How tables and indexes are stored on disk

And how they are queried

Storage concepts

- Table
- Row_id
- Page
- IO
- Heap data structure
- Index data structure b-tree
- Example of a query

Logical Table

column

emp_id	emp_name	emp_dob	emp_salary
10	Nik	1/2/2000	$100,000
20	Kirk	3/2/2000	$200,000
30	Yagami	5/2/2000	$300,000

row

Row_ID

- Internal and system maintained
- In certain databases (mysql -innoDB) it is the same as the primary key but other databases like Postgres have a system column row_id (tuple_id)

row_id	emp_id	emp_name	emp_dob	emp_salary
1	2000	Nik	1/2/2000	$100,000
2	3000	Kirk	3/2/2000	$200,000
3	4000	Yagami	5/2/2000	$300,000

Page

- Depending on the storage model (row vs column store), the rows are stored and read in logical pages.
- The database doesn't read a single row, it reads a page or more in a single IO and we get a lot of rows in that IO.
- Each page has a size (e.g. 8KB in postgres, 16KB in MySQL)
- Assume each page holds 3 rows in this example, with 1001 rows you will have 1001/3 = 333~ pages

row_id	emp_id	emp_name	emp_dob	emp_salary
1	10	Nik	1/2/2000	$100,000
2	20	Kirk	3/2/2000	$200,000
3	30	Yagami	5/2/2000	$300,000
…	..	…	….	….
1000	10000	Eddard	1/27/2000	$250,000

Page 0

1,10,Nik,1/2/2000,
$100,000|2,
20,Kirk,3/2/2000|3,
30,Yagami,5/2/200
0,$300,000

Page 1

(Rows 4,5,6) ……

Page 2

(Rows 7,8,9) ……

…….

Page 333

More
rows….1000,1000
0,Eddard,1/27/200
0,$250,000

IO

- IO operation (input/output) is a read request to the disk
- We try to minimize this as much as possible
- An IO can fetch 1 page or more depending on the disk partitions and other factors
- An IO cannot read a single row, its a page with many rows in them, you get them for free.
- You want to minimize the number of IOs as they are expensive.
- Some IOs in operating systems goes to the operating system cache and not disk

Page 0

1,10,Nik,1/2/2000,$100,000|2,20,Kirk,3/2/2000|3,30,Yagami,5/2/2000,$300,000

Page 1

(Rows 4,5,6) ……

Page 2

(Rows 7,8,9) ……

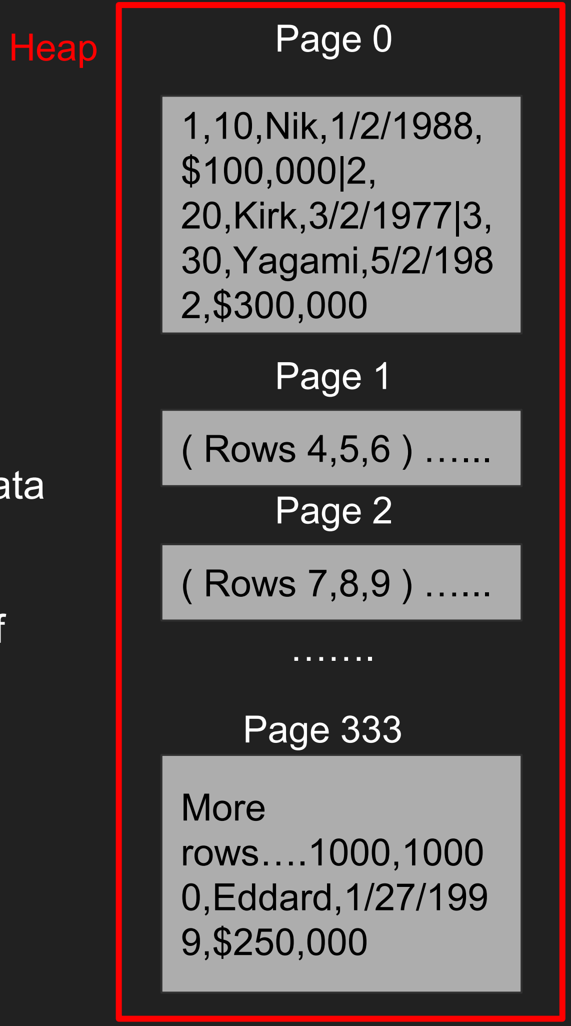
…….

