

Database Storage

Resources

- Architecture of a Database System (Chapter 5)
<https://dsf.berkeley.edu/papers/fntdb07-architecture.pdf>
- Postgres documentation
<https://www.postgresql.org/docs/9.0/storage-page-layout.html>
- Oracle documentation
https://docs.oracle.com/cd/E11882_01/server.112/e40540/physical.htm#CNCPT1389

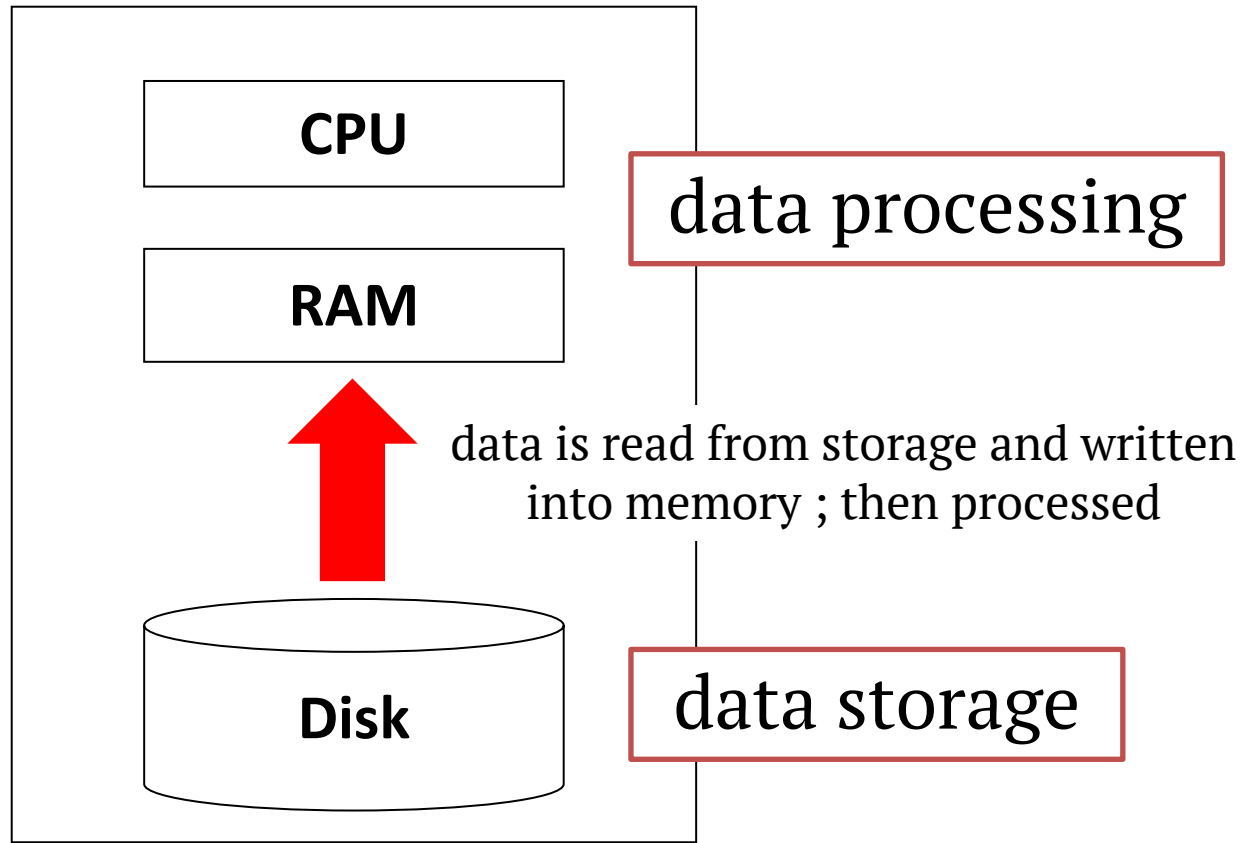
Destiny of Data : Queries

- What happens when we run a query ?
- Are all queries “equal” ?
- Are all systems good at answering queries ?

What happens when we run a query ?

- Well, the data is read and the query evaluated
- Where is data read from ?
 - Disk
 - Data is persistent
 - It may not fit in memory (but there are exceptions)
- Where is the query computed ?
 - CPU
 - At query time, data moves “up” from disk to CPU registers

What happens when we run a query?

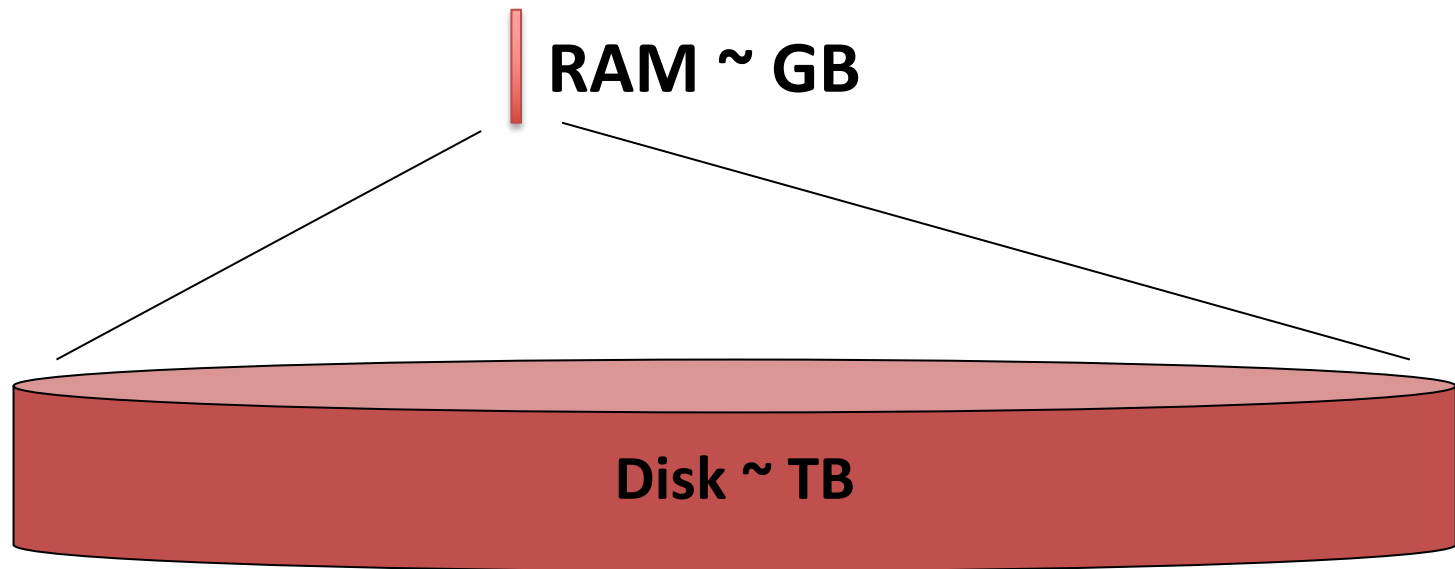


Memory : the state of affairs

sources : <https://jcm.it.net/memoryprice.htm> <https://jcm.it.net/diskprice.htm>

	Speed (Read/Write)	Cost/MB	
Cache	L1 read 3 TB/s	~1000\$/GB	fastest and most costly storage; volatile; managed by computer hardware
RAM	DDR4 read ~ 25 GB/s	~10\$/GB	~100x slower & cheaper than cache
Disk	SSD read ~ 0.5 GB/s	~0.2\$/GB	Primary medium for the long-term storage of data

Memory : the state of affairs



- Data may not fit in memory, and DBMS architecture is specifically designed to account for this

The Query-Evaluation “Game”

- Compute answers to queries on :
 - (Possibly large) volumes of data stored on disk
 - Limited (but fast) memory

