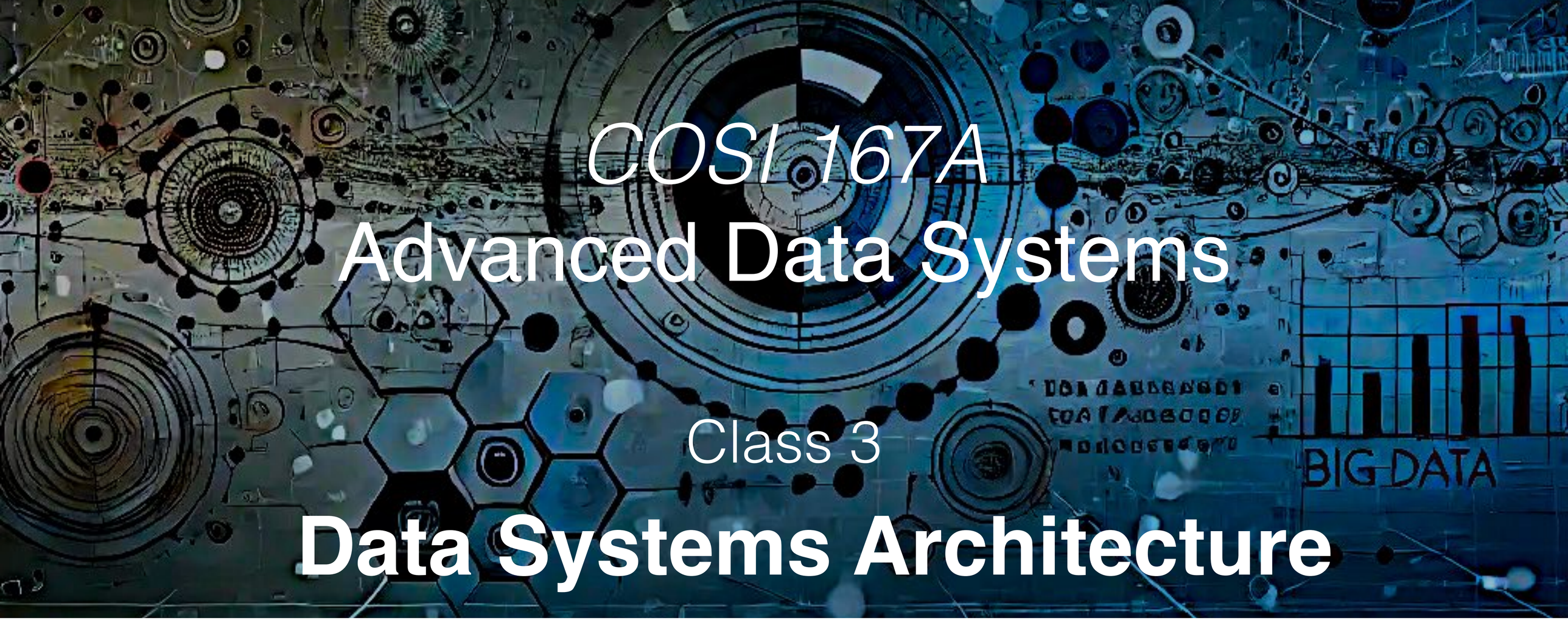


COSI 167A
Advanced Data Systems

Class 3
Data Systems Architecture

Prof. Subhadeep Sarkar

Brandeis UNIVERSITY

https://ssd-brandeis.github.io/COSI-167A/

lab

Today in COSI 167A

What's on the cards?

fundamentals of data **storage**

introduction to **row-stores** and **column-stores**

Class **logistics**

and administrivia

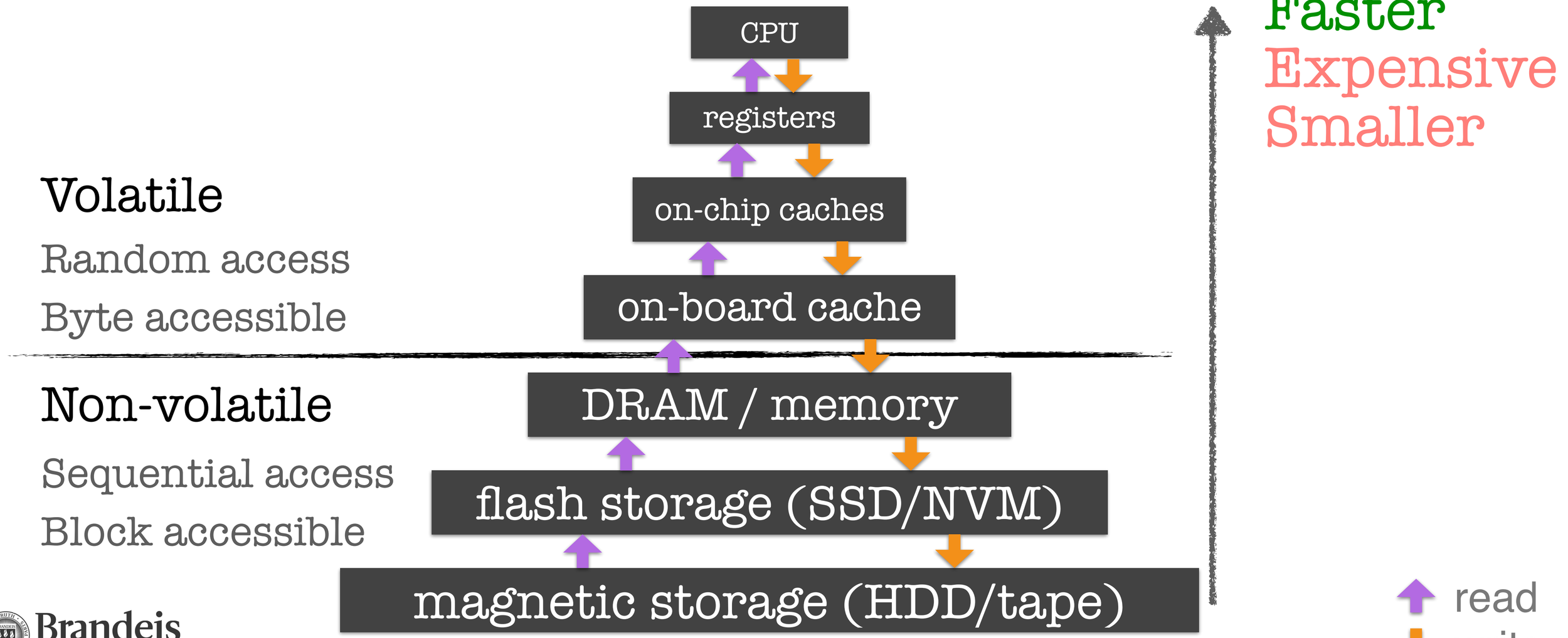
Project 1 (C++/Java) has been released (due on **Sep 20**).

C/C++ learning resources at: https://ssd-brandeis.github.io/COSI-167A/assignments/

The **first technical question** is now available on the class website (due **before the class** on **Sep 10**).

Recap: **Storage hierarchy**

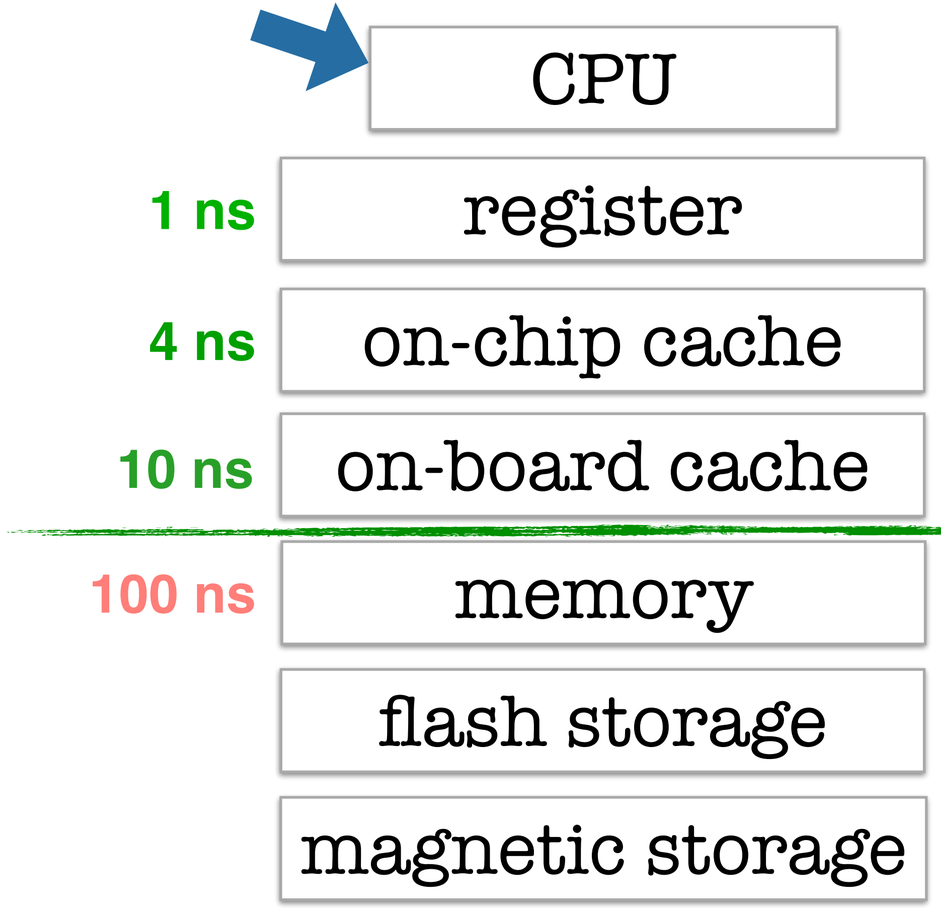
How data moves!



Memory wall

Try not to jump the wall

computations happen here



be careful when you go below the green line

Memory wall

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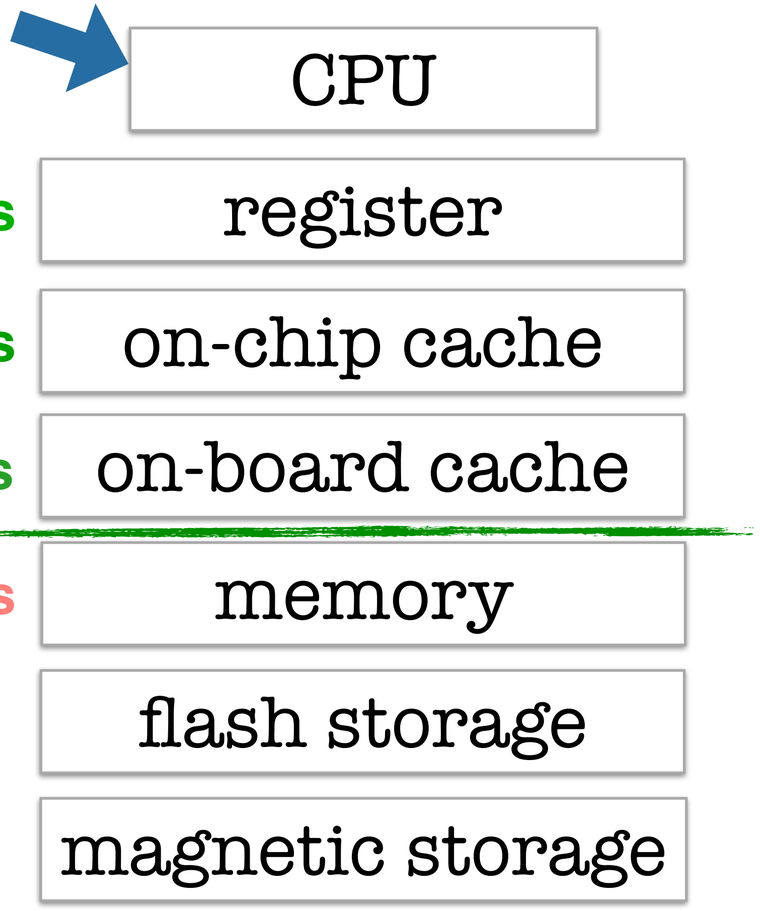
computations happen here



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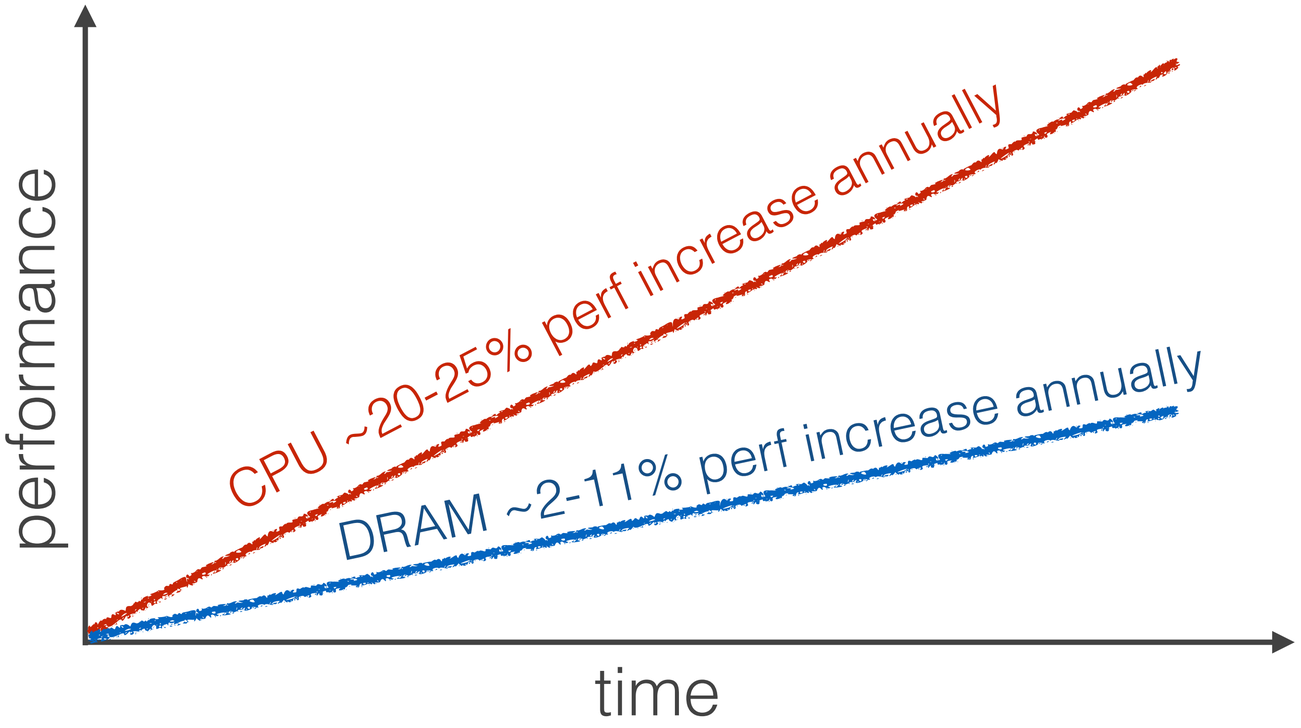


Memory wall

Try not to jump the wall

computations happen here

CPU

1 ns — register

4 ns — on-chip cache

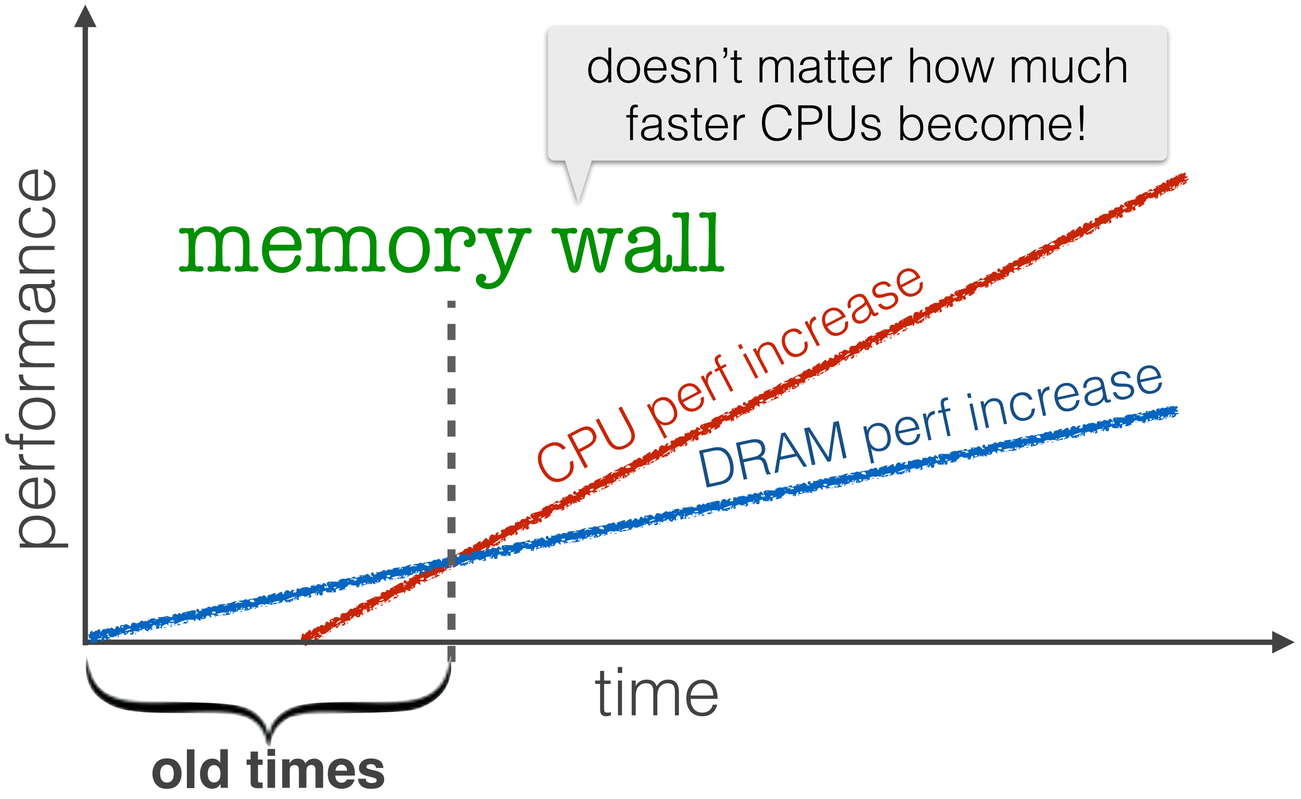
10 ns — on-board cache

100 ns — memory

flash storage

magnetic storage

be careful when you go below the green line



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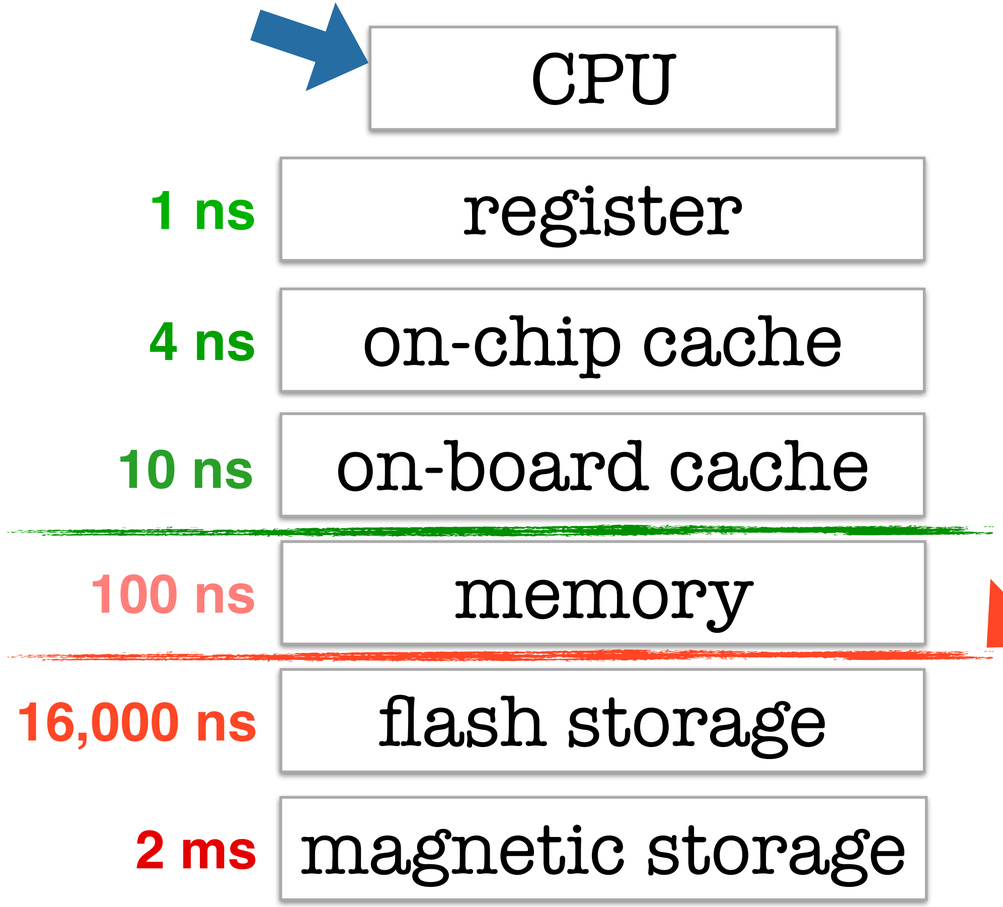

be careful when you go below the green line

be VERY careful when you go below the red line

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Recap: **Storing** data

Things to keep in mind

Disk is 6 orders of magnitude slower than CPU

SSDs are 4 orders of magnitude slower

Memory is 3 orders of magnitude slower

Recap: **Random** vs. **Sequential** access

So, be VERY careful!

