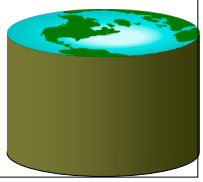
SQL and Query Execution for Aggregation



Example Instances

Reserves

sid	bid	day
22	101	10/10/96
95	103	11/12/96

Sailors

sid	sname	rating	age
22	Dustin	7	45.0
31	Lubber	8	55.5
95	Bob	3	63.5

Boats

bid	bname	color
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red

Queries With GROUP BY

•To generate values for a column based on groups of rows, use aggregate functions in SELECT statements with the GROUP BY clause

```
SELECT      [DISTINCT] target-list
FROM        relation-list
[WHERE      qualification]
GROUP BY    grouping-list
```

- **The target-list contains**
  - **(i) list of column names &**
  - **(ii) terms with aggregate operations (e.g., MIN (S.age)).**
- **column name list (i)** can contain only attributes from the grouping-list.

Group By Examples

For each rating, find the average age of the sailors

```
SELECT S.rating, AVG (S.age)
FROM Sailors S
GROUP BY S.rating
```

For each rating find the age of the youngest sailor with age ≥ 18

```
SELECT S.rating, MIN (S.age)
FROM Sailors S
WHERE S.age >= 18
GROUP BY S.rating
```

Conceptual Evaluation

```
SELECT      [DISTINCT] target-list
FROM        relation-list
[WHERE      qualification]
GROUP BY    grouping-list
```

- **The cross-product of relation-list is computed, tuples that fail qualification are discarded, `unnecessary' fields are deleted, and the remaining tuples are partitioned into groups by the value of attributes in grouping-list.**
- **One answer tuple is generated per qualifying group.**
- **If DISTINCT is specified: drop duplicate answer tuples.**

```
SELECT S.rating, MIN (S.age)
FROM Sailors S
WHERE S.age >= 18
GROUP BY S.rating
```

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
71	zorba	10	16.0
64	horatio	7	35.0
29	brutus	1	33.0
58	rusty	10	35.0

1. Form cross product

rating	age
1	33.0
7	45.0
7	35.0
8	55.5
10	35.0

2. Delete unneeded columns, rows; form groups

Answer Table

3. Perform Aggregation

rating	age
1	33.0
7	35.0
8	55.0
10	35.0

Find the number of reservations for each **red** boat.

```
SELECT B.bid, COUNT(*) AS numres
FROM Boats B, Reserves R
WHERE  R.bid=B.bid
       AND B.color='red'
GROUP BY  B.bid
```

- Grouping over a join of two relations.

SELECT B.bid, COUNT (*) AS scount
FROM Boats B, Reserves R
WHERE R.bid=B.bid AND B.color='red'
GROUP BY B.bid

1

b.bid	b.color	r.bid
101	blue	101
102	red	101
103	green	101
104	red	101
101	blue	102
102	red	102
103	green	102
104	red	102

2

b.bid	b.color	r.bid
102	red	102

answer

b.bid	scount
102	1

Queries With GROUP BY and HAVING

```
SELECT      [DISTINCT] target-list
FROM        relation-list
WHERE       qualification
GROUP BY    grouping-list
HAVING      group-qualification
```

- **Use the HAVING clause with the GROUP BY clause to restrict which group-rows are returned in the result set**

Conceptual Evaluation

- Form groups as before.
- The group-qualification is then applied to eliminate some groups.
  - **Expressions in group-qualification must have a single value per group!**
  - **That is, attributes in group-qualification must be arguments of an aggregate op or must also appear in the grouping-list. (SQL does not exploit primary key semantics here!)**
- One answer tuple is generated per qualifying group.