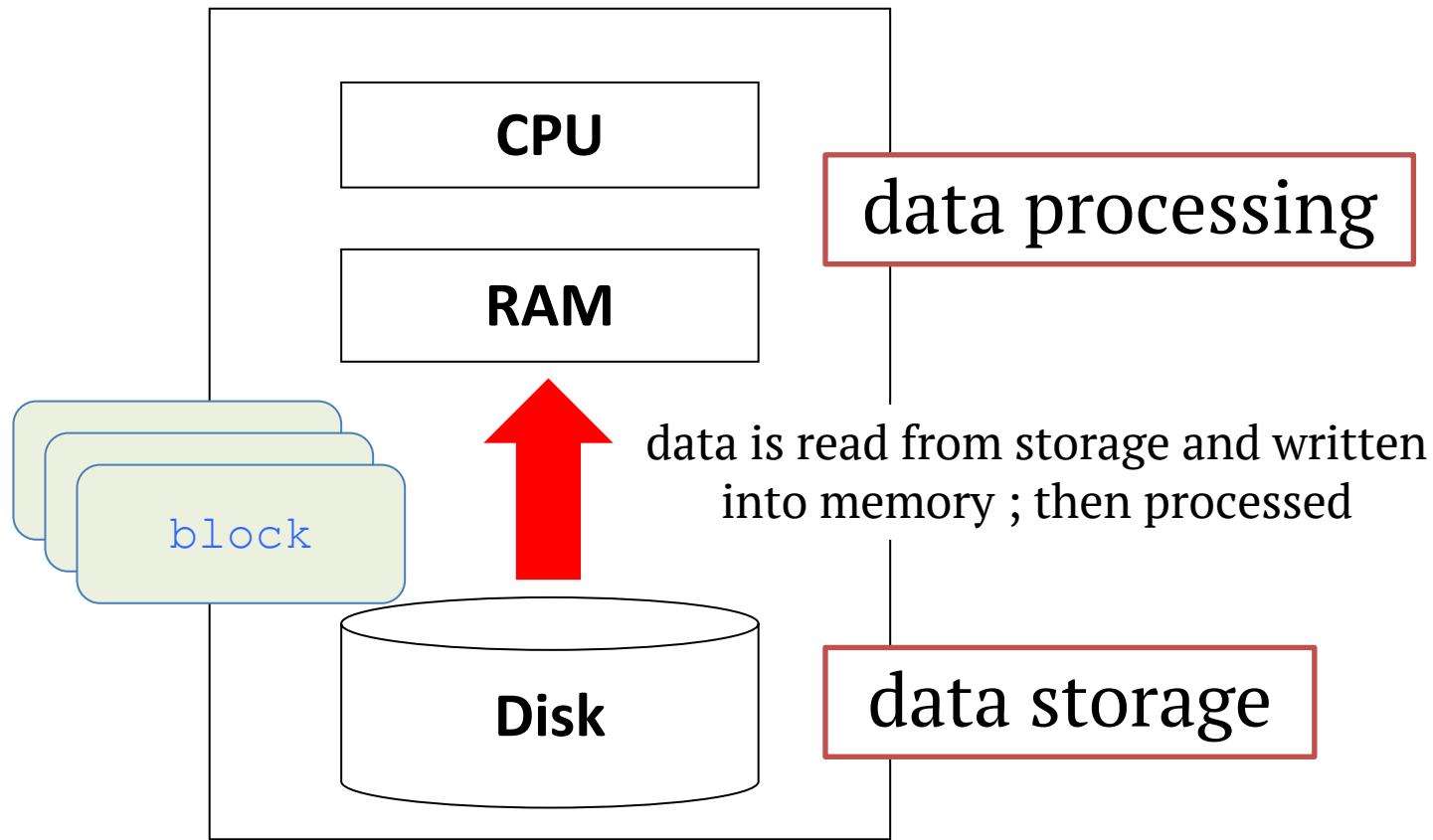
Within a useful time (useful for the user/application)
- To “win the game”, one needs to devise a strategy for :
 - **Organizing** data
 - **Moving** data from disk to memory
 - **Optimizing** query computation

So what is Postgres doing ?

<https://link.springer.com/content/pdf/bbm%3A978-1-4302-0018-5%2F1.pdf>

- Postgres stores table data in multiple ***files***.
 - each file can grow up to 1GB (design choice of the Postgres system)
- A file stores a set of database **records**.
- Records are partitioned into *fixed-length storage units* called **blocks**.
 - default size (tunable) : 8KB (maximum Postgres 32K)
 - each block-id have a 32-bit integer ID (allows ~2 billion blocks)
 - max table size : #blocks x block_size (16TB to 64TB)
- **Blocks are units of both storage allocation and data transfer.**
 - Neither single records (as one may think at first), nor files are transferred from disk to memory : blocks !

What happens when we run a query?





PURCHASE A TICKET

USE YOUR MILES

BOOK USING A DISCOUNT PASS

ROUND TRIP

ONE-WAY

Multi-destination trip

Paris, All airports (PAR)

Arriving at

26 Nov 2019

26 Nov 2019

1 Adult

Economy

☐ Use my Blue Credits

SEARCH

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Explore the La Première suite

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LOG IN

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Cancel

Log in

```
SELECT *                #user profile data
FROM   users_table
WHERE  user_ID = 2309
```

LOG IN

Flying Blue number or e-mail address

[Forgot your Flying Blue number?](#)

Password

[Forgot your password?](#)



Cancel

Log in

```
SELECT  *                #user profile data
FROM    users_table
WHERE   user_ID = 2309
```

Mem

user_table_file

block 1

block 2

2309@Alice@...
2311@Bob@...
2321@Charles@..

block n

Disk

```
SELECT  *                #user profile data
FROM    users_table
WHERE   user_ID = 2309
```

