Lecture 22: Query Execution

Monday, March 6, 2006

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Outline

- Query execution: 15.1 – 15.5

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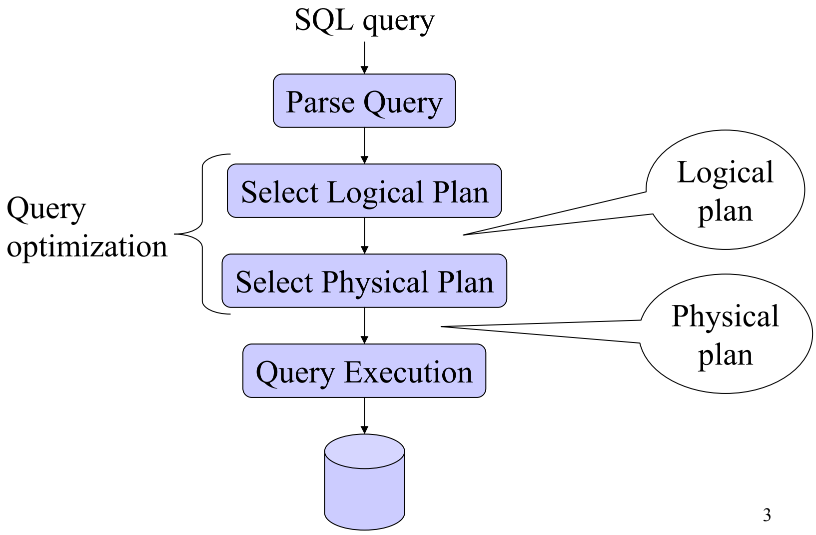
Architecture of a Database Engine



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Logical Algebra Operators

- Union, intersection, difference
- Selection σ
- Projection Π
- Join |x|
- Duplicate elimination δ
- Grouping γ
- Sorting τ

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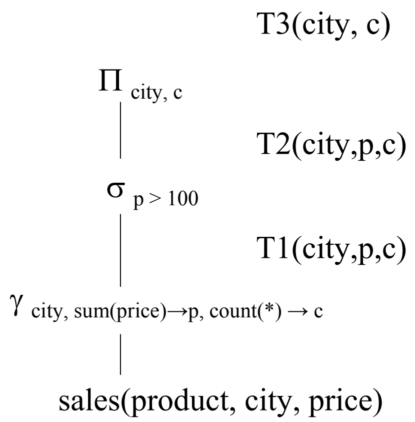
Logical Query Plan

```
SELECT city, count(*)
FROM sales
GROUP BY city
HAVING sum(price) > 100
```



T1, T2, T3 = temporary tables

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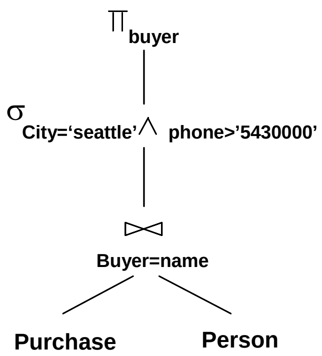
Logical Query Plan

```
SELECT  P.buyer
FROM Purchase P, Person Q
WHERE P.buyer=Q.name AND
      P.city='seattle' AND
     Q.phone > '5430000'
```

Purchase(buyer, city)
Person(name, phone)



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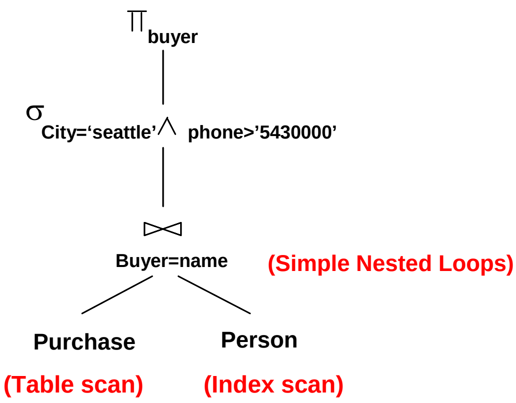
Physical Query Plan

SELECT S.buyer
FROM Purchase P, Person Q
WHERE P.buyer=Q.name AND
Q.city='seattle' AND
Q.phone > '5430000'

Query Plan:
- logical tree
- implementation choice at every node
- scheduling of operations.



