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CS 591: Data Systems Architectures

class 3

Column-Stores Basics

Prof. Manos Athanassoulis

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

Project details are now on-line (more to come)

Google BigTable

APACHE HBASE

AsterixDB

Cassandra

amazon DynamoDB

RocksDB

Couchbase

mongoDB

detailed discussion on Thursday 1/31

Readings **for the project**

The Log-Structured Merge-Tree (LSM-Tree) by Patrick E. O'Neil, Edward Cheng, Dieter Gawlick, Elizabeth J. O'Neil. Acta Inf. 33(4): 351-385, 1996

Monkey: Optimal Navigable Key-Value Store by Niv Dayan, Manos Athanassoulis, Stratos Idreos. SIGMOD Conference 2017

More readings *(for some research projects)*

Measures of Presortedness and Optimal Sorting Algorithms by Heikki Mannila. IEEE Trans. Computers 34(4): 318-325 (1985)

Small Materialized Aggregates: A Light Weight Index Structure for Data Warehousing by Guido Moerkotte. VLDB 1998

The adaptive radix tree: ARTful indexing for main-memory databases by Viktor Leis, Alfons Kemper, Thomas Neumann. ICDE 2013: 38-49

programming language: C/C++

it gives you **control over exactly** what is happening
it helps you **learn the impact** of design decisions

avoid using libraries unless asked to do,
so you can control storage and access patterns

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Reviews

short review (up to half page)

Par. 1: what is the problem & why it is important

Par. 2: what is the main idea of the solution

long review (up to one page)

what is the problem & why it is important?

why is it hard & why older approaches are not enough?

what is key idea and why it works?

what is missing and how can we improve this idea?

does the paper supports its claims?

possible next steps of the work presented in the paper?

Presentations

for every class, **one or two students will be responsible for presenting** the paper (discussing all main points of a long review – see next slide)

during the presentation **anyone can ask questions** (including me!) and each question is **addressed to all** (including me!)

the presenting student(s) will **prepare slides and questions**

what to do now?

A) read the syllabus and the website

B) register to piazza

C) register to gradescope/blackboard

D) register for the presentation (week 2)

E) start submitting paper reviews (week 3)

F) go over the project (more details on the way)

G) start working on the mid-semester report (week 3)

survival guide

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

piazza website: http://piazza.com/bu/spring2019/cs591a1/

presentation registration: https://tinyurl.com/CASCS591A1-presentations

Blackboard website: https://tinyurl.com/CS591A1-blackboard

office hours: Manos (Tu/Th, 2-3pm), Subhadeep (M/W 2-3pm)

material: papers available from BU network

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how can I prepare?

1) Read background research material

- **Architecture of a Database System**. By J. Hellerstein, M. Stonebraker and J. Hamilton. Foundations and Trends in Databases, 2007
- **The Design and Implementation of Modern Column-store Database Systems**. By D. Abadi, P. Boncz, S. Harizopoulos, S. Idreos, S. Madden. Foundations and Trends in Databases, 2013
- **Massively Parallel Databases and MapReduce Systems**. By Shivnath Babu and Herodotos Herodotou. Foundations and Trends in Databases, 2013

2) Start going over the papers

Database Design Abstraction Levels

Logical Design

Physical Design

System Design

Data can be messy!

clean ⇨ schema ⇨ …

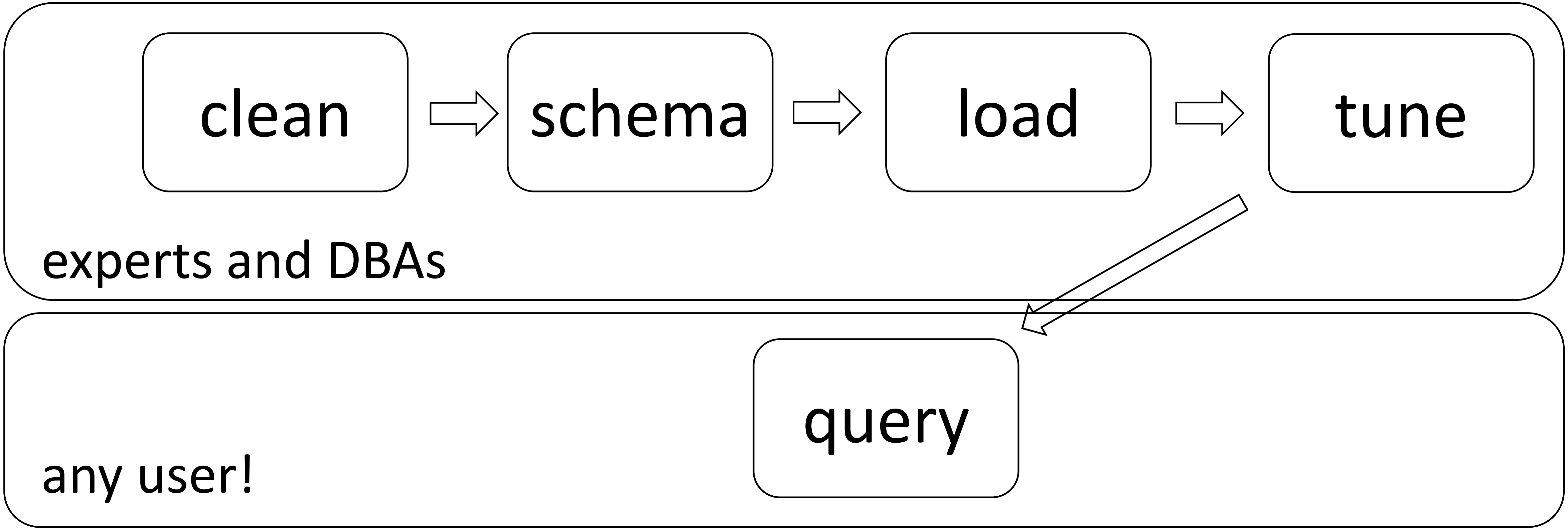
Data can be messy!

clean ⇨ schema ⇨ load ⇨ …

Data can be messy!

clean → schema → load → tune

Data can be messy!



Database Design Abstraction Levels

Logical Design

Physical Design

System Design

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Logical design

What is our data? How to model them?

Hierarchical? Network? Object-oriented? Flat? Key-Value?

Relational!

A collection of **tables**, each being a collection of **rows and columns**

[schema: describes the columns of each table]

Logical design

What is our data? How to model them?

graph data
time-series data

A collection of **tables**, each being a collection of **rows and columns**

[schema: describes the columns of each table]

Logical Schema of "University" Database

Students

***sid**: string, **name**: string, **login**: string, **year_birth**: integer, **gpa**: real*

Courses

***cid**: string, **cname**: string, **credits**: integer*

Enrolled

***sid**: string, **cid**: string, **grade**: string*

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Relational Model and SQL

relations

keys

Students

sid: *string*, ***name***: *string*, ***login***: *string*, ***year_birth***: *integer*, ***gpa***: *real*

Courses

cid: *string*, ***cname***: *string*, ***credits***: *integer*

Enrolled

sid: *string*, ***cid***: *string*, ***grade***: *string*

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Relational Model and SQL

how to create the table students?

create table *students (sid:char(10), name:char(40), login:char(8), age:integer, …)*

Students

sid*: string,* ***name****: string,* ***login****: string,* ***year_birth****: integer,* ***gpa****: real*

how to add a new student?

insert into *students (U1398217312, John Doe, john19, 19, …)*

Courses

cid*: string,* ***cname****: string,* ***credits****: integer*

bring me the names of all students

select *name* ***from*** *students* ***where*** *GPA > 3.5*

Enrolled

sid*: string,* ***cid****: string,* ***grade****: string*

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Relational Model and SQL

student

(sid1, name1, login1, year1, gpa1)
(sid2, name2, login2, year2, gpa2)
(sid3, name3, login3, year3, gpa3)
(sid4, name4, login4, year4, gpa4)
(sid5, name5, login5, year5, gpa5)
(sid6, name6, login6, year6, gpa6)
(sid7, name7, login7, year7, gpa7)
(sid8, name8, login8, year8, gpa8)
(sid9, name9, login9, year9, gpa9)

insert into student (sid1, name1, login1, year1, gpa1)

cardinality: 9

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Relational Model and SQL

student

(sid1, name1, login1, year1, gpa1)
(sid2, name2, login2, year2, gpa2)
(sid3, name3, login3, year3, gpa3)
(sid4, name4, login4, year4, gpa4)
(sid5, name5, login5, year5, gpa5)
(sid6, name6, login6, year6, gpa6)
(sid7, name7, login7, year7, gpa7)
(sid8, name8, login8, year8, gpa8)
(sid9, name9, **login9**, year9, gpa9)

insert into student (sid1, name1, login1, year1, gpa1)

cardinality: 9

what if a student does not have their login yet?

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Relational Model and SQL

student

(sid1, name1, login1, year1, gpa1)
(sid2, name2, login2, year2, gpa2)
(sid3, name3, login3, year3, gpa3)
(sid4, name4, login4, year4, gpa4)
(sid5, name5, login5, year5, gpa5)
(sid6, name6, login6, year6, gpa6)
(sid7, name7, login7, year7, gpa7)
(sid8, name8, login8, year8, gpa8)
(sid9, name9, **NULL**, year9, gpa9)

insert into student (sid1, name1, login1, year1, gpa1)

cardinality: 9

what if a student does not have their login yet?

NULL values do not exist

Relational Model and SQL

how to show all enrollments in CS591A1?

keys

Students

***sid**: string, **name**: string, **login**: string, **year_birth**: integer, **gpa**: real*

Courses

***cid**: string, **cname**: string, **credits**: integer*

Enrolled

***sid**: string, **cid**: string, **grade**: string*

Relational Model and SQL

how to show all enrollments in CS591A1?

Students

***sid**: string, **name**: string, **login**: string, **year_birth**: integer, **gpa**: real*

Courses

***cid**: string, **cname**: string, **credits**: integer*

Enrolled

***sid**: string, **cid**: string, **grade**: string*

foreign keys

using foreign keys we can join information of all three tables

select student.name
from students, courses, enrolled
where course.cname="CS591A1"
and course.cid=enrolled.cid
and student.sid=enrolled.sid

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Database Design Abstraction Levels

Logical Design

Physical Design

System Design

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Physical Design

File Organization

heap files

sorted files

clustered files

more …

Indexes

should I build?

on which attributes/tables?

what index structure?

