Implementation & Computation of DW and Data Cube

Remember: ....What is OLAP?

- The term OLAP („online analytical processing“) was coined in a white paper written for Arbor Software Corp. in 1993
- Data Cube, Storage space
- Partial, total and no materialization (precomputation)
- How to select cuboids for materialization and how to use them
- Indexing
- Multiway array aggregation
- Constraints for the curse of dimensionality
- Discovery driven explanation

- Data warehouse contains huge volumes of data
- OLAP servers demand that the decision support queries be answered in order of seconds
- Highly efficient cube computation techniques
  - Access methods
  - Query processing techniques
Core of multidimensional data analysis is the efficient of aggregation across many sets of dimension

The compute cube operator aggregates over all subsets of dimensions

You would like to create a data cubeAll_Electronics that contains the following:

item, city, year, and sales_in_Euro

Answer following queries

- Compute the sum of sales, grouping by item and city
- Compute the sum of sales, grouping by item
- Compute the sum of sales, grouping by city
The total number of data cuboids is $2^3 = 8$

- $(\text{city}, \text{item}, \text{year})$,
- $(\text{city}, \text{item})$, $(\text{city}, \text{year})$,
- $(\text{city}), (\text{item}), (\text{year})$,
- $(\emptyset)$

$(\emptyset)$, the dimensions are not grouped
- These group-by’s form a lattice of cuboids for the data cube
- The basic cuboid contains all three dimensions

Hasse-Diagram: Helmut Hasse 1898 - 1979 did fundamental work in algebra and number theory
For a cube with n dimensions, there are total $2^n$ cuboids

A cube operator was first proposed by Gray et. All 1997:

http://research.microsoft.com/~Gray/

On-line analytical processing may need to access different cuboids for different queries

Compute some cuboids in advance
- Precomputation leads to fast response times
- Most products support to some degree precomputation
Storage space may explode...
  - If there are no hierarchies the total number for n-dimensional cube is $2^n$

But....
  - Many dimensions may have hierarchies, for example time
    - day < week < month < quarter < year
  - For a n-dimensional data cube, where $L_i$ is the number of all levels (for time $L_{time}=5$), the total number of cuboids that can be generated is
    $$ T = \prod_{i=1}^{n} (L_i + 1) $$

It is unrealistic to precompute and materialize (store) all cuboids that can be generated

Partial materialization
  - Only some of possible cuboids are generated
No materialization
- Do not precompute any of “nonbase” cuboids
  - Expensive computation in during data analysis

Full materialization
- Precompute all cuboids
  - Huge amount of memory....

Partial materialization
- Which cuboids should we precompute and which not?

Partial materialization - Selection of cuboids

- Take into account:
  - the queries, their frequencies, the accessing costs
  - workload characteristics, costs for incremental updates, storage requirements

- Broad context of physical database design, generation and selection of indices
Heuristic approaches for cuboid selection

- Materialize the set of cuboids on which other popular referenced cuboids are based

- It is important to take advantage of materialized cuboids during query processing
  - How to use available index structures on the materialized cuboids
  - How to transform the OLAP operations into the selected cuboids
- Determine which operations should be preformed on the available cuboids
  - This involves transforming any selection, projection, roll-up and drill down operations in the query into corresponding SQL and/or OLAP operations
  
- Determine to which materialized cuboids the relevant operations should be applied
  
- Identifying all materialized cuboids that may potentially be used to answer the query

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**Example**

- Suppose that we define a datacube for ALLElectronics of the form
  
  sales[time,item,location]: sum(salles_in_euro)

- Dimension hierarchies
  - time: day < month < quarter < year
  - item: item_name < brand < type
  - location: country < province_or_state < city
Query

- \{brand, province_or_state\} with year=2000

- Four materialized cubes are available
  1) \{year, item_name, city\}
  2) \{year, brand, country\}
  3) \{year, brand, province_or_state\}
  4) \{item_name, province_or_state\} where year = 2000

- Which should be selected to process the query?

- Finer granularity data cannot be generated from coarser-granularity data
- Cuboid 2 cannot be used since country is more general concept than province_or_state
- Cuboids 1, 3, 4 can be used
  - They have the same set or superset of the dimensions of the query
  - The selection clause in the query can imply the selection in the cuboid
  - The abstraction levels for the item and location dimension in these cuboids are at a finer level than brand and province_or_state
How would the costs of each cuboid compare?