Some operators are from relational algebra, and others (e.g., scan) are not.

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Question in Class

Logical operator:

Product(pname, cname) |×| Company(cname, city)

Propose three physical operators for the join, assuming the tables are in main memory:

1.
2.
3.

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Question in Class

Product(pname, cname) |x| Company(cname, city)

- 1000000 products
- 1000 companies

How much time do the following physical operators take if the data is **<u>in main memory</u>** ?

- Nested loop join time =
- Sort and merge = merge-join time =
- Hash join time =

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Cost Parameters

The *cost* of an operation = total number of I/Os

result assumed to be delivered in main memory

Cost parameters:

- B(R) = number of blocks for relation R
- T(R) = number of tuples in relation R
- V(R, a) = number of distinct values of attribute a
- M = size of main memory buffer pool, in blocks

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Cost Parameters

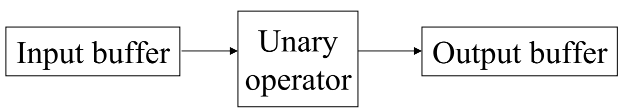
- *Clustered* table R:
  - Blocks consists only of records from this table
  - B(R) << T(R)
- *Unclustered* table R:
  - Its records are placed on blocks with other tables
  - B(R) ≈ T(R)

- When a is a key, V(R,a) = T(R)
- When a is not a key, V(R,a)

Selection and Projection

Selection σ(R), projection Π(R)

- Both are <u>*tuple-at-a-time*</u> algorithms
- Cost: B(R)



Main Memory Hash Join

Hash join: R |x| S

- Scan S, build buckets in main memory
- Then scan R and join

- Cost: B(R) + B(S)
- Assumption: B(S) <= M

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Duplicate Elimination

Duplicate elimination δ(R)

- Hash table in main memory

- Cost: B(R)
- Assumption: B(δ(R)) <= M

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Grouping

Grouping:

Product(name, department, quantity)

$\gamma_{\text{department, sum(quantity)}}$ (Product) → Answer(department, sum)

Main memory hash table

Question: How ?

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Nested Loop Joins

- Tuple-based nested loop R ⋈ S

```
for each tuple r in R do
  for each tuple s in S do
    if r and s join then output (r,s)
```

- Cost: T(R) B(S) when S is clustered
- Cost: T(R) T(S) when S is unclustered

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Nested Loop Joins

- We can be much more clever
- *Question*: how would you compute the join in the following cases ? What is the cost ?
  - B(R) = 1000, B(S) = 2, M = 4
  - B(R) = 1000, B(S) = 3, M = 4
  - B(R) = 1000, B(S) = 6, M = 4

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Nested Loop Joins

- Block-based Nested Loop Join

```
for each (M-2) blocks bs of S do
  for each block br of R do
      for each tuple s in bs
          for each tuple r in br do
              if "r and s join" then output(r,s)
```

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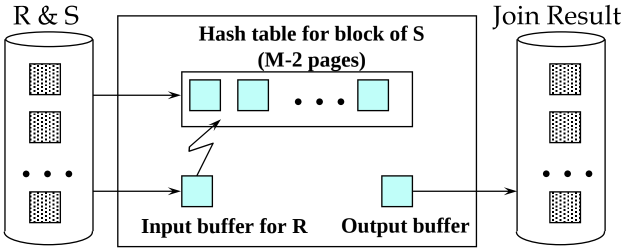
Nested Loop Joins



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Nested Loop Joins

- Block-based Nested Loop Join
- Cost:
  - Read S once: cost B(S)
  - Outer loop runs B(S)/(M-2) times, and each time need to read R: costs B(S)B(R)/(M-2)
  - Total cost: B(S) + B(S)B(R)/(M-2)
- Notice: it is better to iterate over the smaller relation first
- R |x| S: R=outer relation, S=inner relation

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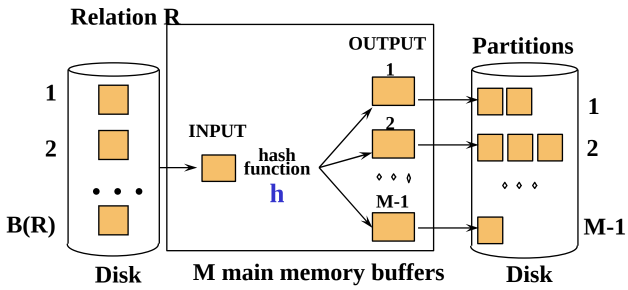
Partitioned Hash Algorithms

