RELATIONAL OPERATORS: SELECTION

CS 564- Fall 2021

ACKs: *Jeff Naughton, Jignesh Patel, AnHai Doan*

WHAT IS THIS LECTURE ABOUT?

Algorithms for the selection operator

LOGICAL VS PHYSICAL OPERATORS

- Logical operators
  - *what* they do
  - e.g., union, selection, project, join, grouping

- Physical operators
  - *how* they do it
  - e.g., nested loop join, sort-merge join, hash join, index join

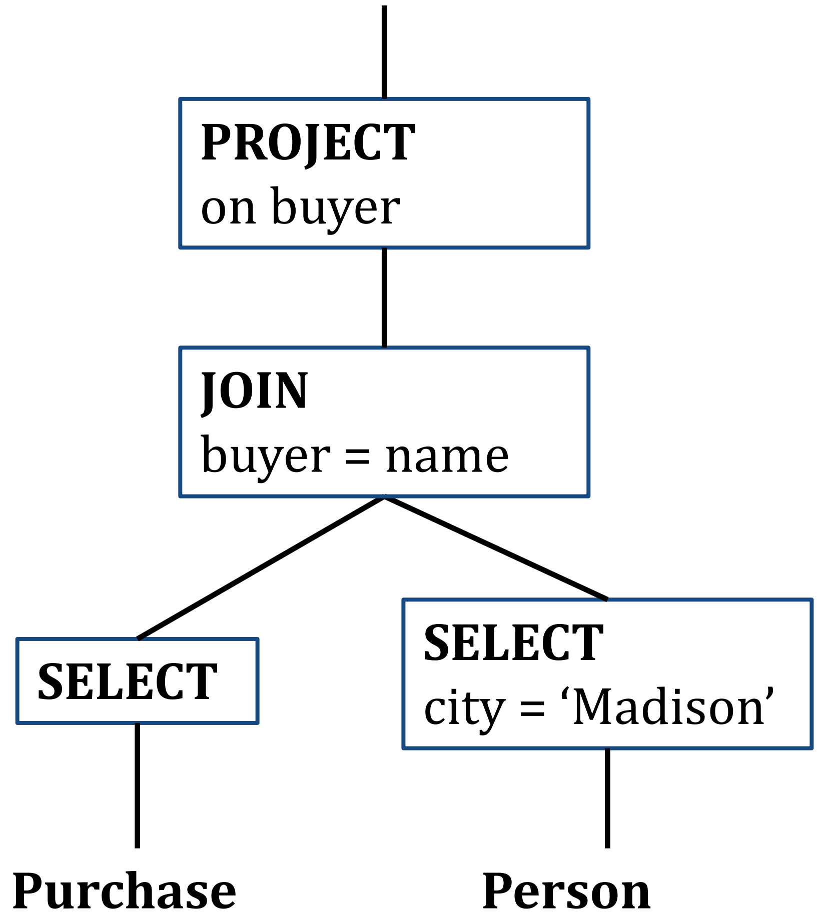
EXAMPLE QUERY

```
SELECT P.buyer
FROM   Purchase P, Person Q
WHERE  P.buyer=Q.name
AND    Q.city='Madison'
```

- Assume that Person has a B+ tree index on city

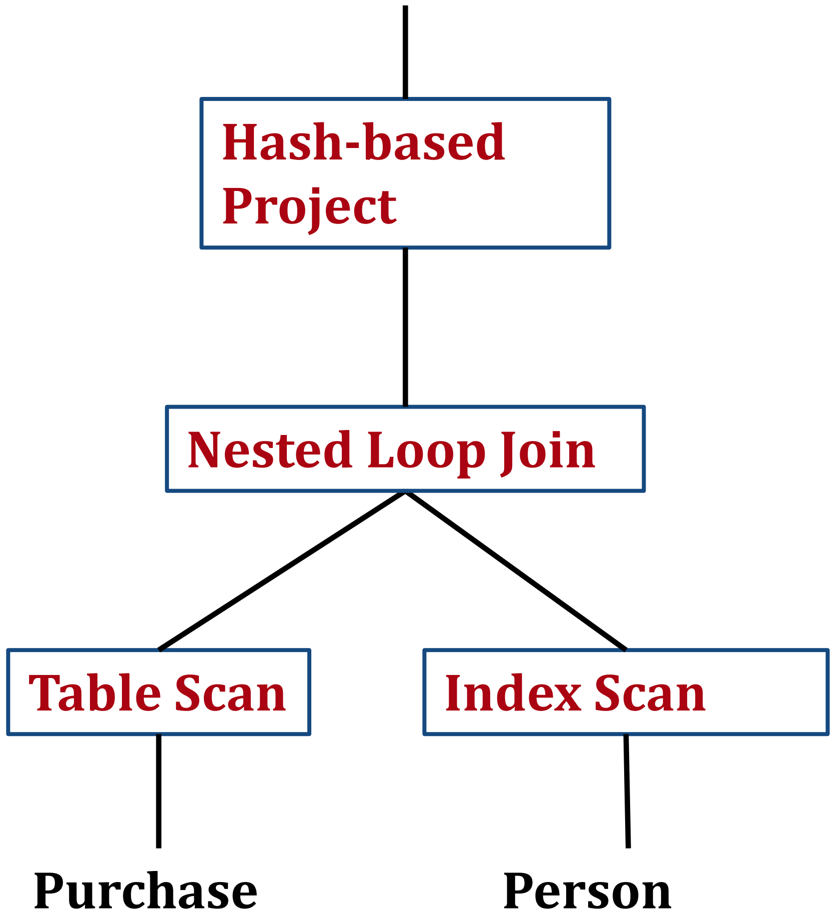
EXAMPLE: LOGICAL PLAN

```
SELECT P.buyer
FROM   Purchase P, Person Q
WHERE  P.buyer=Q.name
AND    Q.city='Madison'
```