Page 333

More rows….1000,10000,Eddard,1/27/2000,$250,000

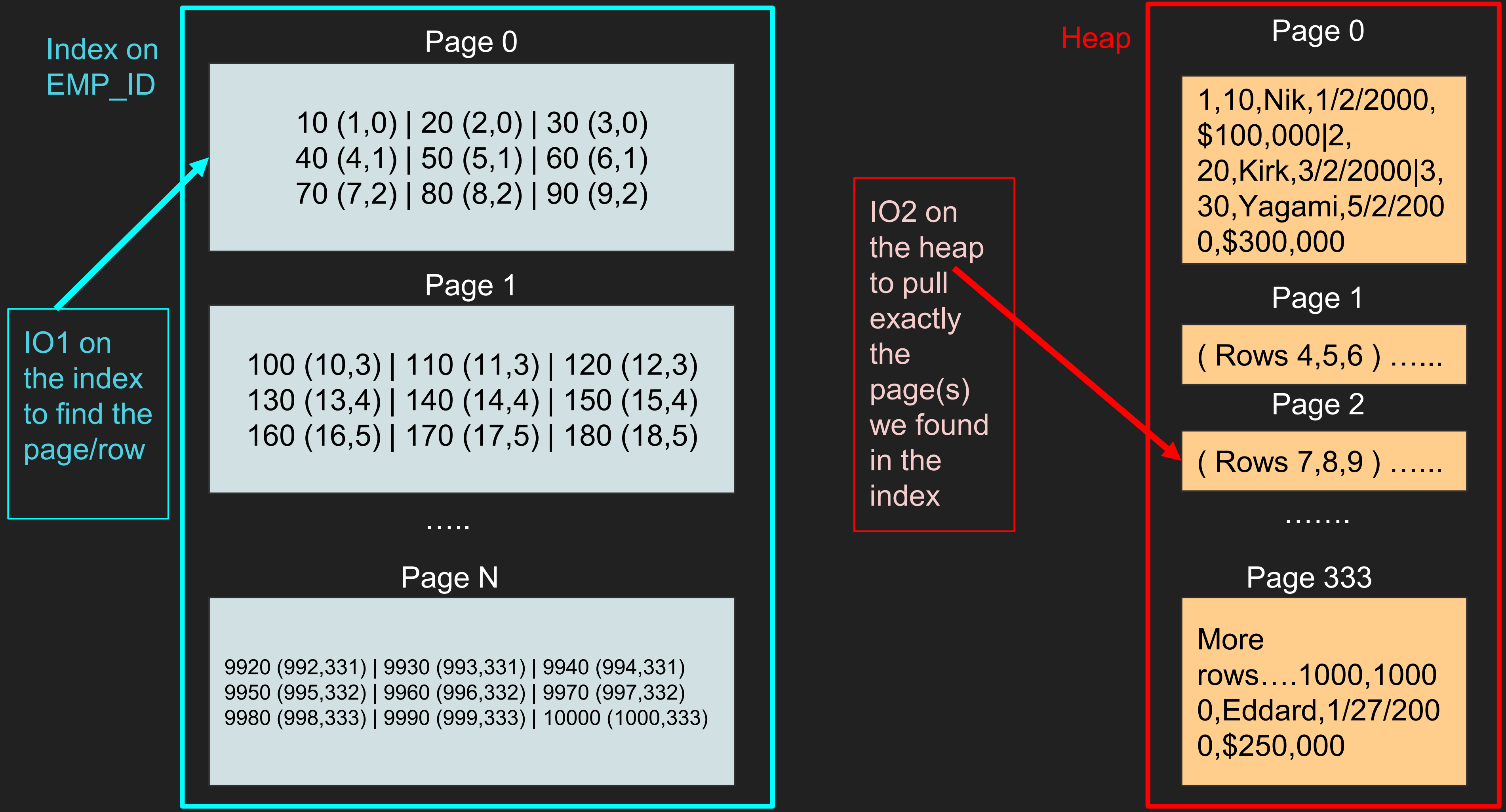
Heap

- The Heap is data structure where the table is stored with all its pages one after another.
- This is where the actual data is stored including everything
- Traversing the heap is expensive as we need to read so much data to find what we want
- That is why we need indexes that help tell us exactly what part of the heap we need to read. What page(s) of the heap we need to pull