Avoid disk accesses (reads/writes) whenever possible

I/Os to secondary storage is *always* **slow**!

Sequential access

read **each block exactly once**; process it; discard it; read next block

modern hardware can predict and **prefetch**; maximize performance

Random access

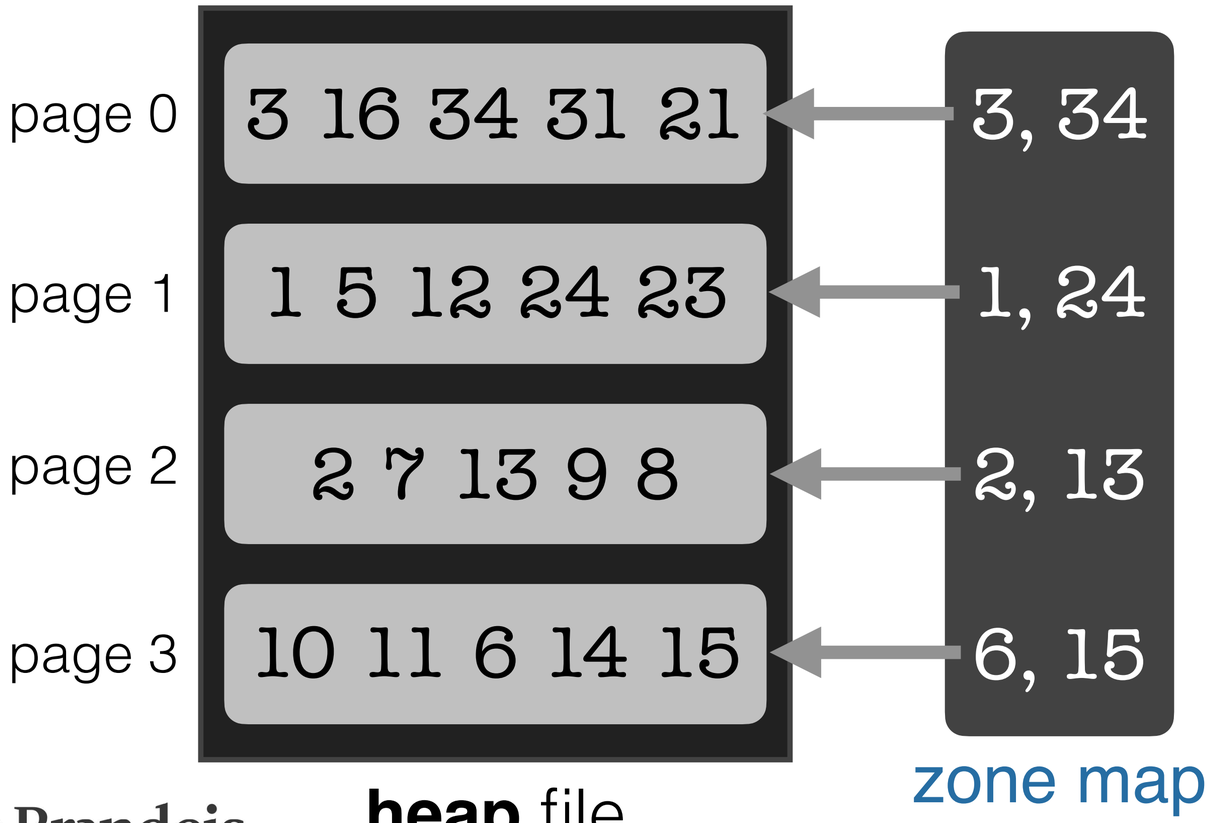
read a block; process it **partially**; discard it; may **read** the block **again**

often leads to **read amplification**

Project 1

Testing the waters!

Implementing a Simple Zone Map



w/o ZM: queries take 4 I/Os

with ZM: query: x<4: 3 I/Os

x<12: 4 I/O

x=1: 1 I/O

x=20: 4 I/O

Thought Experiment

Are **zone maps** more or less useful if data is **sorted**?

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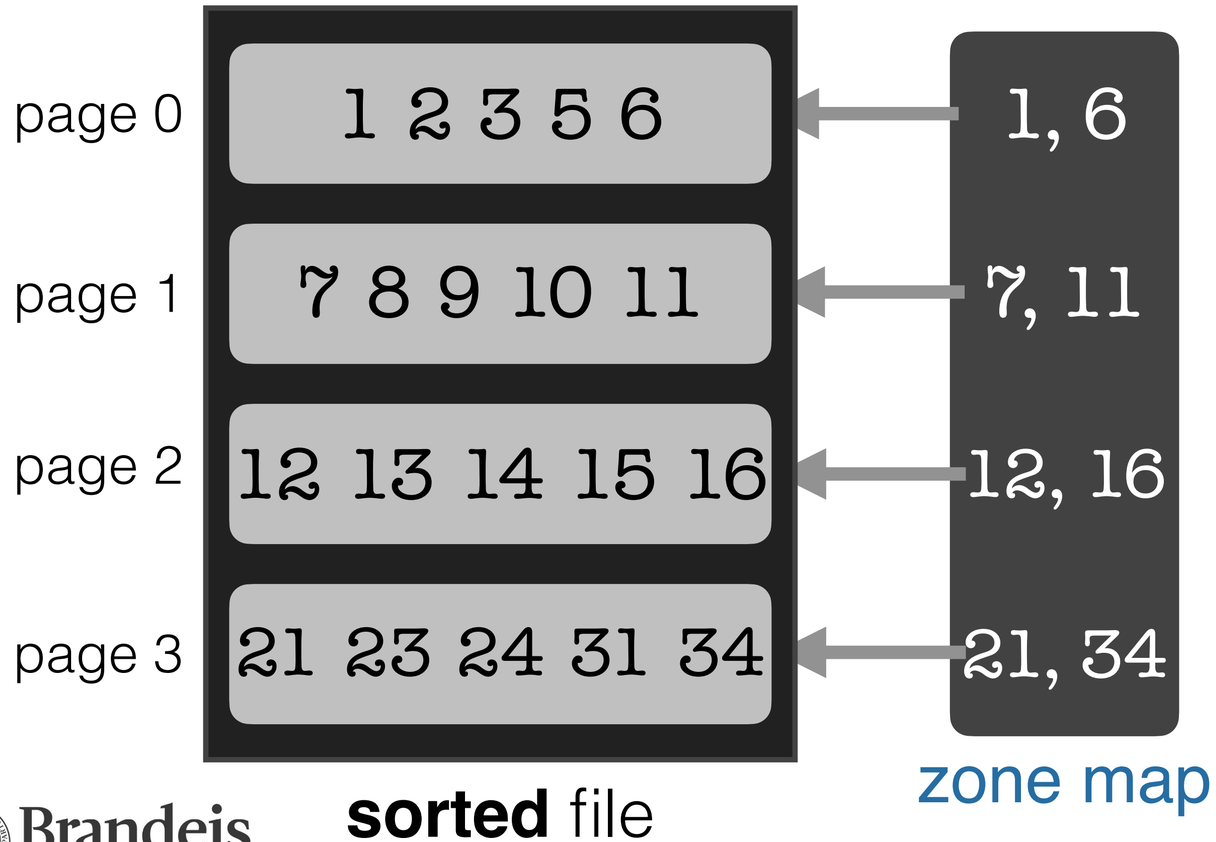
Project 1

Testing the waters!

Implementing a Simple Zone Map



w/o ZM: queries take 4 I/Os

with ZM: query: x<4: 1 I/O

x<12: 2 I/Os

x=1: 1 I/O

x=20: 0 I/Os

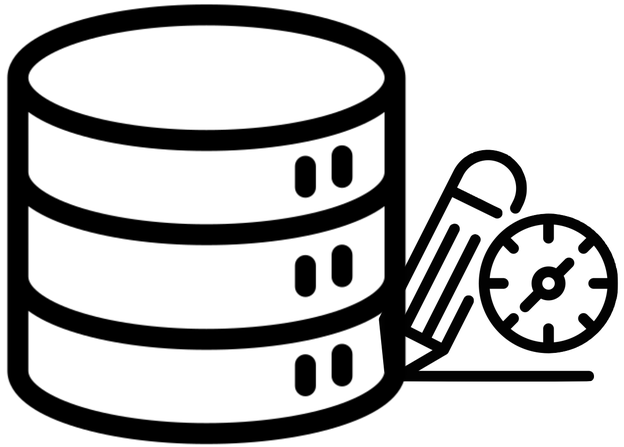
Sorting is inherent indexing!

Zone map is a second index!

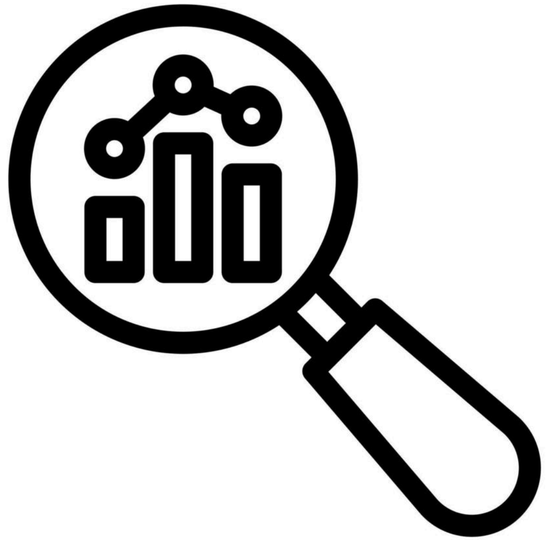
How we store (write) data heavily determines the performance of the system

The **design goals**

Biulding “efficient” data systems



build databases that can **write** data **fast** …



… and **process/analyze** that data **quickly**

Well, just get to work then!

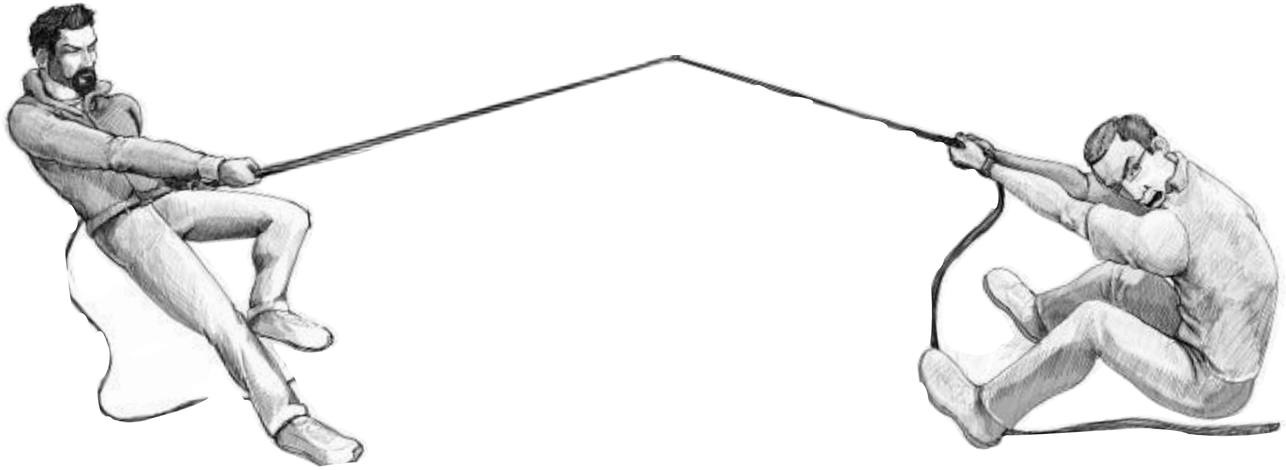
Performance **tradeoff**

The tug of war

hashmap

R: $\mathcal{O}(1)$

U: $\mathcal{O}(1)$



sorted array

R: $\mathcal{O}(logN)$

U: $\mathcal{O}(N)$

Query / **R**ead

Insert / **U**pdate

log

R: $\mathcal{O}(N)$

U: $\mathcal{O}(1)$

Performance **tradeoff**

The tug of war

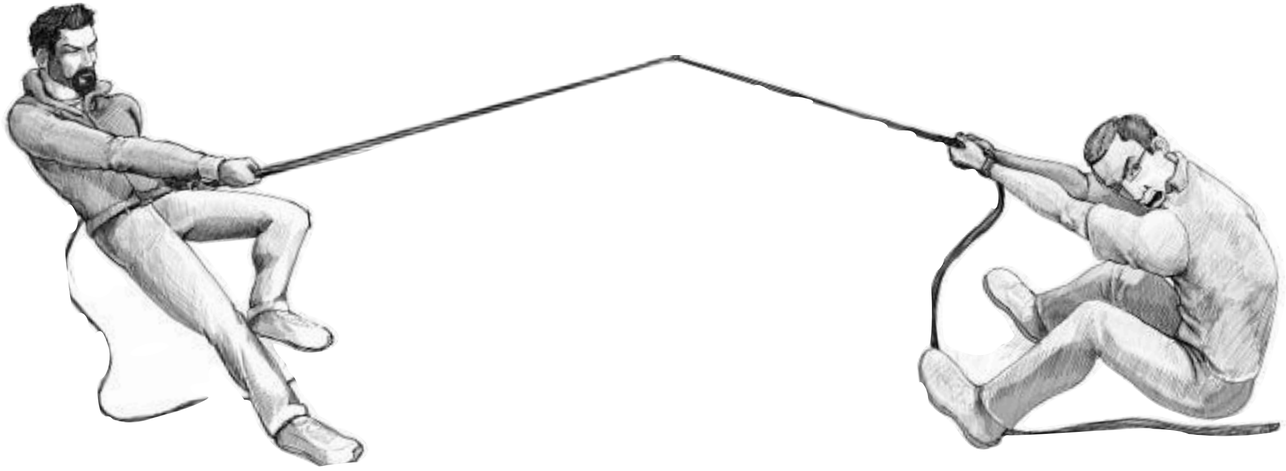
Storage / **M**emory

hashmap

R: $\mathcal{O}(1)$

U: $\mathcal{O}(1)$

M



sorted array

R: $\mathcal{O}(logN)$

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Query / **R**ead

Insert / **U**pdate

log

R: $\mathcal{O}(N)$

U: $\mathcal{O}(1)$

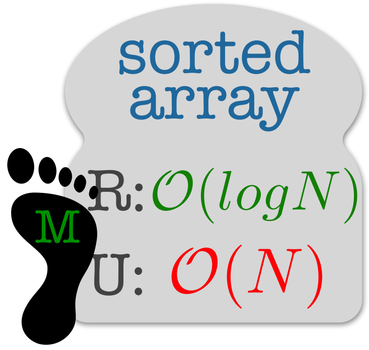
M

Performance **tradeoff**

The tug of war

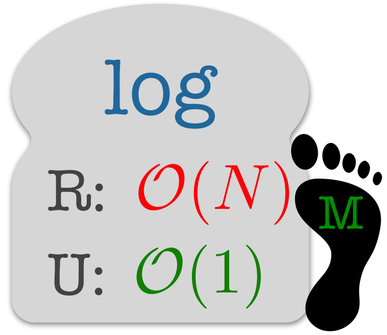
Storage / **M**emory

There is **NO** perfect data structure!



