B+树结构：实际上在硬盘里存储了数据
效率：1.将数据从硬盘中读取到内存里
2.CPU在内存里逐条读取数据

Tutorial: Index

> Sample Queries of Exercise
>
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>
> Modified by ZHU Yueming in May. 16th 2022. Update the explanation of index scan, bitmap index scan and hash join.

How to create Index

This part only for you to exercise, because of the data in flight is large.

1. Import data from those three files:

   ```
   cs307_public_aircrafts.sql
   cs307_public_airlines.sql
   cs307_public_flights.sql
   ```

2. Create Index:

   ```sql
   select * from flights where duration = 505;
   ```

   Result:

   91 rows retrieved starting from 1 in 923 ms (execution: 68 ms, fetching: 855 ms)

   ```sql
   create index duration_index on flights(duration);
   ```

   After creating index, do the same query and the result would be:

   91 rows retrieved starting from 1 in 73 ms (execution: 32 ms, fetching: 41 ms)

EXPLAIN

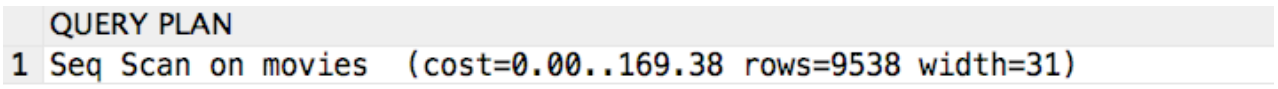
Part 1. Basic Search

Sequence Scan

Scan the whole table:

```
explain select * from movies;
```

Result:



```
QUERY PLAN
Seq Scan on movies  (cost=0.00..169.38 rows=9538 width=31)
```

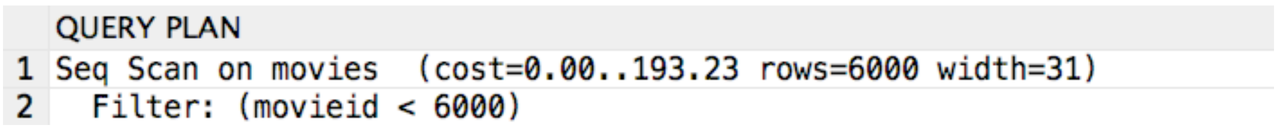
Total evaluation time cost = seq_page_cost + cpu_tuple_cost. 访问硬盘+访问内存

The time cost in seq_page is about 1.0, while time cost in cpu_tuple is about 0.01.
Suppose the data from 9538 rows in table movies are distributed in 74 disk page, and the total time cost would be **74 * 1.0 + 9538 * 0.01 = 169.38**

- Adding where condition

```
explain select * from movies where movieid<6000;
```

Result:



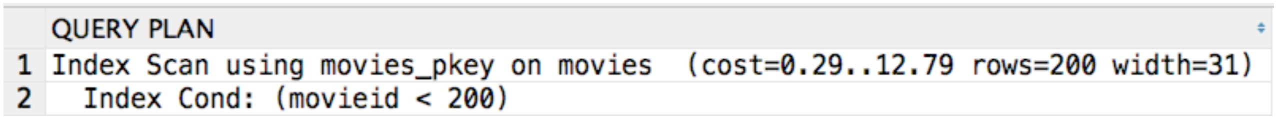
```
QUERY PLAN
Seq Scan on movies  (cost=0.00..193.23 rows=6000 width=31)
  Filter: (movieid < 6000)
```

Index Scan:

First scan the index, and then find the pointer of the record that meets the requirements from the index, and then locate the specific page in the table to fetch.

```
explain select * from movies where movieid<200;
```

Result:



```
QUERY PLAN
Index Scan using movies_pkey on movies  (cost=0.29..12.79 rows=200 width=31)
  Index Cond: (movieid < 200)
```

Part 2. Bitmap

Bitmap Index scan

Scan the index of pages, and then build bitmap that meets the requirements in **cash**, do not need locate the specific page of corresponding data.

Bitmap Heap scan

It is the parent node of Bitmap index scan, so that it is usually executed after several different Bitmap Index Scans. Ather that it does BitmapAnd or BitmapOr of bitmap before fetching the actual data.

Example:

Suppose if a table has index of b+ tree in two columns x and y, then we want to find x = 1 and y = 2 of the table.

