



CS 412 Intro. to Data Mining


Chapter 4. Data Warehousing and On-line Analytical Processing

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Chapter 4: Data Warehousing and On-line Analytical Processing

- ❑ Data Warehouse: Basic Concepts 
- ❑ Data Warehouse Modeling: Data Cube and OLAP
- ❑ Data Warehouse Design and Usage
- ❑ Data Warehouse Implementation
- ❑ Summary

What is a Data Warehouse?

- ❑ Defined in many different ways, but not rigorously
 - ❑ A decision support database that is maintained **separately** from the organization's operational database
 - ❑ Support **information processing** by providing a solid platform of consolidated, historical data for analysis
- ❑ “A data warehouse is a subject-oriented, integrated, time-variant, and nonvolatile collection of data in support of management's decision-making process.” —W. H. Inmon
- ❑ Data warehousing:
 - ❑ The process of constructing and using data warehouses

Data Warehouse—Subject-Oriented

- ❑ Organized around major subjects, such as **customer, product, sales**
- ❑ Focusing on the modeling and analysis of data for decision makers, not on daily operations or transaction processing
- ❑ Provide **a simple and concise** view around particular subject issues by **excluding data that are not useful in the decision support process**

Data Warehouse—Integrated

- ❑ Constructed by integrating multiple, heterogeneous data sources
 - ❑ relational databases, flat files, on-line transaction records
- ❑ Data cleaning and data integration techniques are applied.
 - ❑ Ensure consistency in naming conventions, encoding structures, attribute measures, etc. among different data sources
 - ❑ Ex. Hotel price: differences on currency, tax, breakfast covered, and parking
 - ❑ When data is moved to the warehouse, it is converted

Data Warehouse—Time Variant

- The time horizon for the data warehouse is significantly longer than that of operational systems
 - Operational database: current value data
 - Data warehouse data: provide information from a historical perspective (e.g., past 5-10 years)
- Every key structure in the data warehouse
 - Contains an element of time, explicitly or implicitly
 - But the key of operational data may or may not contain “time element”

Data Warehouse—Nonvolatile

- ❑ Independence
 - ❑ A **physically separate store** of data transformed from the operational environment
- ❑ Static: Operational **update of data does not occur** in the data warehouse environment
 - ❑ Does not require transaction processing, recovery, and concurrency control mechanisms
 - ❑ Requires only two operations in data accessing:
 - ❑ *initial loading of data* and *access of data*

OLTP vs. OLAP

❑ OLTP: Online transactional processing

❑ DBMS operations

❑ Query and transactional processing

❑ OLAP: Online analytical processing

❑ Data warehouse operations

❑ Drilling, slicing, dicing, etc.

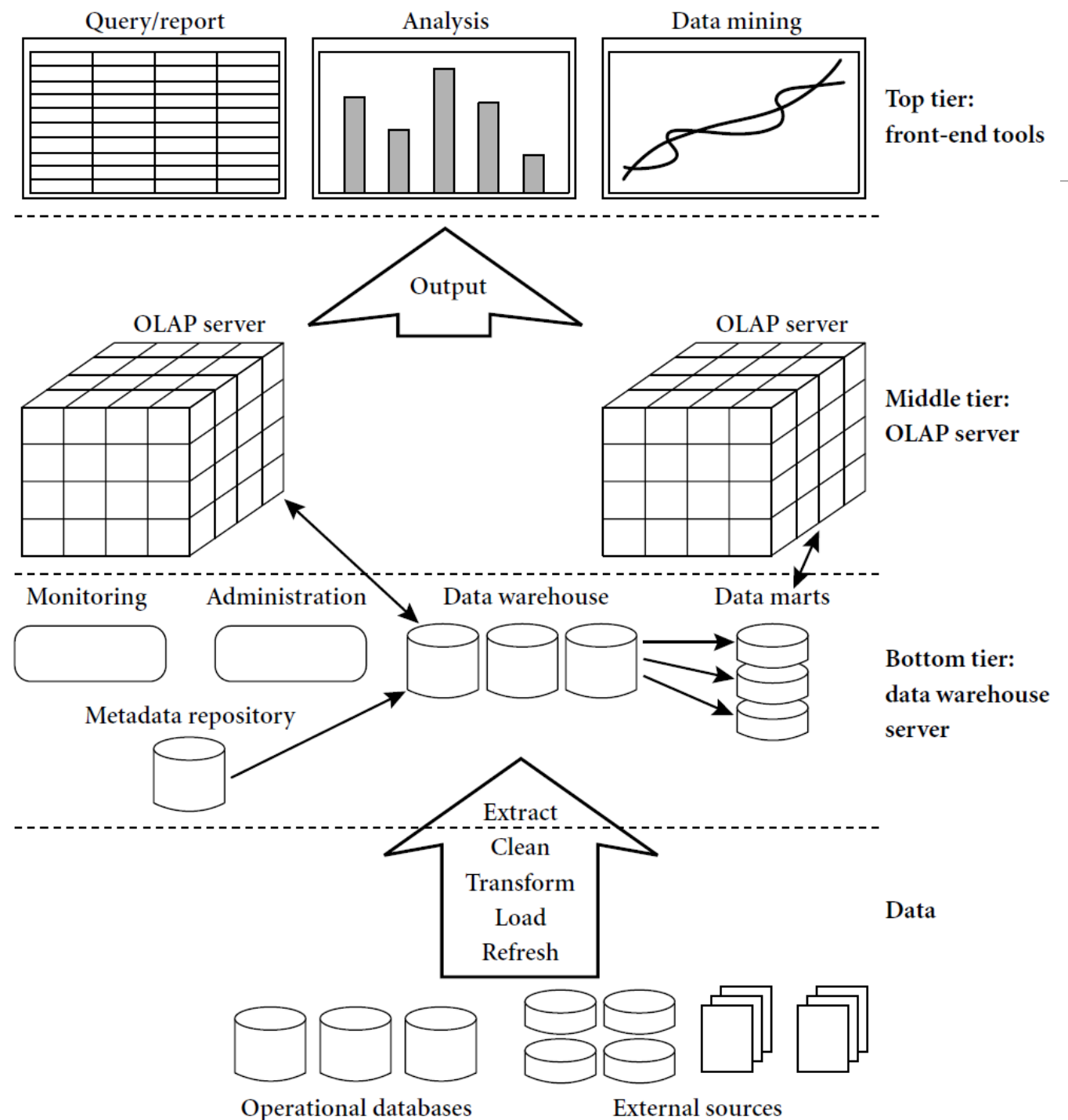
	OLTP	OLAP
users	clerk, IT professional	knowledge worker
function	day-to-day operations	decision support
DB design	application-oriented	subject-oriented
data	current, up-to-date detailed, flat relational isolated	historical, ?? summarized, ? multidimensional integrated, consolidated
usage	repetitive	ad-hoc
access	read/write index/hash on prim. key	lots of scans
unit of work	short, simple transaction	complex query
# records accessed	tens	millions
# users	thousands	hundreds
DB size	100MB-GB	100GB-TB
metric	transaction throughput	query throughput, response

Why a Separate Data Warehouse?