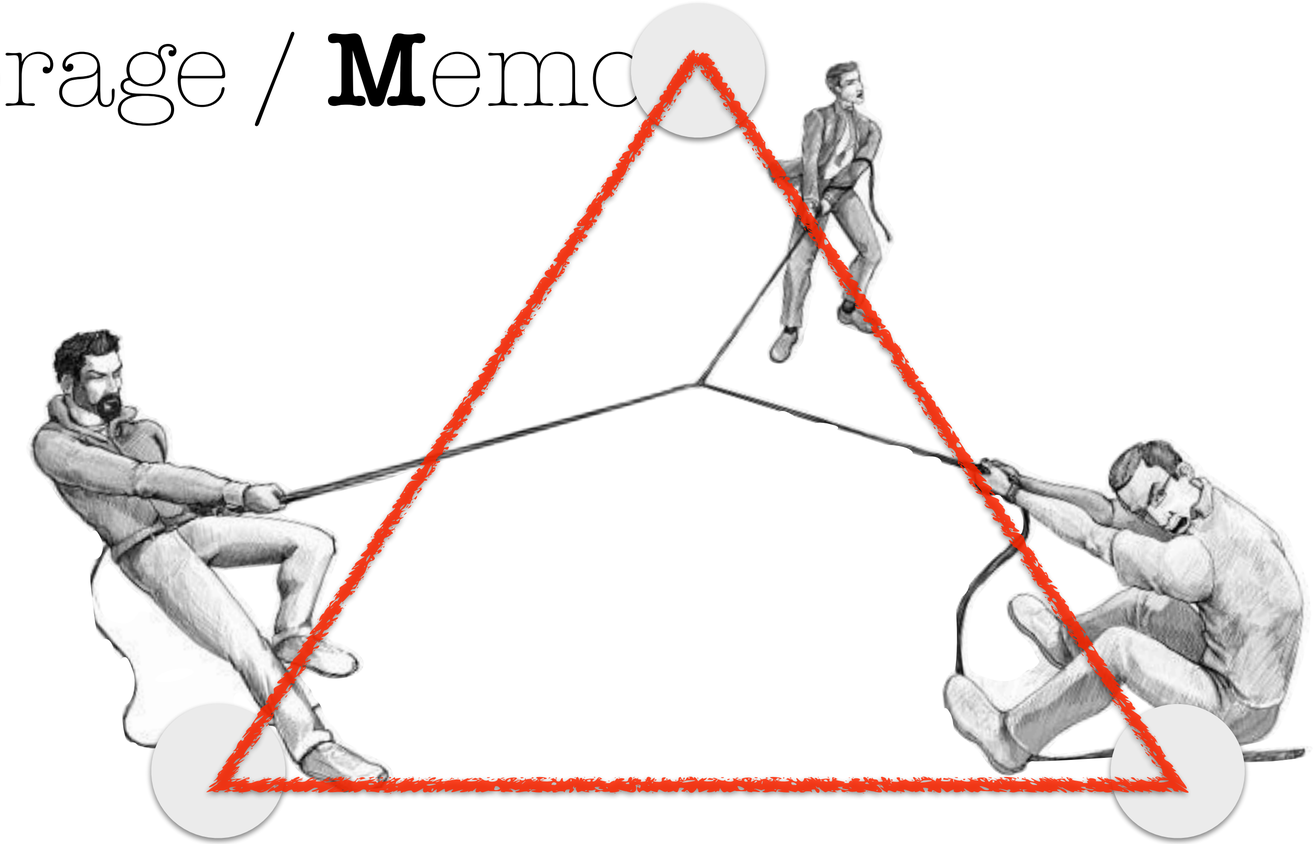
Query / **R**ead

Insert / **U**pdate



RUM conjecture

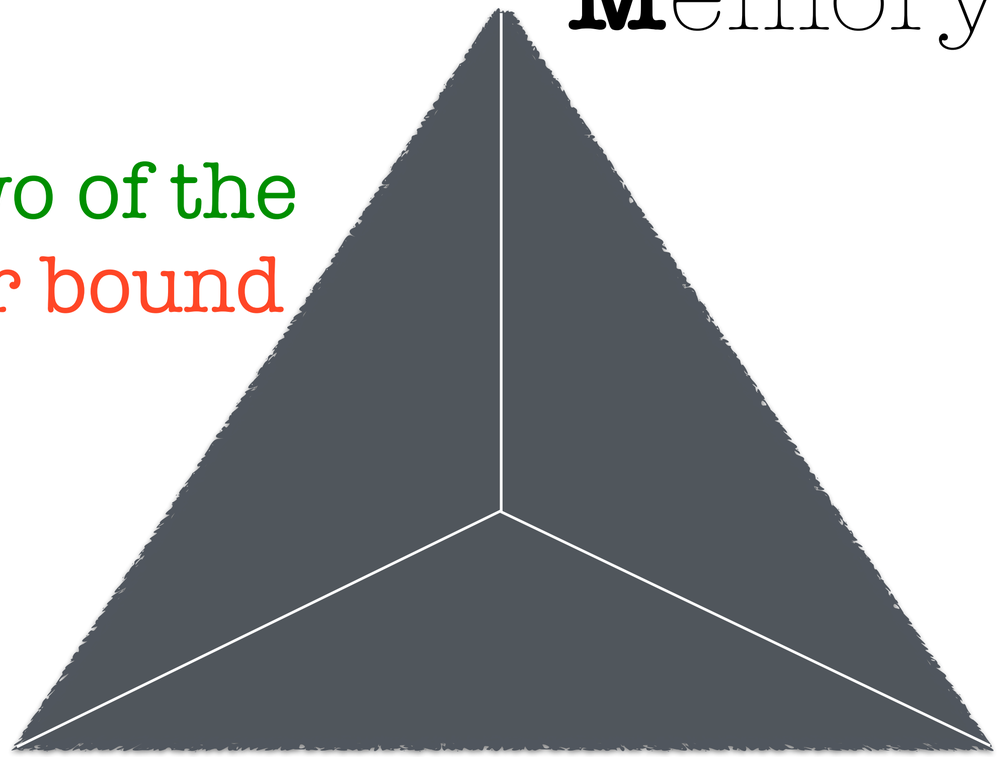
A three-way tradeoff



RUM conjecture

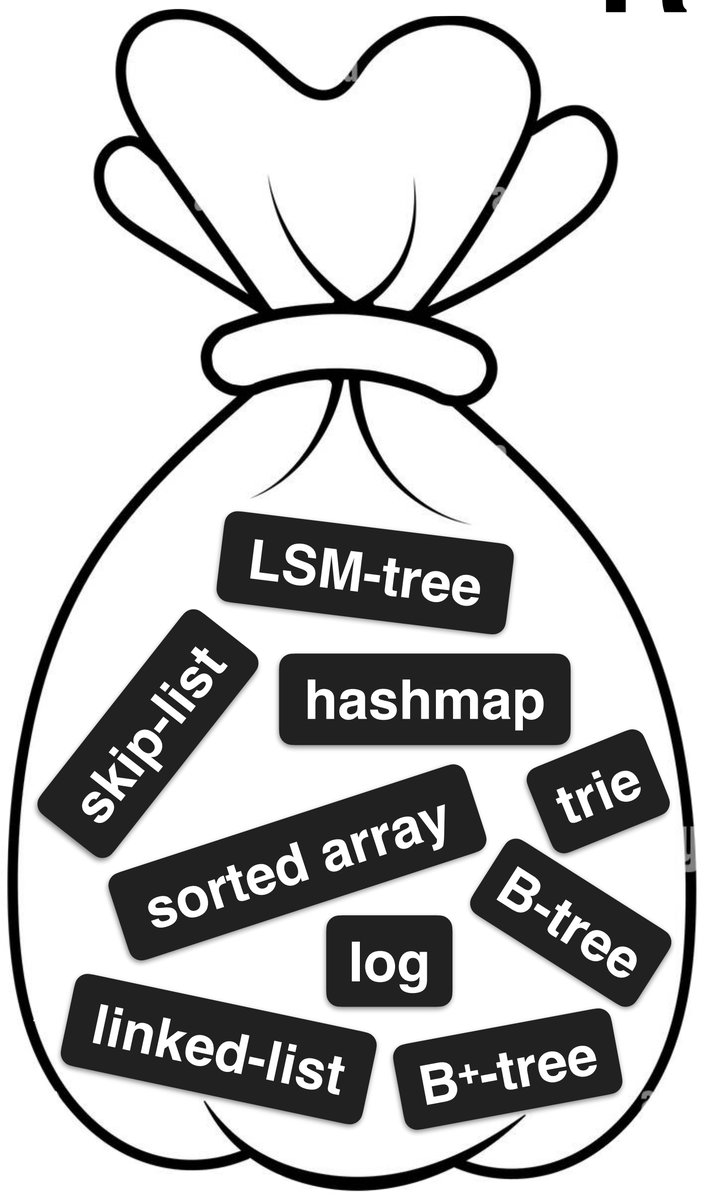
A three-way tradeoff

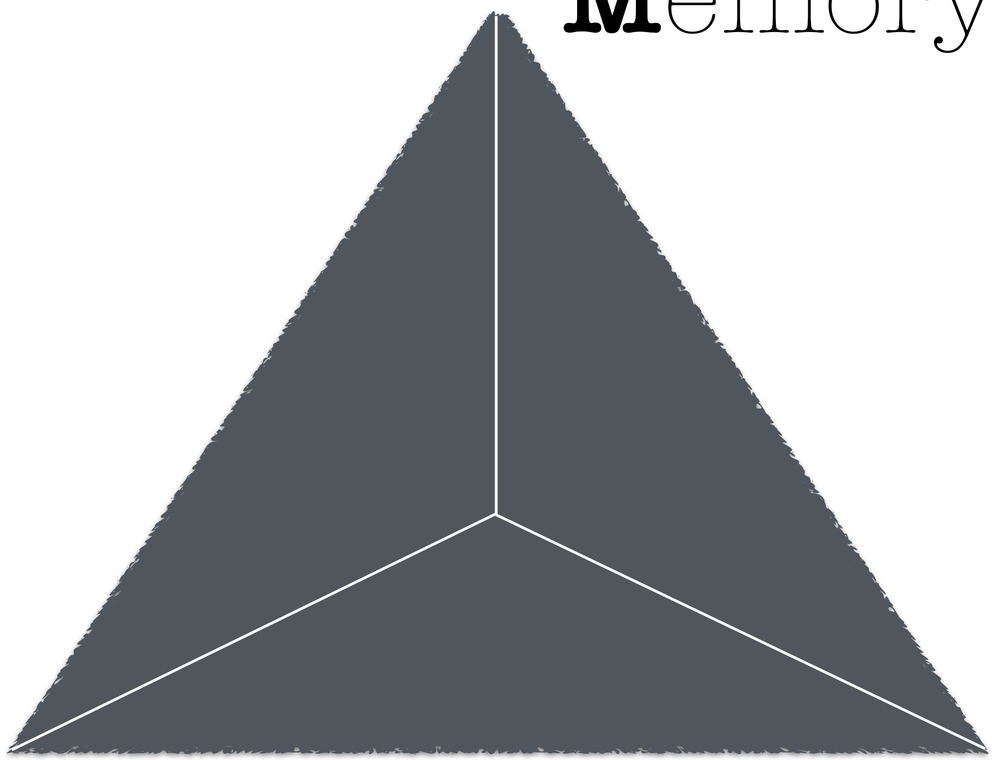
> ... setting an upper bound for two of the RUM axes, implies a hard lower bound for the third axis



