Data Warehousing

CPS 216

Advanced Database Systems

Review

Data warehousing: integrating data for OLAP

- OLAP versus OLTP
- Warehousing versus mediation
- Warehouse maintenance
  - Warehouse data as materialized views
  - Recomputation versus incremental maintenance
  - Self-maintenance

Today

- Star, snowflake, and cube
- ROLAP and MOLAP algorithms

Star schema

Product — Dimension table

PID	name	cost
p1	beer	10
p2	diaper	16
…	…	…

Store — Dimension table

SID	city
s1	Durham
s2	Chapel Hill
s3	RTP
…	…

Sale

OID	date	CID	PID	SID	qty	price
100	11/23/2001	c3	p1	s1	1	12
102	12/12/2001	c3	p2	s1	2	17
105	12/24/2001	c5	p1	s3	5	13
…	…	…	…	…	…	…

Fact table
- Big
- Constantly growing
- Stores measures (often aggregated in queries)

Customer

CID	name	address	city
c3	Amy	100 Main St.	Durham
c4	Ben	102 Main St.	Durham
c5	Carl	800 Eighth St.	Durham
…	…	…	…

Dimension table
- Small
- Updated infrequently

Dimension hierarchies

Product — Brand

Product — Product type — Product category

PID	brandID	typeID
p1	b1	t1
p2	b2	t2
p3	b1	t4
…	…	…

brandID	name
b1	Huggies
b2	Budwiser
…	…

typeID	name	catID
t1	diaper	cat7
t2	beer	cat9
t3	juice	cat9
t4	pacifier	cat7
…	…	…

catID	name
cat7	babies
cat9	beverages
…	…

+ star schema = snowflake schema

Star join indexes

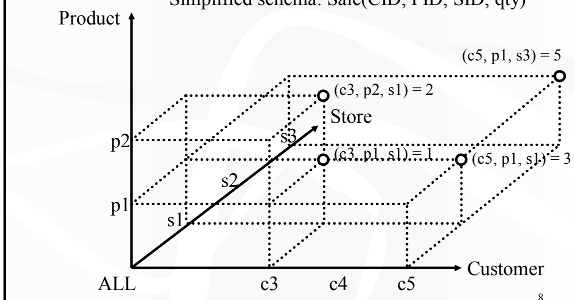
- Queries frequently join fact table with dimension tables
  - » Materialize the join result to speed up queries
- For each combination of dimension attribute values, store the list of tuple ID's in the fact table
  - Brand name, store city, customer city → sales records; Product type, store city → sales records; etc.
  - Conceptually, multi-attribute indexes on the join result
- One index to support each combination of selection conditions on attributes?
  - Too many indexes!

Bitmap join indexes

» O'Neil & Quass, SIGMOD 1997
- Bitmap and projection indexes for each dimension attribute
  – Value of the dimension attribute ↔ tuple ID's in the fact table
- To process an arbitrary combination of selection conditions, use bitmap indexes
  – Bitmaps can be combined efficiently
- To retrieve attribute values for output, use projection indexes

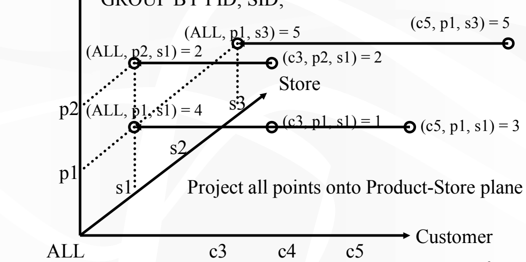
Data cube

Simplified schema: Sale(CID, PID, SID, qty)



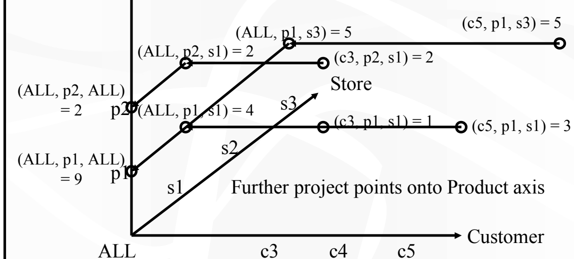
Completing the cube (slide 1)

Total quantity of sales for each product in each store
SELECT SUM(qty) FROM Sale
GROUP BY PID, SID;



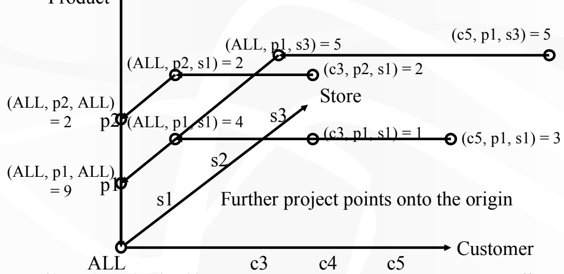
Completing the cube (slide 2)