B-Tree

Tries

Hash

Bitmap

Zonemaps

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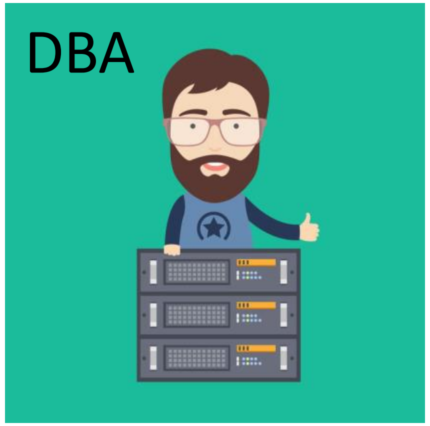
Data systems are declarative!



ask ***what*** you want

data system

system decides ***how***
to store & access

design decisions, physical design
indexing, tuning knobs

research to automate!

adaptivity

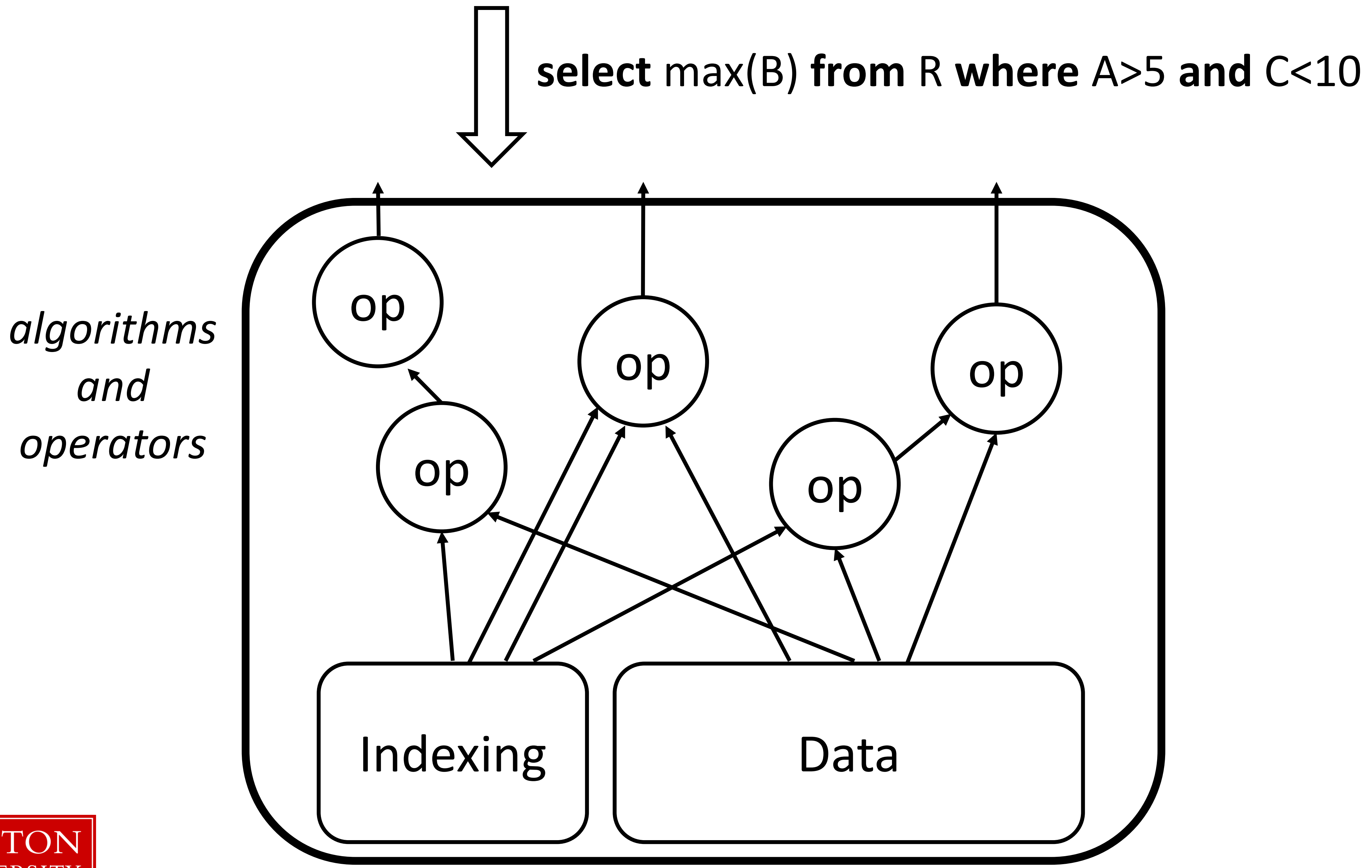
autotuning

Database Design Abstraction Levels

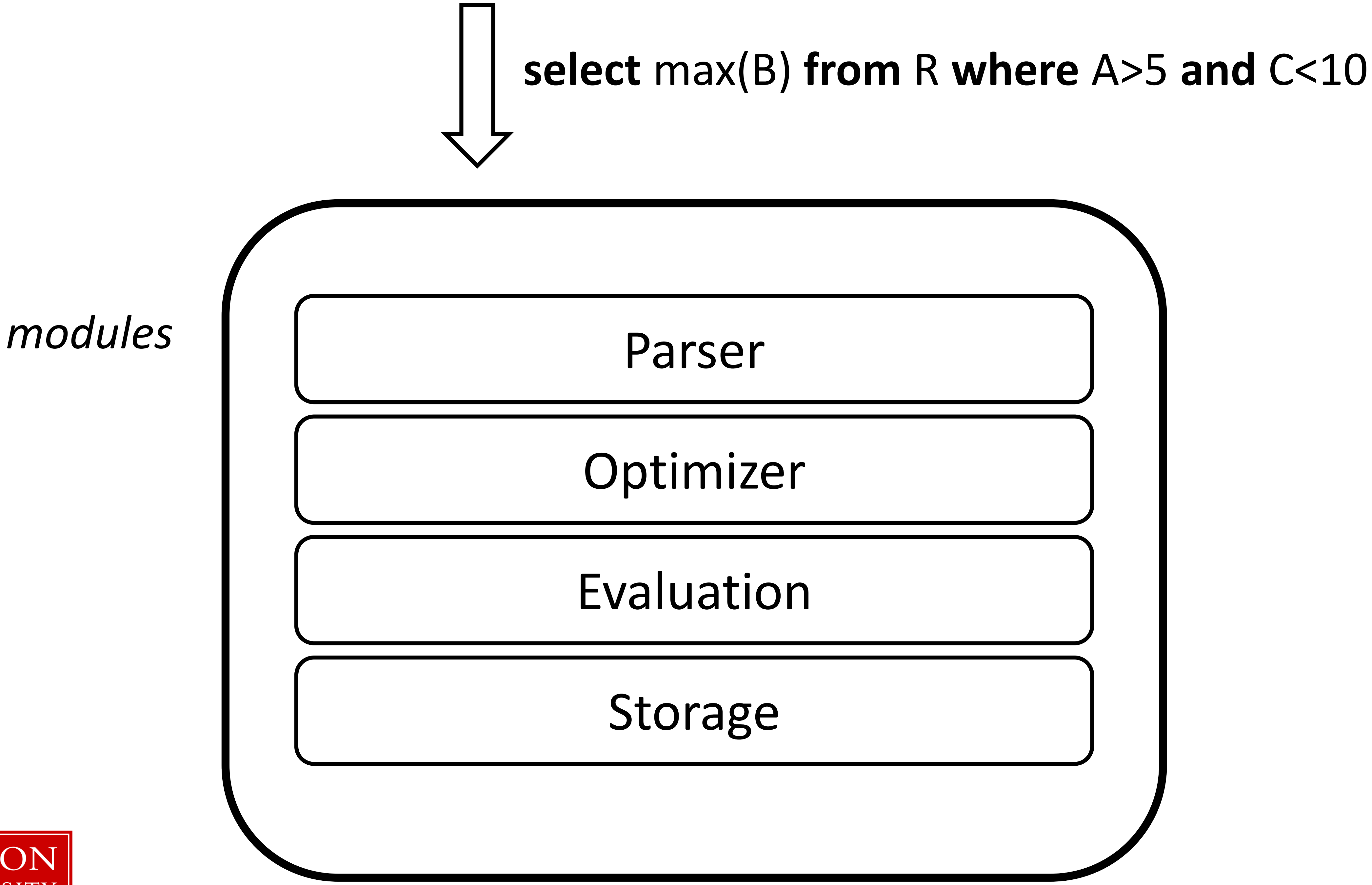
Logical Design

Physical Design

System Design



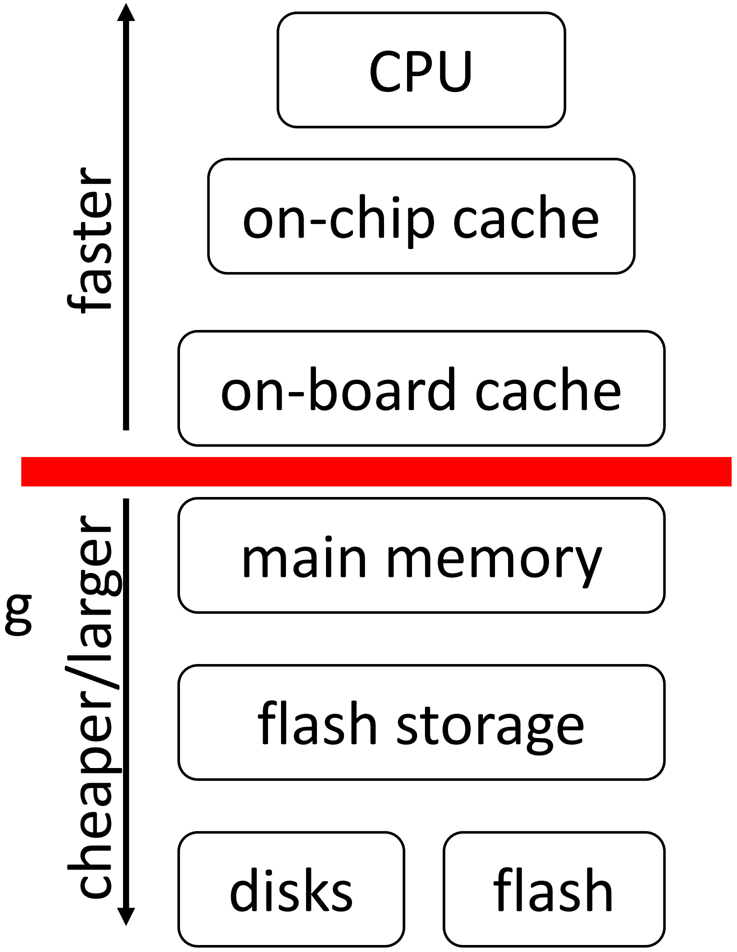
select max(B) **from** R **where** A>5 **and** C<10
algorithms
and
operators
op
op
op
op
op
op
Indexing
Data

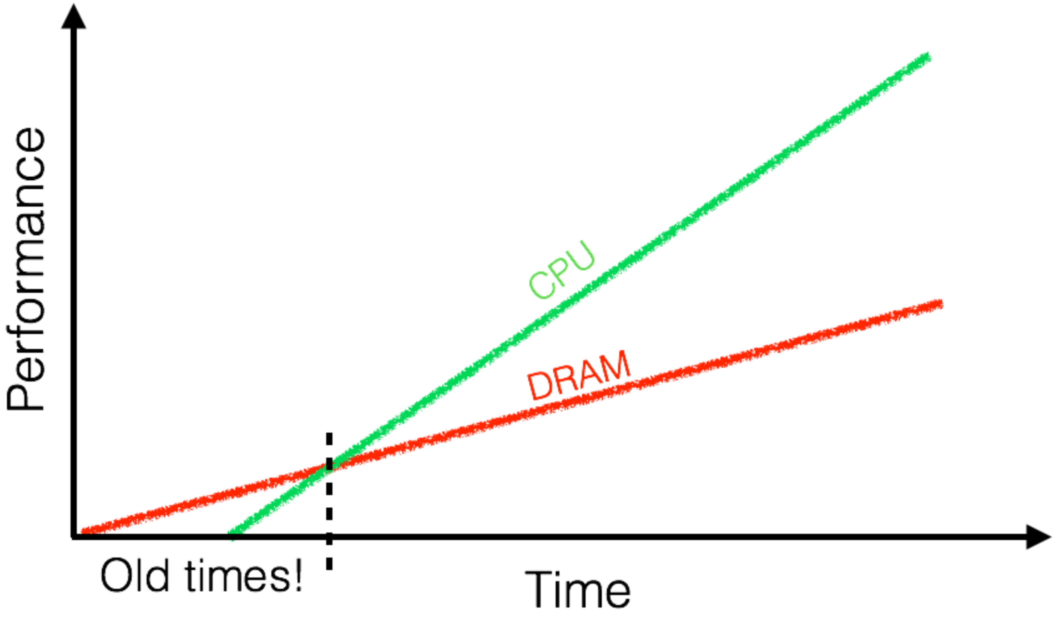

select max(B) **from** R **where** A>5 **and** C<10
modules
Parser
Optimizer
Evaluation
Storage