- ❑ High performance for both systems
 - ❑ DBMS— tuned for OLTP: access methods, indexing, concurrency control, recovery
 - ❑ Warehouse—tuned for OLAP: complex OLAP queries, multidimensional view, consolidation
- ❑ Different functions and different data:
 - ❑ [missing data](#): Decision support requires historical data which operational DBs do not typically maintain
 - ❑ [data consolidation](#): DS requires consolidation (aggregation, summarization) of data from heterogeneous sources
 - ❑ [data quality](#): different sources typically use inconsistent data representations, codes and formats which have to be reconciled
- ❑ Note: There are more and more systems which perform OLAP analysis directly on relational databases

Data Warehouse: A Multi-Tiered Architecture

- ❑ Top Tier: Front-End Tools
- ❑ Middle Tier: OLAP Server
- ❑ Bottom Tier: Data Warehouse Server
- ❑ Data



Three Data Warehouse Models

- ❑ **Enterprise warehouse**

- ❑ Collects all of the information about subjects spanning the entire organization

- ❑ **Data Mart**

- ❑ A subset of corporate-wide data that is of value to a specific groups of users
 - ❑ Its scope is confined to specific, selected groups, such as marketing data mart
 - ❑ Independent vs. dependent (directly from warehouse) data mart

- ❑ **Virtual warehouse**

- ❑ A set of views over operational databases
 - ❑ Only some of the possible summary views may be materialized

Extraction, Transformation, and Loading (ETL)

- ❑ **Data extraction**

- ❑ get data from multiple, heterogeneous, and external sources

- ❑ **Data cleaning**

- ❑ detect errors in the data and rectify them when possible

- ❑ **Data transformation**

- ❑ convert data from legacy or host format to warehouse format

- ❑ **Load**

- ❑ sort, summarize, consolidate, compute views, check integrity, and build indices and partitions

- ❑ **Refresh**

- ❑ propagate the updates from the data sources to the warehouse

Metadata Repository

- ❑ **Meta data** is the data defining warehouse objects. It stores:
 - ❑ Description of the structure of the data warehouse
 - ❑ schema, view, dimensions, hierarchies, derived data defn, data mart locations and contents
 - ❑ Operational meta-data
 - ❑ data lineage (history of migrated data and transformation path), currency of data (active, archived, or purged), monitoring information (warehouse usage statistics, error reports, audit trails)
 - ❑ The algorithms used for summarization
 - ❑ The mapping from operational environment to the data warehouse
 - ❑ Data related to system performance
 - ❑ warehouse schema, view and derived data definitions
 - ❑ Business data
 - ❑ business terms and definitions, ownership of data, charging policies

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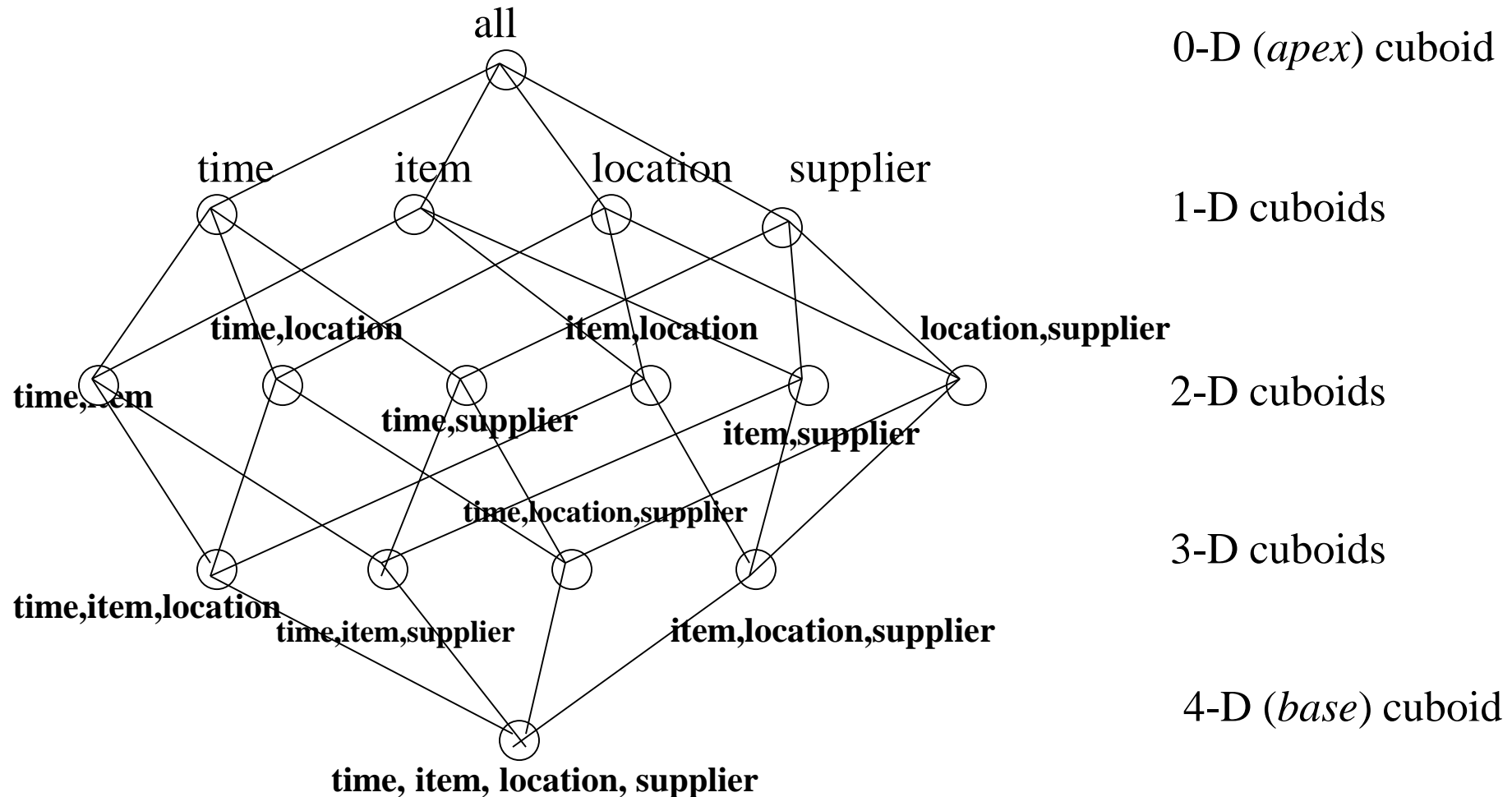
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From Tables and Spreadsheets to Data Cubes