RUM conjecture

A three-way tradeoff





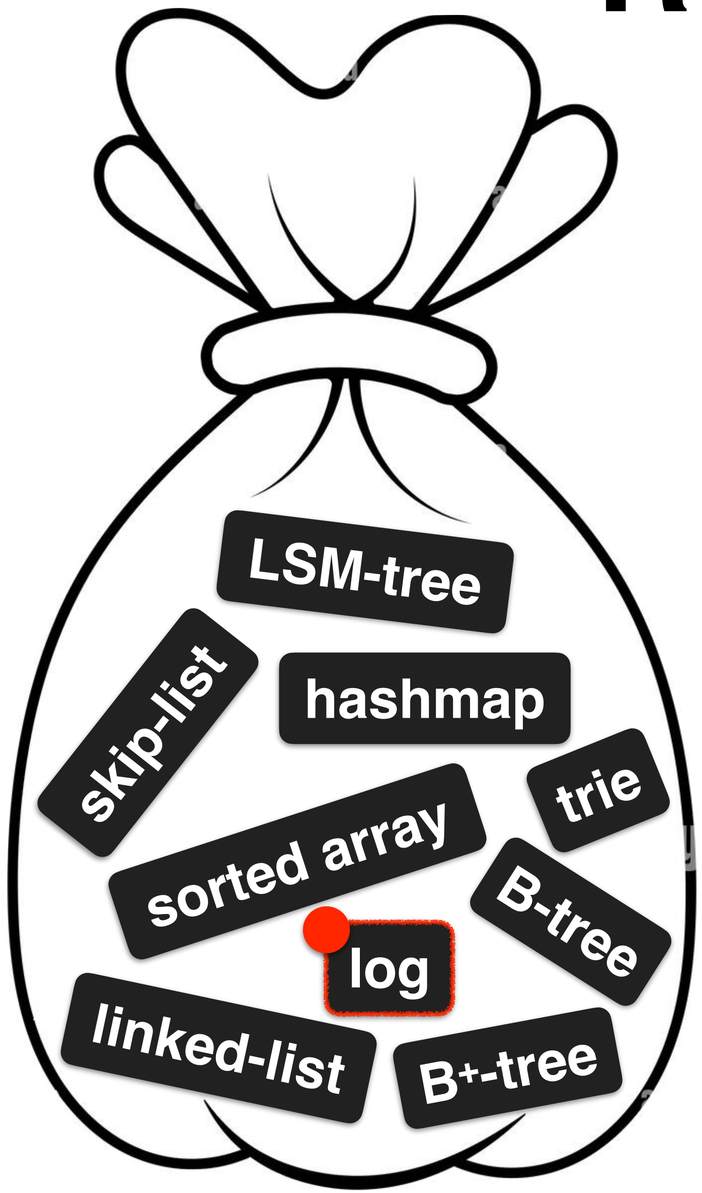
Memory

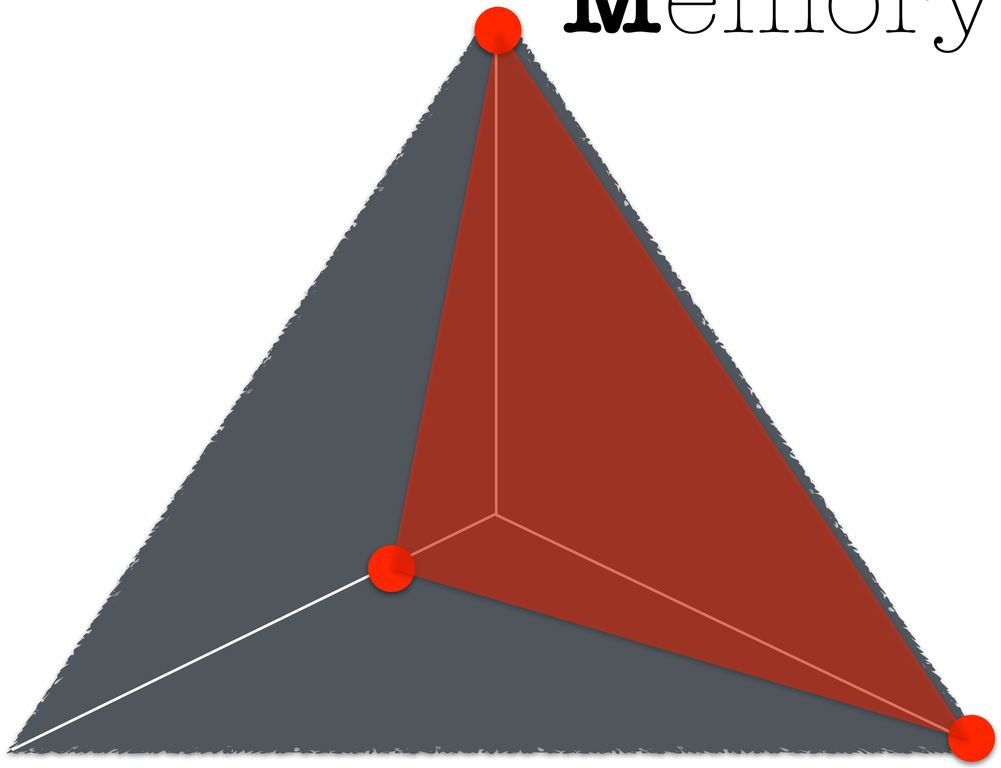
Read

Update

RUM conjecture

A three-way tradeoff





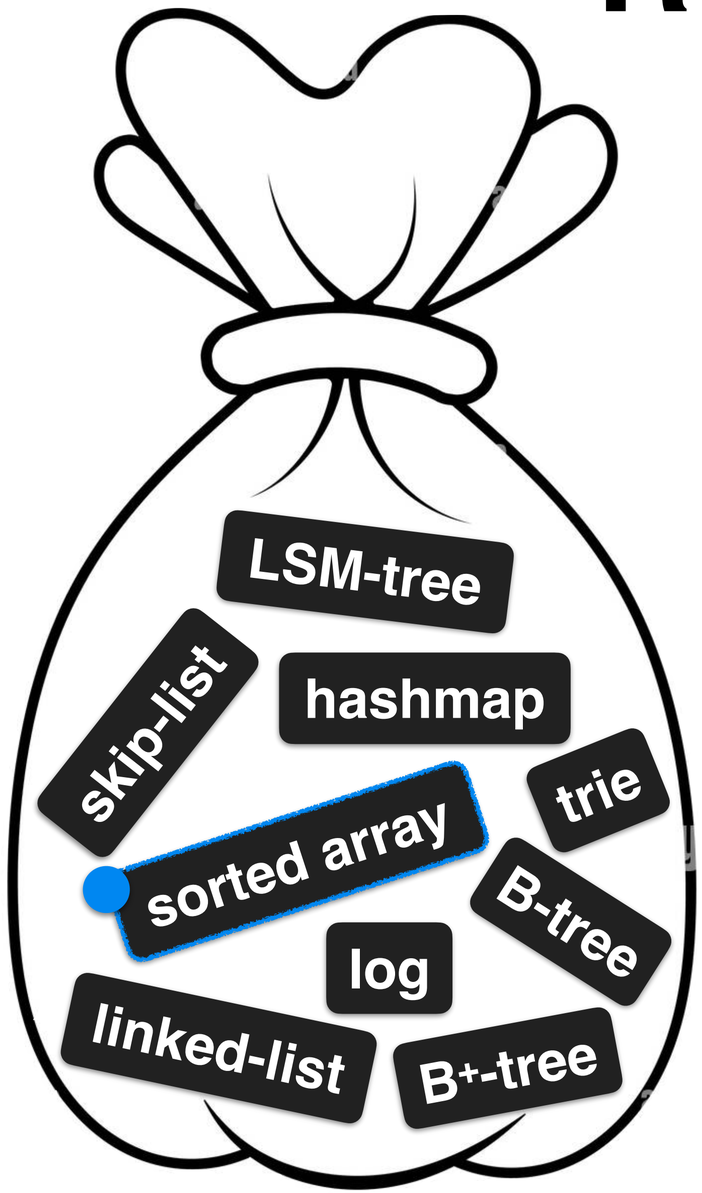
Memory

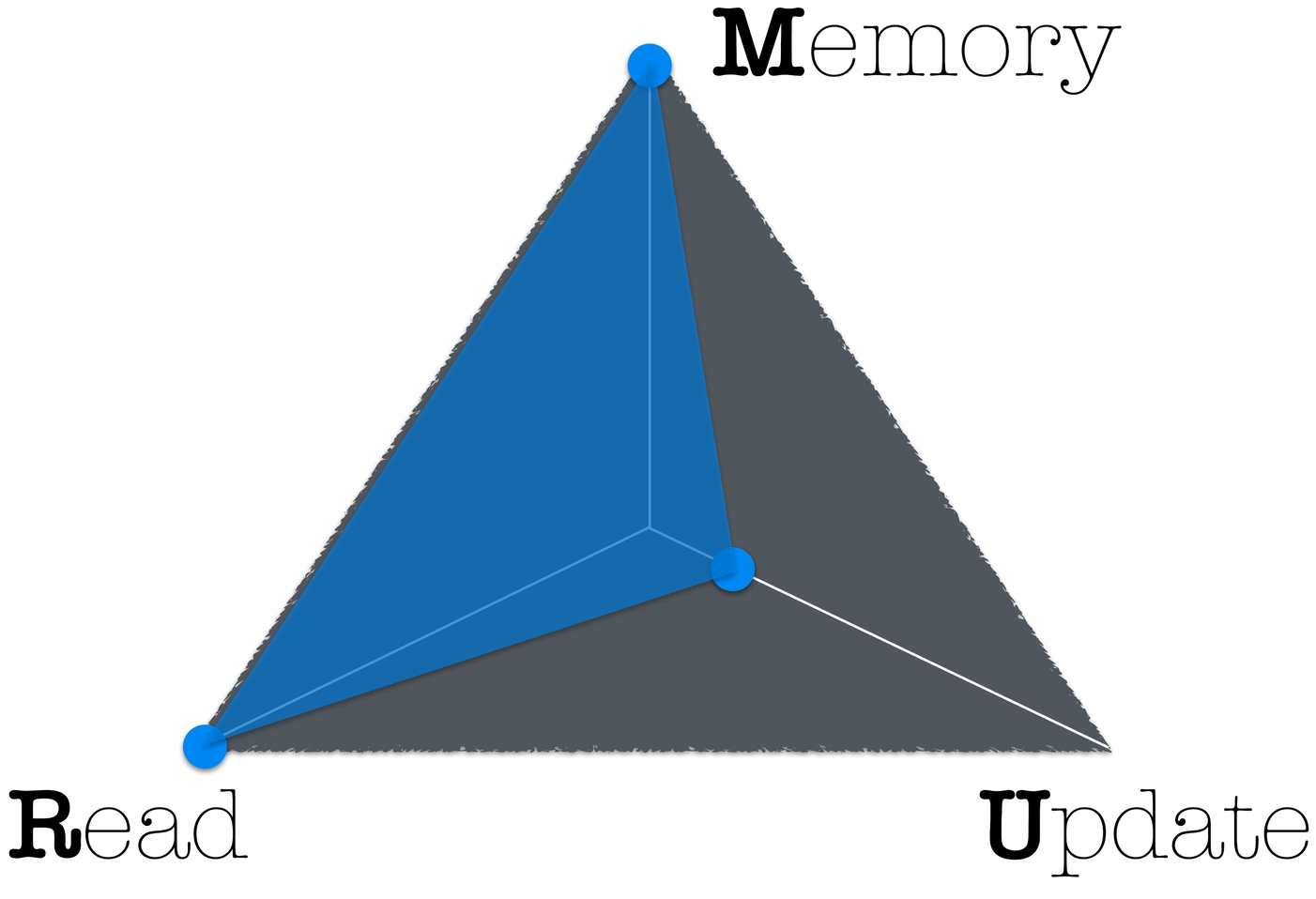
Read

Update

RUM conjecture

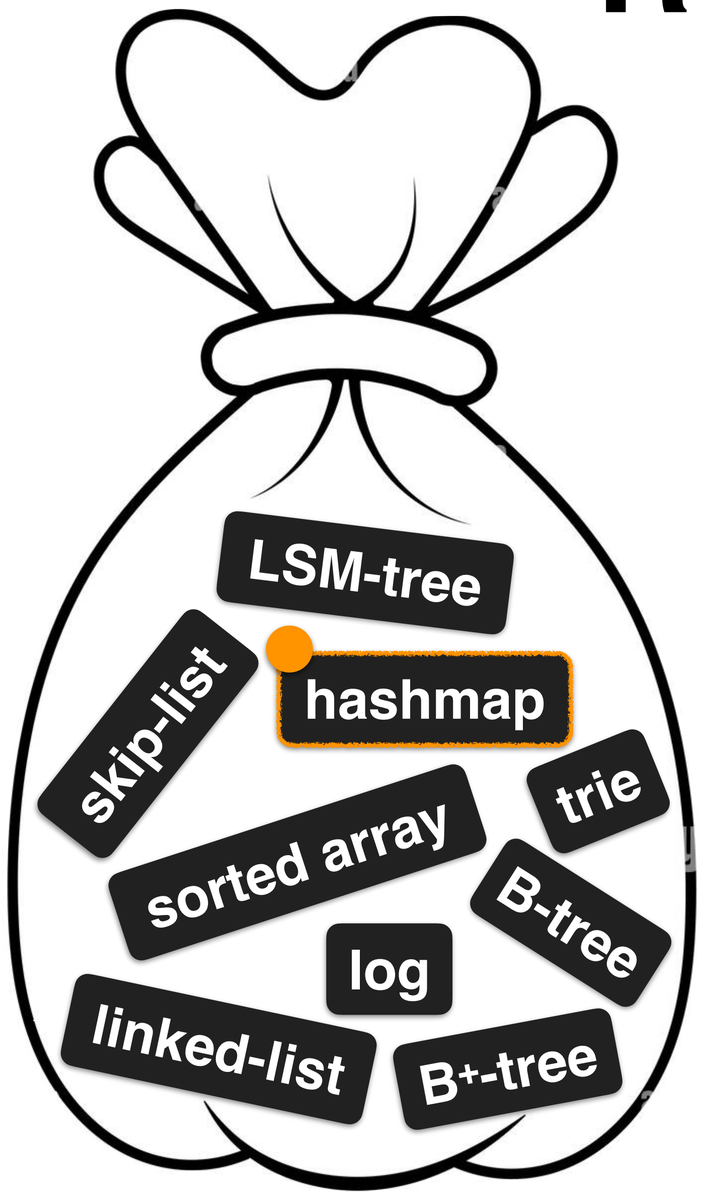
A three-way tradeoff

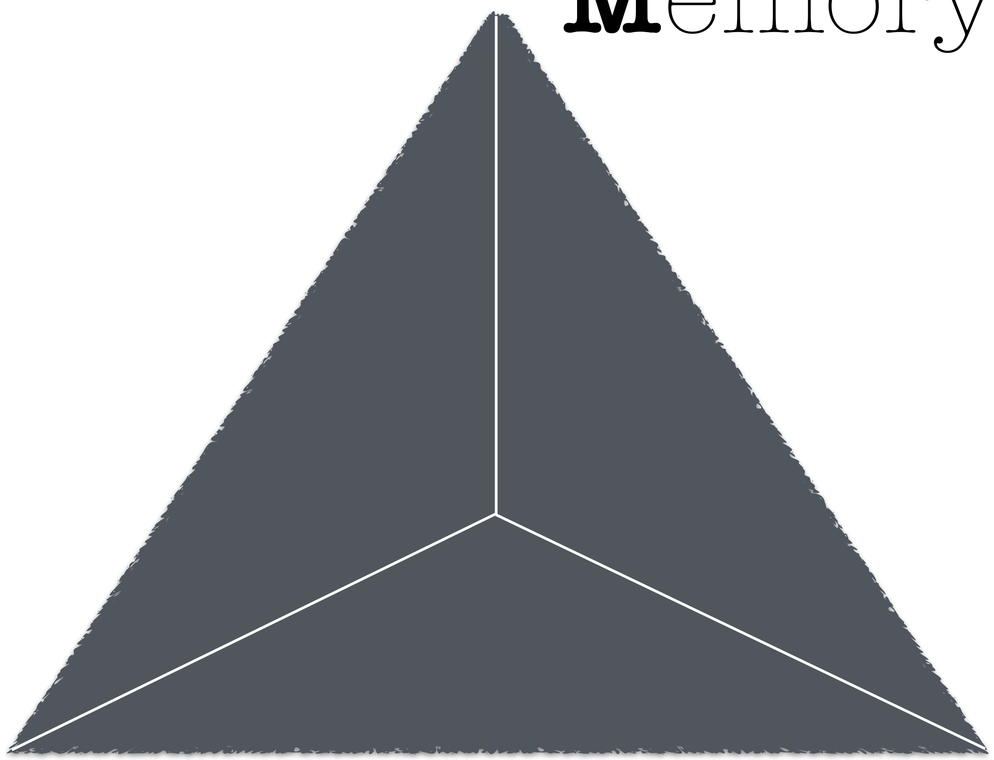




RUM conjecture

A three-way tradeoff





Memory

Read

Update

RUM conjecture

A three-way tradeoff

Thought Experiment 1

Where does a **hashmap** stand for **memory**, **update**, and **read** costs?

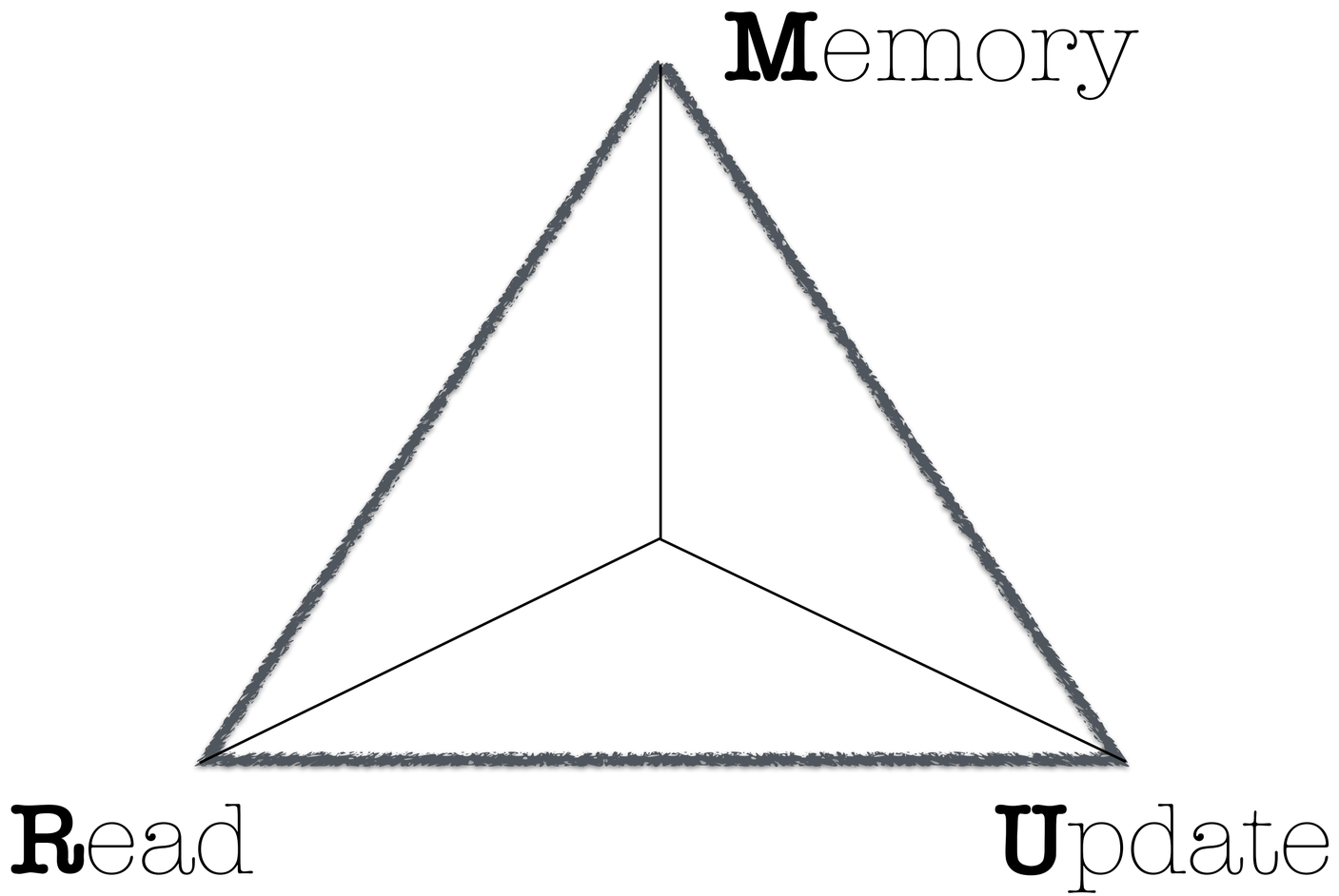
point read

vs

range read

RUM conjecture

A three-way tradeoff

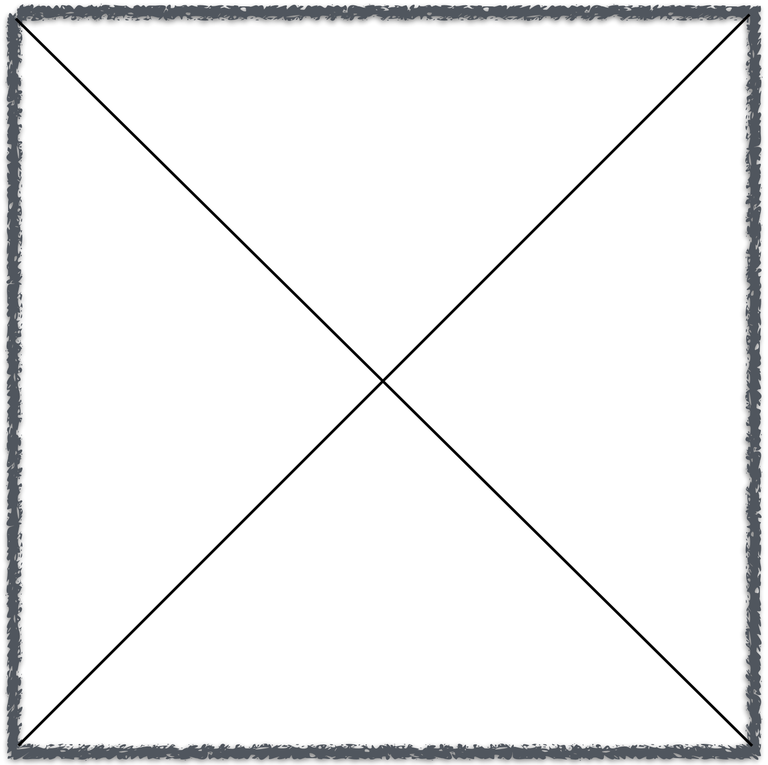


Extending the **RUM tradeoff**

A multi-way tradeoff

Point read

Memory



Range read

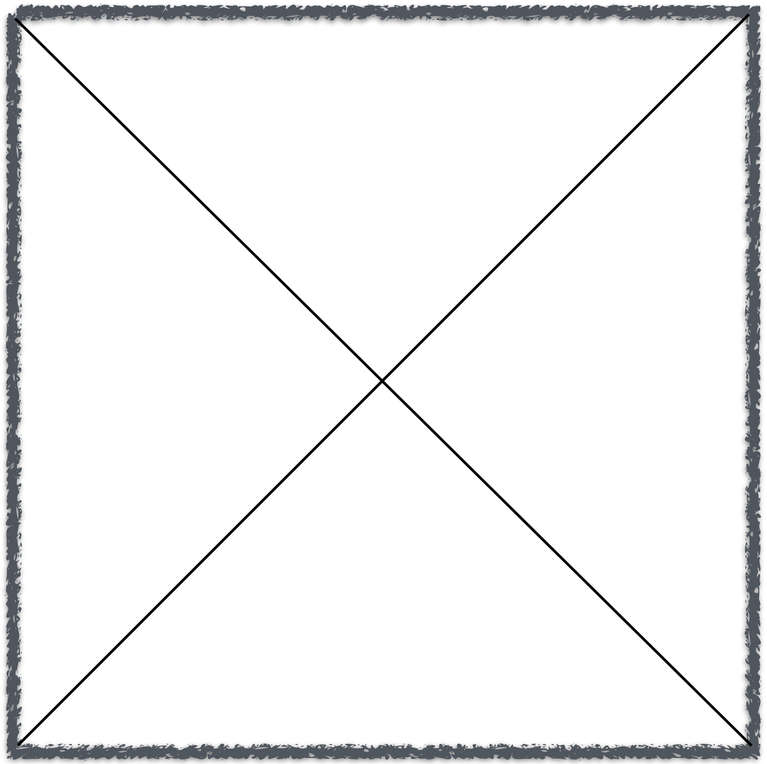
Update

Extending the **RUM tradeoff**

A multi-way tradeoff

Point read

Memory



Range read

Update

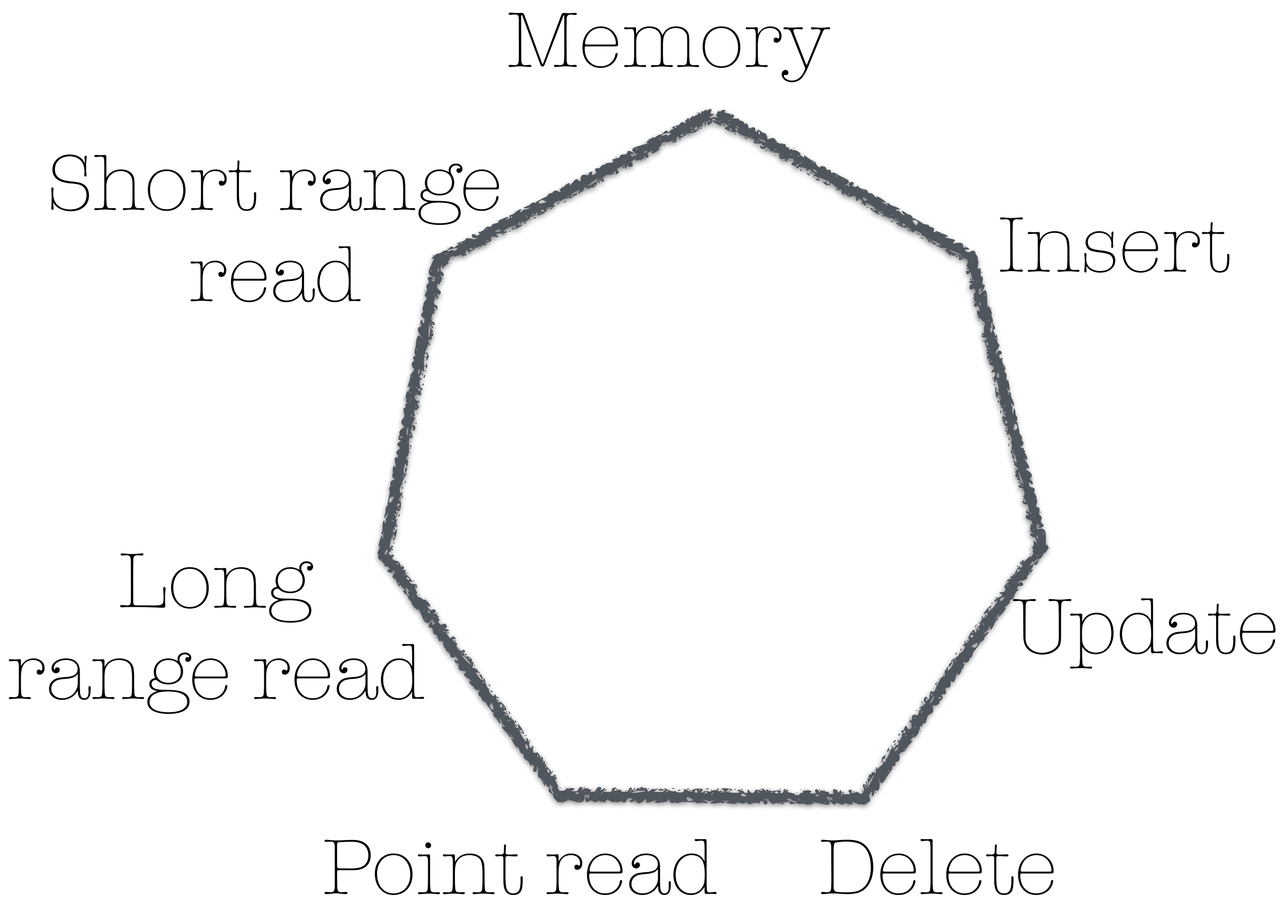
But, what about **deletes**?