memory wall

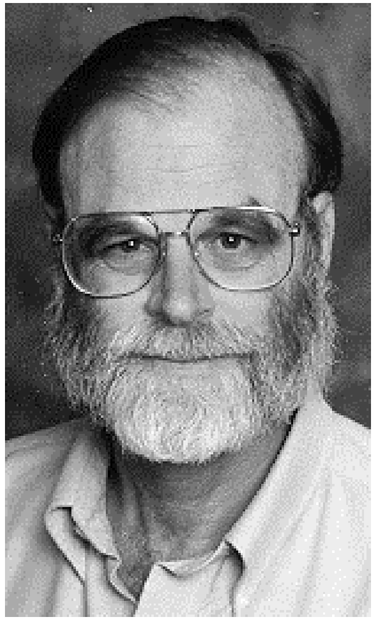
cache miss: looking for something that is not in the cache

memory miss: looking for something that is not in memory





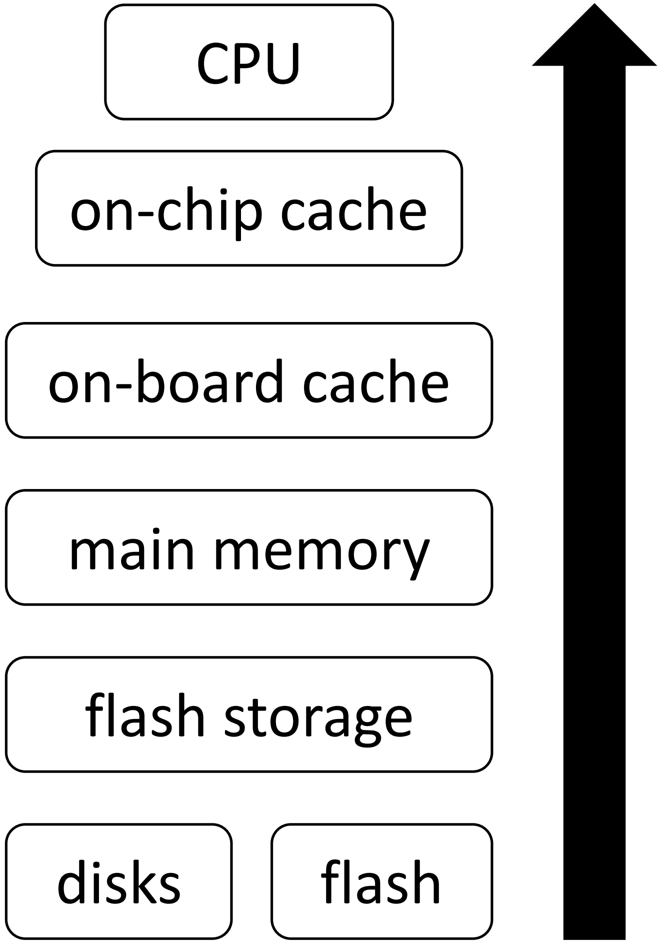
memory hierarchy (by Jim Gray)



	registers/CPU	my head	~0
2x	on chip cache	this room	1min
10x	on board cache	this building	10min
100x	memory	Washington, DC	5 hours
10^6x	disk	Pluto	2 years
10^9x	tape	Andromeda	2000 years

Jim Gray, IBM, Tandem, Microsoft, DEC
"The Fourth Paradigm" is based on his vision
ACM Turing Award 1998
ACM SIGMOD Edgar F. Codd Innovations award 1993

data movement & page-based access

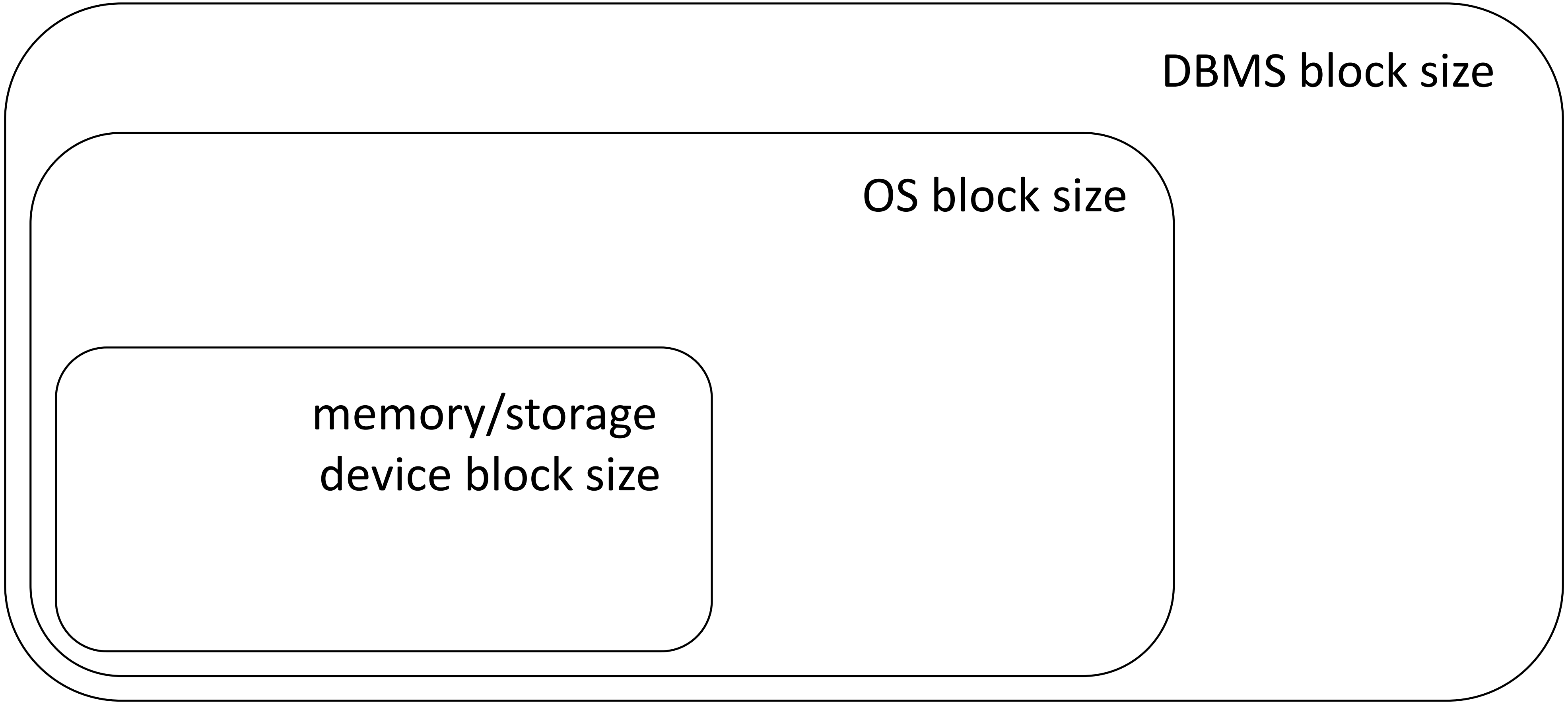


data go through
all necessary levels

also read
unnecessary data

need to read only X
read the whole page

access granularity



file system and DBMS "pages"

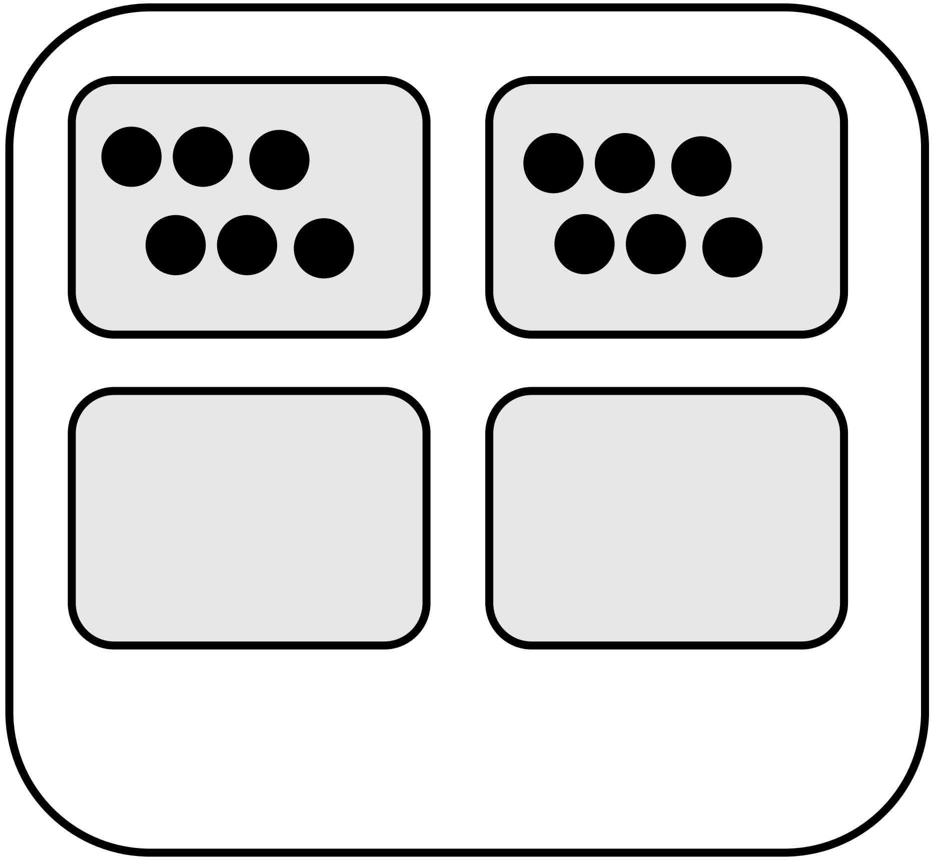
data storage

how to physically place data?