Mem

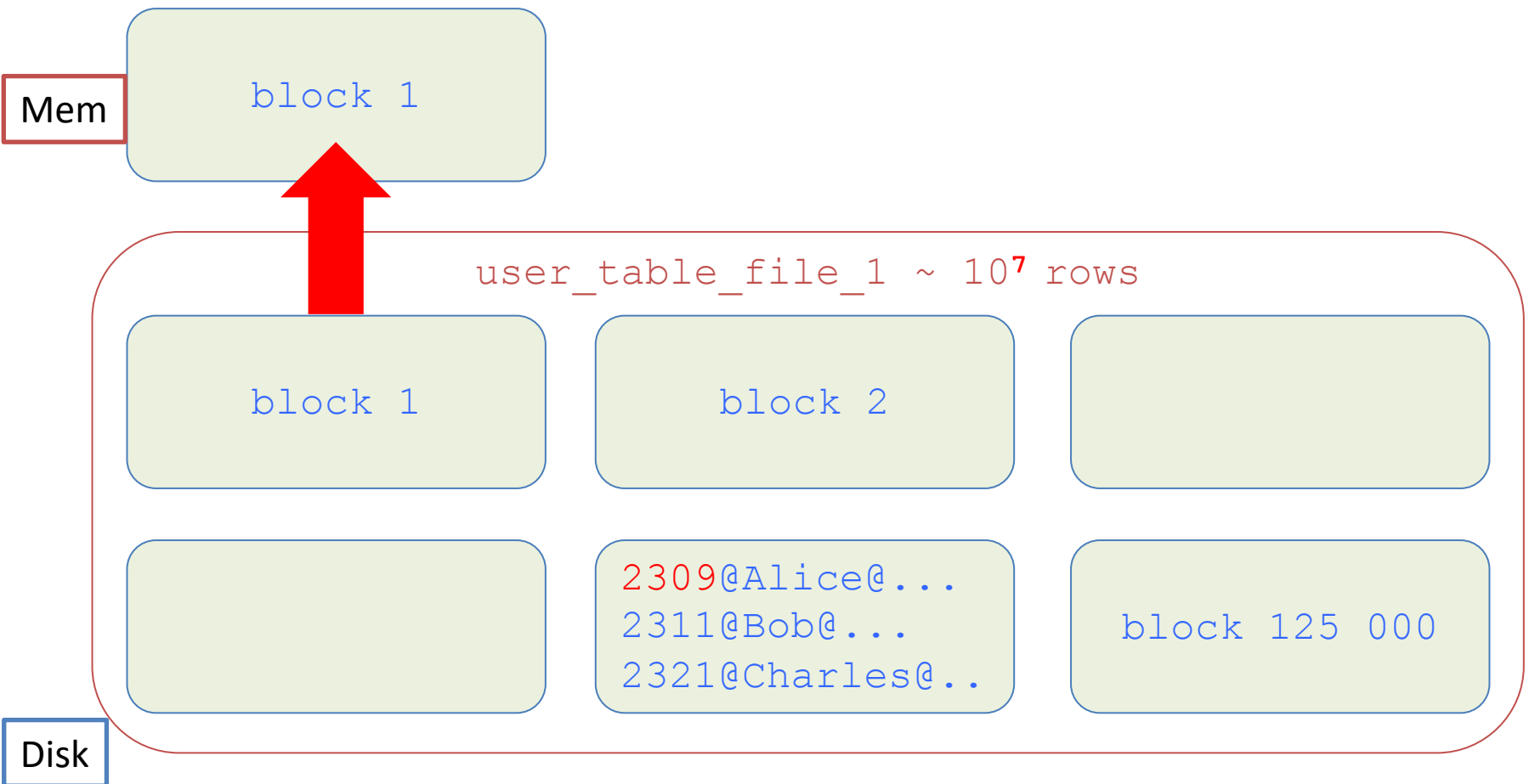
block 1

Assume client record 100 Bytes
Assume block size 8K => 80 clients per block
Assume 30M registered accounts / 80 => 375K blocks
1 file maximum 125K blocks => 3 files

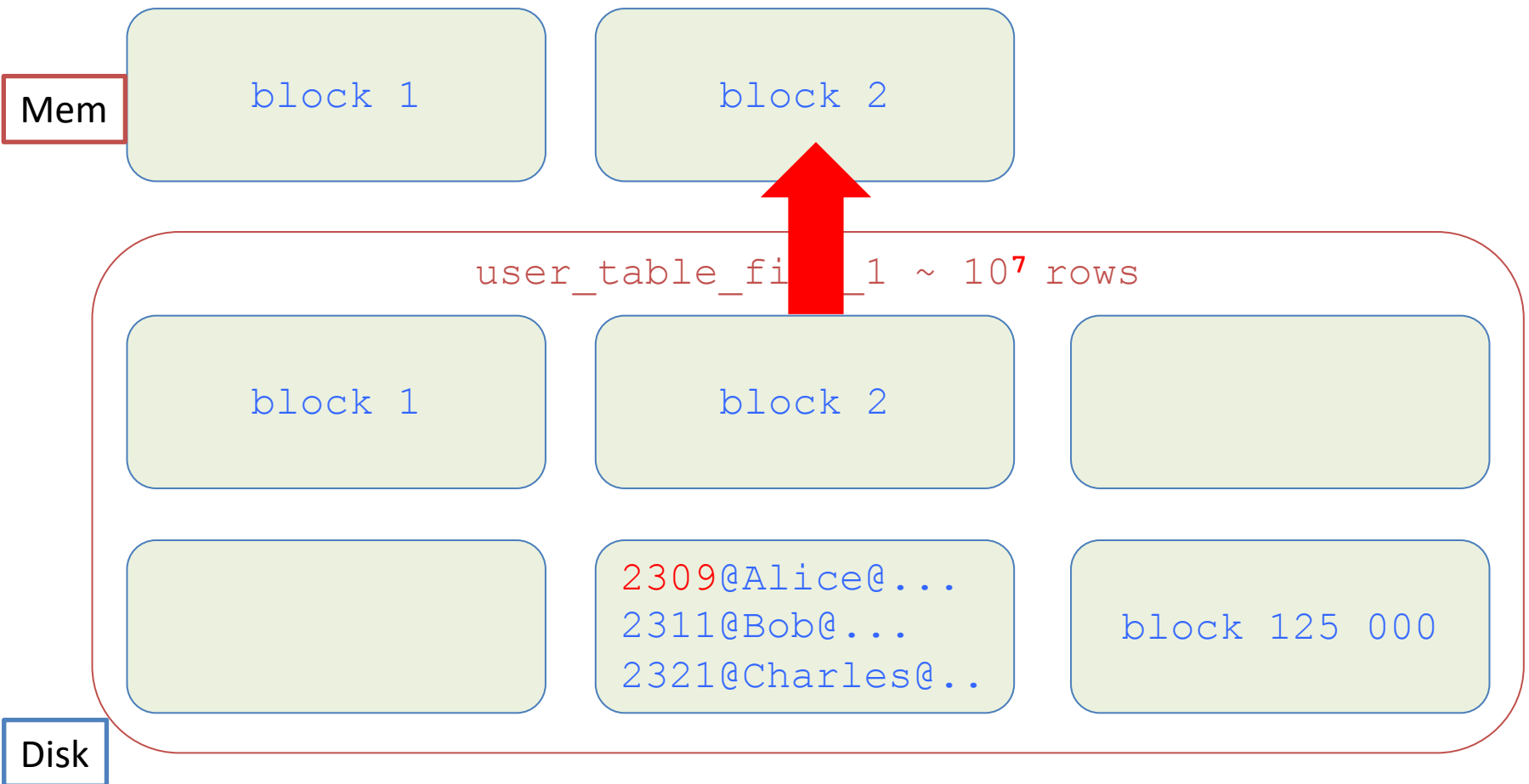
block 125 000

Disk

```
SELECT  *                #user profile data
FROM    users_table
WHERE   user_ID = 2309
```

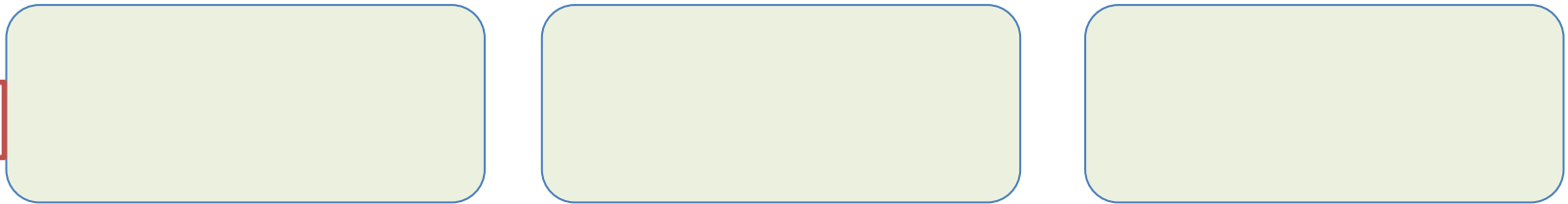



```
SELECT  *                #user profile data
FROM    users_table
WHERE   user_ID = 2309
```



```
SELECT *                #user profile data
FROM   users_table
WHERE  user_ID = 2309
```