EXAMPLE: PHYSICAL PLAN

```
SELECT P.buyer
FROM   Purchase P, Person Q
WHERE  P.buyer=Q.name
AND    Q.city='Madison'
```



SELECTION

SELECT OPERATOR

access path = way to retrieve tuples from a table

- **File Scan:**
  - scan the entire file
  - I/O cost: number of pages N
- **Index Scan:**
  - use an index available on some predicate
  - I/O cost: it varies depending on the index

INDEX SCAN COST

- Hash index: O(1)
  - but we can only use it with equality predicates!
- B+ tree index: the cost depends on whether the index is clustered or not:
    - *unclustered*: we may need to access as many pages from the file as the (#selected tuples)
    - *clustered*: we need to access (#selected tuples)/(#tuples per page) pages in the file
    - **optimization**: we can sort the rids by page number before we retrieve them from the unclustered index

B+ TREE SCAN: EXAMPLE

- A relation with **1,000,000** records
- **100** records on a page (of the heap file)
- **500** (key, rid) pairs on a leaf page
- height of B+ tree = **3**

selectivity = percentage of tuples that satisfy the selection condition

Clustered index + 1% selectivity

- #tuples to retrieve: 1% (1,000,000) = 10,000
- #leaf pages = 10,000/500 = **20**
- #pages in the heap file = 10,000/100 = **100**
- I/O cost = 3 + 20 + 100 = **123 I/Os**

B+ TREE SCAN: EXAMPLE

- A relation with **1,000,000** records
- **100** records on a page (of the heap file)
- **500** (key, rid) pairs on a leaf page
- height of B+ tree = **3**

<u>selectivity</u> = percentage of tuples that satisfy the selection condition

Unclustered index + 1% selectivity

- #tuples to retrieve: 1% (1,000,000) = 10,000
- #leaf pages = 10,000/500 = **20**
- #pages in the heap file = **10,000** (in the worst case)
- I/O cost = 3 + 20 + 10,000 = **10,023 I/Os**

B+ TREE SCAN: EXAMPLE

- A relation with **1,000,000** records
- **100** records on a page (of the heap file)
- **500** (key, rid) pairs on a leaf page
- height of B+ tree = **3**

selectivity = percentage of tuples that satisfy the selection condition

	1% selectivity	**10% selectivity**
clustered	3+20+100	3+200+1,000
unclustered	3+20+10,000	3+200+100,000
unclustered + sorting	3+20+(~10,000)	3+200+(~10,000)

if we first sort, we will read at most all the pages in the B+ tree

GENERAL SELECTIONS

- So far we studied selection on a single attribute
- How do we use indexes when we have multiple selection conditions?
  - `R.A = 10` **`AND`** `R.A > 10`
  - `R.A = 10` **`OR`** `R.B < 20`

INDEX MATCHING

We say that an index *matches* a selection predicate if the index can be used to evaluate it efficiently

- relation **R**(A,B,C,D)
- hash index on composite key (A, B)

```
SELECT *
FROM   R
WHERE  A = 10 AND B = 5 ;
```

match

```
SELECT *
FROM   R
WHERE  A = 5 ;
```

no match

INDEX MATCHING: HASH INDEX

- **selection** = $\mathtt{pred}_1$ AND $\mathtt{pred}_2$ AND …
- $\mathtt{pred}_\mathtt{i}$ =(attribute) $\{<, \leq, \geq, >, =, \neq\}$ (constant)

A hash index on $(A, B, \dots)$ matches the selection condition if *all* attributes in the index search key appear in a predicate with equality (=)