Find the age of the youngest sailor with age ≥ 18, for each rating with at least 2 such sailors

```
SELECT  S.rating,  MIN (S.age)
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

sid	sname	rating	age
22	Dustin	7	45.0
31	lubber	8	55.5
71	zorba	10	16.0
64	horatio	7	35.0
29	brutus	1	33.0
58	rusty	10	35.0

2

rating	age
1	33.0
7	45.0
7	35.0
8	55.5
10	35.0

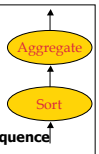
3

rating	m-age	count
1	33.0	1
7	35.0	2
8	55.0	1
10	35.0	1

Answer relation

rating	
7	35.0

Sort GROUP BY: Naïve Solution



- **The Sort iterator ensures that all tuples are output in sequence**
- **The Aggregate iterator keeps running info ("transition values") on agg functions in the SELECT list, per group**
  - **E.g., for COUNT, it keeps count-so-far**
  - **For SUM, it keeps sum-so-far**
  - **For AVERAGE it keeps sum-so-far and count-so-far**
- **As soon as the Aggregate iterator sees a tuple from a new group:**
  - **It produces an output for the old group based on the agg function**
    - **E.g. for AVERAGE it returns (sum-so-far/count-so-far)**
  - **It resets its running info.**
  - **It updates the running info with the new tuple's info**

12

An Alternative to Sorting: Hashing!

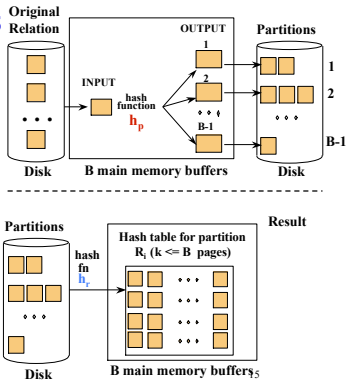
- Idea:
  - Many of the things we use sort for don't exploit the *order* of the sorted data
  - E.g.: forming groups in GROUP BY
  - E.g.: removing duplicates in DISTINCT
- Often good enough to match all tuples with equal field-values
- Hashing does this!
  - And may be cheaper than sorting! (Hmmm…!)
  - But how to do it for data sets bigger than memory??

General Idea

- Two phases:
  - **Partition**: use a hash function h_p to split tuples into partitions on disk.
    - We know that all matches live in the same partition.
    - Partitions are "spilled" to disk via output buffers
  - **ReHash**: for each partition on disk, read it into memory and build a main-memory hash table based on a hash function h_r
    - Then go through each bucket of this hash table to bring together matching tuples

Two Phases

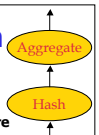
- **Partition:**
- **Rehash:**



Analysis

- How big of a table can we hash in two passes?
  - B-1 "spill partitions" in Phase 1
  - Each should be no more than B blocks big
  - Answer: B(B-1).
    - Said differently: We can hash a table of size N blocks in about $\sqrt{N}$ space
  - Much like sorting!
- Have a bigger table? **Recursive partitioning!**
  - In the ReHash phase, if a partition *b* is bigger than B, then recurse:
    - pretend that *b* is a table we need to hash, run the Partitioning phase on *b*, and then the ReHash phase on each of its (sub)partitions

Hash GROUP BY: Naïve Solution (similar to the Sort GROUPBY)



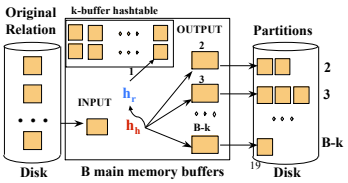
- The Hash iterator permutes its input so that all tuples are output in groups
- The Aggregate iterator keeps running info ("transition values") on agg functions in the SELECT list, per group
  - E.g., for COUNT, it keeps `count-so-far`
  - For SUM, it keeps `sum-so-far`
  - For AVERAGE it keeps `sum-so-far` *and* `count-so-far`
- When the Aggregate iterator sees a tuple from a new group:
  1. It produces an output for the old group based on the agg function
     - E.g. for AVERAGE it returns (`sum-so-far/count-so-far`)
  2. It resets its running info.
  3. It updates the running info with the new tuple's info

We Can Do Better!

- Combine the summarization into the hashing process
  - During the ReHash phase, don't store tuples, store pairs of the form <GroupVals, TransVals>
  - When we want to insert a new tuple into the hash table
    - If we find a matching GroupVals, just update the TransVals appropriately
    - Else insert a new <GroupVals,TransVals> pair
- What's the benefit?
  - Q: How many pairs will we have to handle?
  - A: Number of distinct values of GroupVals columns
    - Not the number of tuples!!
  - Also probably "narrower" than the tuples
- Can we play the same trick during sorting?

Even Better: Hybrid Hashing

- What if the set of <GroupVals,TransVals> pairs fits in memory
  - It would be a waste to spill it to disk and read it all back!
  - Recall this could be true even if there are *tons* of tuples!
- Idea: keep a smaller 1st partition in memory during phase 1!
  - Output its stuff at the end of Phase 1.
  - Q: how do we choose the number k?



A Hash Function for Hybrid Hashing

- Assume we like the hash-partition function h_p
- Define h_h operationally as follows:
  - $h_h(x) = 1$ if in-memory hashtable is not yet full
  - $h_h(x) = 1$ if x is already in the hashtable
  - $h_h(x) = h_p(x)$ otherwise
- This ensures that:
  - Bucket 1 fits in k pages of memory
  - If the entire set of distinct hashtable entries is smaller than k, we do *no spilling!*