Mem



user_table_file_1 ~ 10⁷ rows

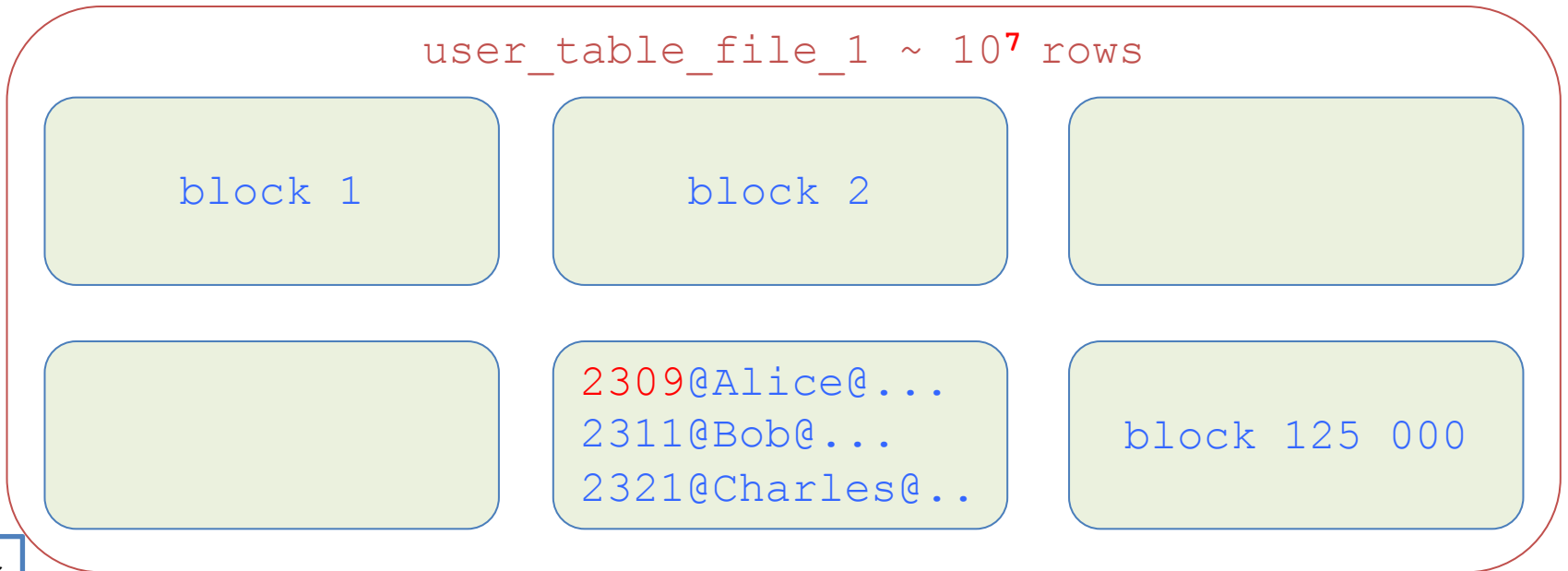
block 1

block 2

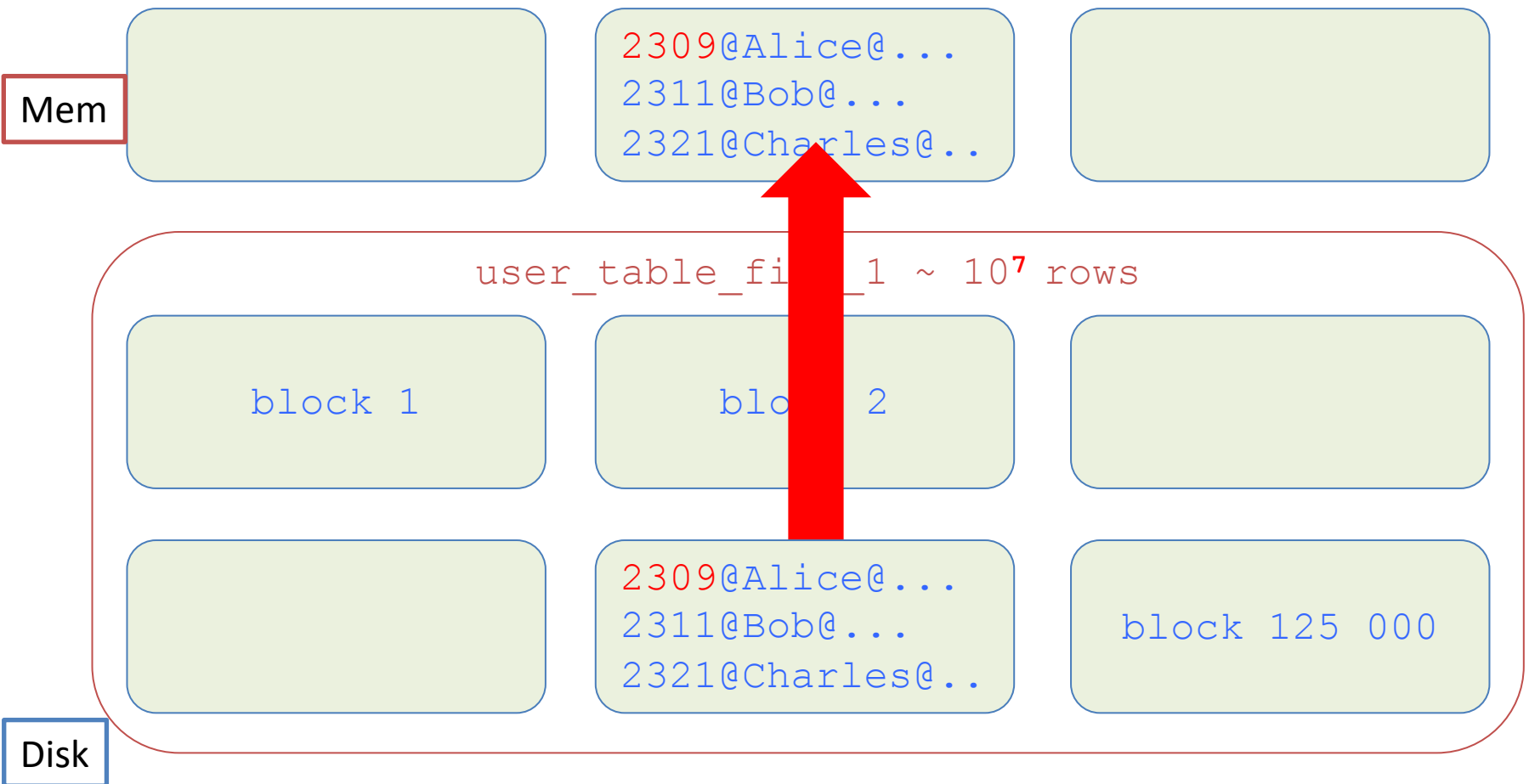
2309@Alice@...
2311@Bob@...
2321@Charles@..

block 125 000

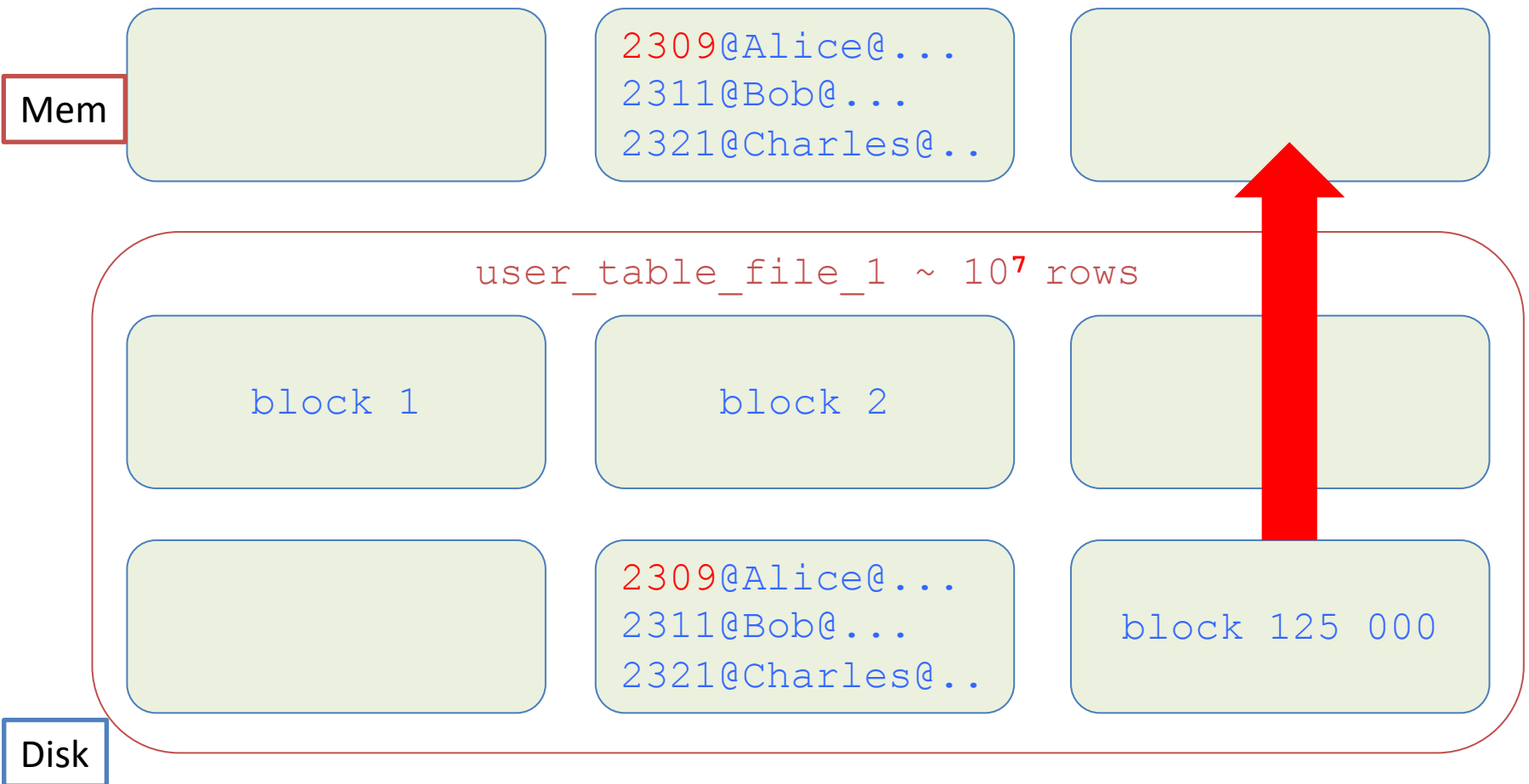
Disk



```
SELECT  *                #user profile data
FROM    users_table
WHERE   user_ID = 2309
```



```
SELECT  *                #user profile data
FROM    users_table
WHERE   user_ID = 2309
```



```
SELECT *                                #user profile data
FROM   users_table
WHERE  user_ID = 2309
```



```
SELECT  *                #user profile data
FROM    users_table
WHERE   user_ID = 2309    #PK
```