- ❑ A **data warehouse** is based on a multidimensional data model which views data in the form of a data cube
- ❑ A data cube, such as sales, allows data to be modeled and viewed in multiple dimensions
 - ❑ **Dimension tables**, such as item (item_name, brand, type), or time(day, week, month, quarter, year)
 - ❑ **Fact table** contains **measures** (such as dollars_sold) and keys to each of the related dimension tables
- ❑ **Data cube**: A lattice of cuboids
 - ❑ In data warehousing literature, an n-D base cube is called a **base cuboid**
 - ❑ The top most 0-D cuboid, which holds the highest-level of summarization, is called the **apex cuboid**
 - ❑ The lattice of cuboids forms a **data cube**.

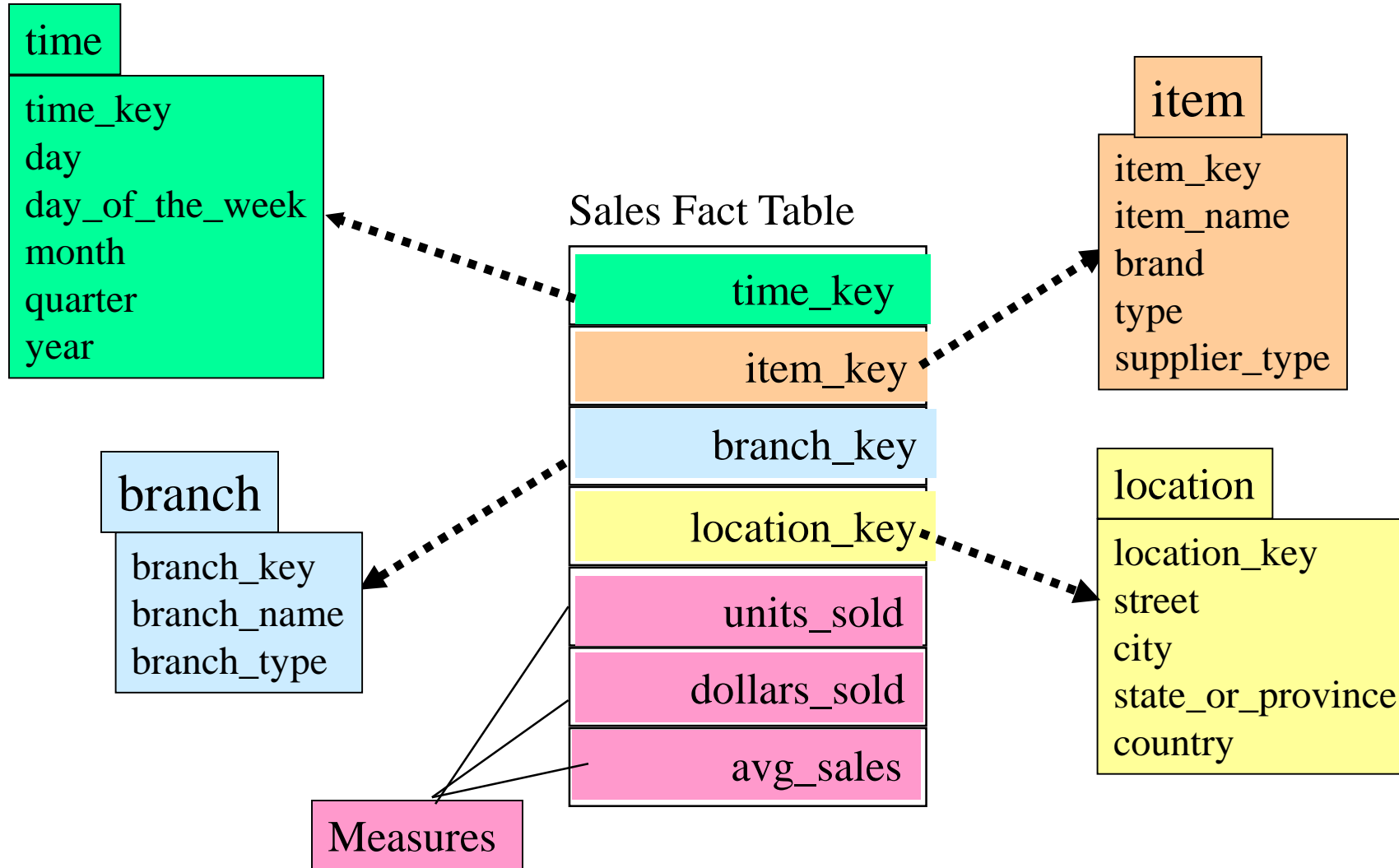
Data Cube: A Lattice of Cuboids



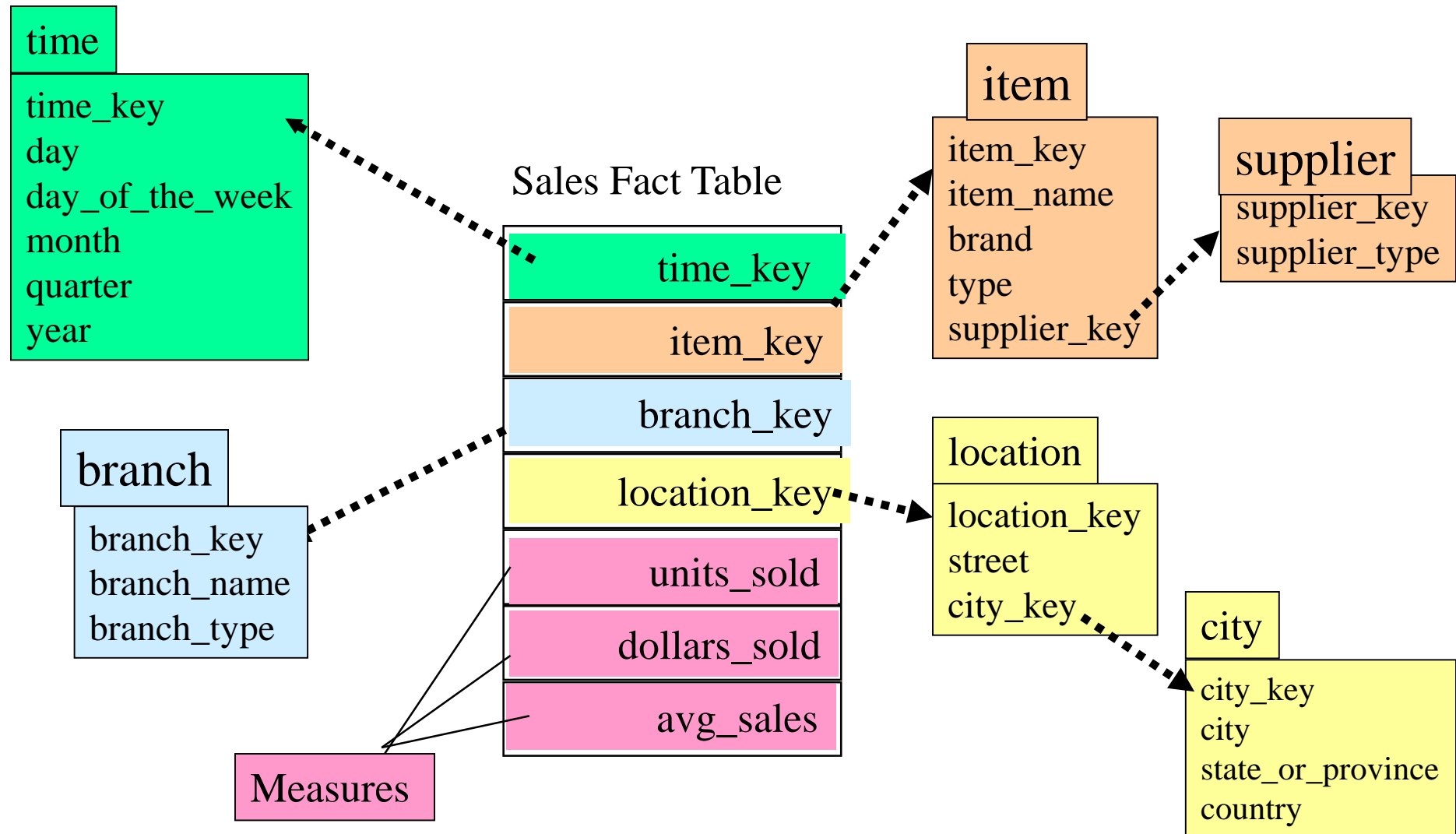
Conceptual Modeling of Data Warehouses

- ❑ Modeling data warehouses: dimensions & measures
 - ❑ Star schema: A fact table in the middle connected to a set of dimension tables
 - ❑ Snowflake schema: A refinement of star schema where some dimensional hierarchy is normalized into a set of smaller dimension tables, forming a shape similar to snowflake
 - ❑ Fact constellations: Multiple fact tables share dimension tables, viewed as a collection of stars, therefore called **galaxy schema** or fact constellation