*Student (**sid**: string, **name**: string, **login**: string, **year_birth**: integer, **gpa**: real)*

student

(sid1, name1, login1, year1, gpa1)
(sid2, name2, login2, year2, gpa2)
(sid3, name3, login3, year3, gpa3)
(sid4, name4, login4, year4, gpa4)
(sid5, name5, login5, year5, gpa5)
(sid6, name6, login6, year6, gpa6)
(sid7, name7, login7, year7, gpa7)
(sid8, name8, login8, year8, gpa8)
(sid9, name9, login9, year9, gpa9)



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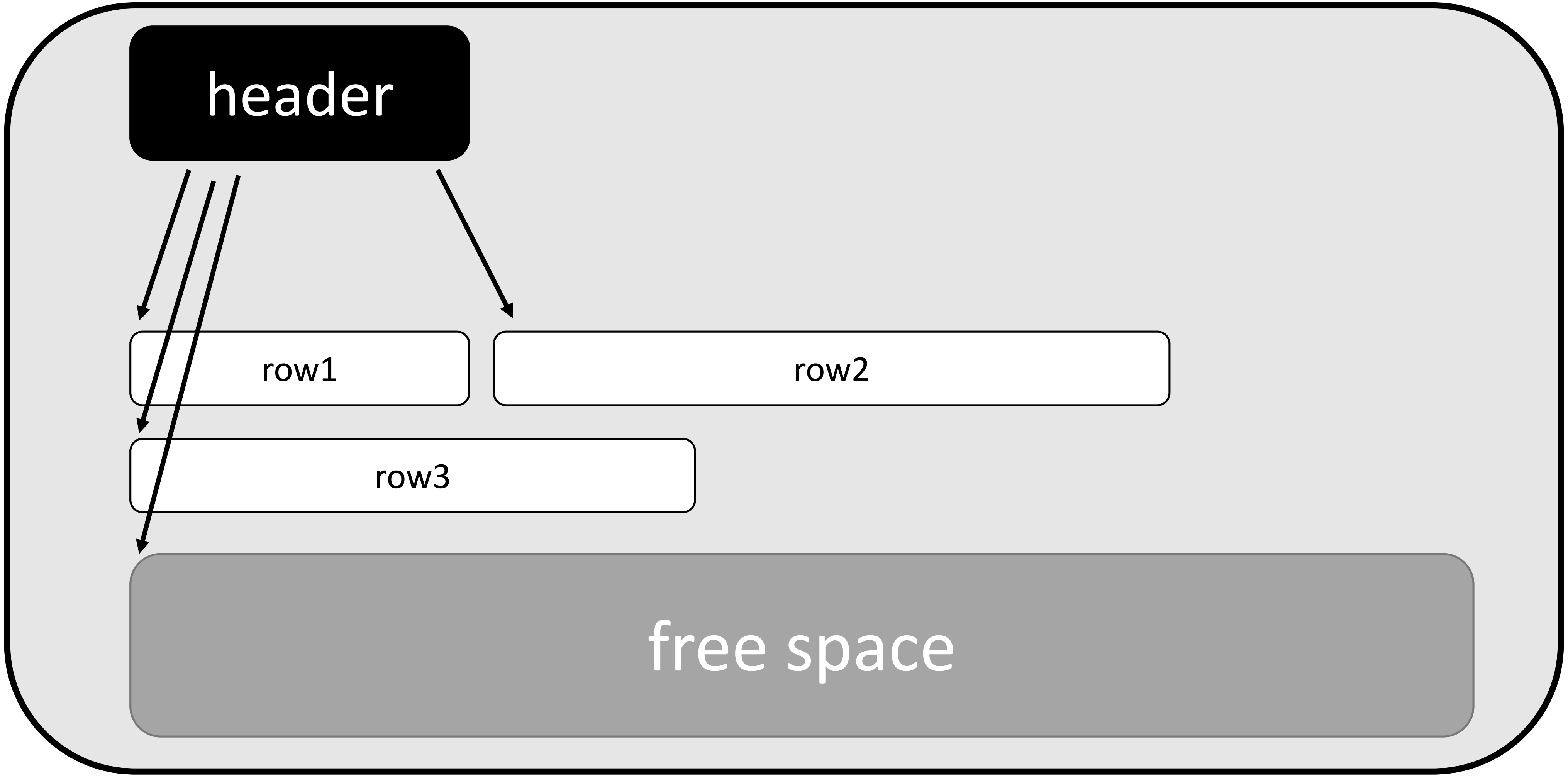
slotted page



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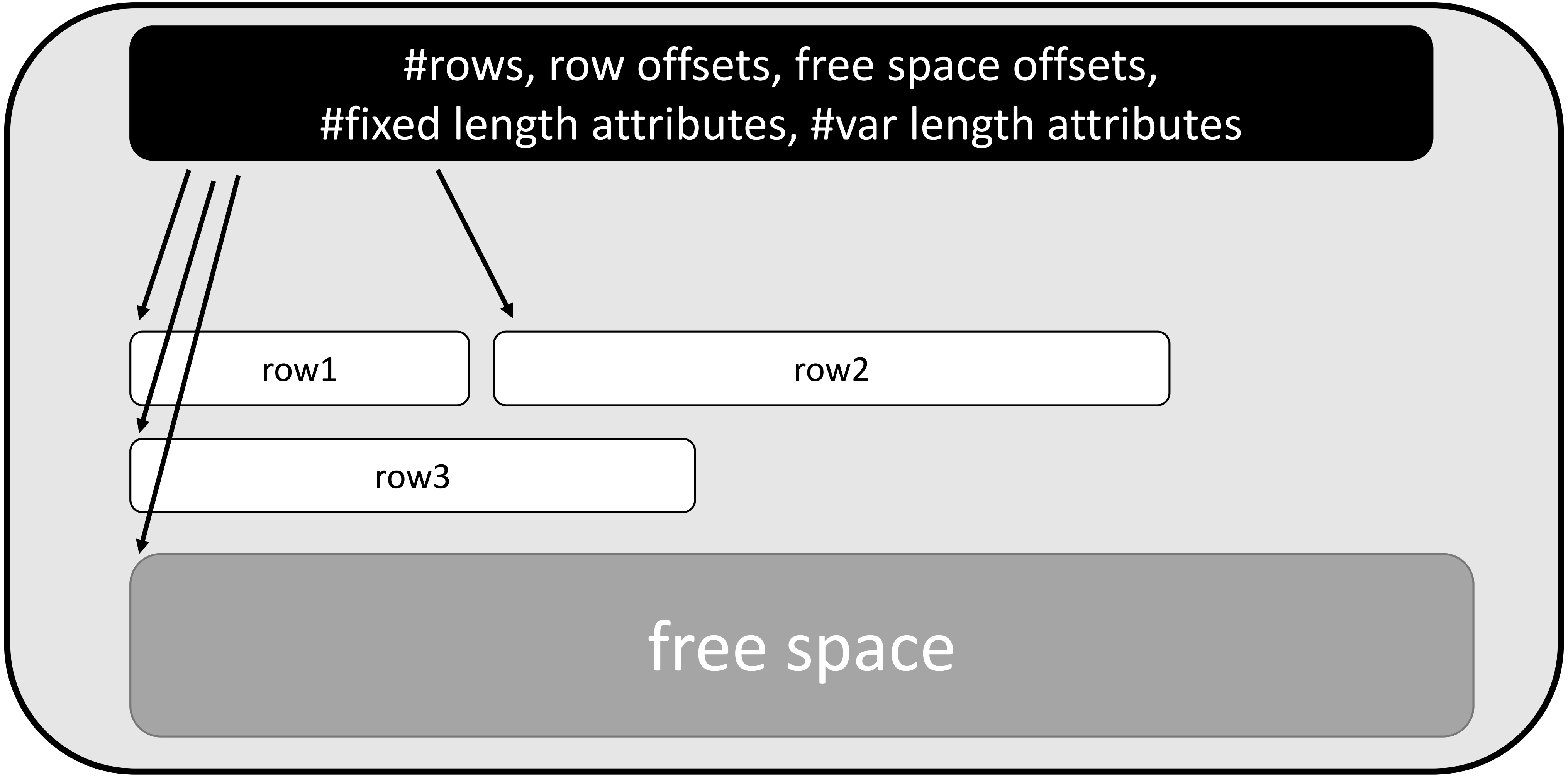
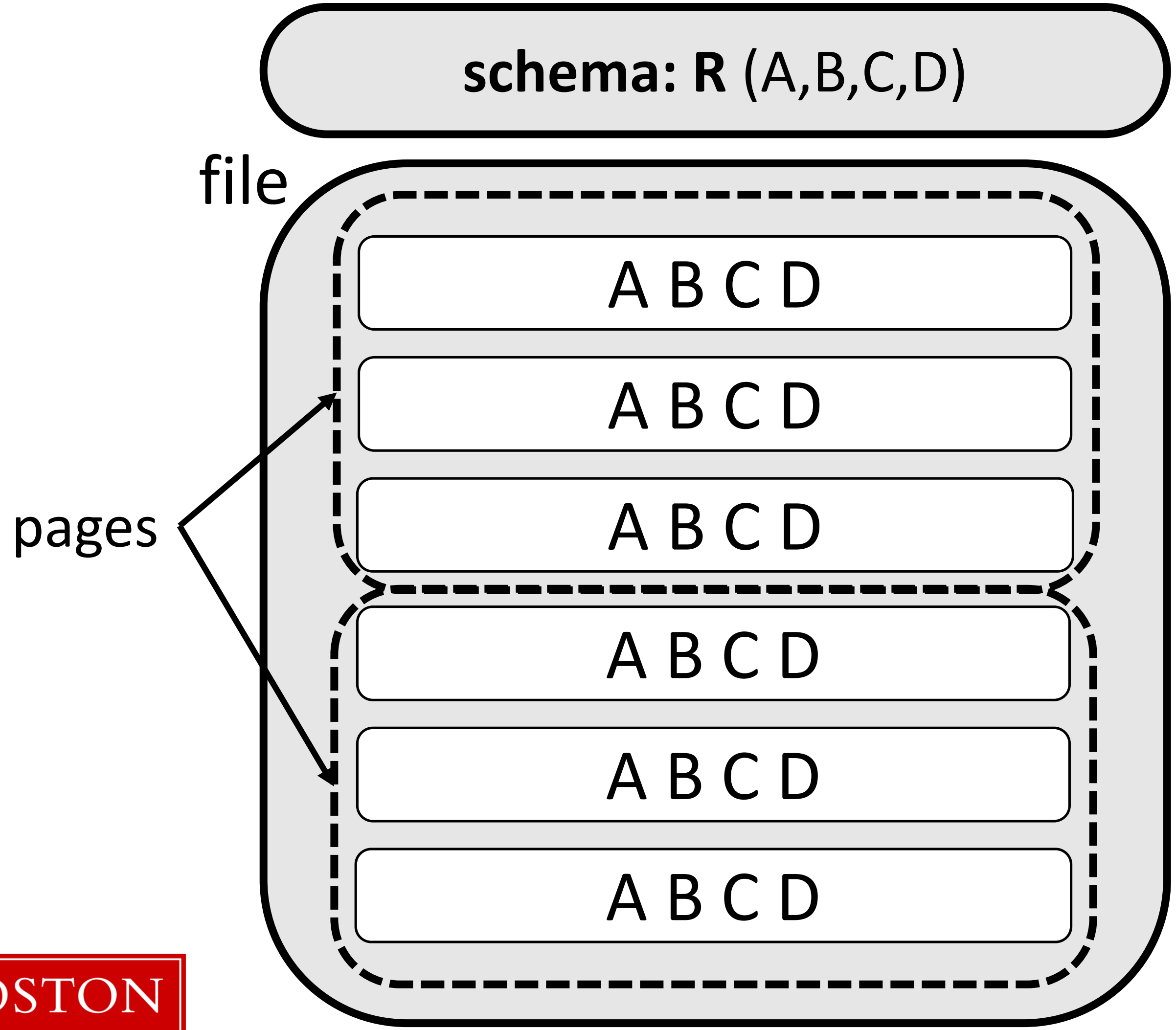
slotted page