Are **updates** the same as **inserts**?

What about **selectivity** of range reads?

Extending the **RUM tradeoff**

A multi-way tradeoff



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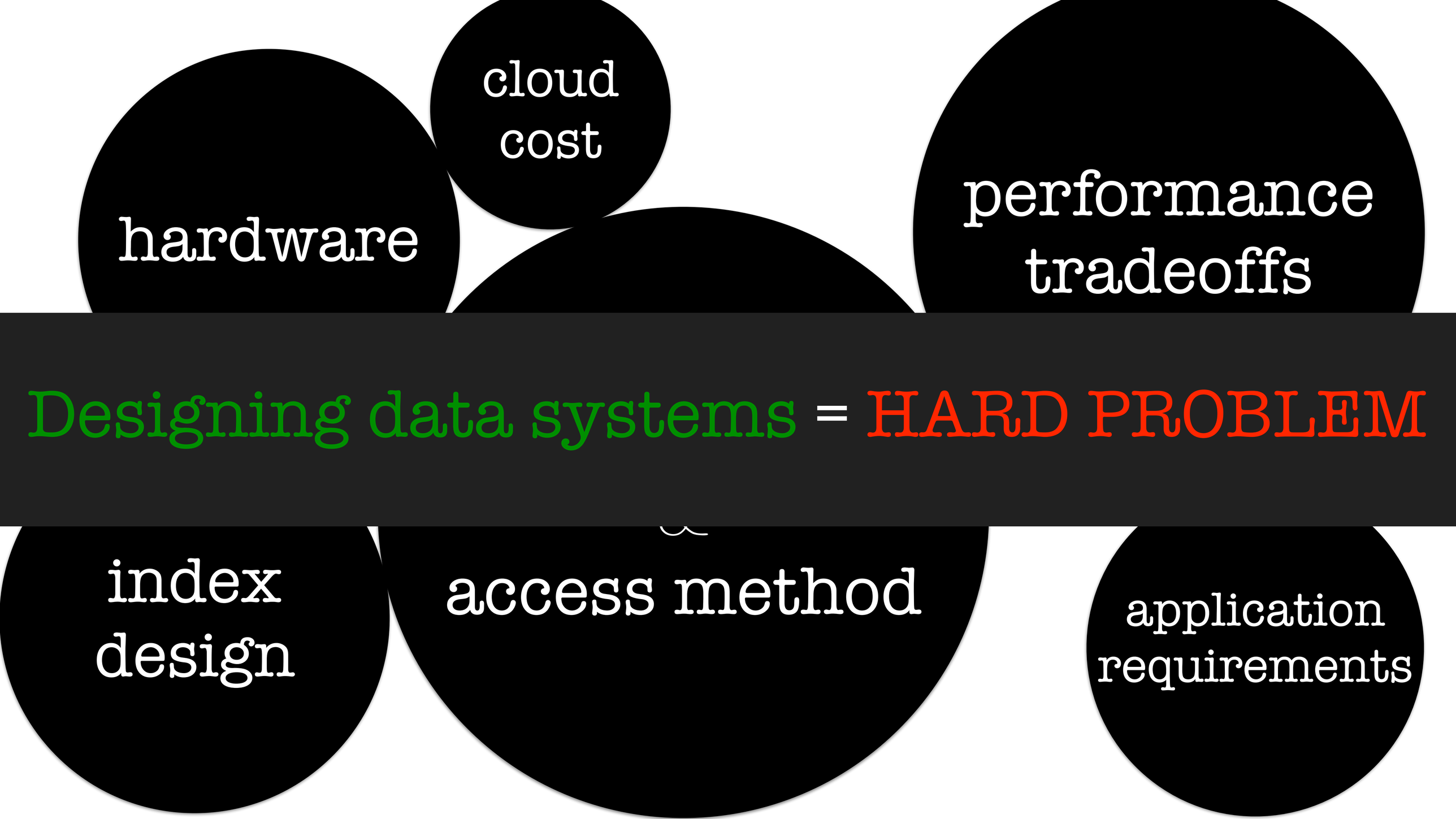
cloud
cost
hardware
performance
tradeoffs
Designing data systems = HARD PROBLEM
index
design
access method
application
requirements

Designing data systems

Solving a hard problem

Ask for the HiPPO

Highest Paid Person's Opinion

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Designing data systems

Solving a hard problem

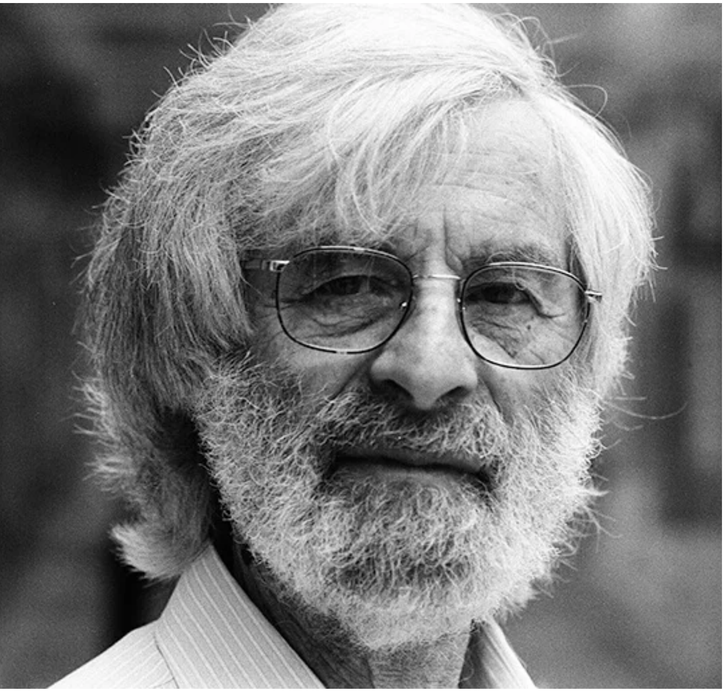
No one knows everything!

Ask for the HiPPO

Highest Paid Person's Opinion

Designing data systems

Solving a hard problem



Lesley Lamport, Microsoft Research

MA ’63, PhD ’72 Brandeis University

ACM Turing Award 2013

No one knows everything!

The Part-Time Parliament

LESLIE

Digital E

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Paxos Made Simple

Leslie Lamport

01 Nov 2001

Abstract

The Paxos algorithm, when presented in plain English, is very simple.

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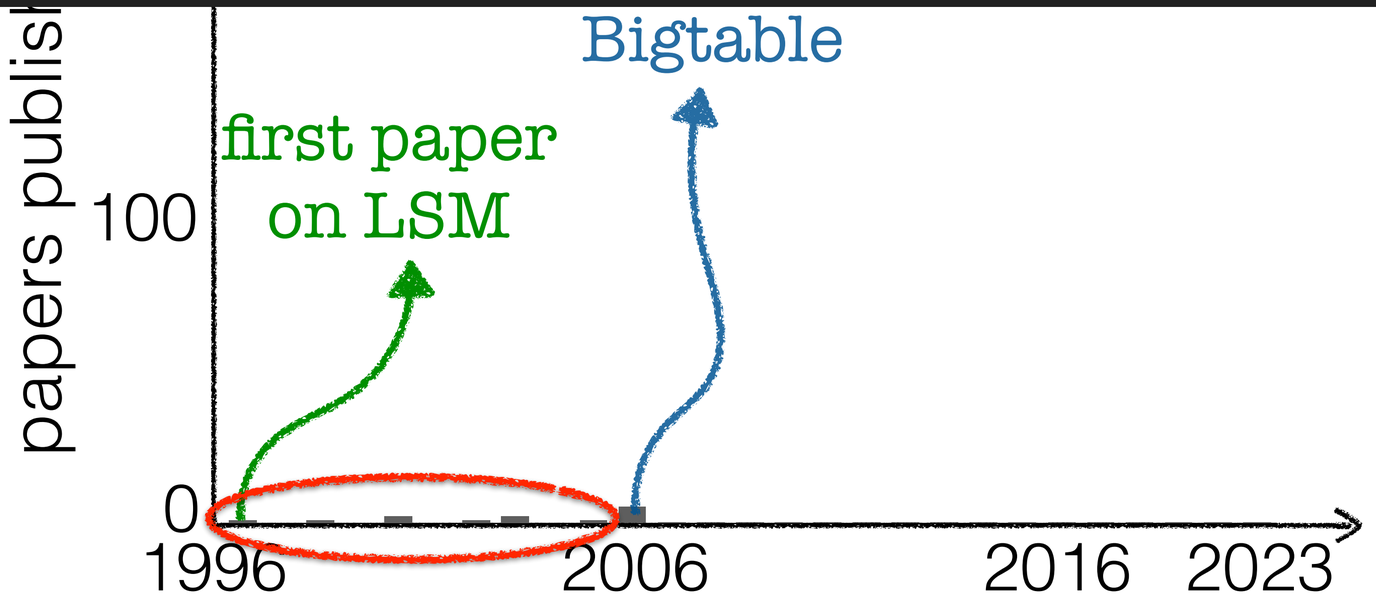
Designing data systems

Solving a hard problem

Patrick O'Neil, UMass Boston

Co-inventor of the LSM-tree

No one knows everything!



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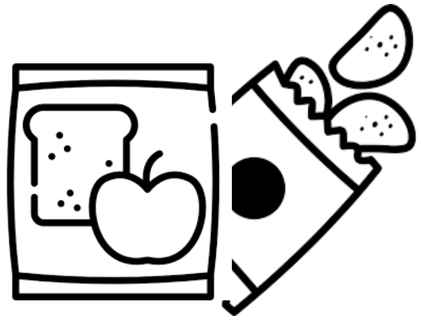
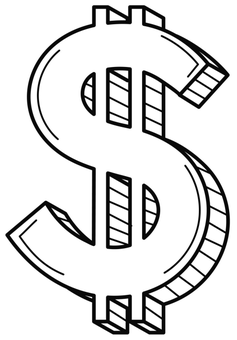
* data from Google scholar

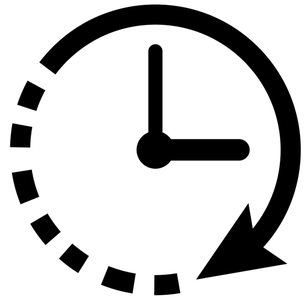
Designing data systems

Solving a hard problem

Get the COSI 167 students







Perfectly tuned data system!

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Designing data systems

Solving a hard problem

Manual designing &
hand-tuning hundreds of knobs
do NOT SCALE

Designing data systems

Solving a hard problem

Manual designing &
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do NOT SCALE