In reality DB
use
indexes !!

index

ROW for **user_ID** = 2309
block 7459 offset 45

Mem

user_table_file_1 ~ 10⁷ rows

block 1

block 2

2309@Alice@...
2311@Bob@...
2321@Charles@..

block n

Disk

```
SELECT *                #user profile data
FROM   users_table
WHERE  user_ID = 2309    #PK
```

In reality DB
use
indexes !!

Mem

index
ROW for **user_ID** = 2309
block 7459 offset 45

user_table_file_1 ~ 10^7 rows

block 1

block 2

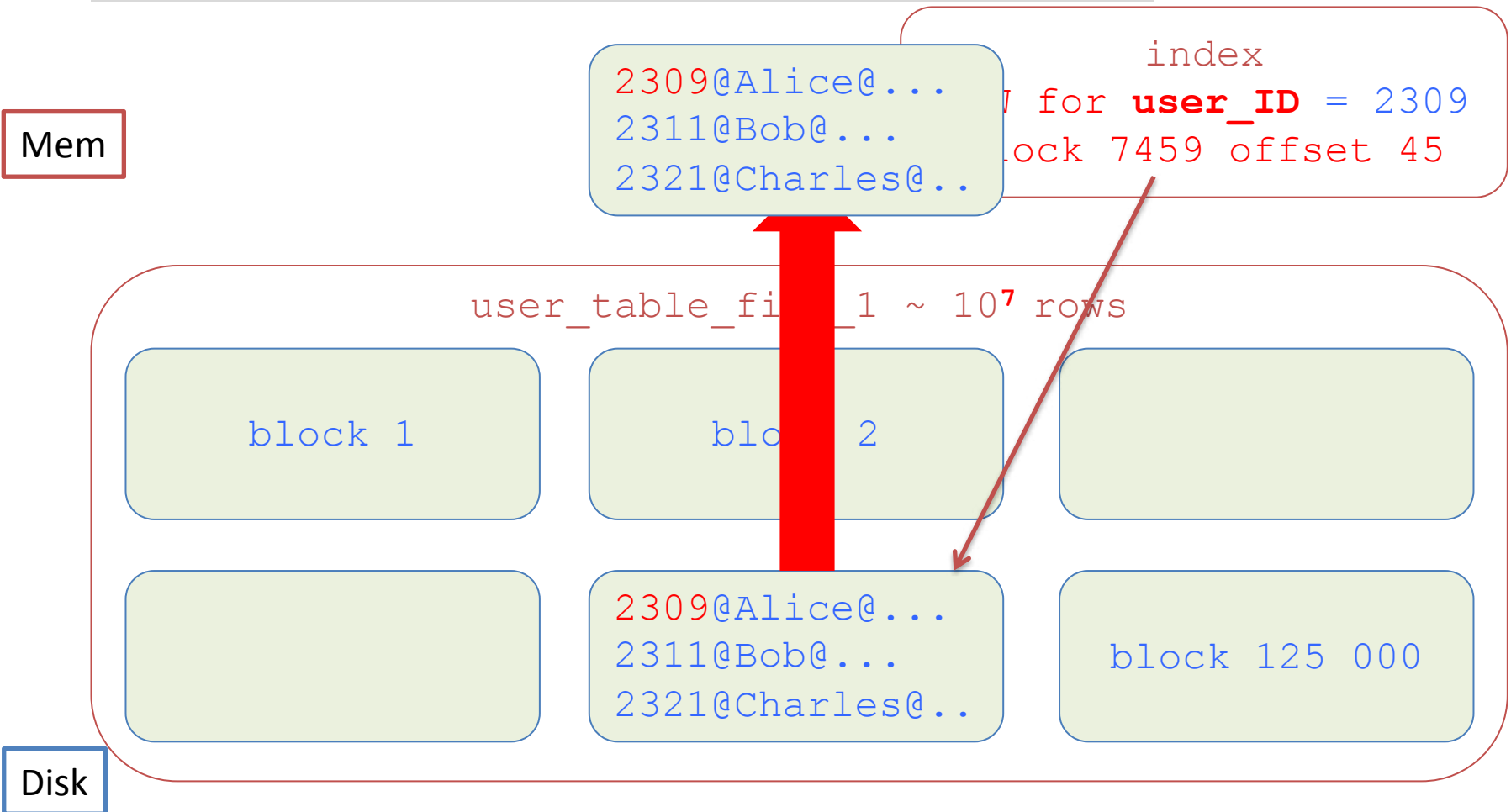
2309@Alice@...
2311@Bob@...
2321@Charles@..

block n

Disk

```
SELECT *           #user profile data
FROM   users_table
WHERE  user_ID = 2309 #PK
```

In reality DB
use
indexes !!





```
SELECT    SUM(price)
FROM      tickets_table
WHERE     year = NOW.year
```

```
SELECT  SUM(price)
FROM    tickets_table
WHERE   year = NOW.year
```

Analytics
case

Mem

each block **i**

index on PK
is useless here

tickets_table_file

block 1

block 2

block n

Disk

```
SELECT SUM(price)
FROM   tickets_table
WHERE  year = NOW.year
```

Analytics
case

Mem

each block **i**

index on PK
is useless here

tickets_table_file

block 1

block 2

Quiz : how many files and blocks/year with a 40 Byte ticket record in Postgres ? Assume 100M tickets/year.

How many files and blocks/year with a 40 Byte ticket record in Postgres ? Assume 100M tickets/year.