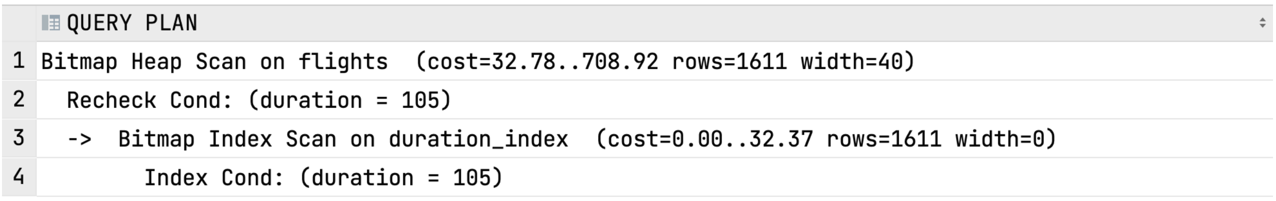
In this case, the process scans **index** pages of x and y, and builds two bitmaps in cash, the one is for the condition x = 1, the other is for the condition y = 2. After that process the `bitmap heap scan` with `BitmapAnd` operation, and then generate a final bitmap.

```
x=1:      00000000 01110001 00111001 00000000 00000000 01110111
y=2:      00000000 00010001 10000001 00001011 00000000 00000000
BitmapAnd:00000000 00010001 00000001 00000000 00000000 00000000
```

Explain:

```
explain select * from flights where duration = 105;
```

Result:



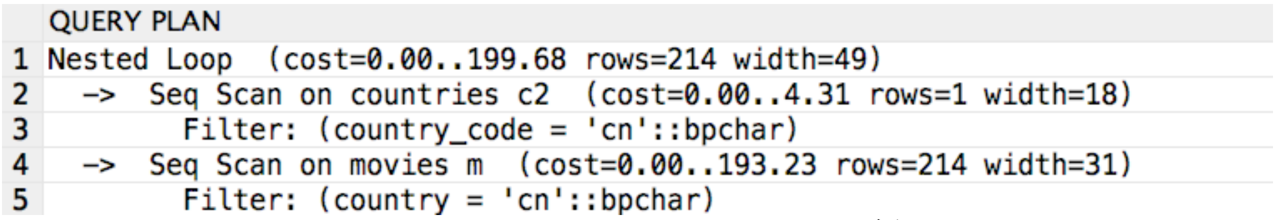
```
QUERY PLAN
Bitmap Heap Scan on flights  (cost=32.78..708.92 rows=1611 width=40)
  Recheck Cond: (duration = 105)
  ->  Bitmap Index Scan on duration_index  (cost=0.00..32.37 rows=1611 width=0)
        Index Cond: (duration = 105)
```

Part 3. Join

Nest Loop

```
explain select *
        from movies m
          join
          countries c2 on m.country = c2.country_code
        where c2.country_code = 'cn';
```

Result:



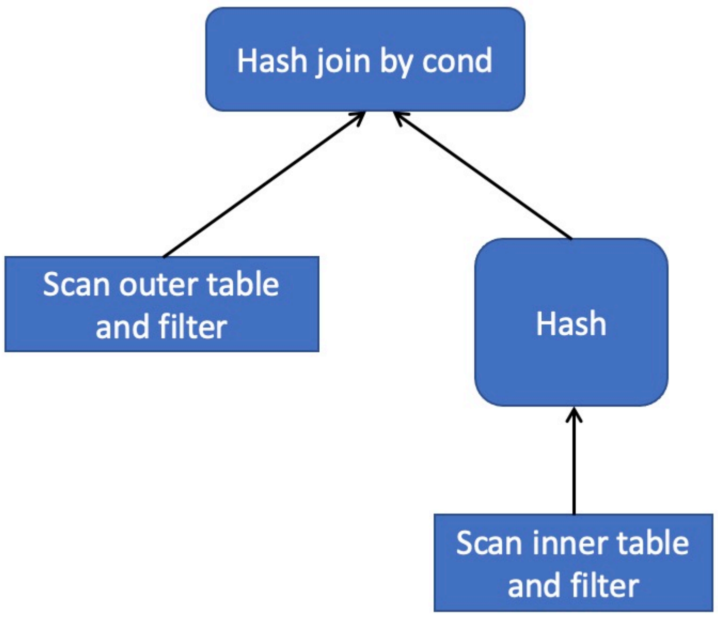
```
QUERY PLAN
Nested Loop  (cost=0.00..199.68 rows=214 width=49)
  ->  Seq Scan on countries c2  (cost=0.00..4.31 rows=1 width=18)
        Filter: (country_code = 'cn'::bpchar)
  ->  Seq Scan on movies m  (cost=0.00..193.23 rows=214 width=31)
        Filter: (country = 'cn'::bpchar)
```