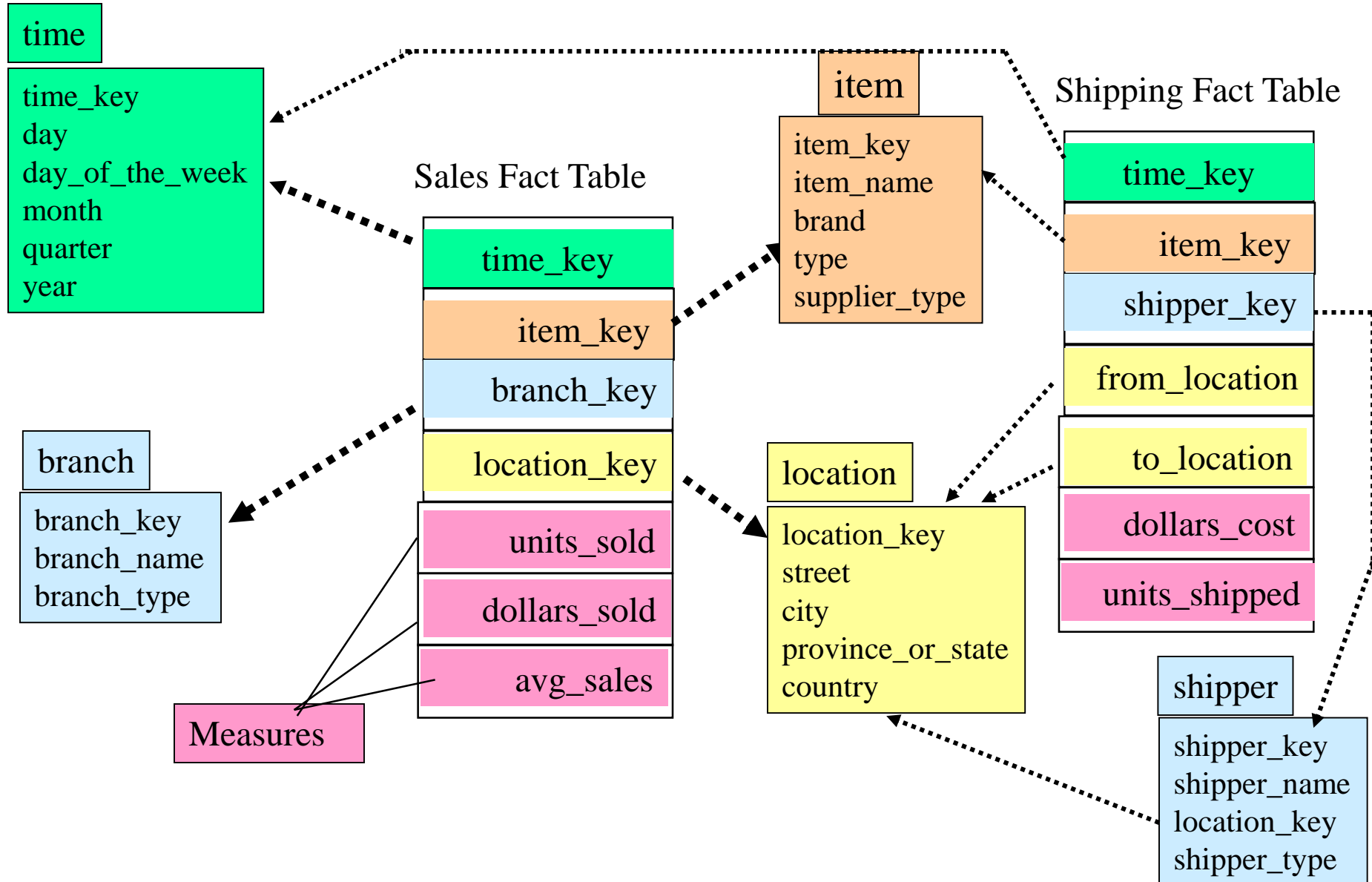
Star Schema: An Example



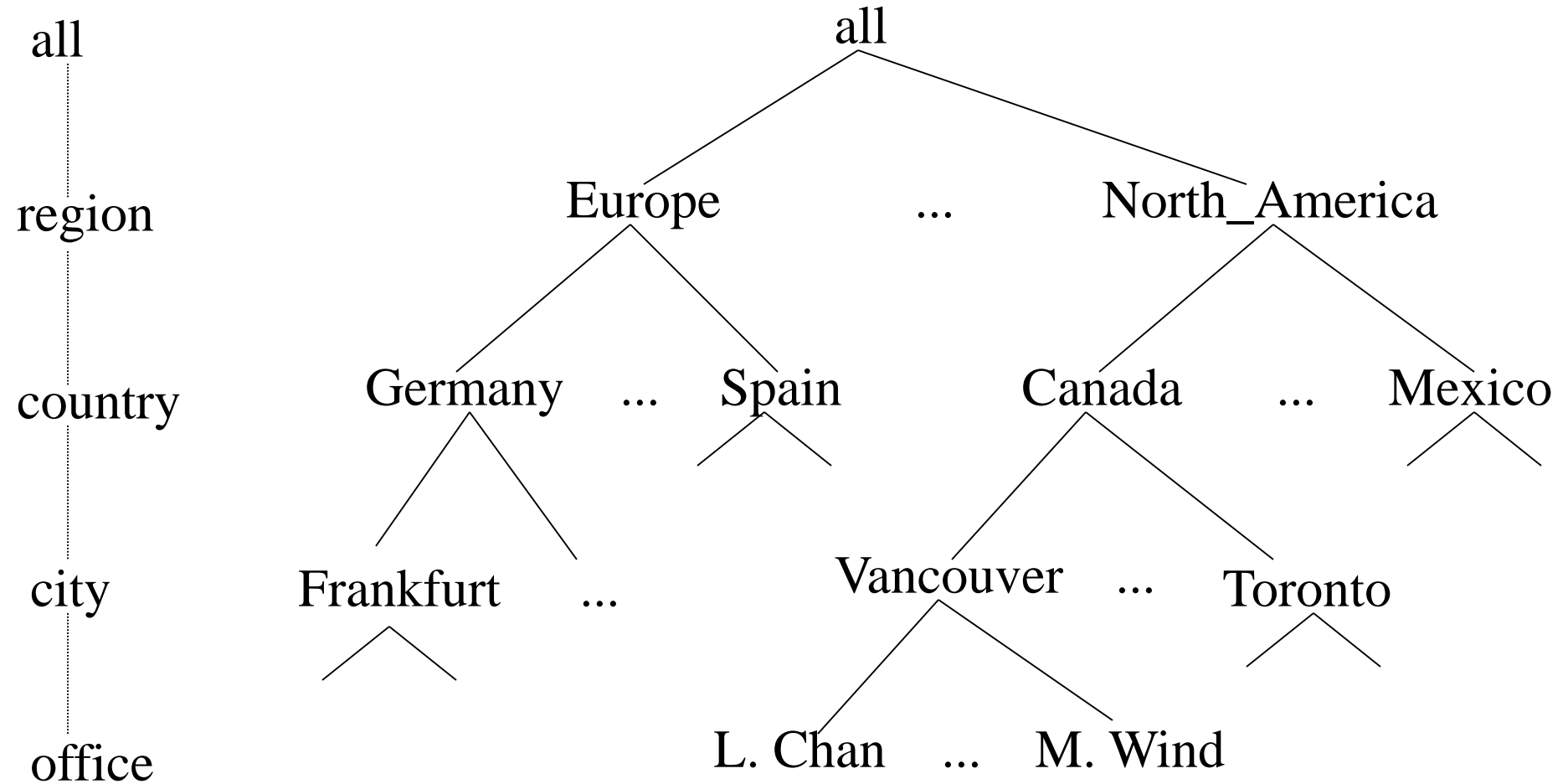
Snowflake Schema: An Example



Fact Constellation: An Example



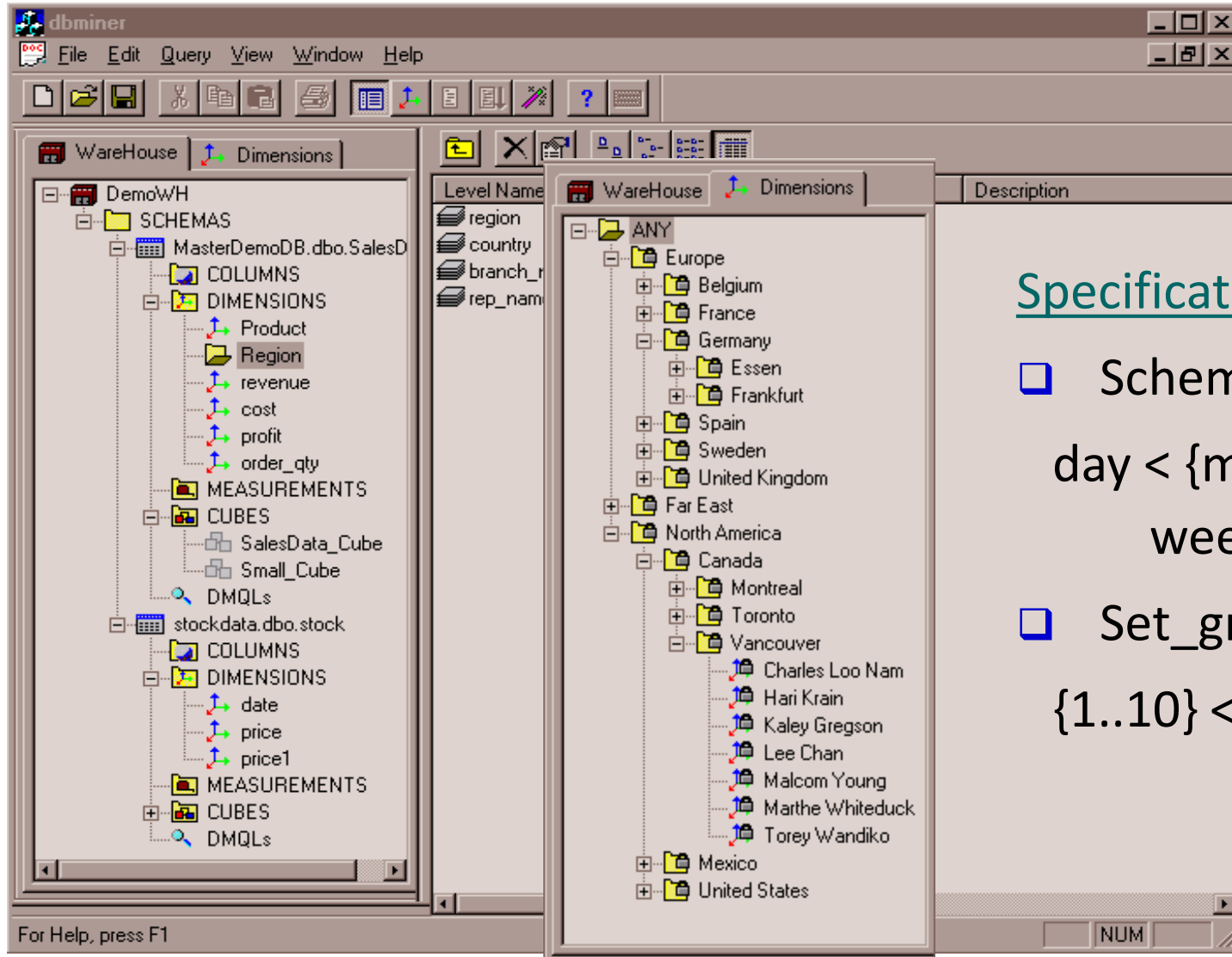
A Concept Hierarchy for a Dimension (location)



Data Cube Measures: Three Categories

- ❑ Distributive: if the result derived by applying the function to n aggregate values is the same as