Self-designing, self-tuning, and
adaptive data systems

Designing data systems

Solving a hard problem

Self-designing, self-tuning, and adaptive data systems

Adaptive data layouts: row stores vs. column stores vs. hybrids

Self-tuning LSM-engines

Adaptive (**adaptive**) indexing

Workload-aware data re-organization

Self-designing storage engines

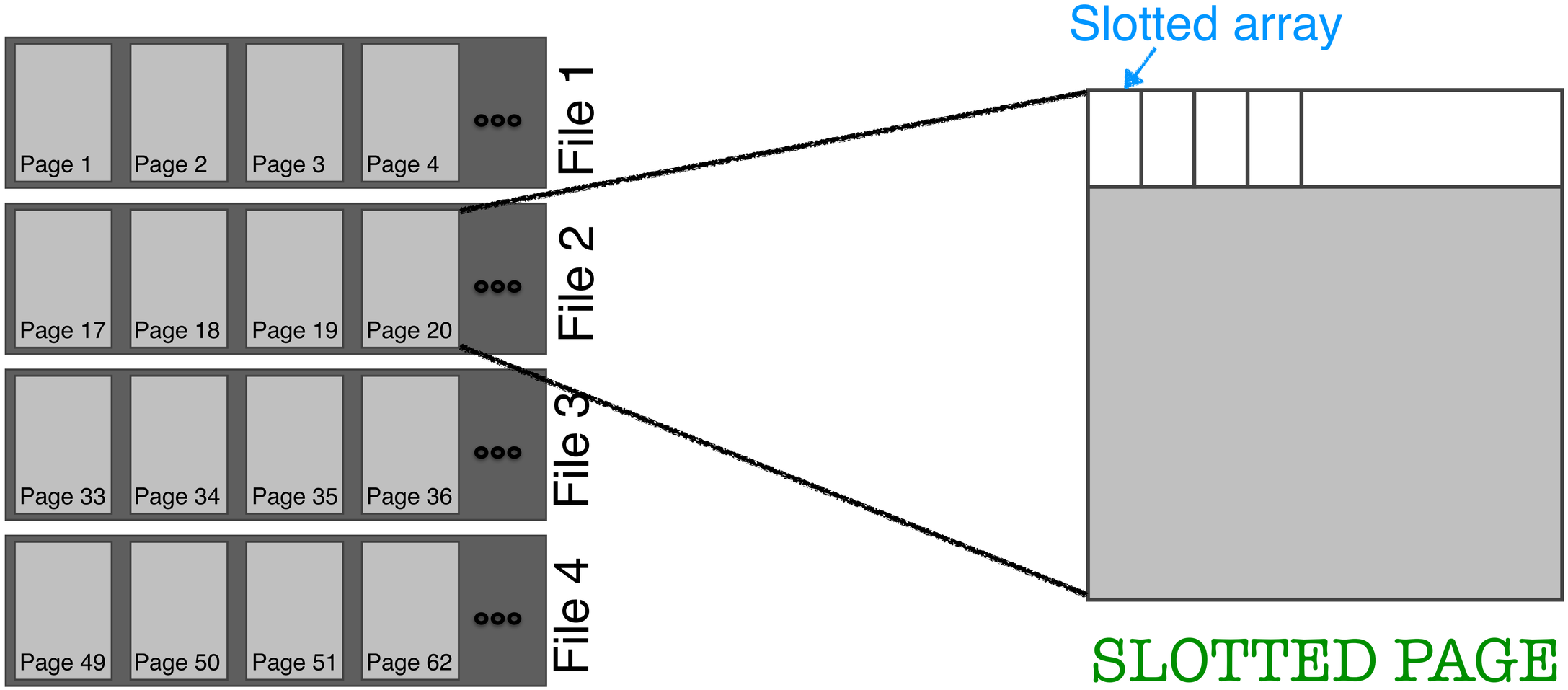
Hardware-conscious memory manager

Cloud cost-optimized data systems

Understanding **data placement**

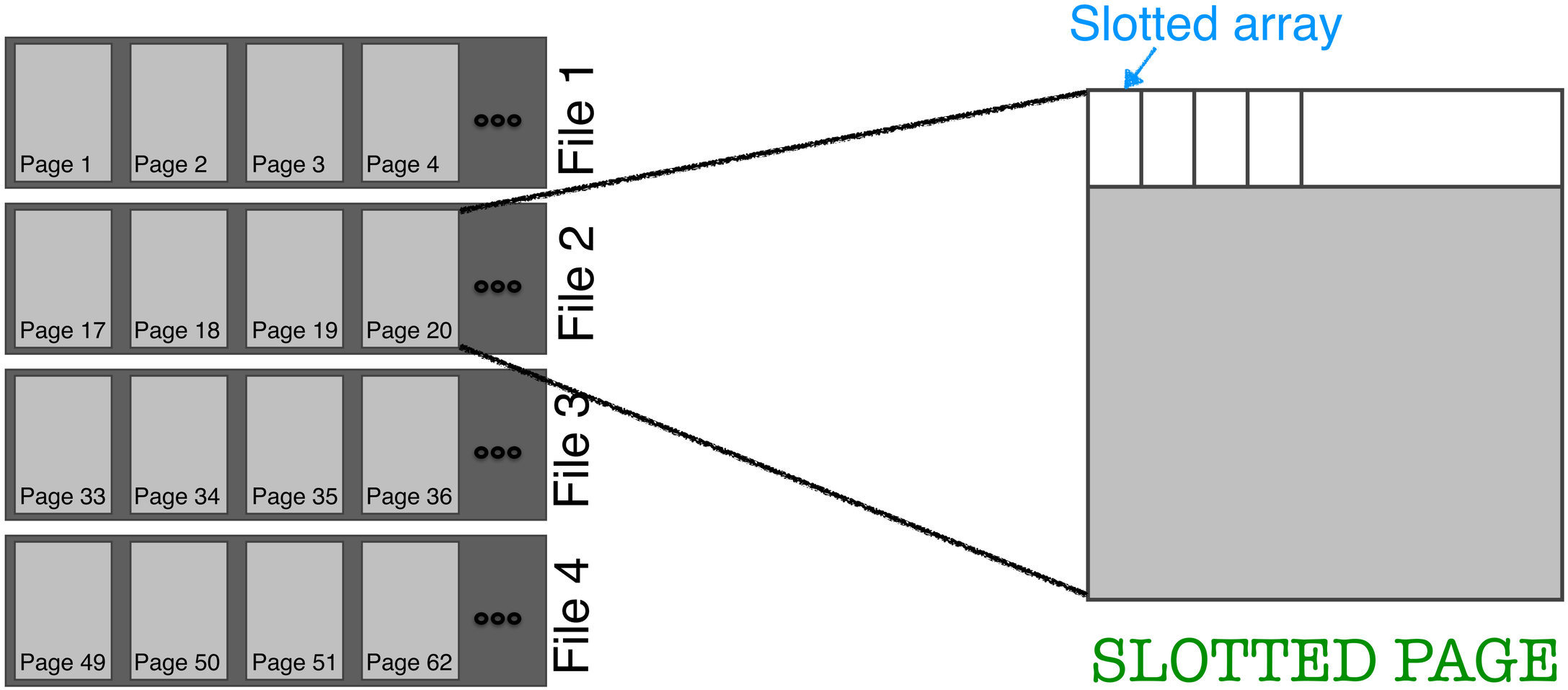
Understanding **data placement**

Files, pages, tuples



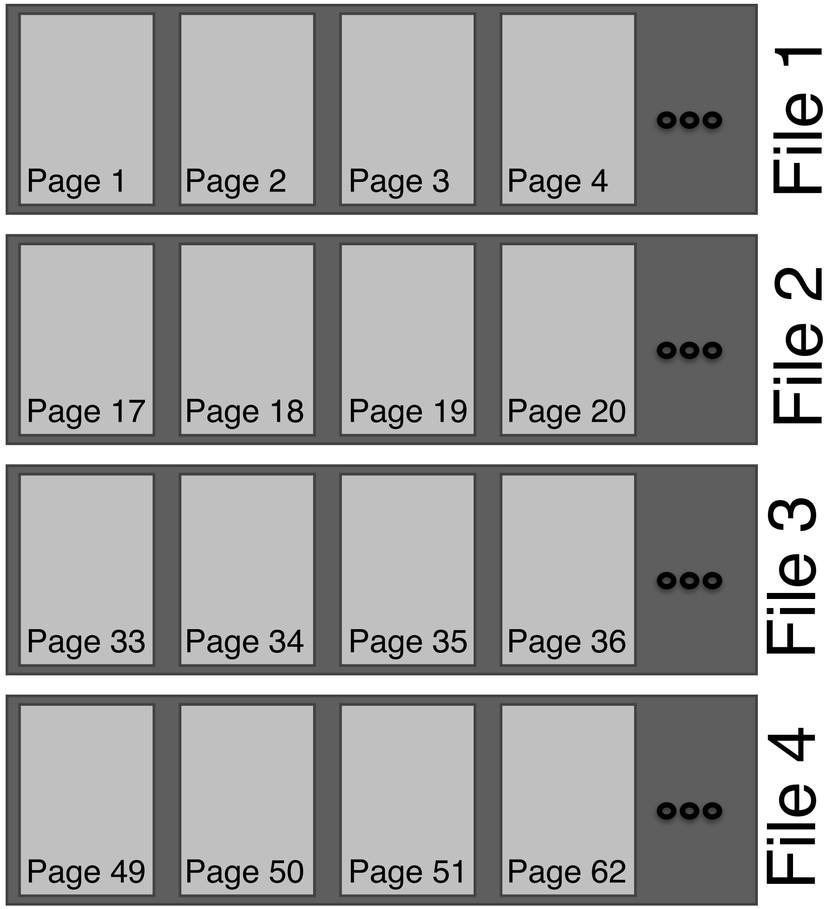
Understanding **data placement**

Files, pages, tuples

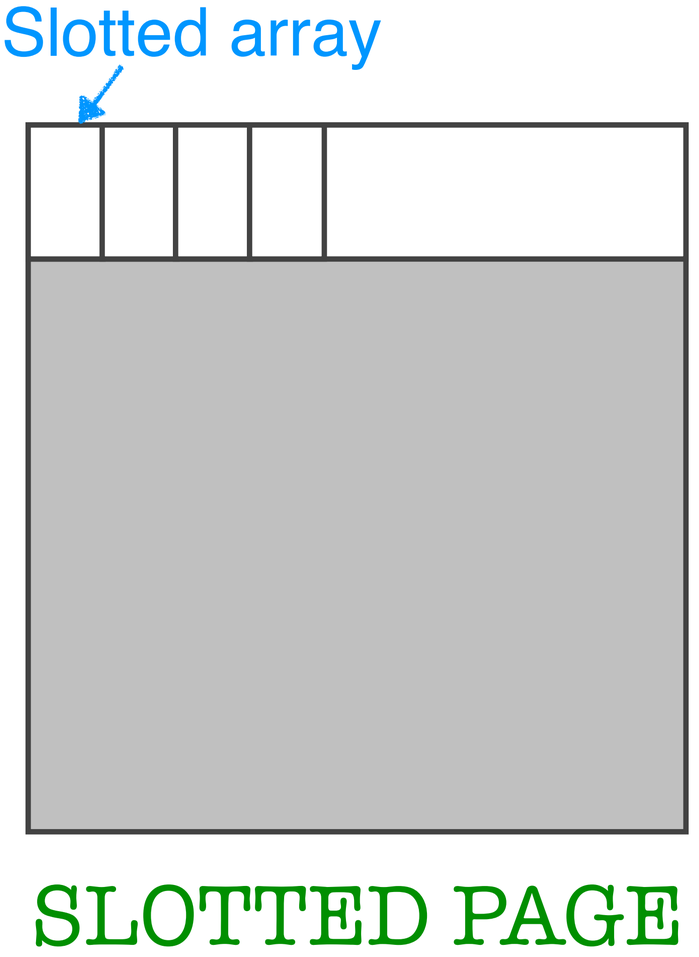


Understanding **data placement**

Files, pages, tuples

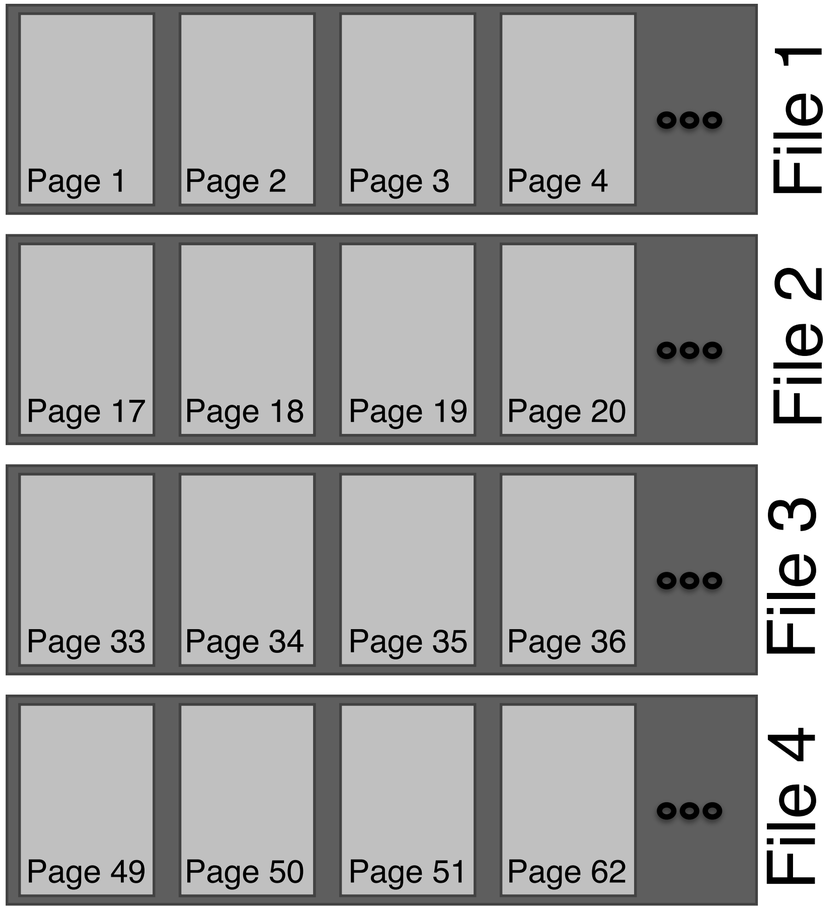


insert(Tuple 1)

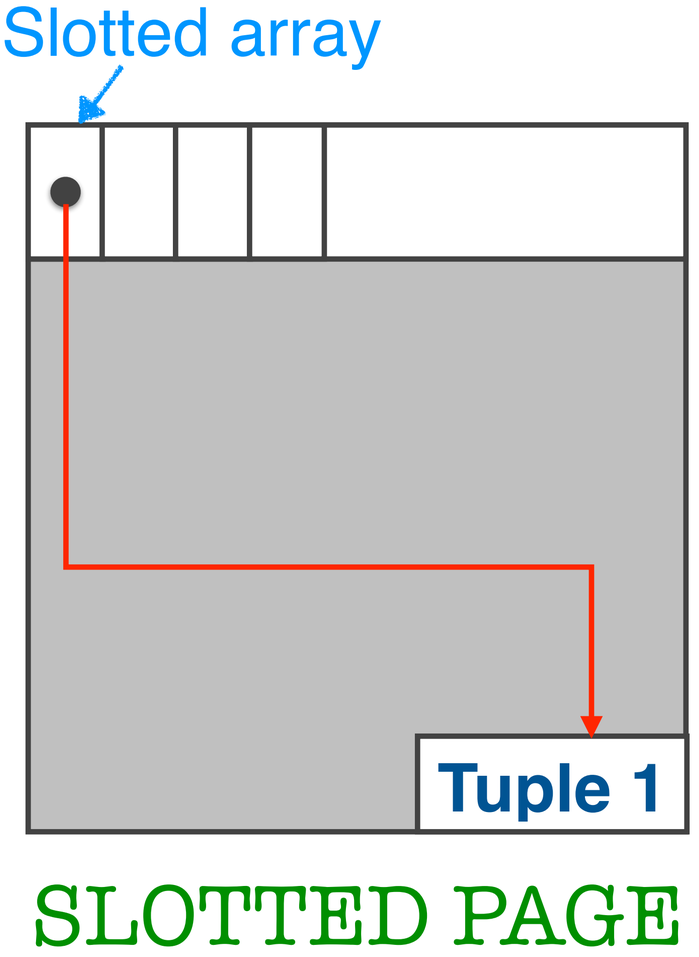


Understanding **data placement**

Files, pages, tuples



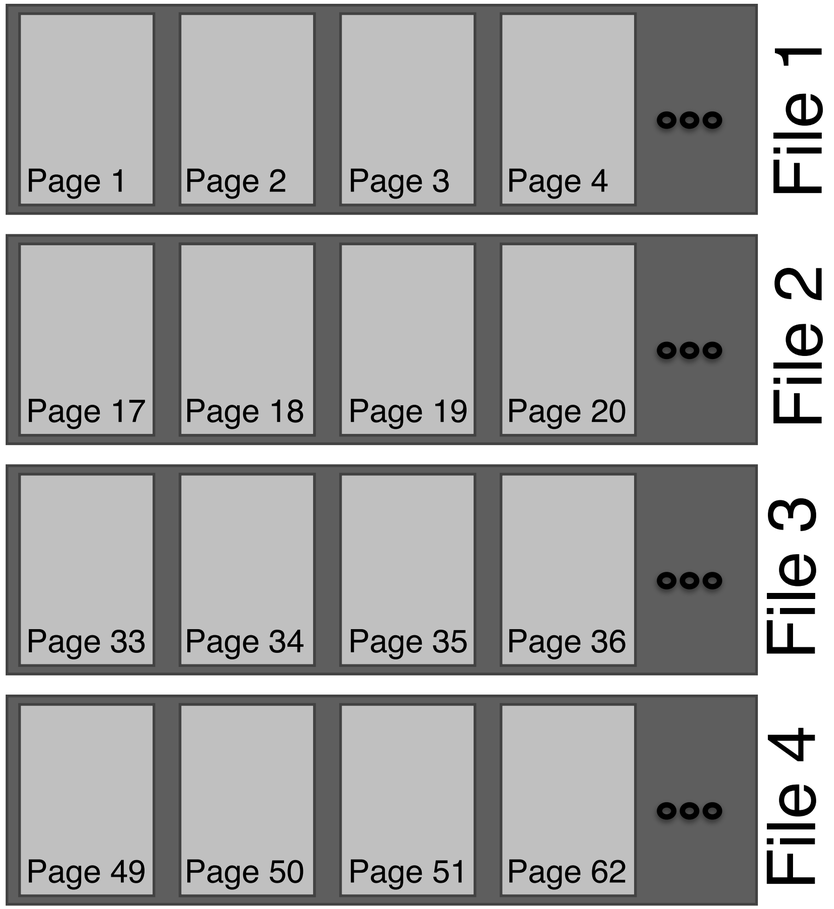
insert(Tuple 1)



SLOTTED PAGE

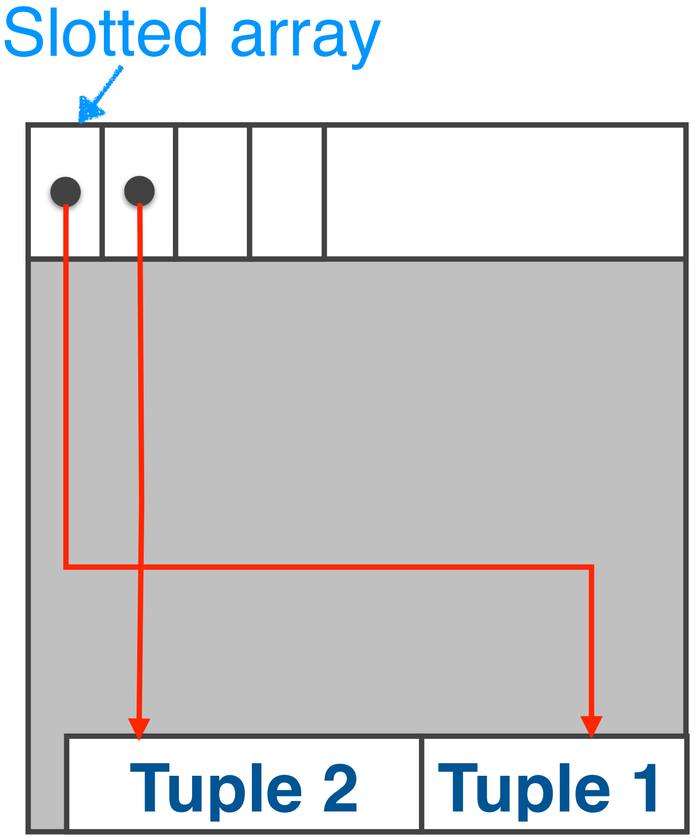
Understanding **data placement**

Files, pages, tuples



insert(Tuple 1)

insert(Tuple 2)



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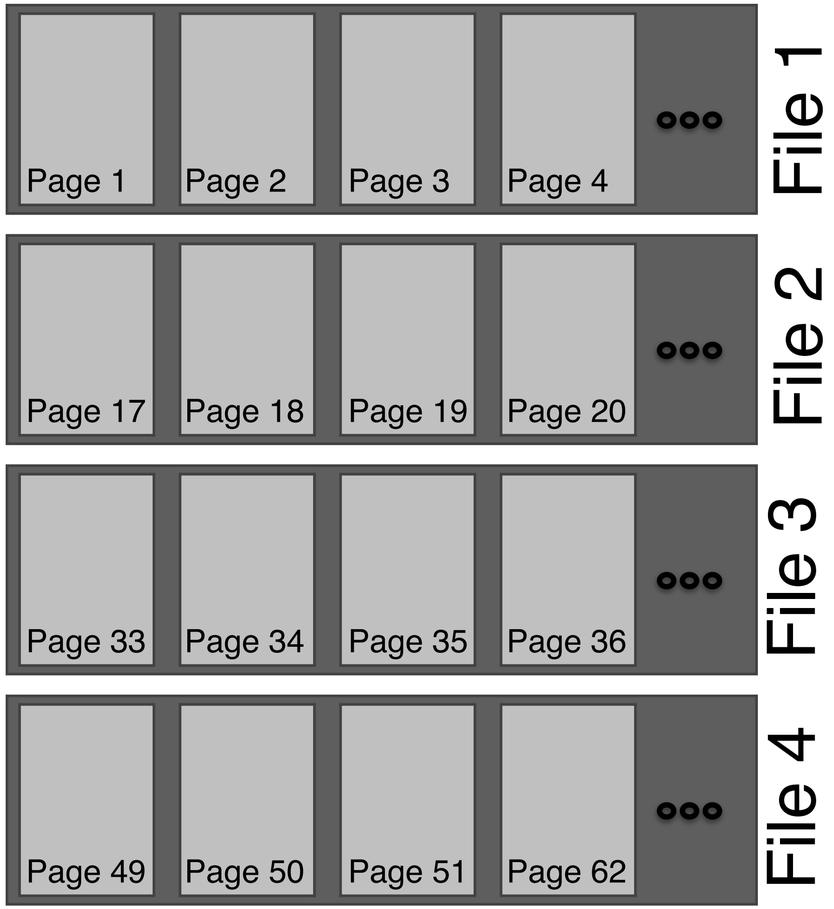
Understanding **data placement**

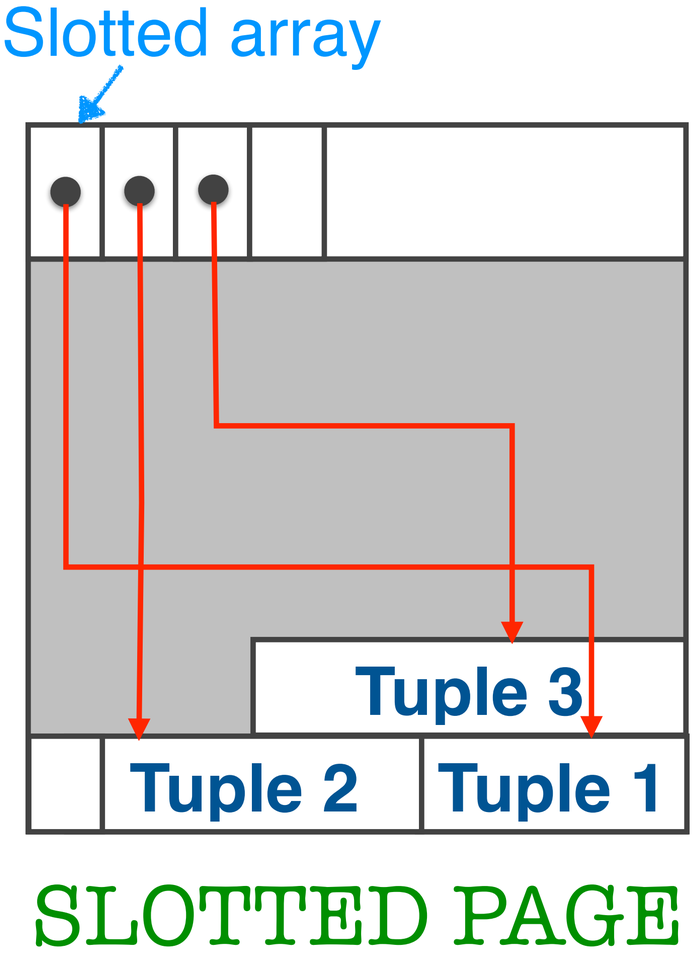
Files, pages, tuples



insert(Tuple 1)

insert(Tuple 2)

insert(Tuple 3)



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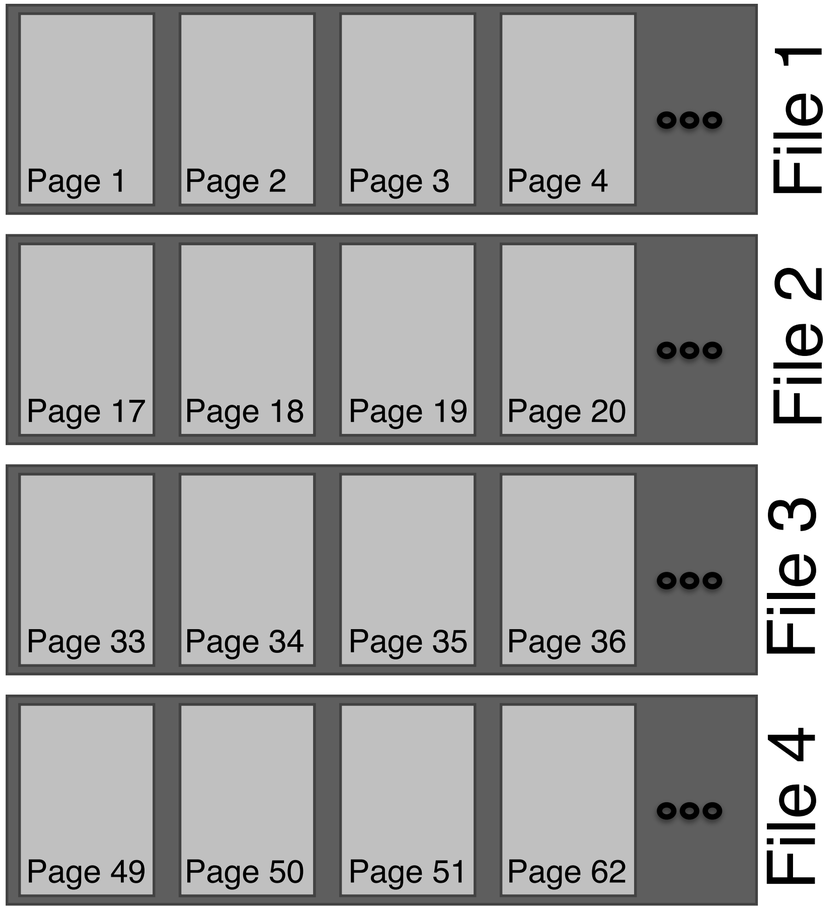
Understanding **data placement**