- Idea: partition a relation R into buckets, on disk
- Each bucket has size approx. B(R)/M



- Does each bucket fit in main memory ?
  - Yes if B(R)/M <= M, i.e. $B(R) <= M^2$

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Duplicate Elimination

- Recall: δ(R) = duplicate elimination
- Step 1. Partition R into buckets
- Step 2. Apply δ to each bucket (may read in main memory)

- Cost: 3B(R)
- Assumption: $B(R) <= M^2$

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Grouping

- Recall: $\gamma(R)$ = grouping and aggregation
- Step 1. Partition R into buckets
- Step 2. Apply γ to each bucket (may read in main memory)

- Cost: 3B(R)
- Assumption:B(R) <= M^2

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Partitioned Hash Join

R |x| S

- Step 1:
  - Hash S into M buckets
  - send all buckets to disk
- Step 2
  - Hash R into M buckets
  - Send all buckets to disk
- Step 3
  - Join every pair of buckets

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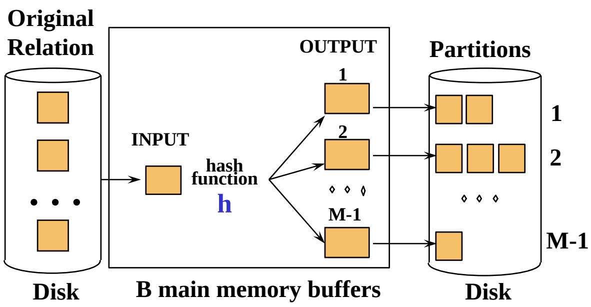
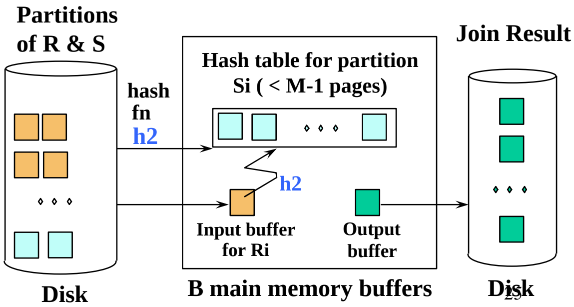
Hash-Join

- Partition both relations using hash fn **h**: R tuples in partition i will only match S tuples in partition i.



- Read in a partition of R, hash it using **h2 (<> h!)**. Scan matching partition of S, search for matches.



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Partitioned Hash Join

- Cost: 3B(R) + 3B(S)
- Assumption: min(B(R), B(S)) <= M^2

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External Sorting

- Problem:
- Sort a file of size B with memory M
- Where we need this:
  - ORDER BY in SQL queries
  - Several physical operators
  - Bulk loading of B+-tree indexes.
- Will discuss only 2-pass sorting, for when $B < M^2$

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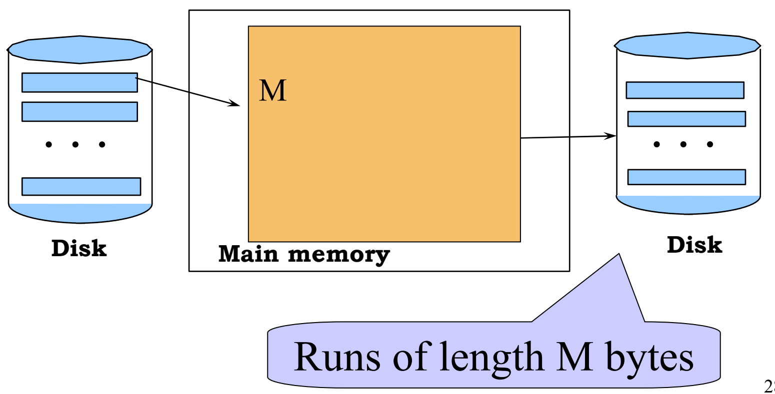
External Merge-Sort: Step 1