Total quantity of sales for each product
SELECT SUM(qty) FROM Sale GROUP BY PID;



Completing the cube (slide 3)

Total quantity of sales
SELECT SUM(qty) FROM Sale;



CUBE operator

» Gray et al., ICDE 1996
- Sale(CID, PID, SID, qty)
- Proposed SQL extension:
  SELECT SUM(qty) FROM Sale
  GROUP BY CUBE CID, PID, SID;
- Output contains:
  – Normal groups produced by GROUP BY
    - (c1, p1, s1, sum), (c1, p2, s3, sum), etc.
  – Groups with one or more ALL's
    - (ALL, p1, s1, sum), (c2, ALL, ALL, sum), (ALL, ALL, ALL, sum), etc.
- Can you write a CUBE query using only GROUP BY's?

ROLLUP operator

- Sometimes CUBE is too much
  - (…, state, city, street, …, age, DOB, …)
  - CUBE state, city, street returns meaningless groups
    - (ALL, ALL, 'Main Street'): sales on any Main Street?
  - CUBE age, DOB returns useless groups
    - (ALL, DOB): DOB functionally determines age!
- Proposed SQL extension:
  GROUP BY ROLLUP state, city, street;
- Output contains groups with ALL's only as suffix
  - ('NC', 'Durham', 'Main Street'), ('NC', 'Durham', ALL), ('NC', ALL, ALL), (ALL, ALL, ALL)
  - But not (ALL, ALL, 'Main Street') or (ALL, 'Durham', ALL)

13

Computing GROUP BY

- ROLAP (Relational OLAP)
  - Use standard relational engine
  - Sorting and clustering
  - Using indexes
  - Automatic summary tables
- MOLAP (Multidimensional OLAP)
  - Use a sparse multidimensional array

14

Sorting and clustering

- Sort (or cluster, e.g., using hashing) tuples according to GROUP BY attributes
  - Tuples in the same group are processed together
  - Only one intermediate aggregate result needs to be kept—low memory requirement
- What if GROUP BY attributes ≠ sort attributes?
  - Still fine if GROUP BY attributes form a prefix of the sort order
  - Otherwise, need to keep intermediate aggregate results around

15

More on sort order

- Sort by the order in which GROUP BY attributes appear?
  - Not necessary; e.g., GROUP BY PID, SID can be processed just as efficiently by sorting on SID, PID
- Sort by the order in which GROUP BY ROLLUP attributes appear?
  - Useful; e.g., GROUP BY ROLLUP state, city, street can be processed efficiently by sorting on state, city, street, but not by sorting on street, city, state

16

Using bitmap join indexes

» O'Neil & Quass, SIGMOD 1997

- Use the bitmap join indexes on GB_1, GB_2, …, GB_k
- For each value v_1 of GB_1 in order:
  For each value v_2 of GB_2 in order: …
  For each value v_k of GB_k in order:
  Intersect bitmaps to locate tuples;
  Retrieve their measures;
  Calculate aggregate for group (v_1, v_2, …, v_k);
- Helps if data is sorted by GB_1, GB_2, …, GB_k
  - So measures in the same group are clustered

17

Automatic summary tables

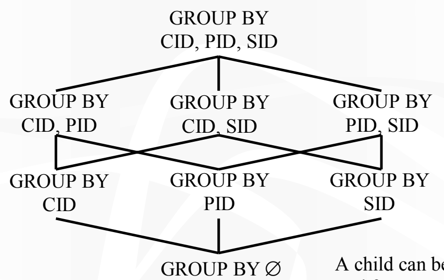
- Computing GROUP BY aggregates is expensive
- OLAP queries perform GROUP BY all the time

- Idea: precompute and store the aggregates!