Files, pages, tuples

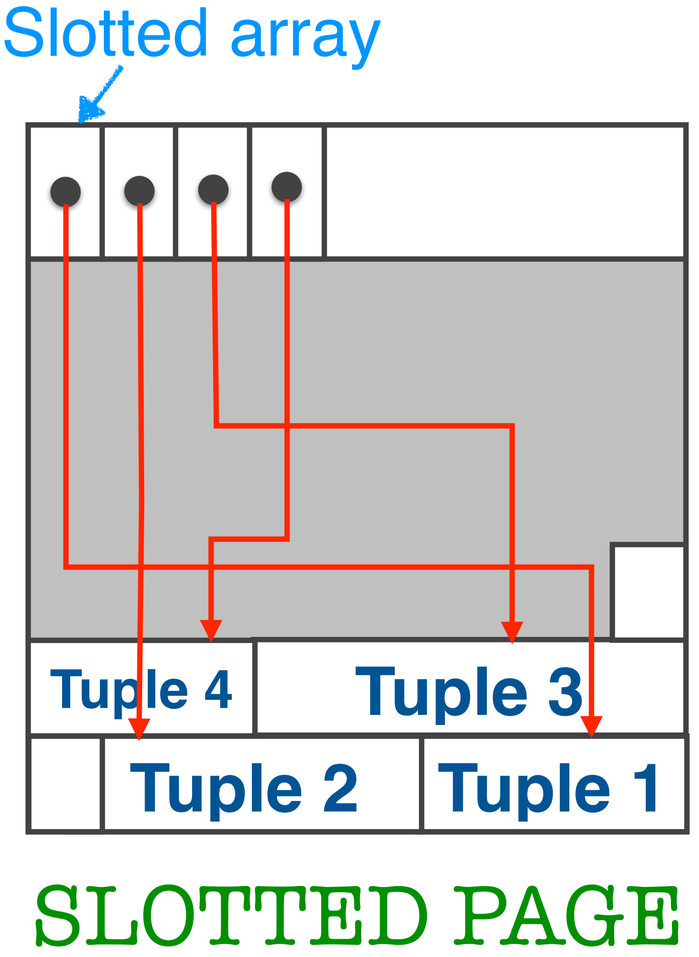


insert(Tuple 1)

insert(Tuple 2)

insert(Tuple 3)

insert(Tuple 4)



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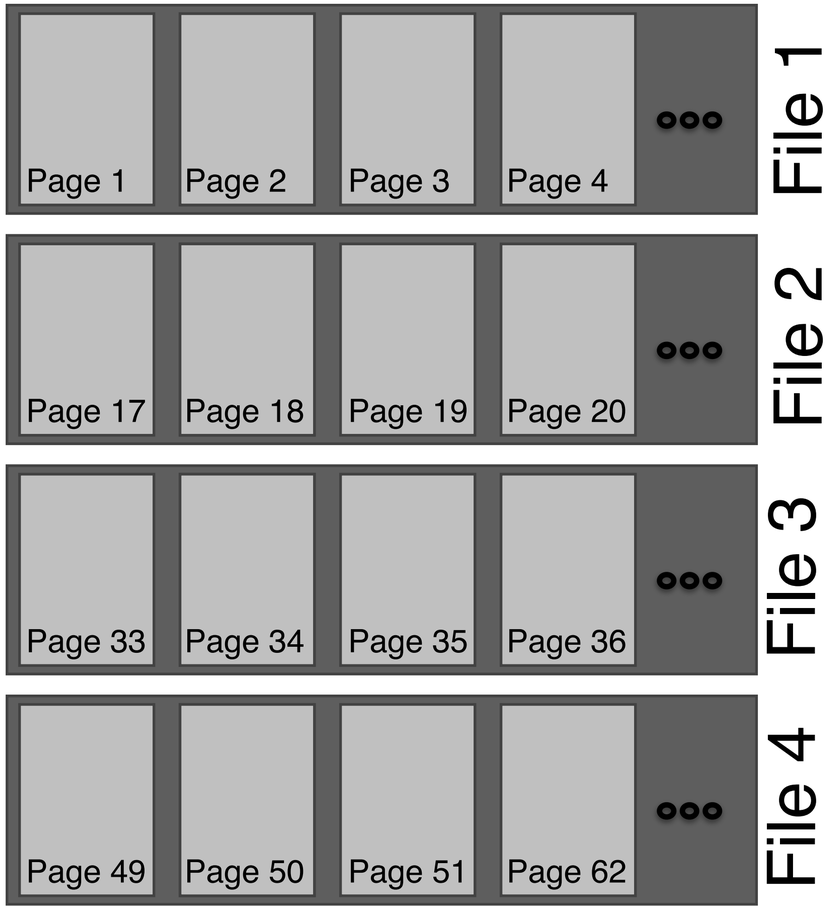
Understanding **data placement**

Files, pages, tuples

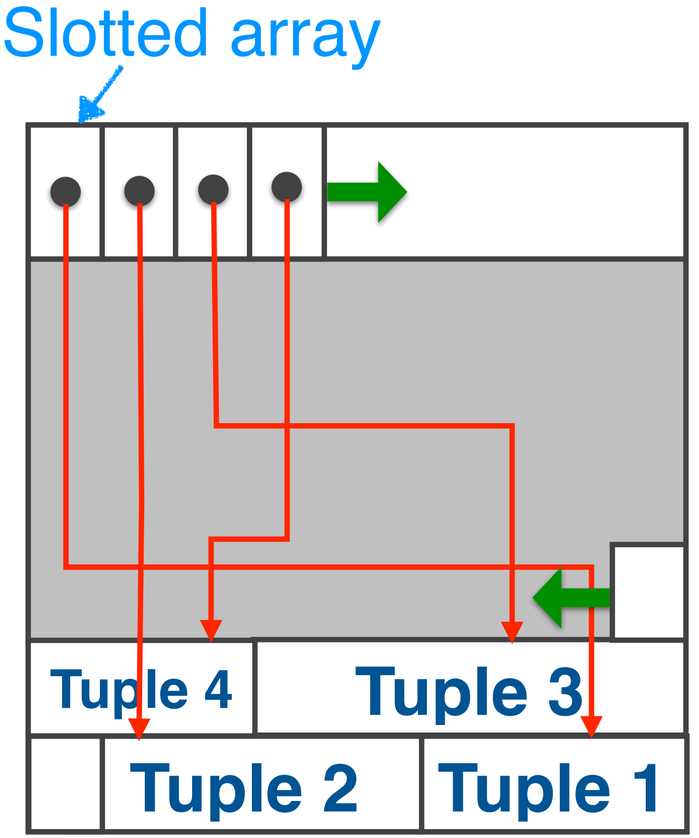


insert(Tuple 1)

insert(Tuple 2)

insert(Tuple 3)

insert(Tuple 4)



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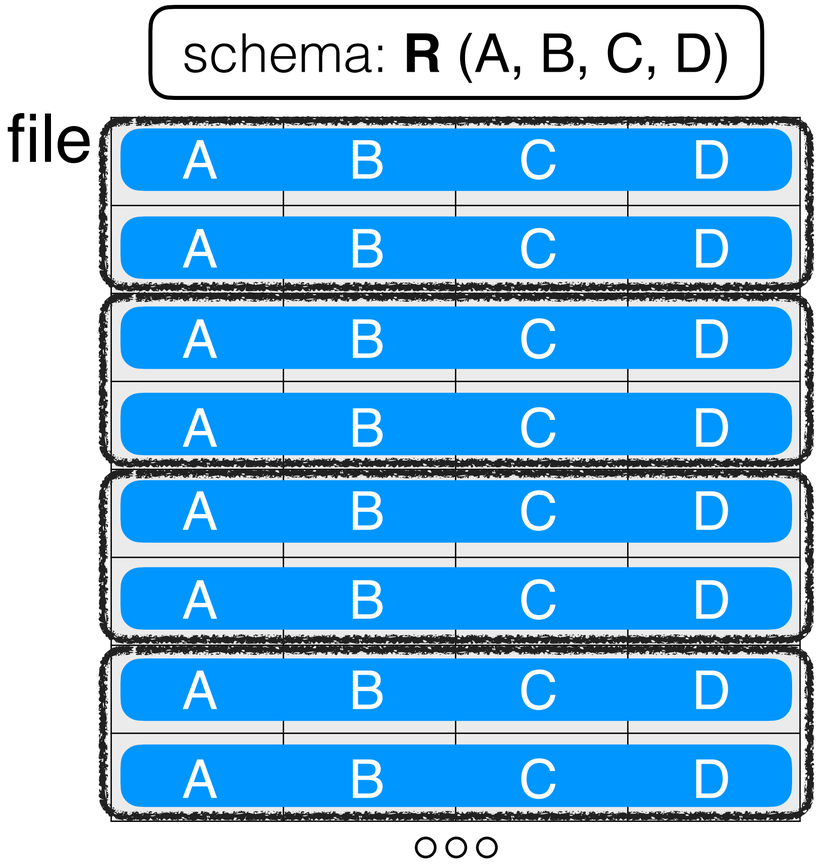
Querying over **slotted pages**

Understanding the schema



Thought Experiment 2

select A,B,C,D from R

Thought Experiment 3

select A from R

Problem?

Read amplification

Solution?

Column stores

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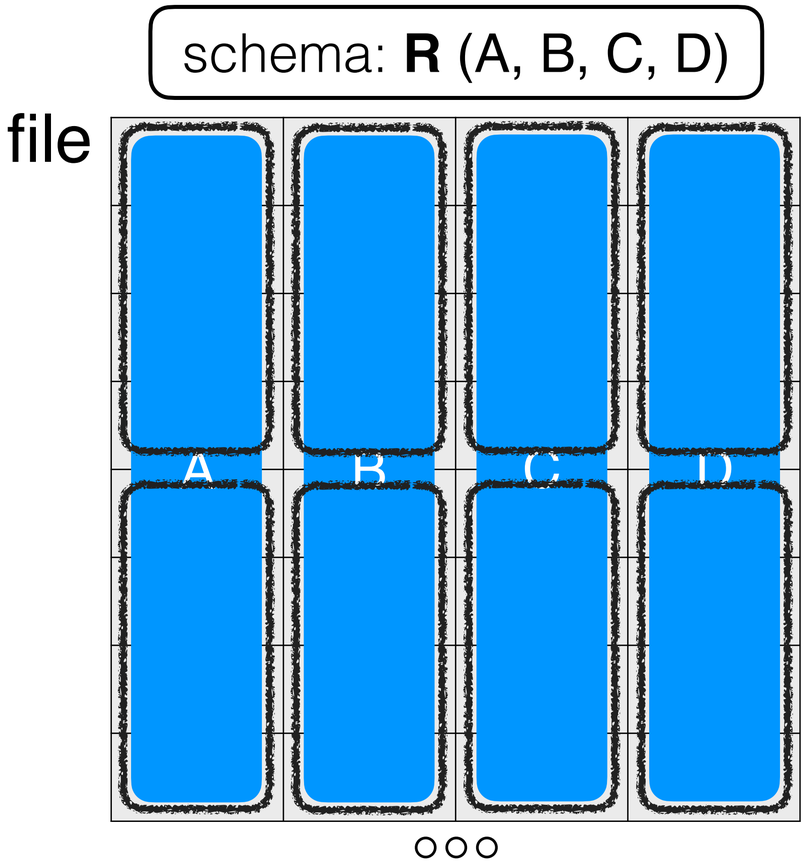
Querying over **slotted pages**

Understanding the schema



Thought Experiment 3

select A from R

Thought Experiment 2

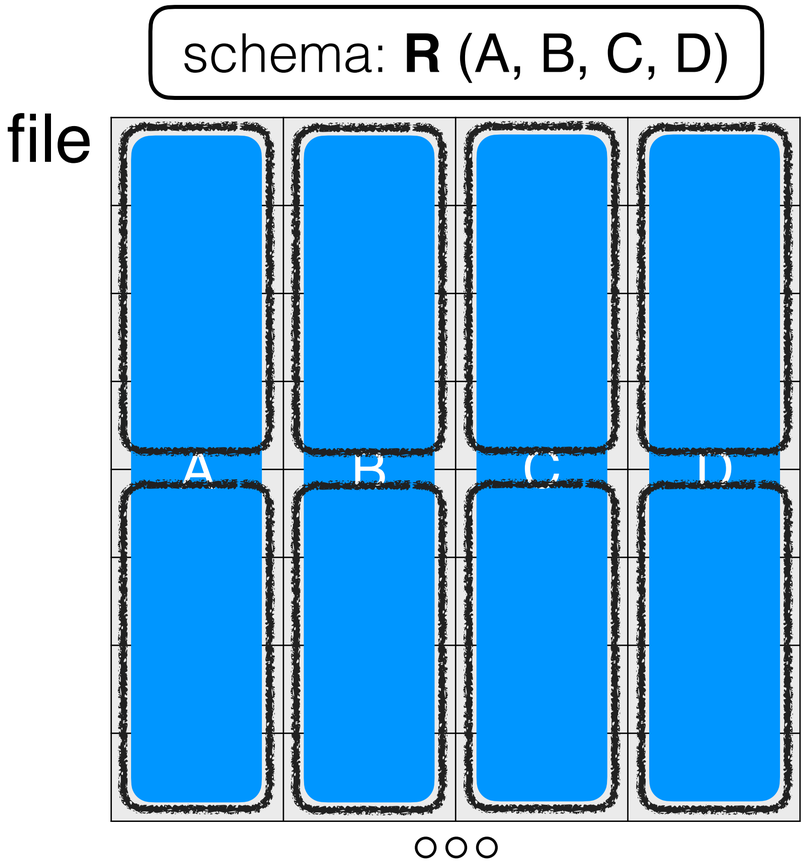
select A,B,C,D from R

Problem?

Tuple reconstruction

Querying over **slotted pages**

Understanding the schema



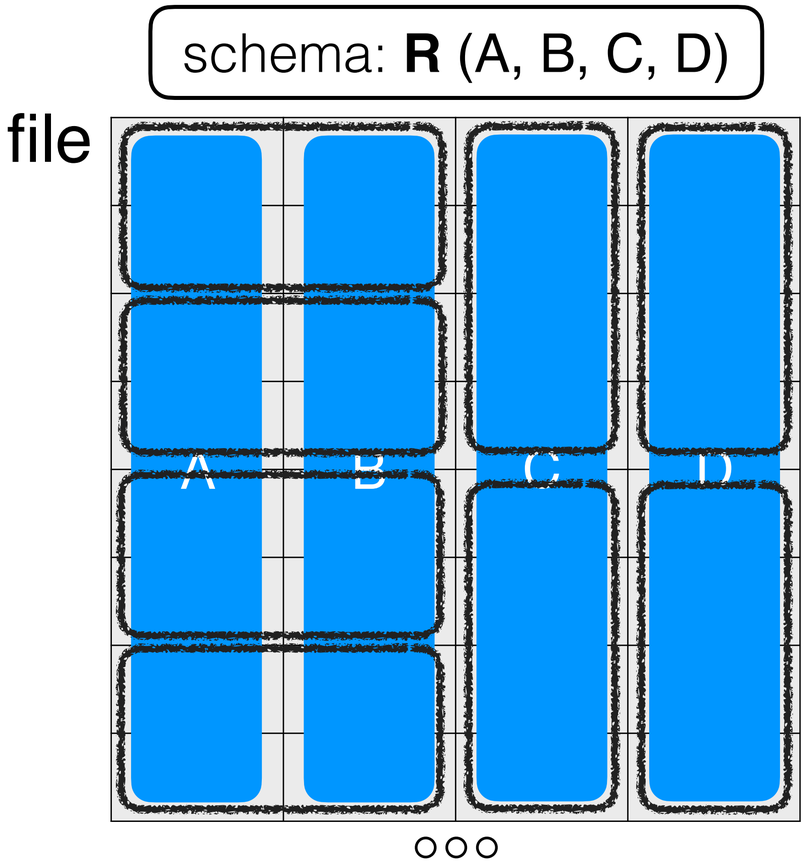
Thought Experiment 4

select A+B from R

Can we do something better?

Querying over **slotted pages**

Understanding the schema



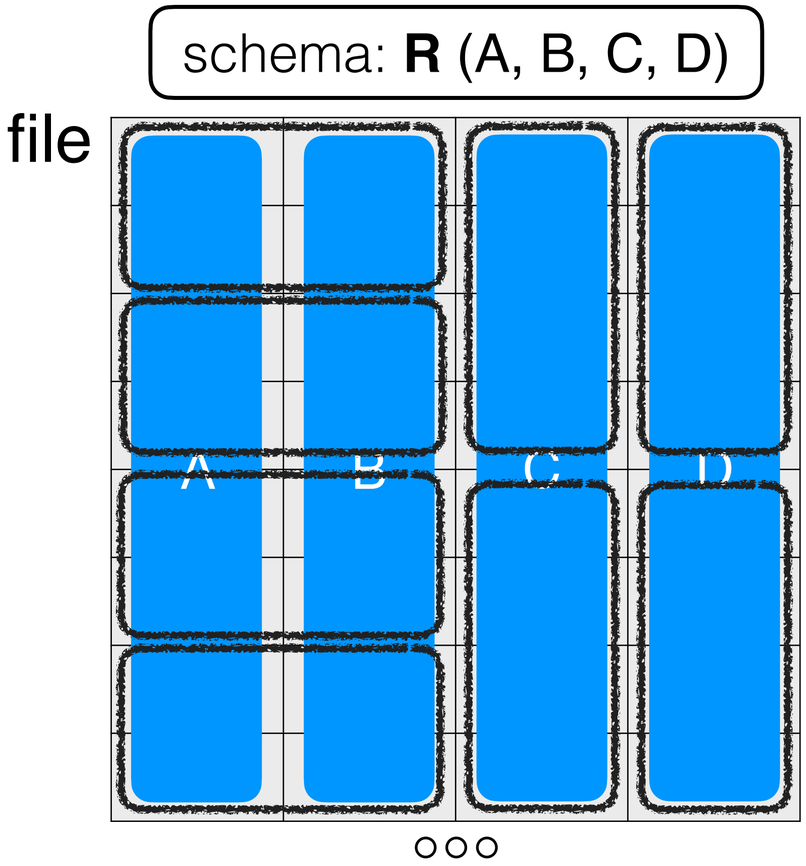
Thought Experiment 4

select A+B from R

Can we do something better?