that derived by applying the function on all the data without partitioning
 - ❑ E.g., count(), sum(), min(), max()
- ❑ Algebraic: if it can be computed by an algebraic function with M arguments (where M is a bounded integer), each of which is obtained by applying a distributive aggregate function
 - ❑ $\text{avg}(x) = \text{sum}(x) / \text{count}(x)$
 - ❑ Is min_N() an algebraic measure? How about standard_deviation()?
- ❑ Holistic: if there is no constant bound on the storage size needed to describe a subaggregate.
 - ❑ E.g., median(), mode(), rank()

View of Warehouses and Hierarchies



Specification of hierarchies

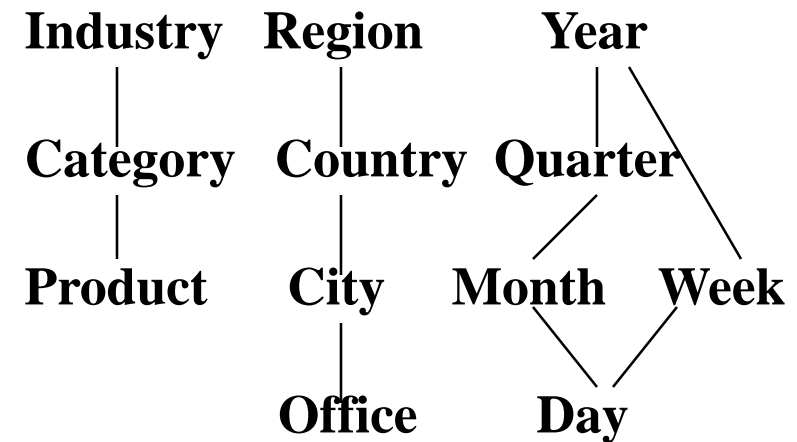
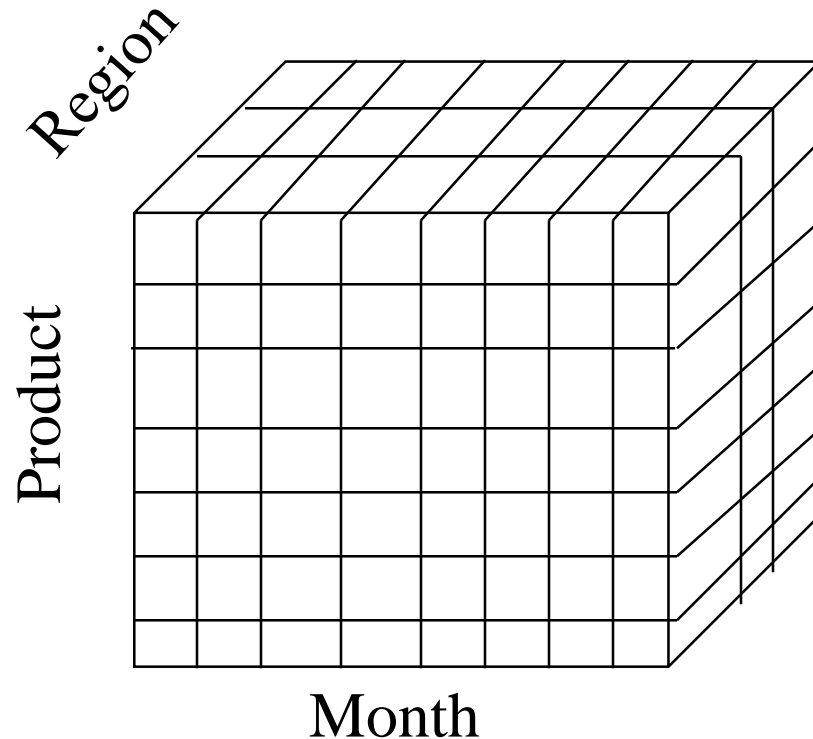
- ☐ Schema hierarchy
day < {month < quarter;
week} < year
- ☐ Set_grouping hierarchy
{1..10} < inexpensive