- Phase one: load M bytes in memory, sort



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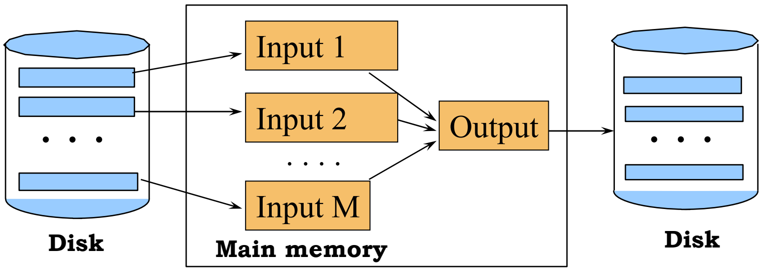
External Merge-Sort: Step 2

- Merge M – 1 runs into a new run
- Result: runs of length M (M – 1)≈ M^2



If B <= M^2 then we are done

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Cost of External Merge Sort

- Read+write+read = 3B(R)
- Assumption: B(R) <= M^2

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Duplicate Elimination

Duplicate elimination $\delta(R)$

- Idea: do a two step merge sort, but change one of the steps
- Question in class: which step needs to be changed and how ?
- Cost = 3B(R)
- Assumption: $B(\delta(R)) <= M^2$

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Grouping

Grouping: $\gamma_{a,\ sum(b)}$ (R)

- Same as before: sort, then compute the sum(b) for each group of a's
- Total cost: 3B(R)
- Assumption: $B(R) <= M^2$

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Merge-Join

Join R |x| S

- Step 1a: initial runs for R
- Step 1b: initial runs for S
- Step 2: merge and join

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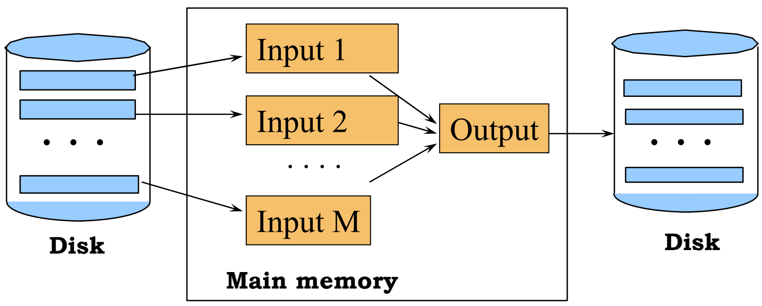
Merge-Join



M_1 = B(R)/M runs for R
M_2 = B(S)/M runs for S
If B <= M^2 then we are done

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Two-Pass Algorithms Based on Sorting

Join R |x| S

- If the number of tuples in R matching those in S is small (or vice versa) we can compute the join during the merge phase
- Total cost: 3B(R)+3B(S)
- Assumption: $B(R) + B(S) <= M^2$

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Index Based Selection

- Selection on equality: $\sigma_{a=v}(R)$
- Clustered index on a: cost B(R)/V(R,a)
- Unclustered index on a: cost T(R)/V(R,a)

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Index Based Selection

- Example:

B(R) = 2000
T(R) = 100,000
V(R, a) = 20

cost of $\sigma_{a=v}(R)$ = ?

- Table scan (assuming R is clustered):
  - B(R) = 2,000 I/Os
- Index based selection:
  - If index is clustered: B(R)/V(R,a) = 100 I/Os
  - If index is unclustered: T(R)/V(R,a) = 5,000 I/Os
- Lesson: don't build unclustered indexes when V(R,a) is small !

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Index Based Join

- R $\bowtie$ S
- Assume S has an index on the join attribute
- Iterate over R, for each tuple fetch corresponding tuple(s) from S
- Assume R is clustered. Cost:
  - If index is clustered: B(R) + T(R)B(S)/V(S,a)
  - If index is unclustered: B(R) + T(R)T(S)/V(S,a)

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Index Based Join

- Assume both R and S have a sorted index (B+ tree) on the join attribute
- Then perform a merge join
  - called zig-zag join
- Cost: B(R) + B(S)

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Summary of External Join Algorithms

- Block Nested Loop: B(S) + B(R)*B(S)/M
- Partitioned Hash: 3B(R)+3B(S);
  - min(B(R),B(S)) <= M^2
- Merge Join: 3B(R)+3B(S
  - B(R)+B(S) <= M^2
- Index Join: B(R) + T(R)B(S)/V(S,a)

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