- Cuboid 1 would cost the most, since both *item_name* and *city* are at a lower level than *brand* and *province_or_state*

- If not many *year* values associated with *items* in the cube, and there are several *item names* for each *brand*, then cuboid 3 will be better than cuboid 4

- Efficient indices available for cuboid 4, cuboid 4 better choice (bitmap indexes)

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Indexing OLAP Data: Bitmap Index

- Index on a particular column
- Each value in the column has a bit vector: bit-op is fast
- The length of the bit vector: # of records in the base table
- The *i*-th bit is set if the *i*-th row of the base table has the value for the indexed column

<table>
<thead>
<tr>
<th>Base table</th>
<th>Index on Region</th>
<th>Index on Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cust</td>
<td>Region</td>
<td>Type</td>
</tr>
<tr>
<td>C1</td>
<td>Asia</td>
<td>Retail</td>
</tr>
<tr>
<td>C2</td>
<td>Europe</td>
<td>Dealer</td>
</tr>
<tr>
<td>C3</td>
<td>Asia</td>
<td>Dealer</td>
</tr>
<tr>
<td>C4</td>
<td>America</td>
<td>Retail</td>
</tr>
<tr>
<td>C5</td>
<td>Europe</td>
<td>Dealer</td>
</tr>
</tbody>
</table>
**Bitmap Index**

- Allows quick search in data cubes
- Advantageous compared to hash and tree indices
- Useful for low-cardinality domains because comparison, join, and aggregation operations are reduced to bitmap arithmetic's
  - (Reduced processing time!)
- Significant reduction in space and I/O since a string of character can be represented by a bit

**Join indexing method**

- The join indexing method gained popularity from its use in relational database query processing
- Traditional indexing maps the value in a given column to a list of rows having that value

- If two relations $R(RID,A)$ and $S(B,SID)$ join on two attributes $A$ and $B$, then the join index record contains the pair $(RID,SID)$ from $R$ and $S$ relation
- Join index records can identify joinable tuples without performing costly join operators
Indexing OLAP Data: Join Indices

In data warehouses, join index relates the values of the dimensions of a start schema to rows in the fact table.

- E.g. fact table: Sales and two dimensions city and product
  - A join index on city maintains for each distinct city a list of R-IDs of the tuples recording the Sales in the city
- Join indices can span multiple dimensions

Resulting join index tables

<table>
<thead>
<tr>
<th>Join index table for location/sales</th>
<th>Join index table for item/sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>location</td>
<td>sales_key</td>
</tr>
<tr>
<td>Main Street</td>
<td>T57</td>
</tr>
<tr>
<td>Main Street</td>
<td>T288</td>
</tr>
<tr>
<td>Main Street</td>
<td>T884</td>
</tr>
</tbody>
</table>

Join index table linking two dimensions: location/item/sales

<table>
<thead>
<tr>
<th>location</th>
<th>item</th>
<th>sales_key</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Street</td>
<td>Sony-TV</td>
<td>T57</td>
</tr>
</tbody>
</table>
Multiway Array Aggregation

- Sometimes we need to precompute all of the cuboids for a given data cube
  - (full materialization)
- Cuboids can be stored on secondary storage and accessed when necessary
- Methods must take into account the limited amount of main memory and time
- Different techniques for ROLAP and MOLAP

Partitioning

- Usually, entire data set does not fit in main memory
- Sort distinct values, partition into blocks that fit

- Optimizations
  - Partitioning
    - External Sorting, Hashing, Counting Sort
  - Ordering dimensions to encourage pruning
    - Cardinality, Skew, Correlation
  - Collapsing duplicates
    - Can’t do holistic aggregates anymore!
- Relational OLAP (ROLAP) uses tuples and relational tables as its basic data structures
- Multidimensional OLAP (MOLAP) uses a multidimensional array
- Explore different cube computation techniques

**ROLAP cube computation**

- Sorting hashing and grouping operations are applied to the dimension attributes in order to reorder and group related tuples
- Aggregate may be computed from previously computed aggregates, rather than from the base fact tables
MOLAB and cube computation

- MOLAP cannot perform the value-based reordering because it uses direct array addressing
  - Partition arrays into chunks (a small subcube which fits in memory).
  - Compressed sparse array addressing for empty cell arrays
- Compute aggregates in “multiway” by visiting cube cells in the order which minimizes the number of times to visit each cell, and reduces memory access and storage cost

Example 3-D data array containing the dimensions A, B, C

- Array is partitioned into small, memory based chunks
  - Array is partitioned into 64 chunks
- Full materialization
  - The base cuboid denoted by ABC from which all other cuboids are directly computed. This cuboid is already computed
  - The 2-D cuboids AB, AC, BC (has to be computed)
  - The 1-D cuboid A, B, C (has to be computed)
  - 0-D (apex) must be also computed
What is the best traversing order to do multi-way aggregation?