querying over slotted pages



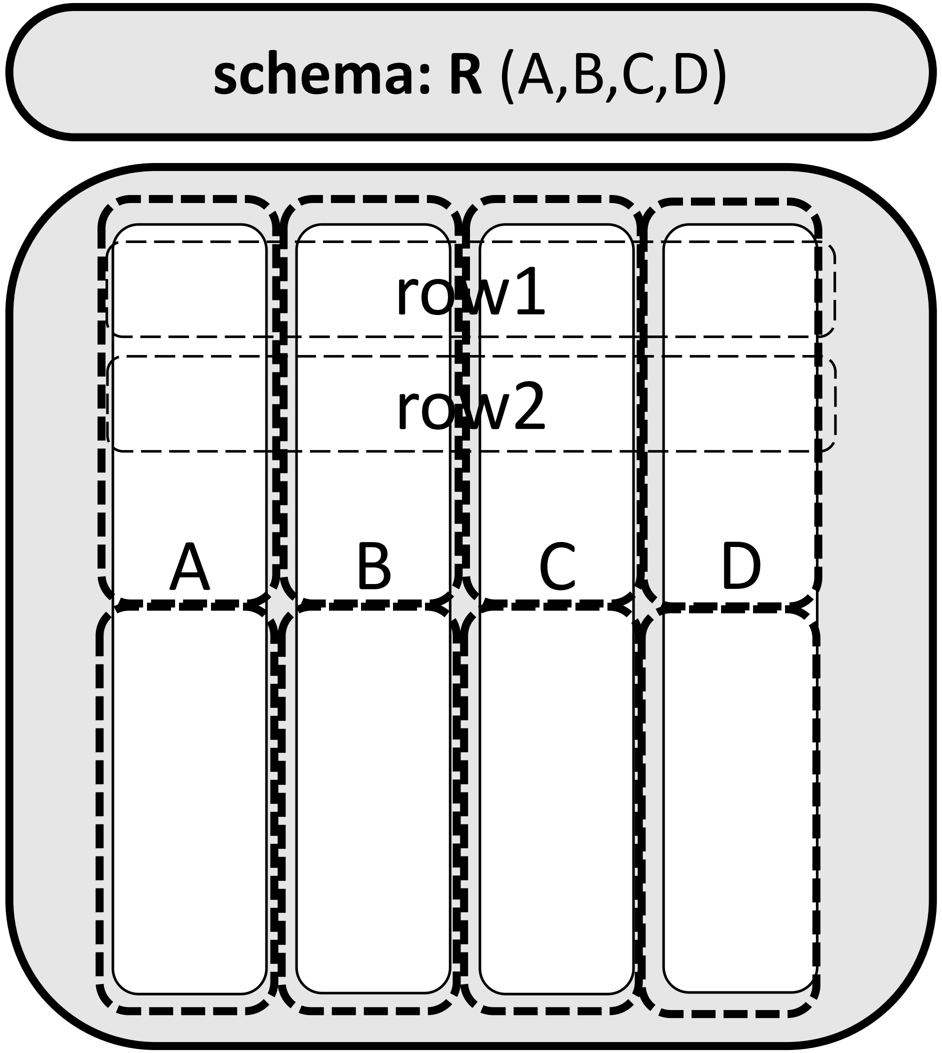
select A,B,C,D **from** R

select A **from** R

each page contains **entire** rows (all their columns)

rows are **contiguous**
(with possible free space at the end)

querying over slotted pages



each page contains **columns!**

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

select A **from** R

select (A+B) **from** R

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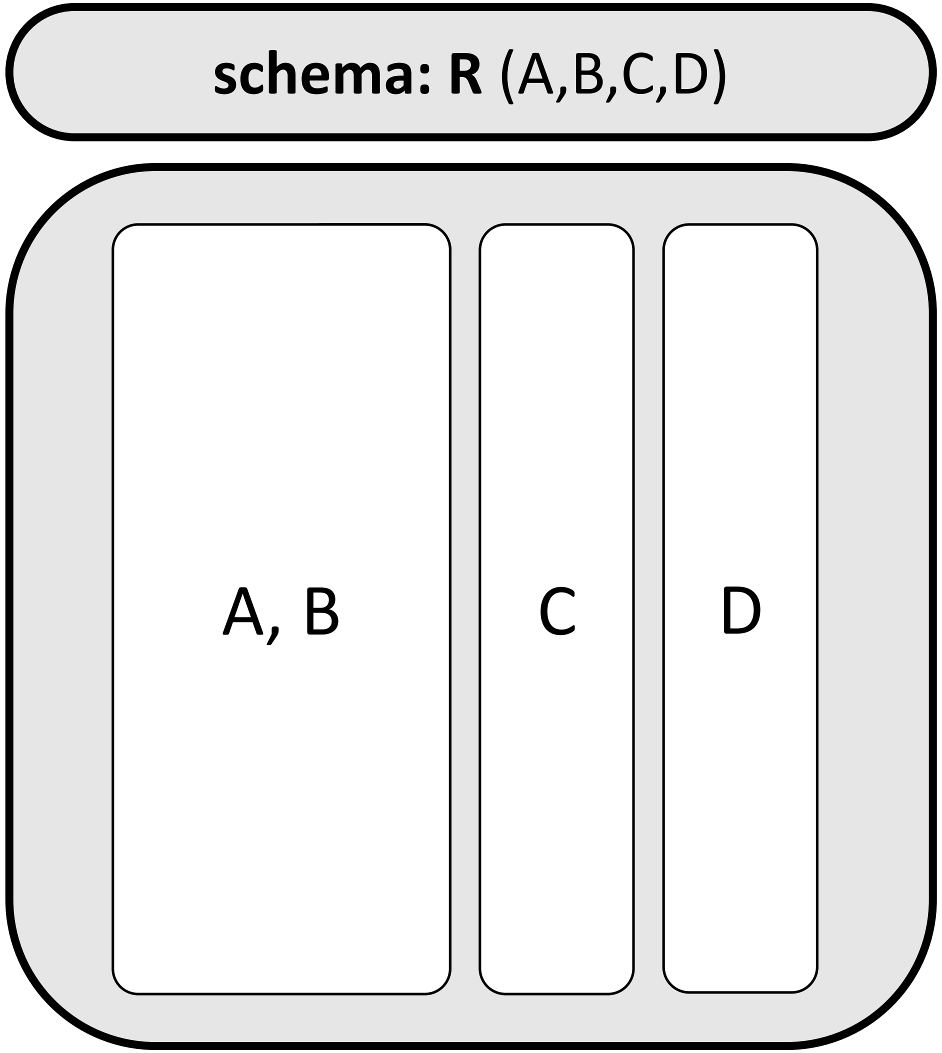
querying over slotted pages



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

select A **from** R

select (A+B) **from** R

each page contains **columns** or ***groups of columns*!**

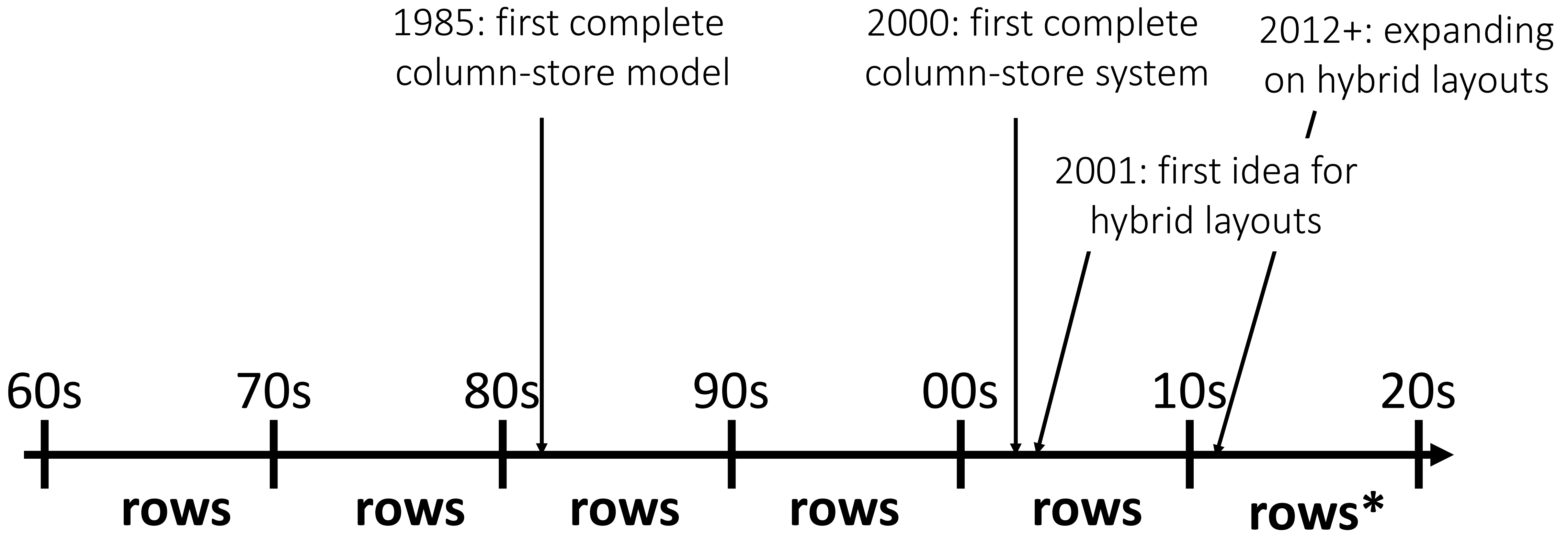
what if I had both queries?

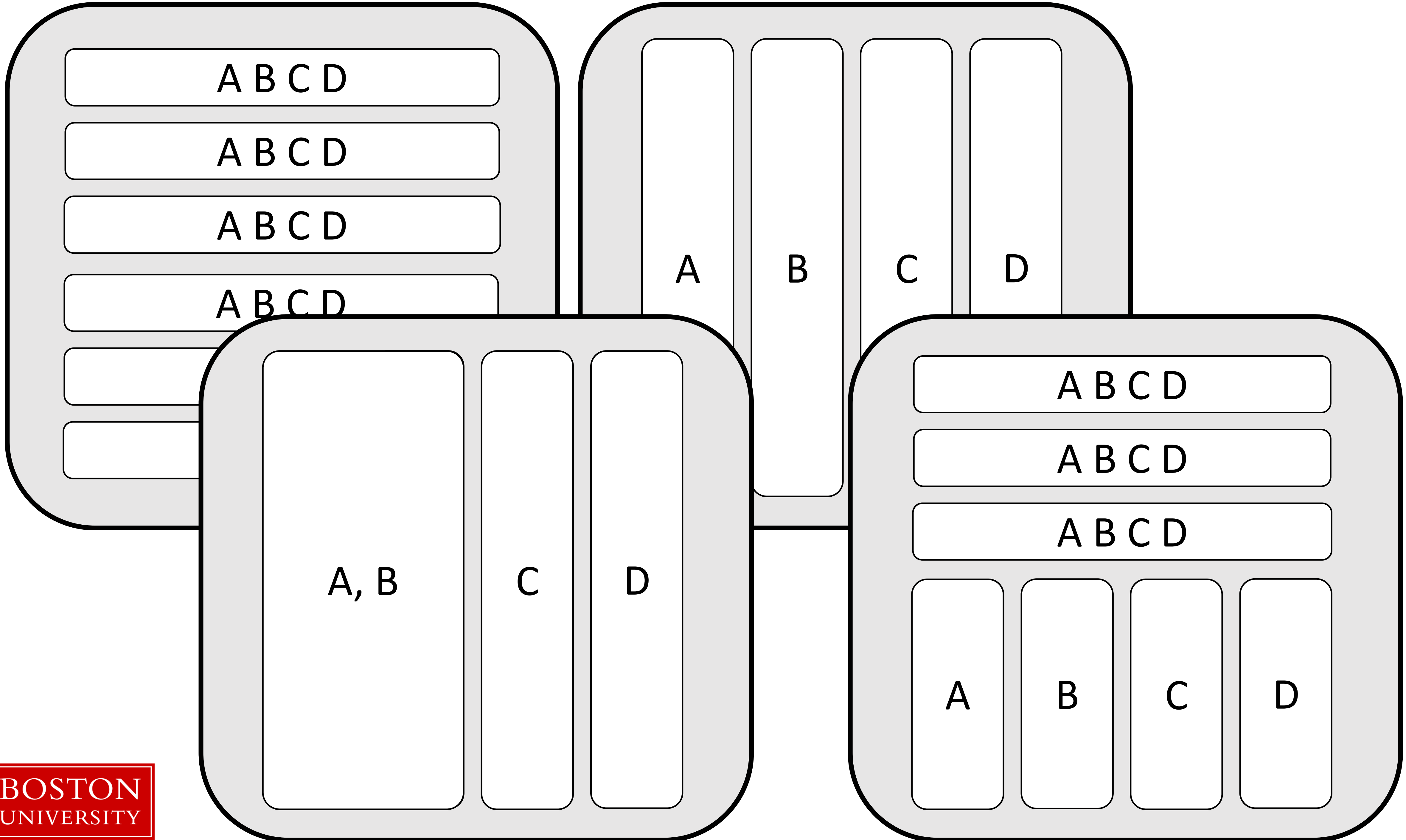
not clear!