» Automatic summary tables
  - Maintained automatically as base data changes
  - Just another index/materialized view

18

Aggregation view lattice



A child can be computed from any parent

19

Selecting views to materialize

- Factors in deciding what to materialize
  - What is its storage cost?
  - What is its update cost?
  - Which queries can benefit from it?
  - How much can a query benefit from it?
- Example
  - GROUP BY ∅ is small, but not useful to most queries
  - GROUP BY CID, PID, SID is useful to any query, but too large to be beneficial

» Harinarayan et al., SIGMOD 1996; Gupta & Mumick, ICDE 1999

20

Interlude: TPC-D, -H, and -R

- TPC-D: standard OLAP benchmark until 1999
  - With aggressive use of precomputation techniques (materialized views, automatic summary tables), vendors were able to "cheat" and achieve amazing performance
- Now, TPC-D has been replaced by
  - TPC-H: ad hoc OLAP queries
    - Cannot use materialized views
  - TPC-R: business-reporting OLAP queries
    - Can use materialized views

» http://www.tpc.org/

21

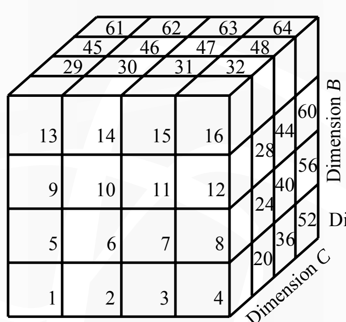
From tables to arrays

» Zhao et al., SIGMOD 1997

- "Chunk" an *n*-dimensional cube into *n*-dimensional subcubes
  - For a dense chunk (>40% full), store it as is
  - For a sparse chunk (<40% full), compress it using <*coordinate*, *value*> pairs
- To convert a table into chunks
  - Pass 1: Partition table into memory-size partitions, each of which contains a number of chunks
  - Pass 2: Read partitions back in one at a time, and chunk each partition in memory

22

Dimension order



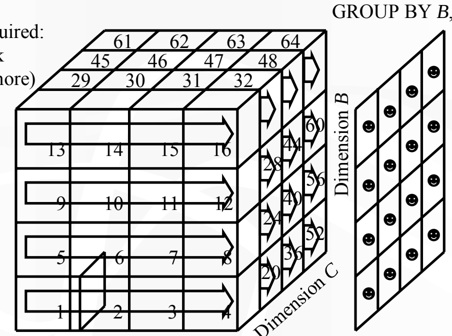
Dimension order: *A*, *B*, *C* = Sort order: *C*, *B*, *A*

23

Basic array cubing

Memory required: 1 chunk (could be more)

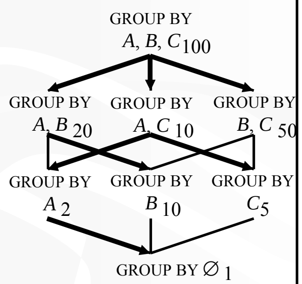
GROUP BY *B*, *C*



24

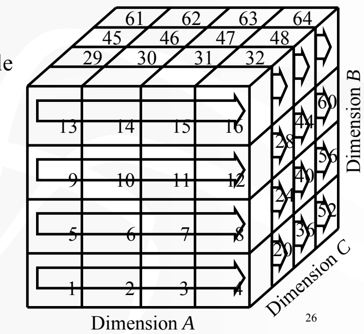
Minimal spanning tree

- Recall the aggregation lattice
- MST of the lattice: parent is always chosen to be the one with minimum size
- Compute each node from its parent in the MST



Multiway array cubing

- Goal: compute all aggregates at the same time in a single pass over the array, using minimum amount of memory
- GROUP BY *B*, *C* requires 1 chunk
- GROUP BY *A*, *C* requires 4 chunks
- GROUP BY *A*, *B* requires 16 chunks



Memory requirement

- Dimension order is $D_1, D_2, \ldots, D_n$
- Aggregate to compute projects out D_p (i.e., GROUP BY $D_1, \ldots, D_{p-1}, D_{p+1}, \ldots, D_n$)
- The memory required is roughly $|D_1| \cdot |D_1| \cdot \ldots \cdot |D_{p-1}|$ chunks
  - Where $|D_i|$ denotes the number of chunks along D_i

» It is harder to aggregate away dimensions that come later in the dimension order

Minimum-memory spanning tree

- MMST of the aggregation lattice
  - Parent is always chosen to be the one that makes the child require the minimum memory to compute
  - Note that results are produced in dimension order too, so computation of the entire MMST can be pipelined
- Choose an optimal dimension order to minimize the total amount of memory required by MMST
  - It turns out that this optimal order is $D_1, D_2, \ldots, D_n$, where $|D_1| \leq |D_2| \leq \ldots \leq |D_n|$

ROLAP versus MOLAP

- Multiway array cubing algorithm (MOLAP) beats sorting-based ROLAP algorithms
  - Compressed array representation is more compact than table representation
  - Sorting-based ROLAP spends too much time on comparing and copying
  - In MOLAP, order is implied by the array positions

» An alternative ROLAP techinque
  - Convert table to array
  - Do MOLAP processing
  - Dump the result cube to a table

Next time

Data mining