Suppose we would like to compute the $b_0c_0$ chunk of the BC cuboid

- We allocate space for this chunk in the chunk memory
- By scanning chunks 1 to 4 of the $b_0c_0$ chunk is computed
- The chunk memory can be assigned to the next chunks
- BC cuboid can be computed using only one chunk of memory!
Multi-way Array Aggregation for Cube Computation

Multiway of computation

- When chunk 1 is being scanned, all other 2-D chunks relating to the chunk 1 can be simultaneously be computed
Example

- Suppose the size of the array for each dimension A, B, C is 40,400,4000
  - The size of each partition is therefore 10,100,1000
  - Size of BC is 400*4000=1,600,000
  - Size of AC is 40*4000=160,000
  - Size of AB is 40*400=16,000

- Scanning in the order 1 to 64
  - Aggregation of chunk b_y c_z requires scanning 4 chunks
  - Aggregation of chunk a_x c_z requires scanning 13 chunks
  - Aggregation of chunk a_x b_y requires scanning 49 chunks
Multi-way Array Aggregation for Cube Computation

- To avoid bringing 3-D chunk into memory more than once
- Ordering 1-64:
  - One for chunk of the BC plane 100*1000
  - For one row of the AC plane 10*4000
  - For the whole AB plane 40*400
  - + -------------------
  - = 156.000
Suppose, scanned in different order, first aggregation towards the smallest AB plane, and then towards the AC plane:

- One for chunk of the AB plane $400 \times 4000$
- For one row of the AC plane $10 \times 4000$
- For the whole BC plane $10 \times 100$

+$\underline{\text{-------------------}}$

$=1.641.000$

- 10 times more memory

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Multi-Way Array Aggregation for Cube Computation

- Method: the planes should be sorted and computed according to their size in ascending order
- Idea: keep the smallest plane in the main memory, fetch and compute only one chunk at a time for the largest plane
- Limitation of the method: computing well only for a small number of dimensions
- The number of the cuboids is exponential to the number of dimensions ($2^N$)
Overcome the curse of dimensionality

- Use constraints, for example “iceberg cube”

- Compute only those combinations of attribute values that satisfy a **minimum support requirement** or other aggregate condition, such as average, min, max, or sum

- The term "iceberg" was selected because these queries retrieve a relatively small amount of the data in the cube, i.e. the "tip of the iceberg"

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Iceberg Cube

- Computing only the cuboid cells whose count or other aggregates satisfying the condition like
  
  `HAVING COUNT(*) >= minsup`

- **Motivation**
  
  - Only calculate “interesting” cells — data above certain threshold
  - Avoid explosive growth of the cube

  - Suppose 100 dimensions, only 1 base cell. How many aggregate cells if count >= 1? What about count >= 2?
BUC (Bottom-Up Computation)

- This algorithm computes the cube beginning with the smallest, most aggregated cuboid and recursively works up to the largest, least aggregated cuboids.
- If the cuboid does not satisfy the minimum support condition, then the algorithm does not calculate the next largest cuboid.

Discovery driven Exploration

- A user analyst search for interesting patterns in the cube by the operations
- User following his one hypothesis and knowledge tries to recognize exceptions or anomalies
- Problems:
  - Search space very large
- Solution:
  - Indicate data exceptions automatically
Exception

- Data value which significantly different, based on statistical model
- Residual value
  - Scale values based on the standard deviation
  - If the scaled value exceeds a specified threshold

Kinds of Exceptions and their Computation

- Parameters
  - SelfExp: surprise of cell relative to other cells at same level of aggregation
  - InExp: surprise beneath the cell (less aggregate, finer resolution)
  - PathExp: surprise beneath cell for each drill-down path
- Computation of exception indicator (modeling fitting and computing SelfExp, InExp, and PathExp values) can be overlapped with cube construction
- Exception themselves can be stored, indexed and retrieved like precomputed aggregates
Discovery-Driven Data Cubes

Data Cube, Storage space
Partial, total and no materialization (precomputation)
How to select cuboids for materialization and how to use them
Indexing
Multiway array aggregation
Constraints for the curse of dimensionality
Discovery driven explanation
Data Cleaning

- (De)normalization (?)
- Missing Values
- ...