other hybrids?

what if only inserts?

column-stores history line





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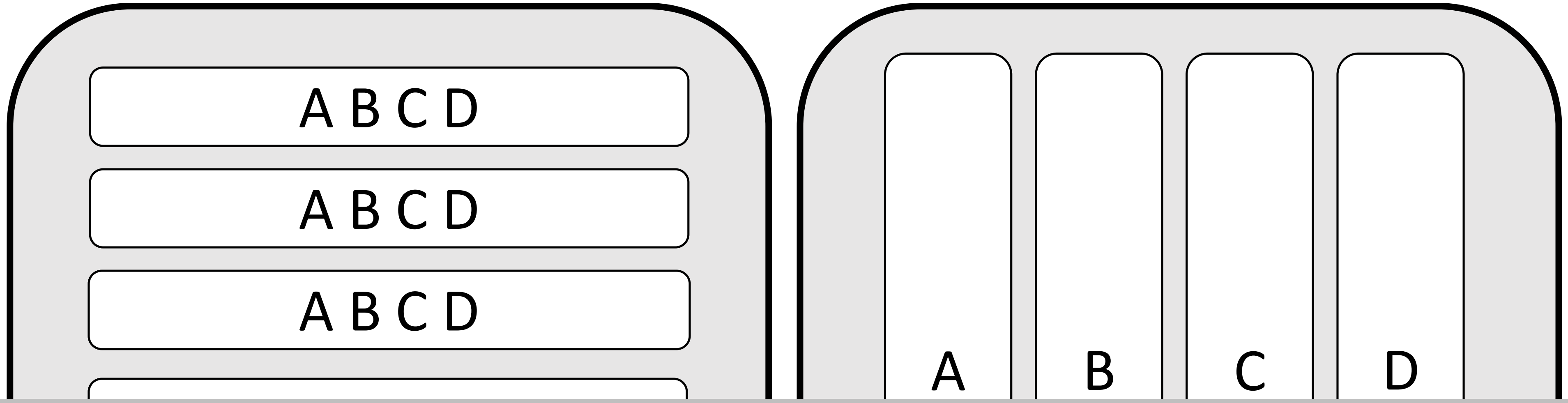
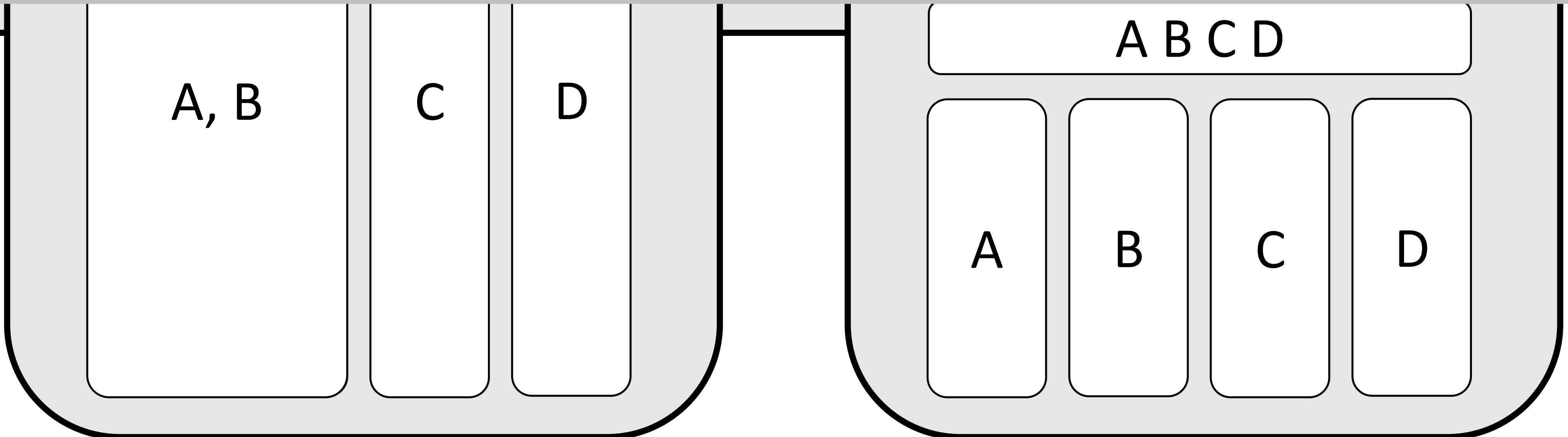


the way we physical store data dictates
what are the possible efficient access methods



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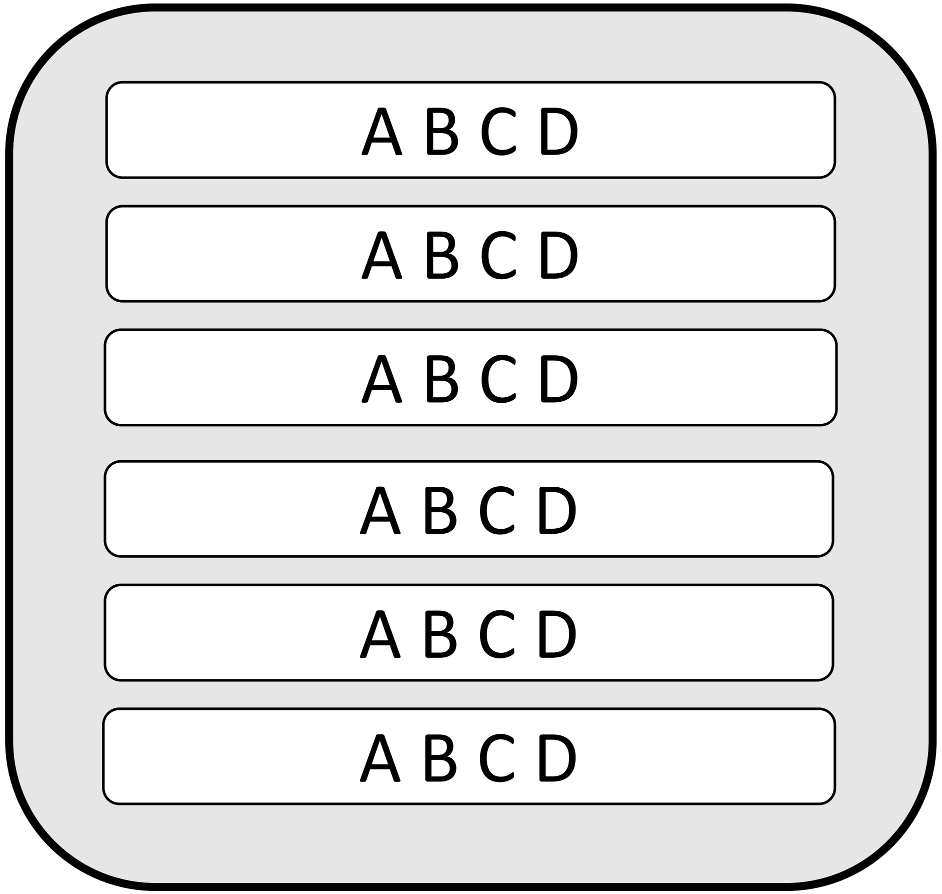
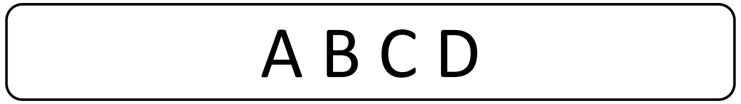
query evaluation

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





one row at a time

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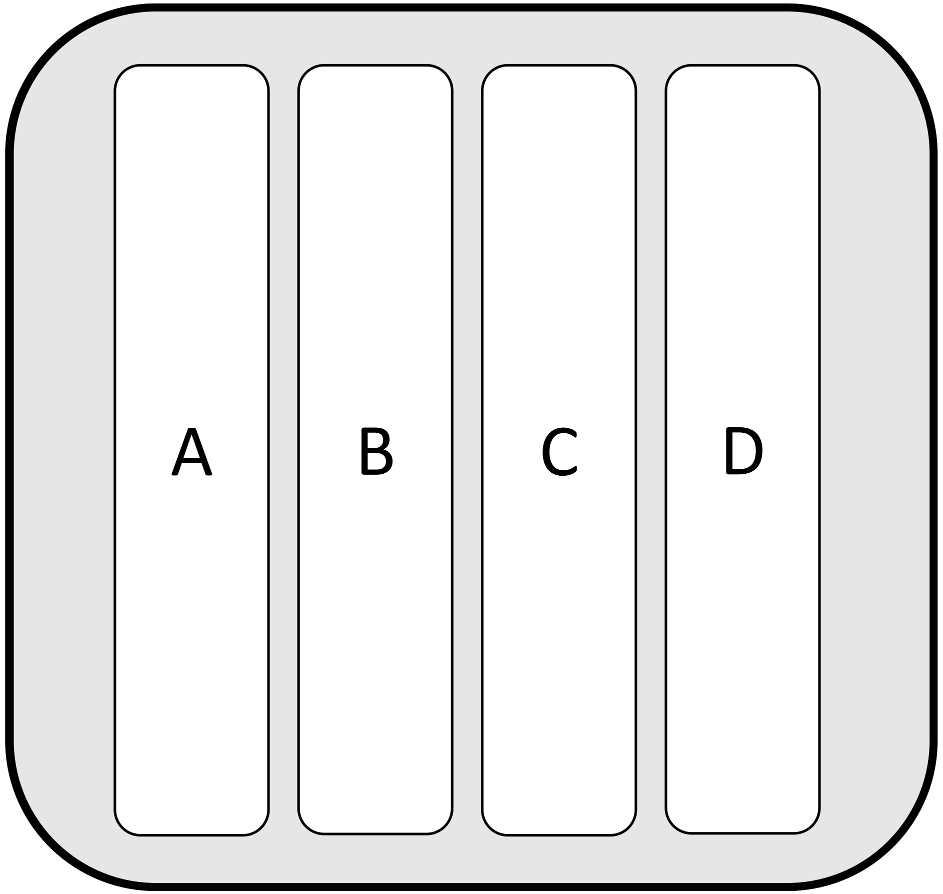
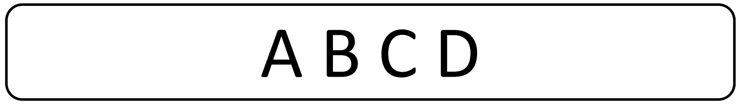
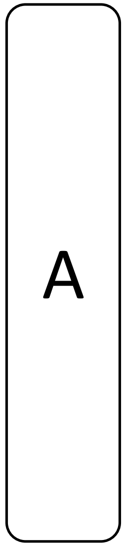