Multidimensional Data

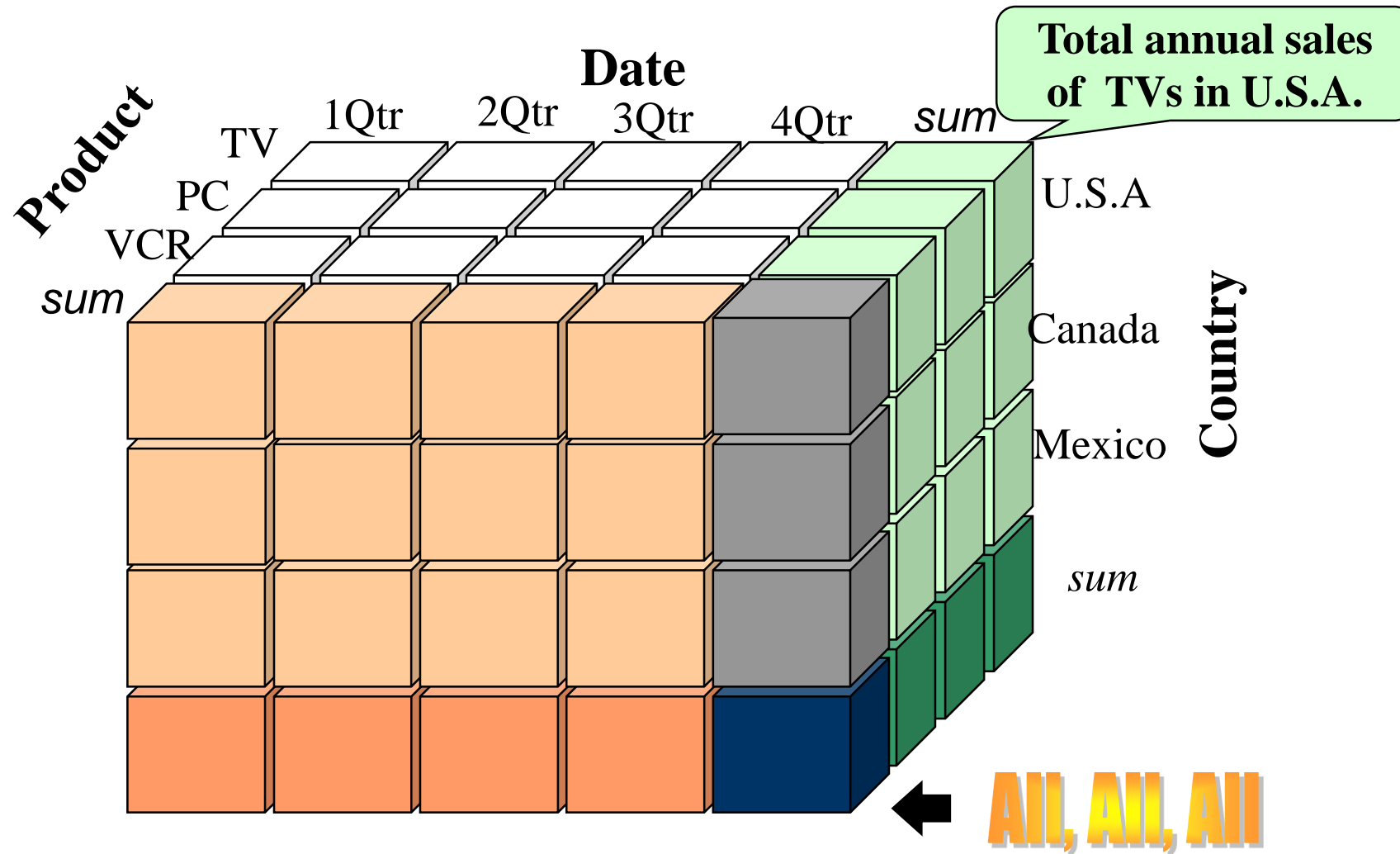
- ❑ Sales volume as a function of product, month, and region