EXAMPLE

relation **R**(A,B,C,D)

selection condition	**hash index on (A,B,C)**	**hash index on (B)**
A=5 **AND** B=3	no	yes
A>5 **AND** B<4	no	no
B=3	no	yes
A=5 **AND** C>10	no	no
A=5 **AND** B=3 **AND** C=1	yes	yes
A=5 **AND** B=3 **AND** C=1 **AND** D >6	yes	yes

INDEX MATCHING: B+ TREE

- **selection** = `pred`$_1$ `AND pred`$_2$ `AND` …
- `pred`$_i$ =`(attribute)` $\{<, \leq, \geq, >, =, \neq\}$ `(constant)`

A B+ tree index on $(A, B, \dots)$ matches the selection condition if:

- the attributes in the predicates form a prefix of the search key of the B+ tree
- any operators can be used (not only equality!)

EXAMPLE

relation **R**(A,B,C,D)

selection condition	**B+ tree on (A,B,C)**	**B+ tree on (B,C)**
A=5 **AND** B=3	yes	yes
A>5 **AND** B<4	yes	yes
B=3	no	yes
A=5 **AND** C>10	yes	no
A=5 **AND** B=3 **AND** C=1	yes	yes
A=5 **AND** B=3 **AND** C=1 **AND** D >6	yes	yes

MORE ON INDEX MATCHING

A predicate can match *more than one* index

- hash index on (A) and B+ tree index on (B, C)
- selection: `A=7 AND B=5 AND C=4`

Which index should we use?

1. use the hash index, then check the conditions B=5, C=4 for every retrieved tuple
2. use the B+ tree, then check the condition A=7 for every retrieved tuple
3. use both indexes, intersect the rid sets, and only then fetch the tuples

SELECTION WITH DISJUNCTION

- **selection** = $\texttt{pred}_1$ OR $\texttt{pred}_2$ OR …
- $\texttt{pred}_i$ =(attribute) $\{<, \leq, \geq, >, =, \neq\}$ (constant)

The available indexes need to match **every** predicate in the disjunction!

DISJUNCTION: EXAMPLE

- hash index on (A) **+** hash index on (B)
- selection: `A=7` **`OR`** `B>5`

- Only the first predicate matches an index
- The only option is to do a file scan

DISJUNCTION: EXAMPLE

- hash index on (A) **+** B+ tree on (B)
- `A=7` **`OR`** `B>5`

- One solution is to do a file scan
- A second solution is to use both indexes, fetch the rids, and then do a union, and only then retrieve the tuples

Why do we need to perform the union before fetching the tuples?

GENERAL FORMULA

- hash index on (A) **+** B+ tree on (B)
- `(A=7 OR C>5) AND B > 5`

- We can use the B+ tree to fetch the tuples that satisfy the second predicate (B >5), then filter according to the first

CHOOSING THE RIGHT INDEX

Selectivity of an access path = *fraction* of tuples that need to be retrieved

- We want to choose the *most selective* path!
- Estimating the selectivity of an access path is generally a hard problem

ESTIMATING SELECTIVITY (1)

- selection: `A=3` **`AND`** `B=4` **`AND`** `C=5`
- hash index on (A,B,C)

The selectivity can be approximated by the formula:

1/(# search keys)

- *#keys* is known from the index
- this assumes that the values are distributed *uniformly* across the tuples

EXAMPLE

- selection: `A=3` **`AND`** `B=4` **`AND`** `C=5`
- *clustered* hash index on (A,B,C)
- *#pages* = 10,000
- *#keys in hash index* = 100

- selectivity = *1%*
- number of pages retrieved $= \ 10{,}000 * 1\% \ = \ 100$
- I/O cost = 100 + (a small constant)

ESTIMATING SELECTIVITY (2)

- selection: `A=3 AND B=4 AND C=5`
- hash index on (B,A)

If we don't know the *#keys* for the index, we can estimate selectivity as follows:

- multiply the selectivity for each primary conjunct
- If *#keys* is not known for an attribute, use 1/10 as default value
- this assumes independence of the attributes!

ESTIMATING SELECTIVITY (3)

- Selection: `A>10 AND A<60`

- If we have a range condition, we assume that the values are uniformly distributed
- The selectivity will be approximated by $\frac{interval}{High-Low}$

Example: if A takes values in [0,100] then the selectivity will be $\sim \frac{60-10}{100-0} = 50\%$

ESTIMATING SELECTIVITY (3)

- Selection: `A>10 AND A<60`

- If we have a range condition, we assume that the values are uniformly distributed
- The selectivity will be approximated by $\frac{interval}{High-Low}$

Example: if A takes values in [0,100] then the selectivity will be $\sim \frac{60-10}{100-0} = 50\%$