select max(B) **from** R **where** A>5 **and** C<10

tuple reconstruction/early materialization



one row at a time



late materialization

column at a time

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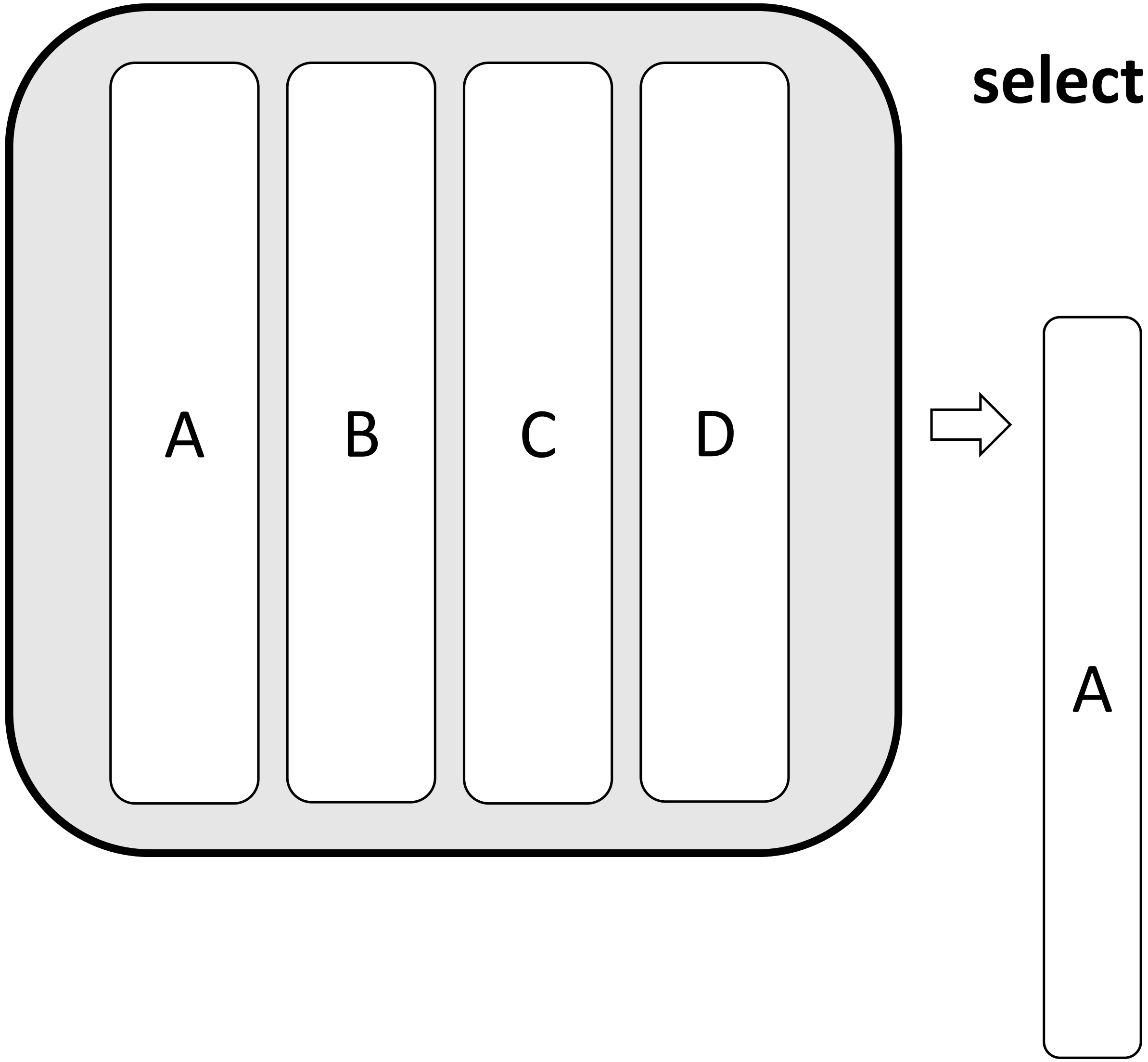
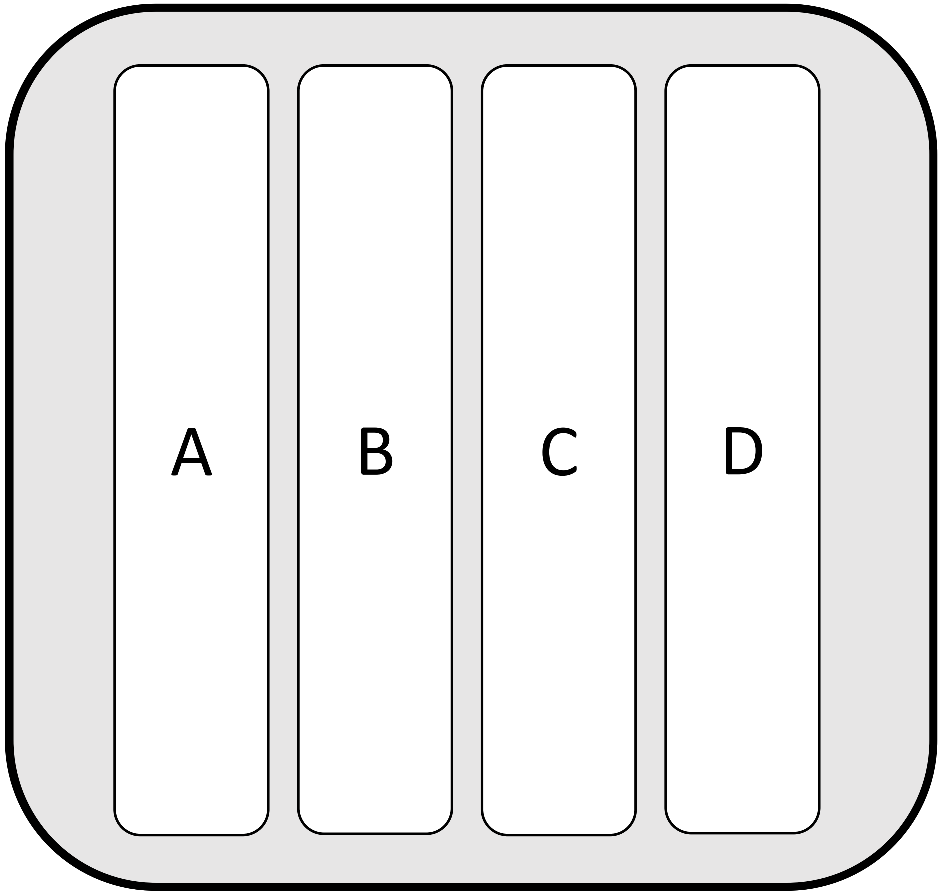
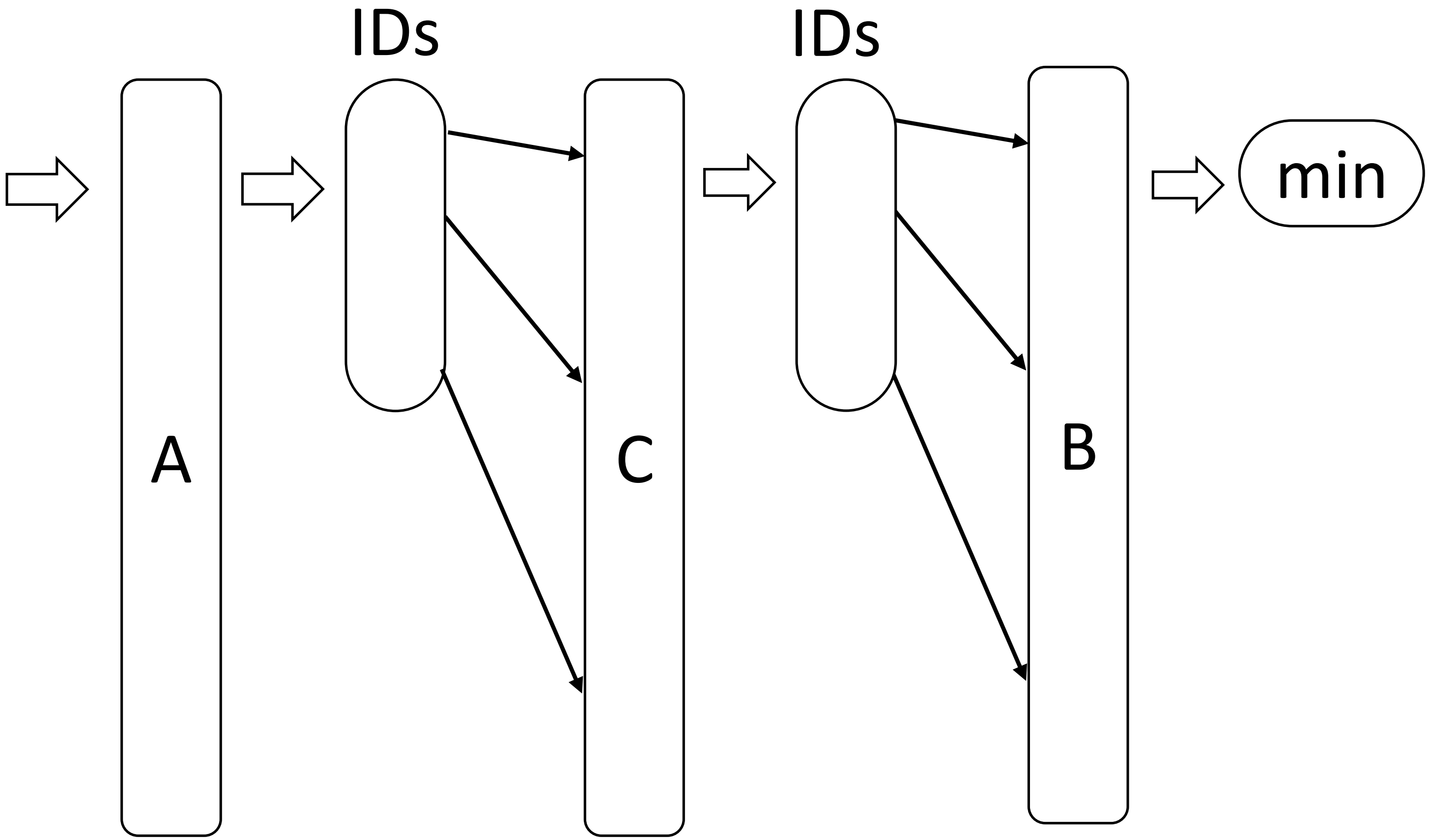
select max(B) **from** R **where** A>5 **and** C<10




```
int* input=A;
int* output; /*needs allocation*/
for (i=0; i<num_tuples; i++,input++)
    if (*input>5)
    {
        *output=i;
        outpt++;
    }
```

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





sequential access patterns

read only useful data

what is the benefit?

easy to code: working over fixed width and dense columns

scan

```
for (i=0,j=0; i<size; i++)
    if (column[i] qualifies)
        res[j++]=i;
```

no complex checks

no function calls

no aux metadata

easy to prefetch

as few ifs as possible

fetch

```
for (i=0,j=0; i<fetch_size; i++)
    intermediate_result[j++]=column[ids[i]];
```