- Postgres
 - Block size = 8K
 - 1 file maximum 125K blocks
- 1 ticket = 40Bytes
- 100M tickets per year
- Storage cost :
 - 40Bytes x 100M = 4 000 M per year
 - 4000 M / 8 K = 500M blocks
 - 500K / 125K = 4 fichiers

The Query-Evaluation “Game”

- **Blocks are units of both storage allocation and data transfer.**
 - Neither single records (as one may think at first), nor files are transferred from disk to memory : **blocks !**

The Query-Evaluation “Game”

- To “win the game” the DB seeks to minimize the number of block transferred from disk to memory
 - avoid loading a block twice
 - avoid loading useless blocks
 - keep as many blocks as possible in main memory
 - Locality principle
 - reduce the number of disk accesses

Block organization



Header

Free space

Records

Block organization

Header

number of record entries : N

Free space

Records

Record 1

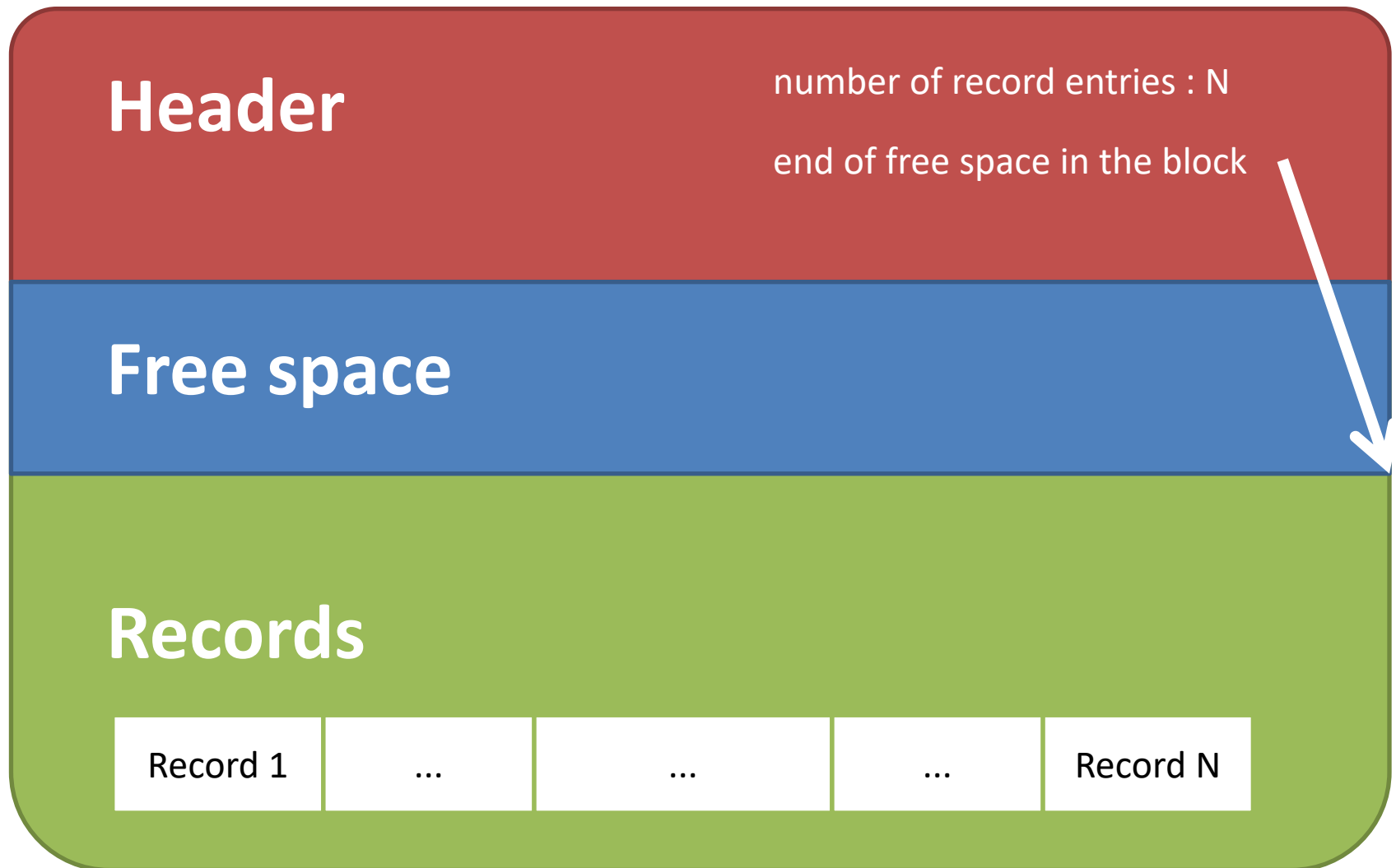
...

...

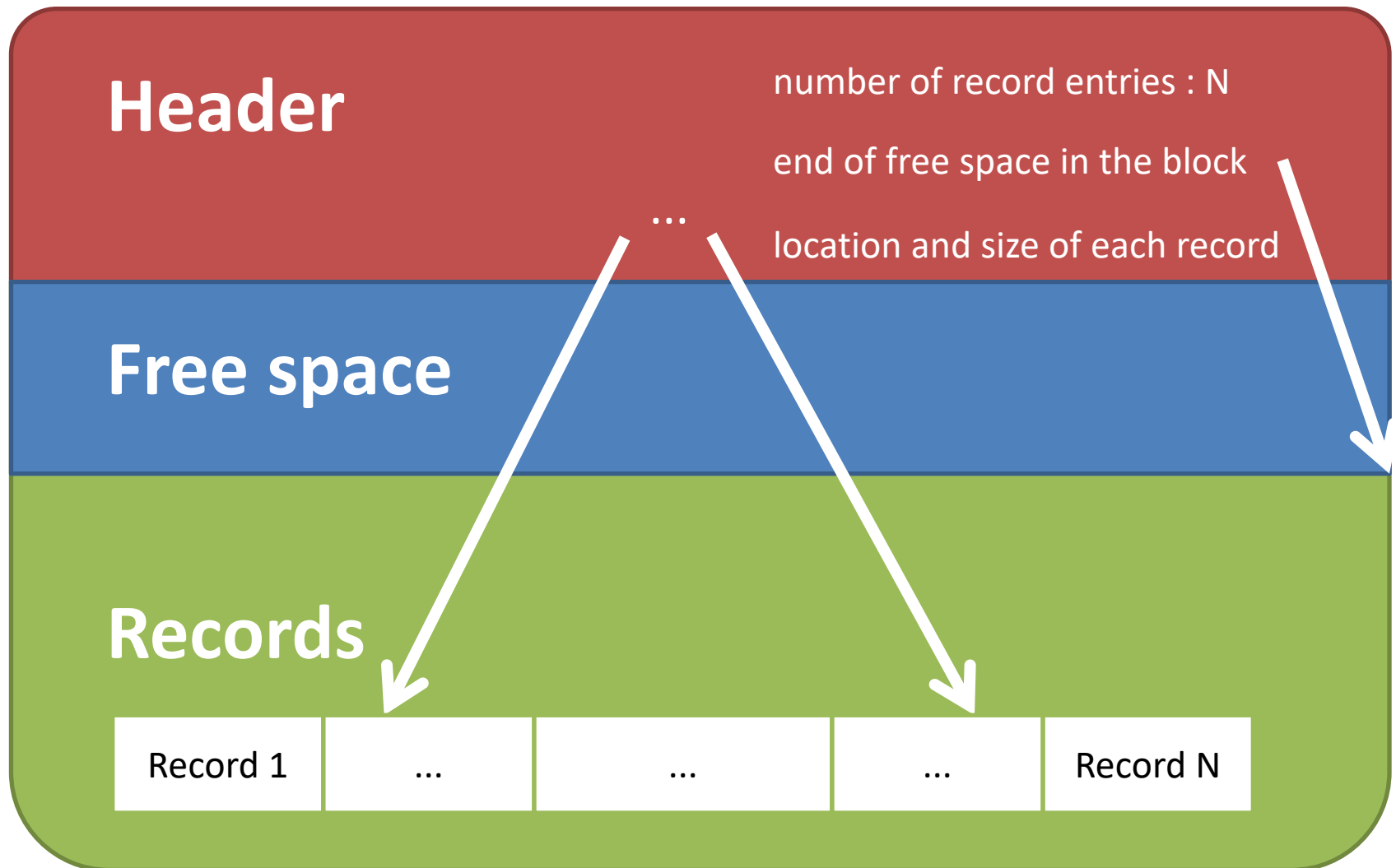
...