Querying over **slotted pages**

Understanding the schema



Thought Experiment 5

select A+B from R
select A,B,C,D from R
select A from R

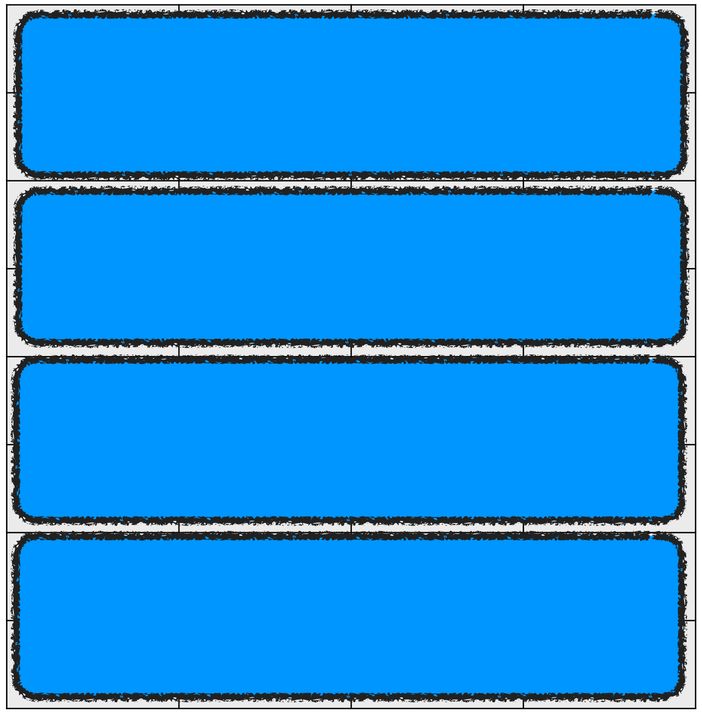
What if we have all three queries?

What if we only have inserts/updates?

Querying over **slotted pages**

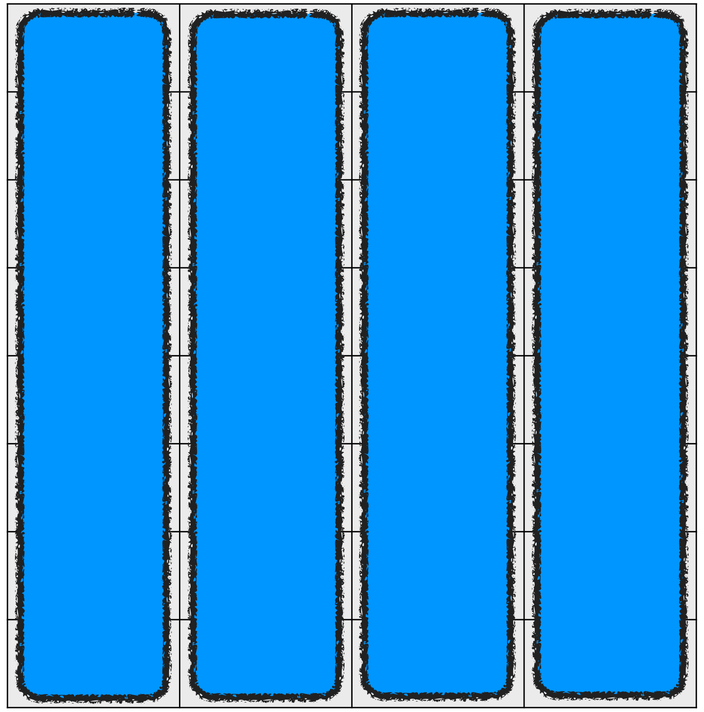
Understanding the schema

schema: **R** (A, B, C, D)



row store

schema: **R** (A, B, C, D)

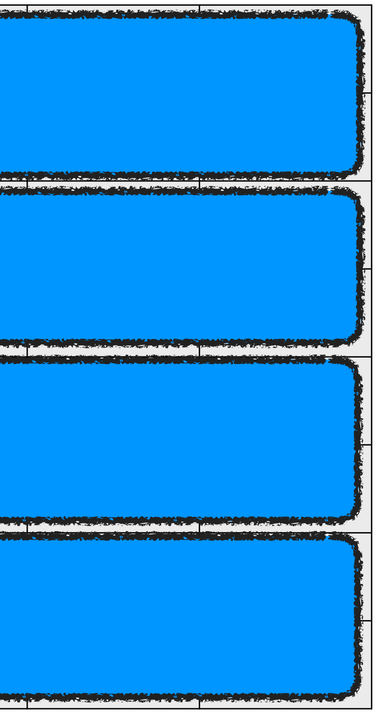


column store

Querying over **slotted pages**

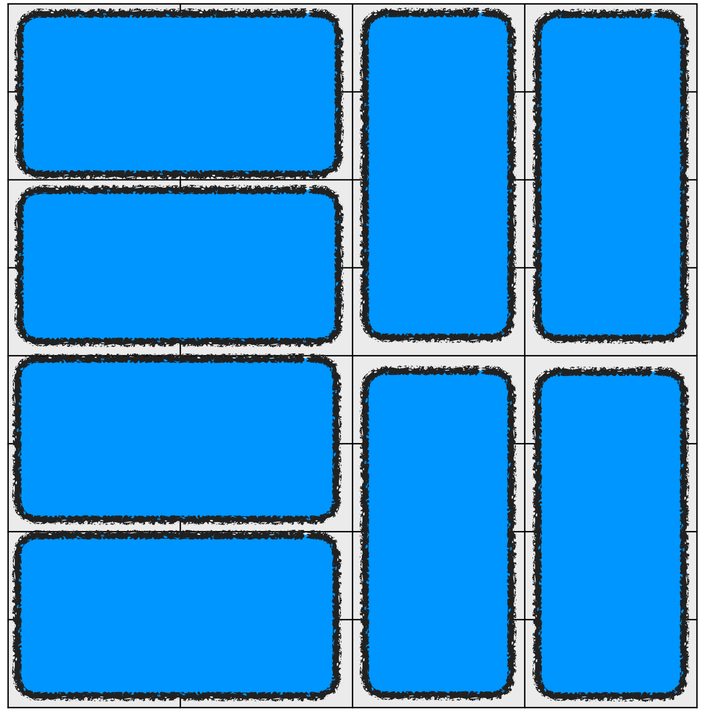
Understanding the schema

R (A, B, C, D)

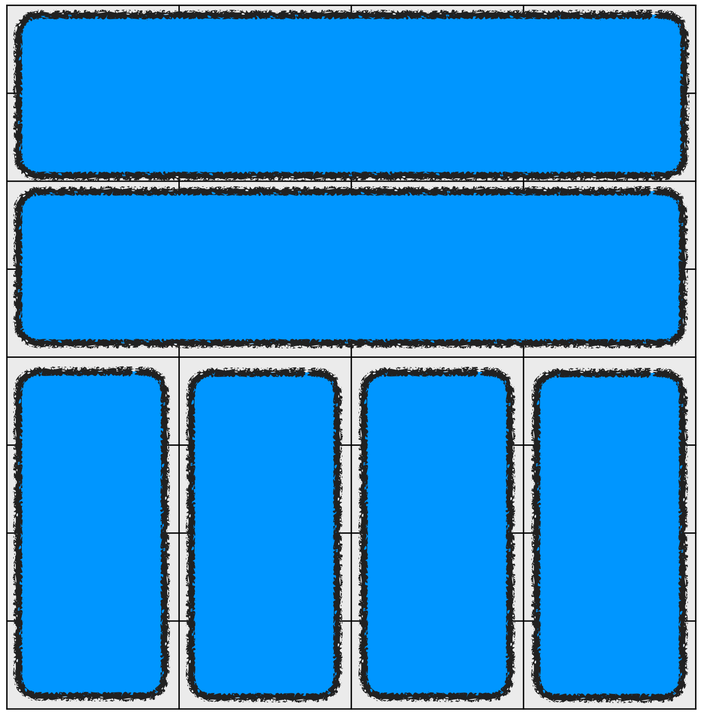


store

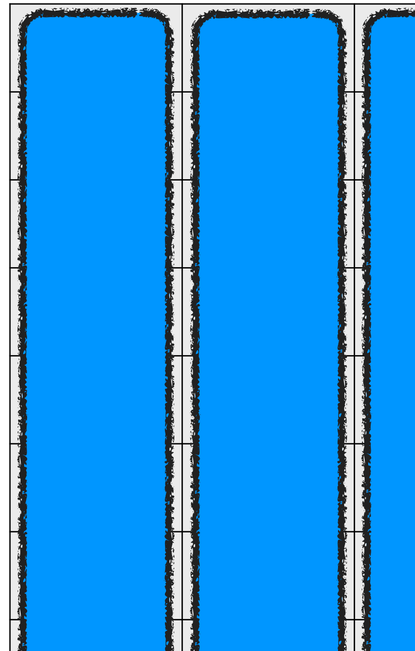
schema: **R** (A, B, C, D)



schema: **R** (A, B, C, D)



schema: **R** (A,



hybrid data layouts

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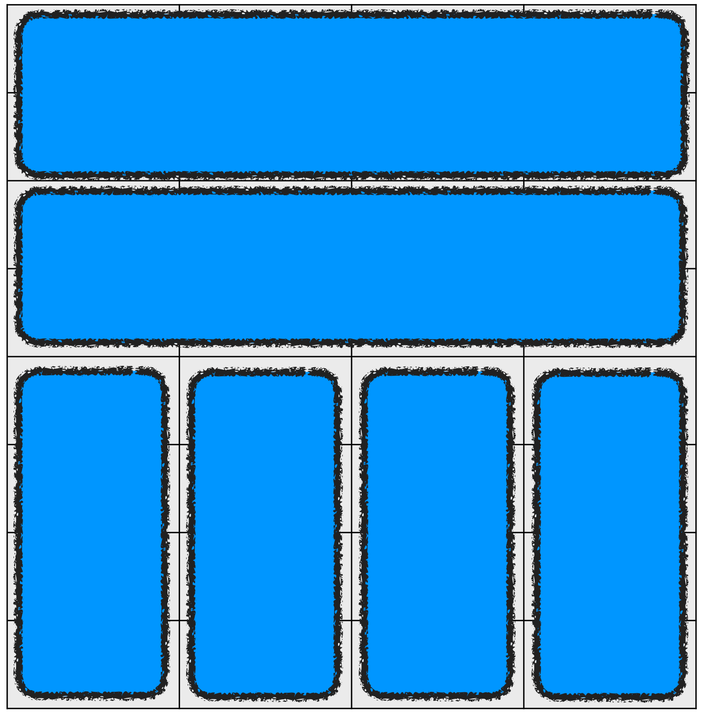
Querying over **slotted pages**

Understanding the schema

schema: **R** (A, B, C, D)



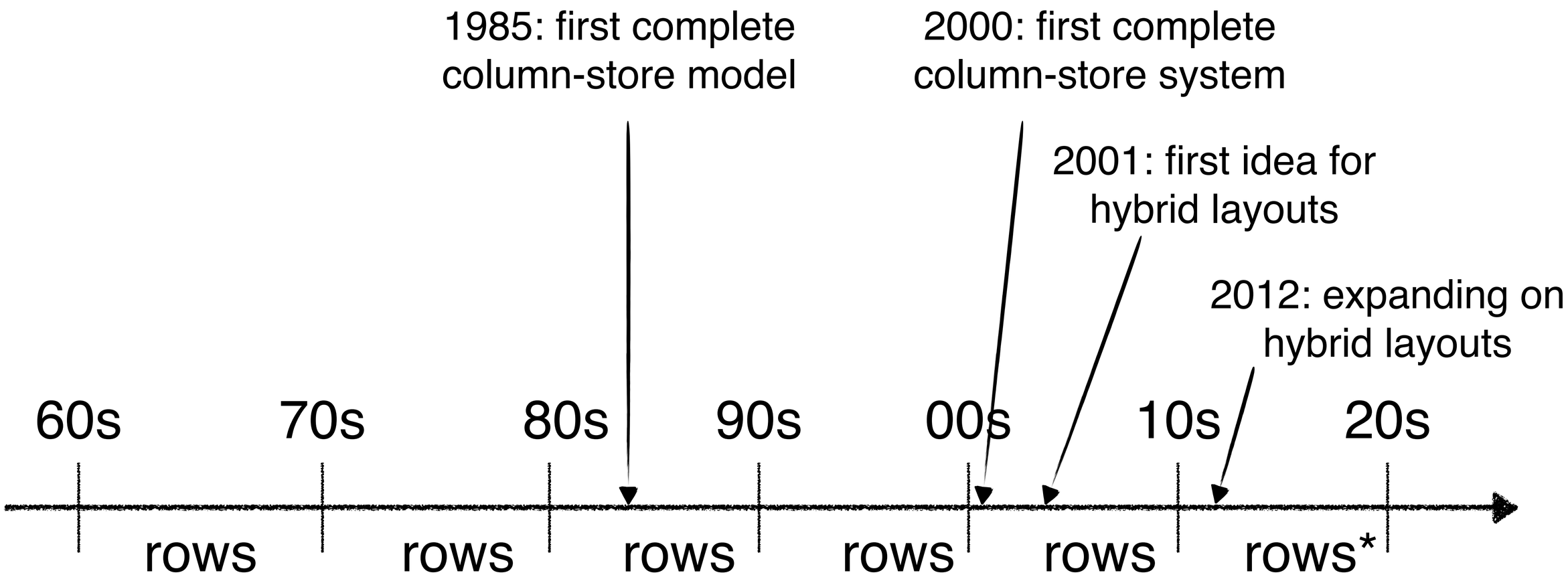
Thought Experiment 6

When would you have this data layout?

Queries on a subset of data

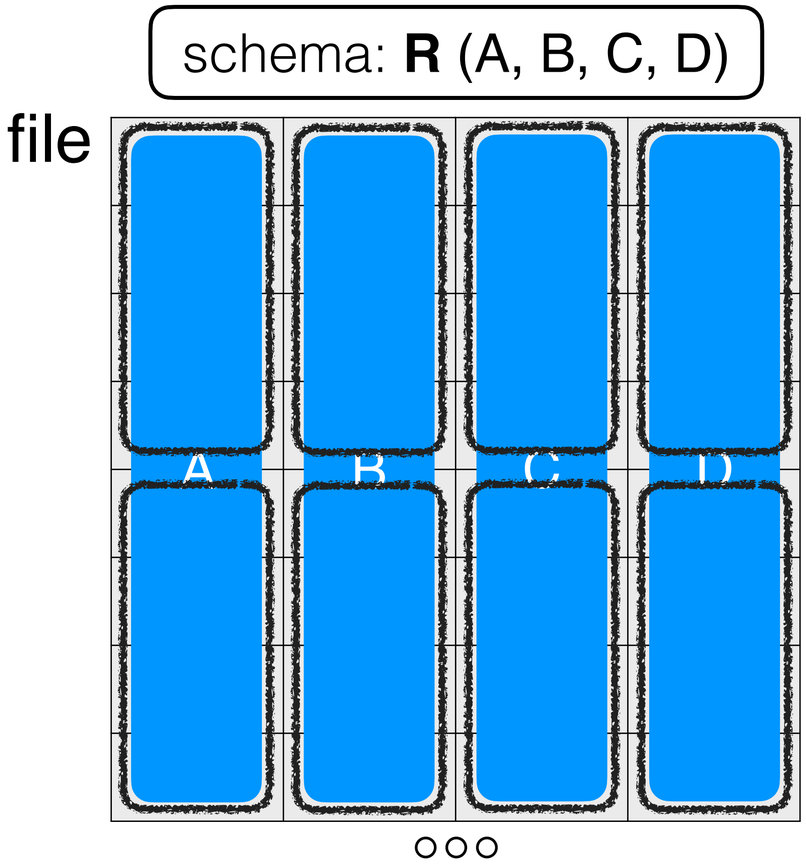
Evolution of column store

From row sotres to column stores



Querying over **slotted pages**

Understanding the schema



Thought Experiment

select max(B) from R
where A>5 and C<10

Home work!

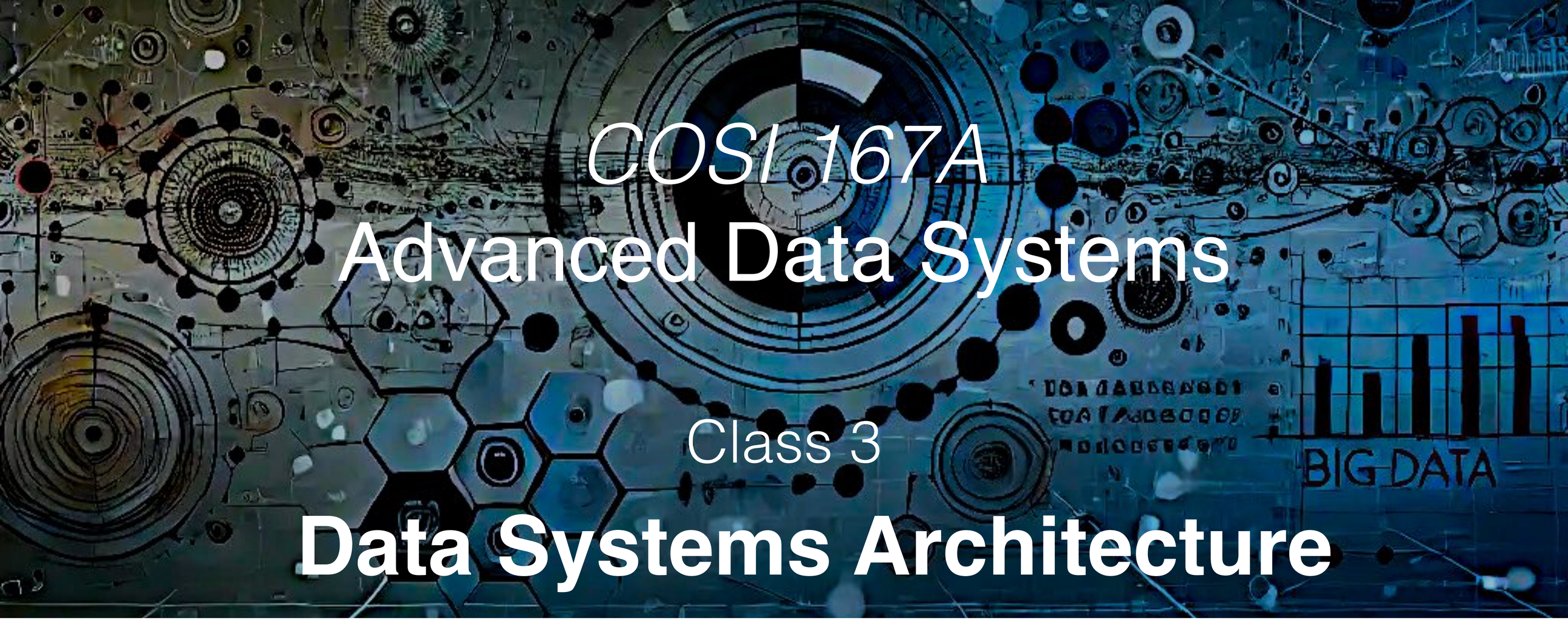
Next time in COSI 167A

Row stores vs. Column stores

[P] "Column-Stores vs. Row-Stores: How Different Are They Really?", *SIGMOD*, 2008

TECHNICAL QUESTION 1

[B] "C-Store: A Column-oriented DBMS", *VLDB*, 2005



COSI 167A
Advanced Data Systems

Class 3
Data Systems Architecture

Prof. Subhadeep Sarkar

Brandeis UNIVERSITY

https://ssd-brandeis.github.io/COSI-167A/

lab