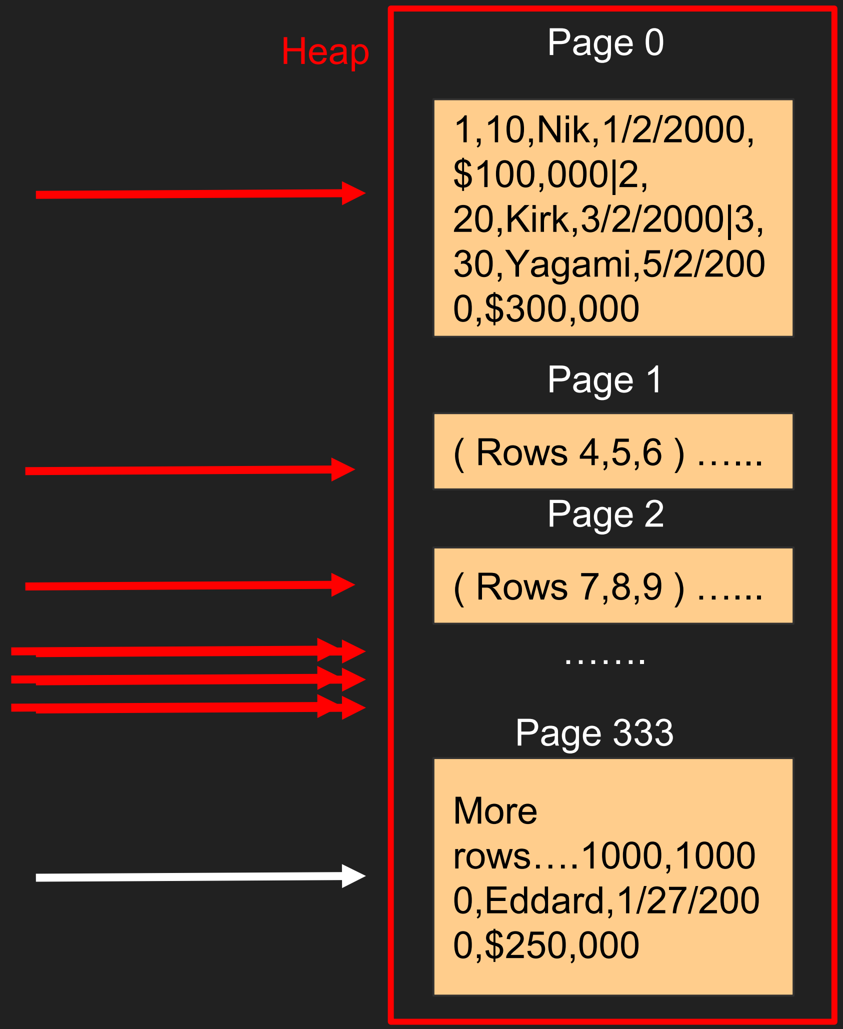


Index

- An index is another data structure separate from the heap that has “pointers” to the heap
- It has part of the data and used to quickly search for something
- You can index on one column or more.
- Once you find a value of the index, you go to the heap to fetch more information where everything is there
- Index tells you EXACTLY which page to fetch in the heap instead of taking the hit to scan every page in the heap
- The index is also stored as pages and cost IO to pull the entries of the index.
- The smaller the index, the more it can fit in memory the faster the search
- Popular data structure for index is b-trees.


Index on
EMP_ID
Page 0
10 (1,0) | 20 (2,0) | 30 (3,0)
40 (4,1) | 50 (5,1) | 60 (6,1)
70 (7,2) | 80 (8,2) | 90 (9,2)
Page 1
100 (10,3) | 110 (11,3) | 120 (12,3)
130 (13,4) | 140 (14,4) | 150 (15,4)
160 (16,5) | 170 (17,5) | 180 (18,5)
…..
Page N
9920 (992,331) | 9930 (993,331) | 9940 (994,331)
9950 (995,332) | 9960 (996,332) | 9970 (997,332)
9980 (998,333) | 9990 (999,333) | 10000 (1000,333)
IO1 on the index to find the page/row
IO2 on the heap to pull exactly the page(s) we found in the index
Heap
Page 0
1,10,Nik,1/2/2000,
$100,000|2,
20,Kirk,3/2/2000|3,
30,Yagami,5/2/200
0,$300,000
Page 1
(Rows 4,5,6) ……
Page 2
(Rows 7,8,9) ……
…….
Page 333
More
rows….1000,1000
0,Eddard,1/27/200
0,$250,000

No Index -
SELECT * FROM EMP WHERE EMP_ID = 10000;



With Index -
SELECT * FROM EMP WHERE EMP_ID = 10000;

10000 (1000,333)

Index on EMP_ID

Page 0

10 (1,0) | 20 (2,0) | 30 (3,0)
40 (4,1) | 50 (5,1) | 60 (6,1)
70 (7,2) | 80 (8,2) | 90 (9,2)

Page 1

100 (10,3) | 110 (11,3) | 120 (12,3)
130 (13,4) | 140 (14,4) | 150 (15,4)
160 (16,5) | 170 (17,5) | 180 (18,5)

.....

Page N

9920 (992,331) | 9930 (993,331) | 9940 (994,331)
9950 (995,332) | 9960 (996,332) | 9970 (997,332)
9980 (998,333) | 9990 (999,333) | 10000 (1000,333)

10000 (1000,333)
Fetch page 333, and pull row 10000

With Index -
SELECT * FROM EMP WHERE EMP_ID = 10000;

Heap

Page 0

1,10,Nik,1/2/1988,$100,000|2,20,Kirk,3/2/1977|3,30,Yagami,5/2/1982,$300,000

Page 1

(Rows 4,5,6) ……

Page 2

(Rows 7,8,9) ……

…….

Page 333

More rows….1000,10000,Eddard,1/27/1999,$250,000

Notes

- Sometimes the heap table can be organized around a single index. This is called a clustered index or an Index Organized Table.
- Primary key is usually a clustered index unless otherwise specified.
- MySQL InnoDB always have a primary key (clustered index) other indexes point to the primary key “value”
- Postgres only have secondary indexes and all indexes point directly to the row_id which lives in the heap.

Storage concepts - Summary

- Table
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- Page
- IO
- Heap data structure
- Index data structure b-tree
- Example of a query