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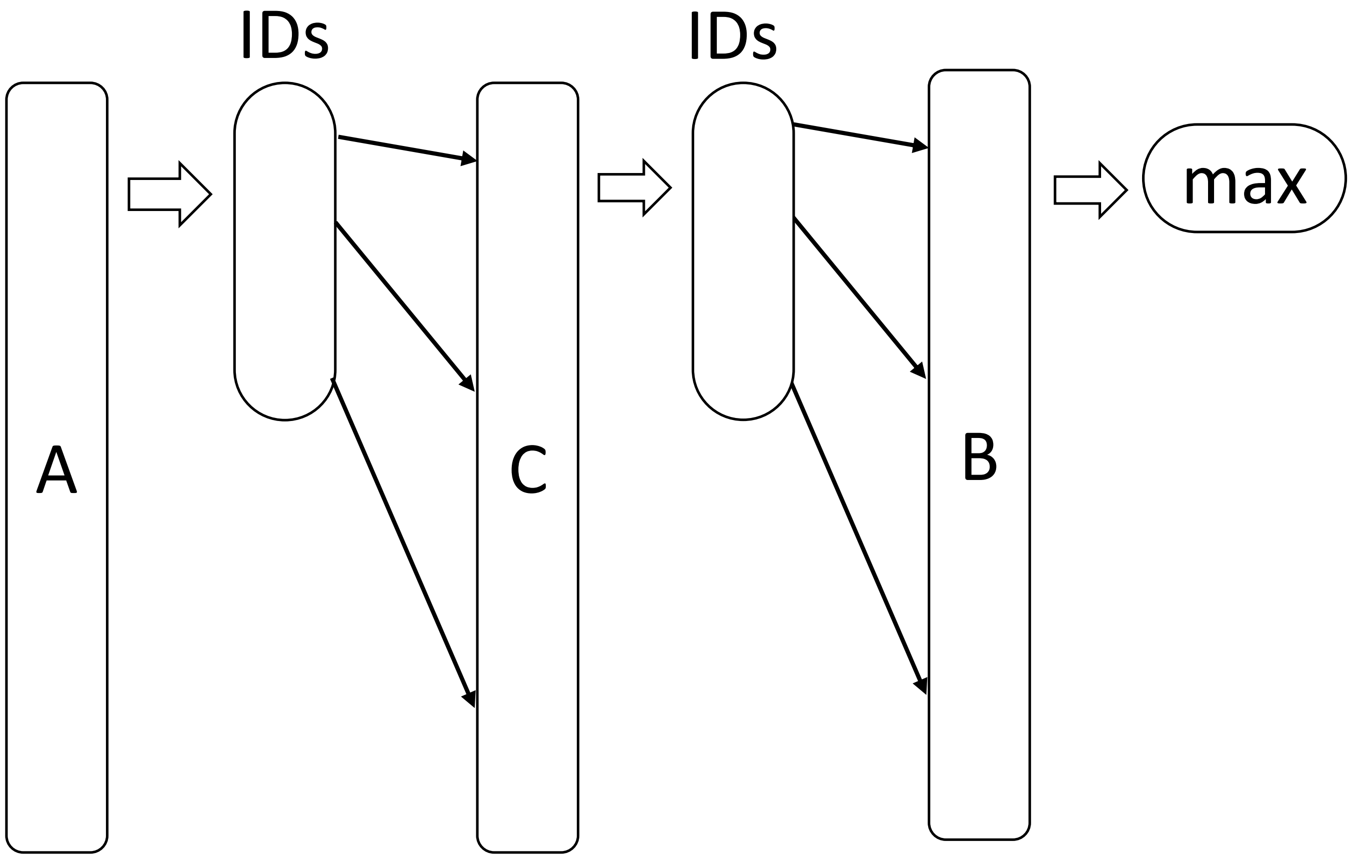
select max(B) **from** R **where** A>5 **and** C<10



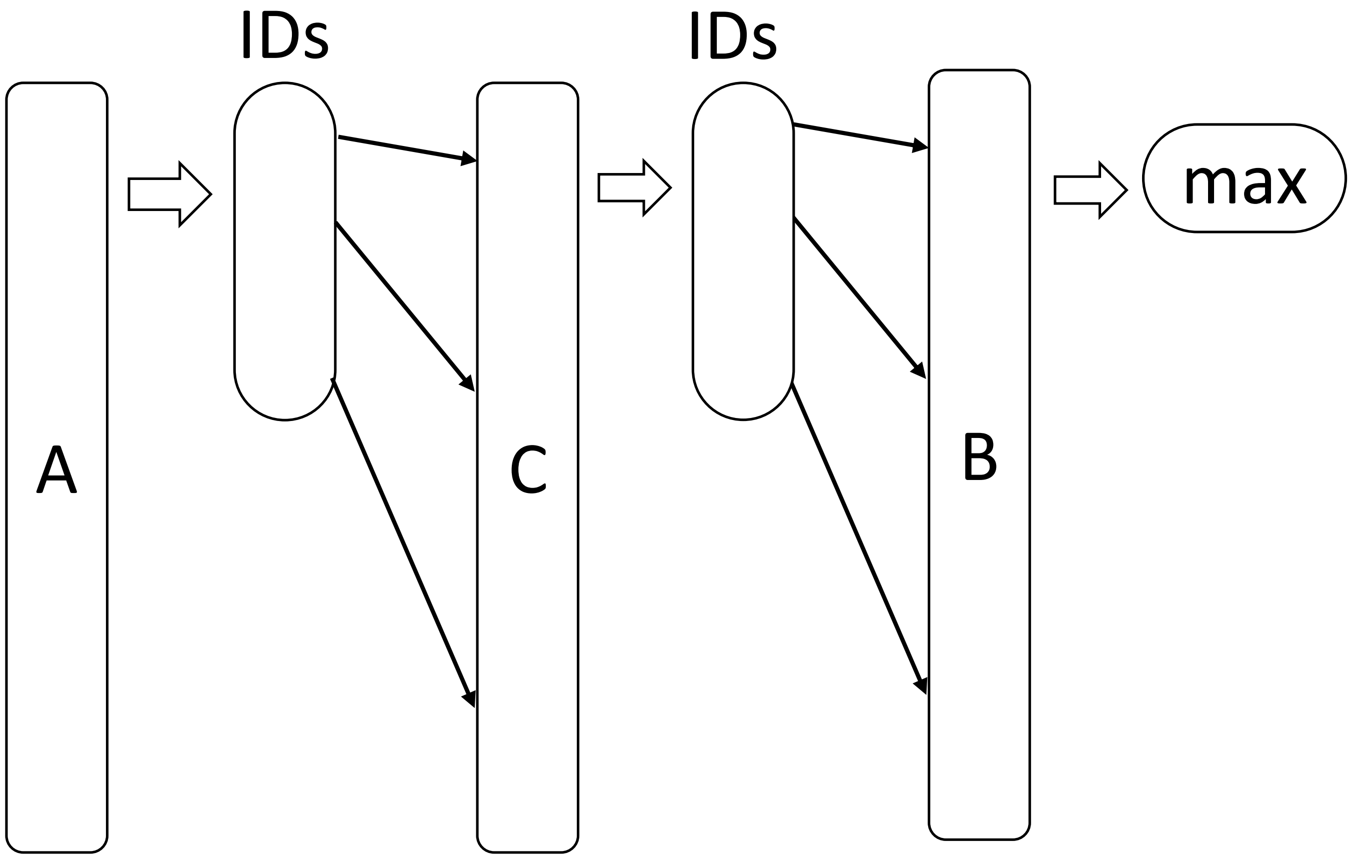
alternatives query plans

scan A & C in parallel and merge

start from C (why?)

use bit vectors (why?)

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



whole column?

row at a time

column at a time

block/vector at a time

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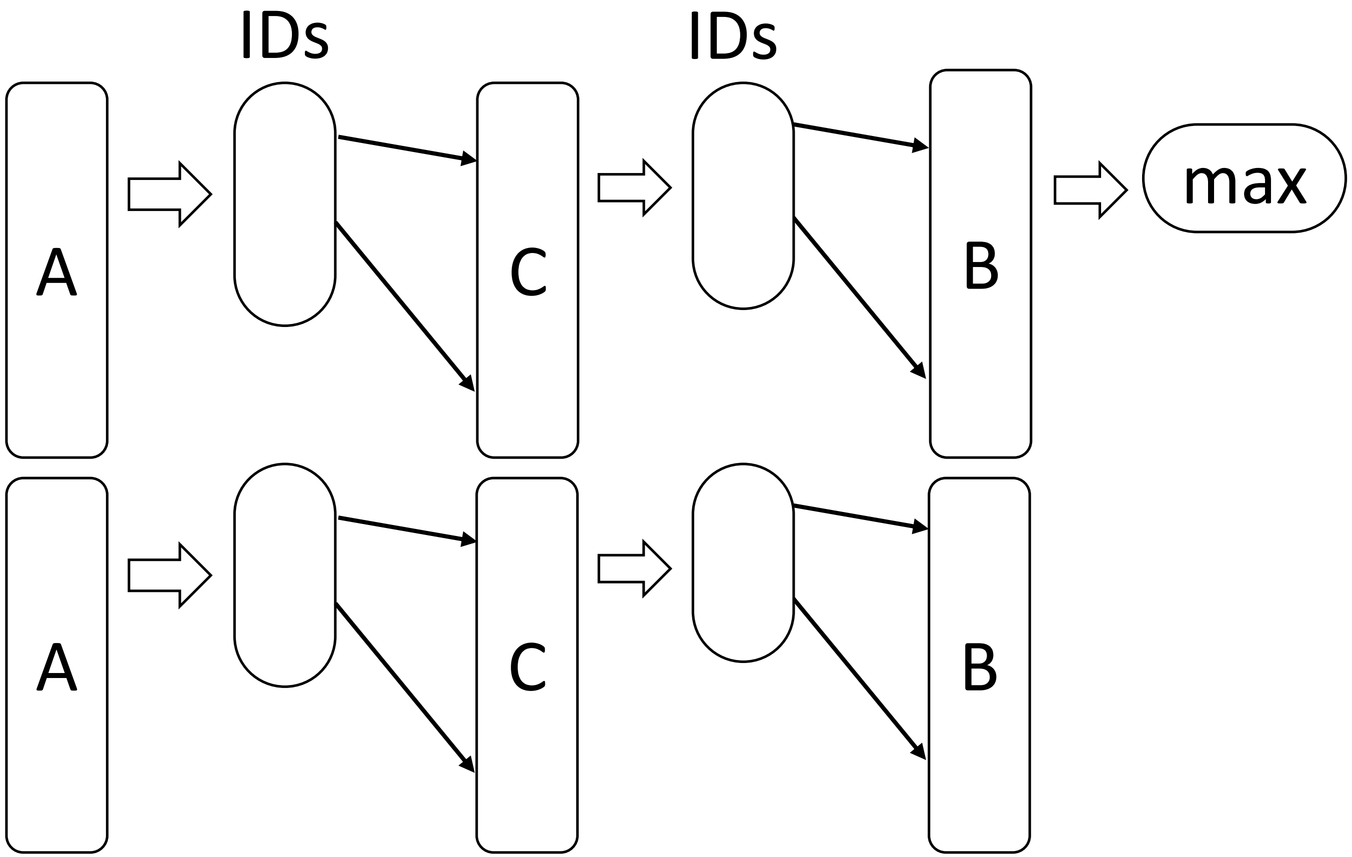
select max(B) **from** R **where** A>5 **and** C<10



whole column?

row at a time

column at a time

block/vector at a time

why column-stores are here now?

late materialization – no need to reconstruct tuples

read only useful data

minimize data movement across the memory hierarchy

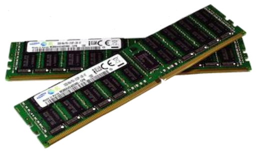
but it required a complete re-write

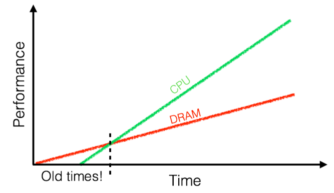
why not before?

legacy technology to catch up

more important: **analytical workloads** (as opposed to only OLTP)

new hardware: **larger memories & memory wall**





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CS 591: Data Systems Architectures

class 3

Column-Stores Basics

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