Record N

Block organization



Block organization



Record organization

<https://www.postgresql.org/docs/9.0/storage-page-layout.html>

Header

bitmap of null values
insert transaction timestamp
number of attributes in tuple
optional object id field

Values

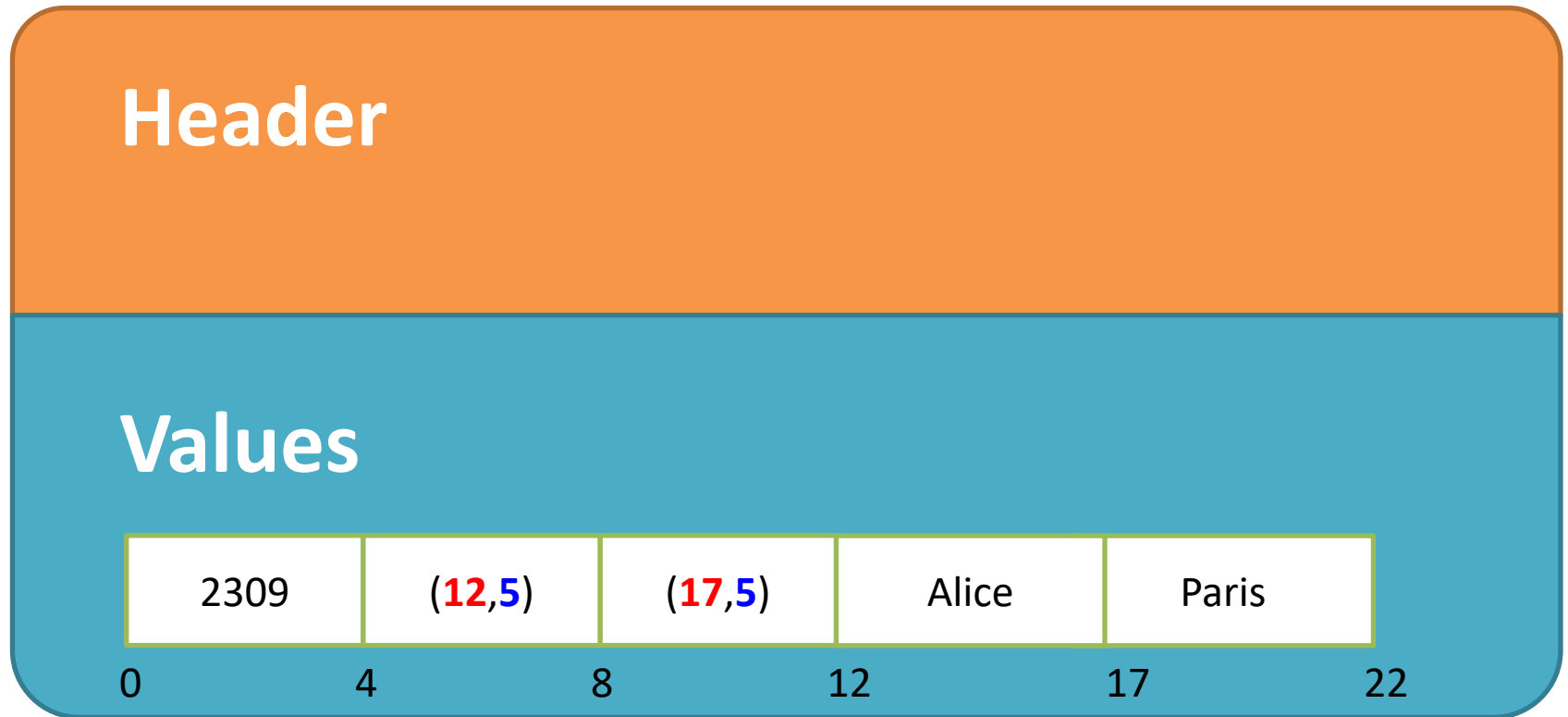
2309	Alice	Paris
------	-------	-------

- Postgres : fixed-size header (~23 bytes), followed by optional null bitmap, optional object ID field, user data

Record organization

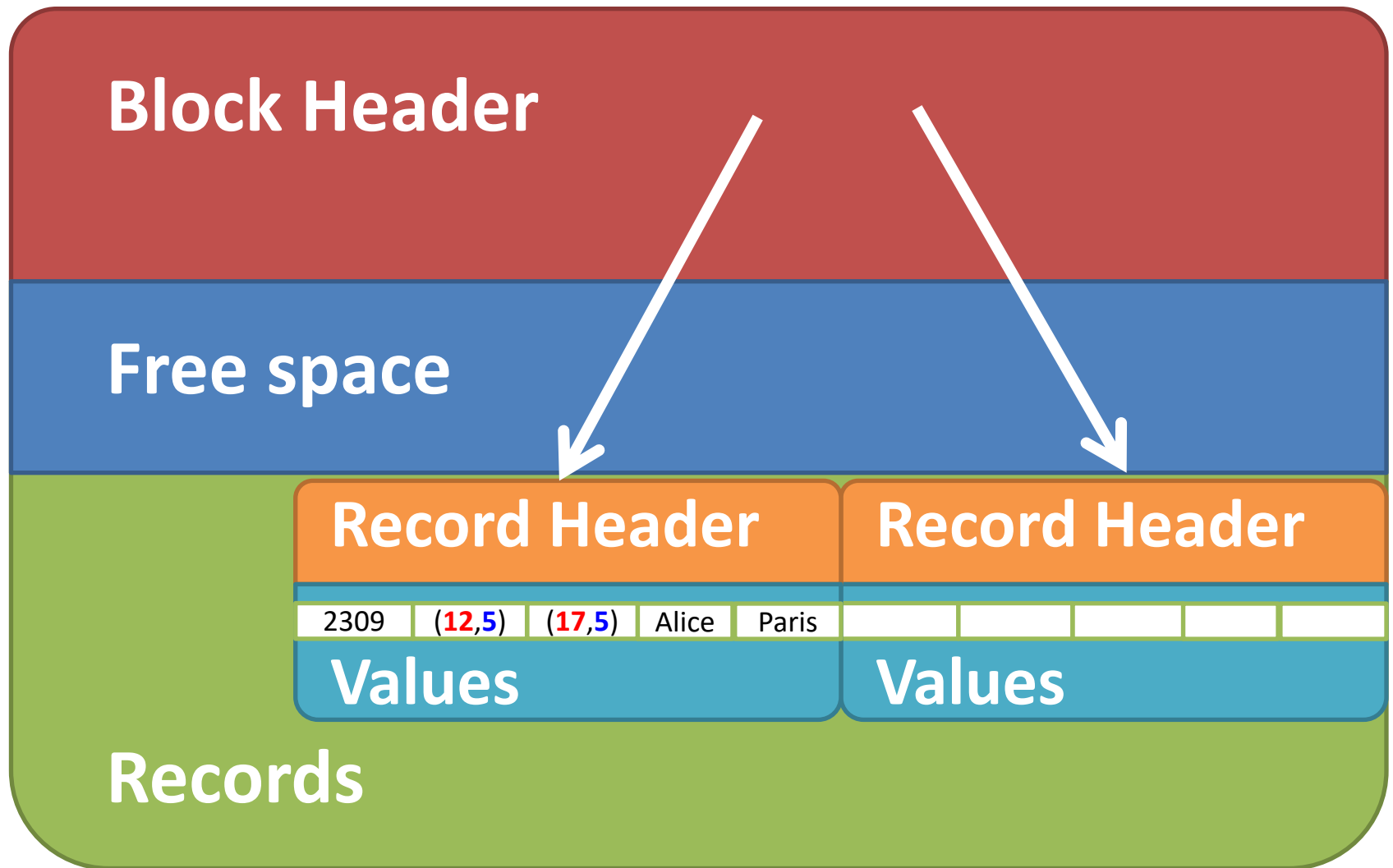
- Most of records are variable length
 - they occur as soon as one uses the ***varchar*** type
- Attributes are stored in order
 - Following the CREATE TABLE statement
- Variable length attributes can be represented by fixed size (offset, length), with actual data stored after all fixed length attributes
 - Efficient for searching a field in the middle of the row