双层for循环

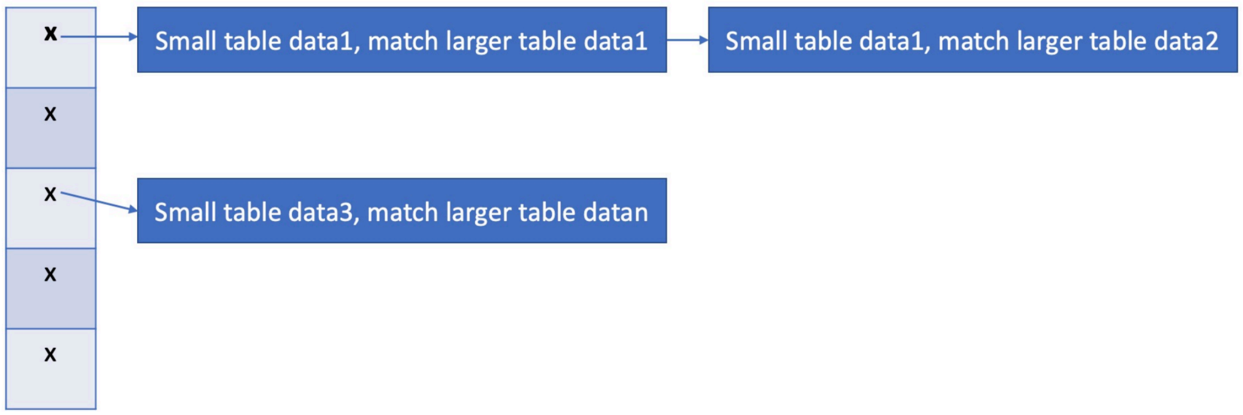
Hash Join

If there are two tables the one is smaller and the other is larger. Firstly, scan the smaller one by its specific scan method and build the hash table, then scan the larger one by its specific method to match the hash table. Finally do hash join according to the condition.

The whole process:



The hash join: 先扫描小的表，符合的拿出来构建一个hash，在扫描大的表，做一个hash链接


x
x
x
x
x
Small table data1, match larger table data1
Small table data1, match larger table data2
Small table data3, match larger table datan

Example:

```sql
explain select *
        from movies m
          join credits c
            on m.movieid = c.movieid
        where c.credited_as = 'D' and m.movieid < 200;
```

Result:

```
QUERY PLAN
Hash Join  (cost=15.29..901.94 rows=188 width=41)
  Hash Cond: (c.movieid = m.movieid)
  ->  Seq Scan on credits c  (cost=0.00..863.08 rows=8980 width=10)
        Filter: (credited_as = 'D'::bpchar)
  ->  Hash  (cost=12.79..12.79 rows=200 width=31)
        ->  Index Scan using movies_pkey on movies m  (cost=0.29..12.79 rows=200 width=31)
              Index Cond: (movieid < 200)
```

See more in this link

Part 4. multi-key indexes

Step 1

```
create table my_movies
  as
    select *
   from movies;
```

Step 2

```
create index movies_multi_index on my_movies(movieid,year_released, runtime);
```

前生效，中后不生效

Step 3 Compare with following queries

```
explain select * from my_movies where movieid=20;
explain select * from my_movies where movieid<100 and year_released=2000; 生效
explain select * from my_movies where year_released=2000;
explain select * from my_movies where runtime=200;
```

Part 5. Create index on function

Step 1 索引数根据源数据进行查询的，但是如果用函数改变了索引就没用了

```
create index movies_title_index on my_movies(title);
```

Step 2 Compare following two queries, whether index is effected.

```
explain select * from my_movies where title = 'Armaan';
explain select * from my_movies where upper(title) = 'ARMAAN';
```

Step 3 Create index on upper() function

```
create index movies_upper_title_index on my_movies(upper(title));
```

Step 4 whether index is effected in follow query

```
explain select * from my_movies where upper(title) = 'ARMAAN';
```