Record organization



- Variable length attributes represented by fixed size
(offset, length)
with actual data stored after all fixed length attributes

Summing up

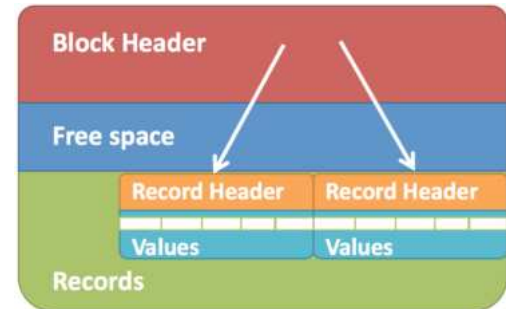
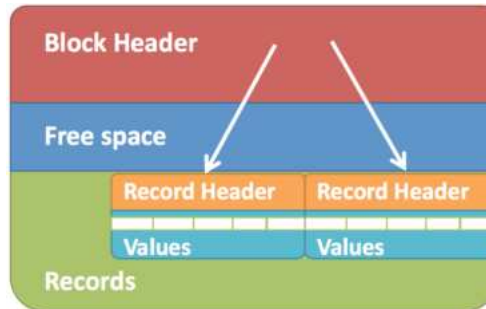
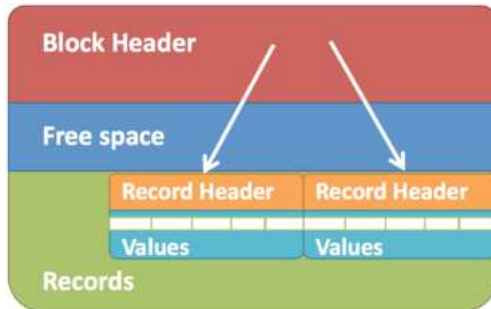


Summing up

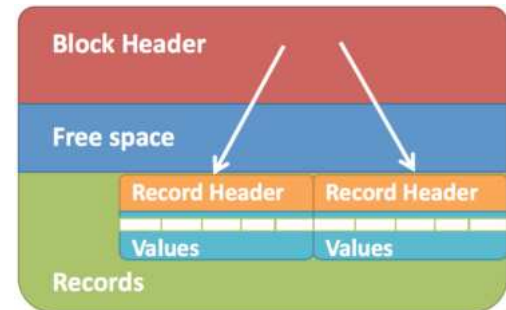
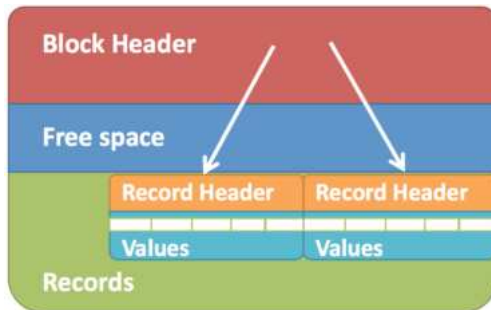
[https://www.sqlite.org/fileformat.html#:~:text=The%20first%20100%20bytes%20of%20the%20database%20file%20comprise%20the,first%20\(big%2Dendian\).](https://www.sqlite.org/fileformat.html#:~:text=The%20first%20100%20bytes%20of%20the%20database%20file%20comprise%20the,first%20(big%2Dendian).)

File Header

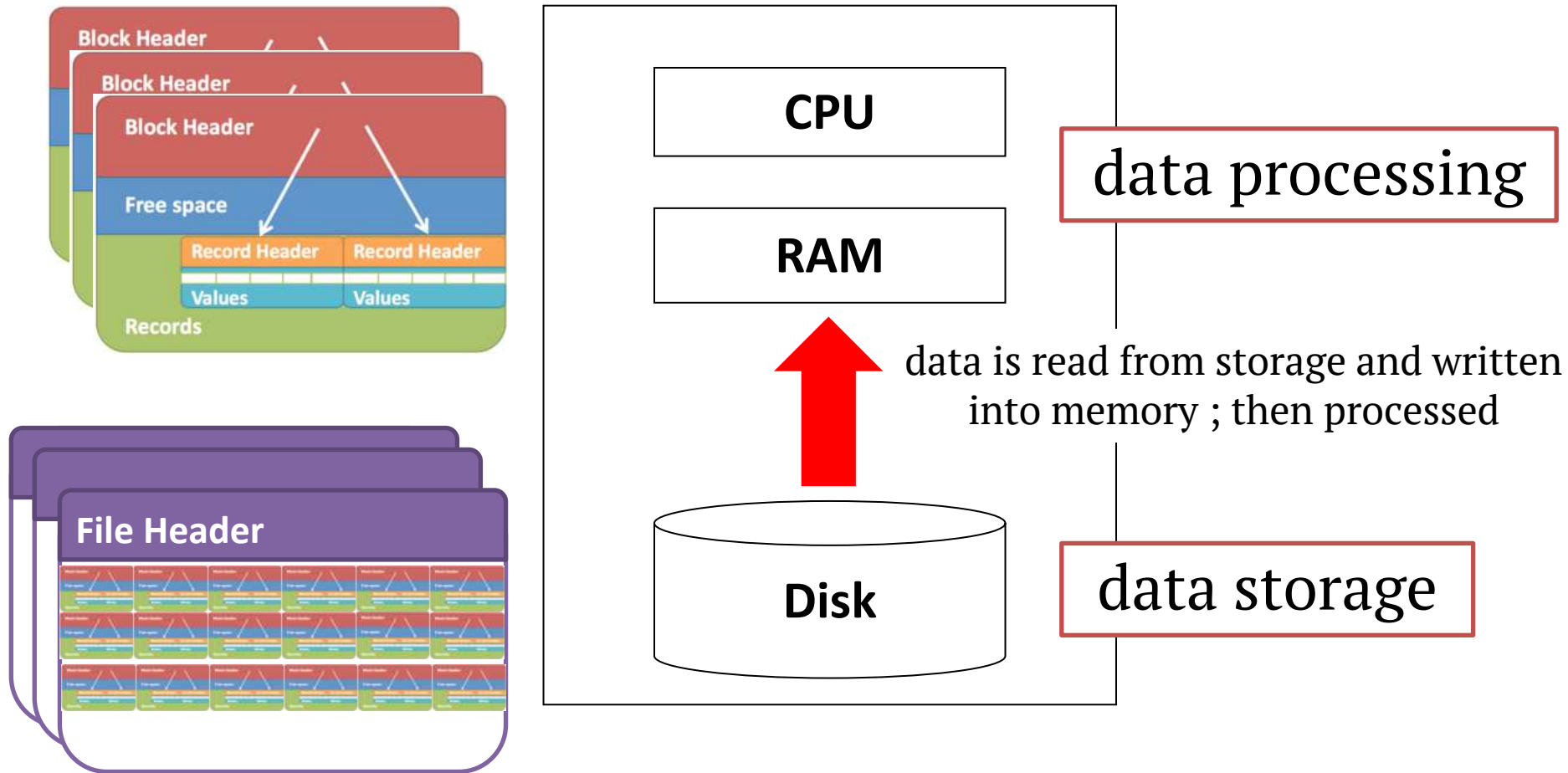
file type (DBMS has many)
the database page size
number of free blocks ...



...



What happens when we run a query?



Summing up

- Databases physical organization store records in **blocks** that are moved from disk to memory
- Performances depend on block movement
- Factors that impact block movement are :
 - Of course, DBMS architecture (system)
 - The type of query (user)
 - The relational schema design (user)
 - We will see the importance of “star-schemas”
 - Tuning (eg., indexes) (DB admin)
 - Optimizations (system)