Dimensions: *Product, Location, Time*

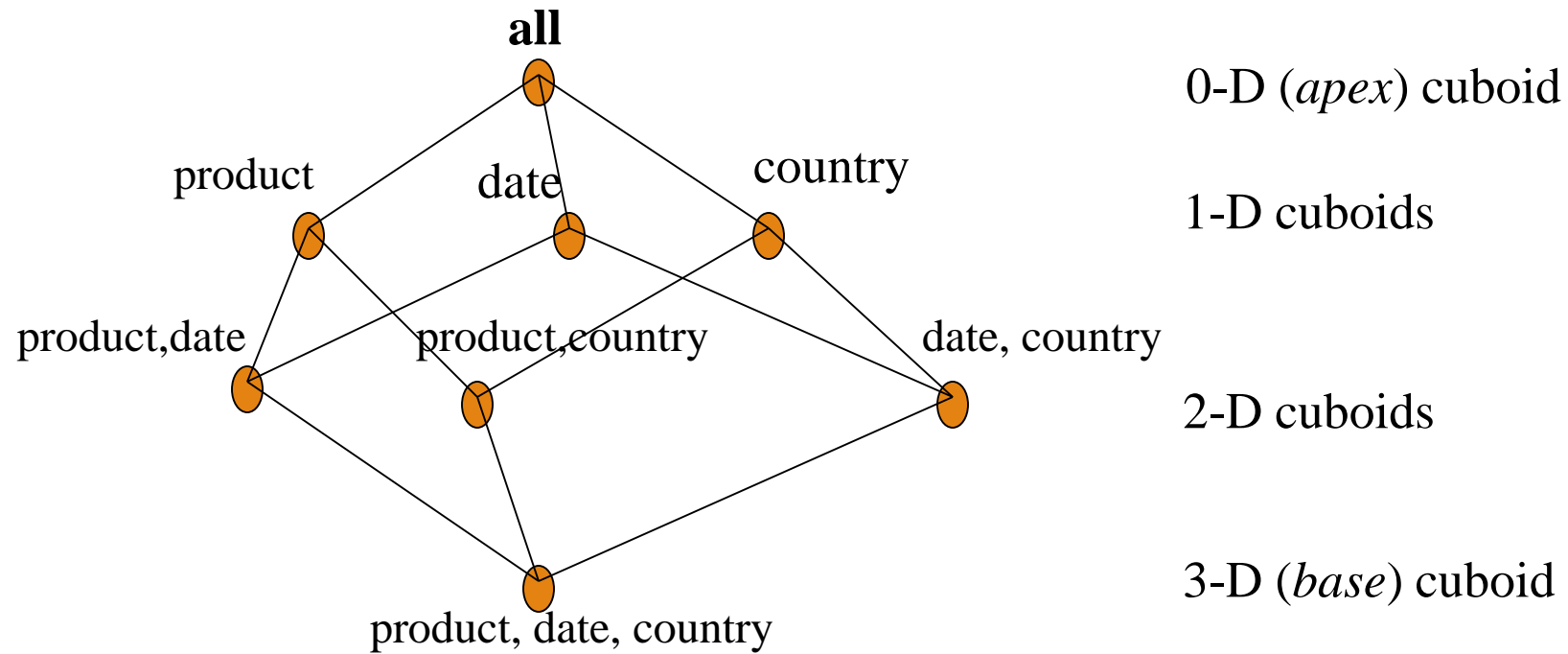
Hierarchical summarization paths



A Sample Data Cube



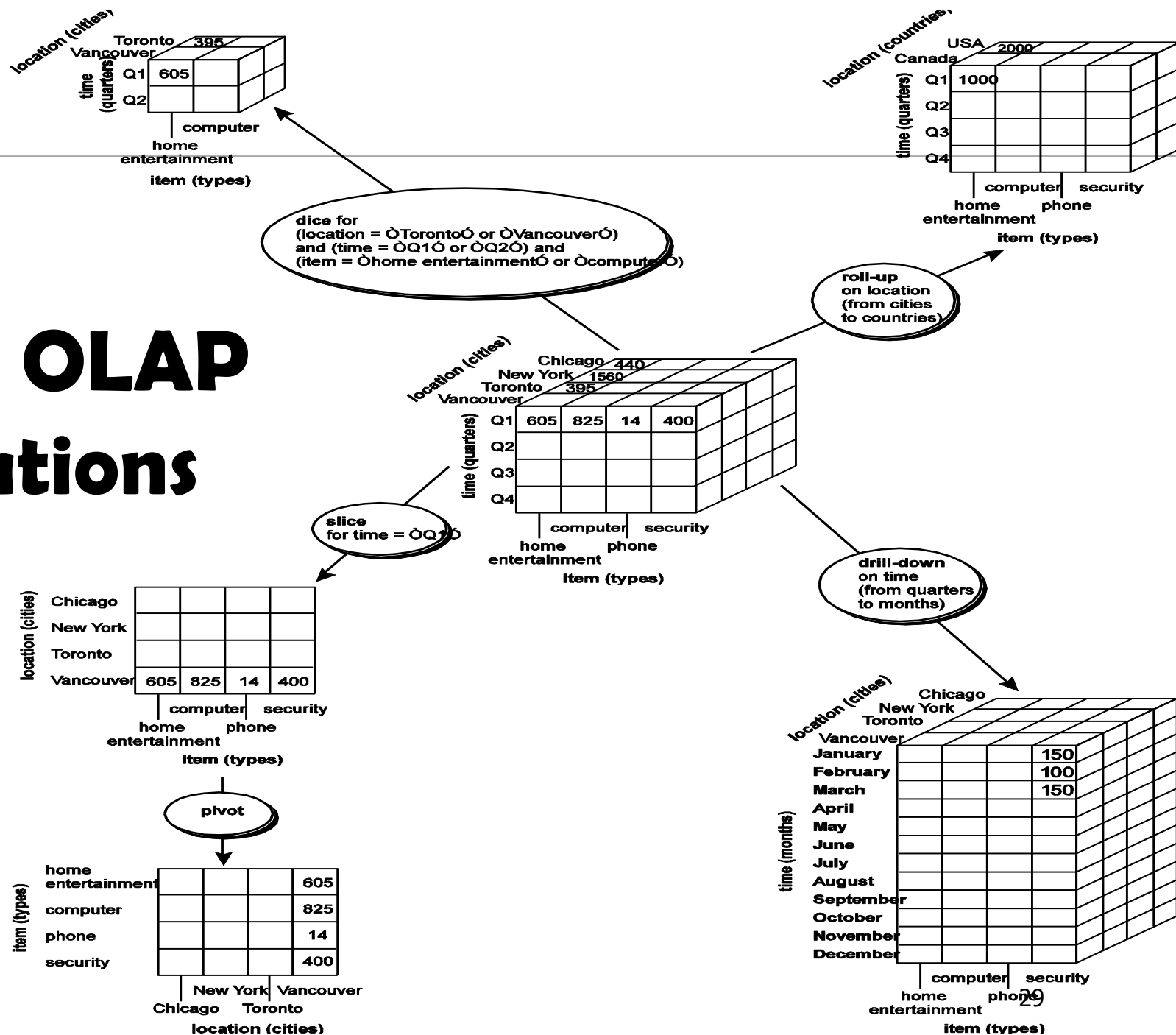
Cuboids Corresponding to the Cube



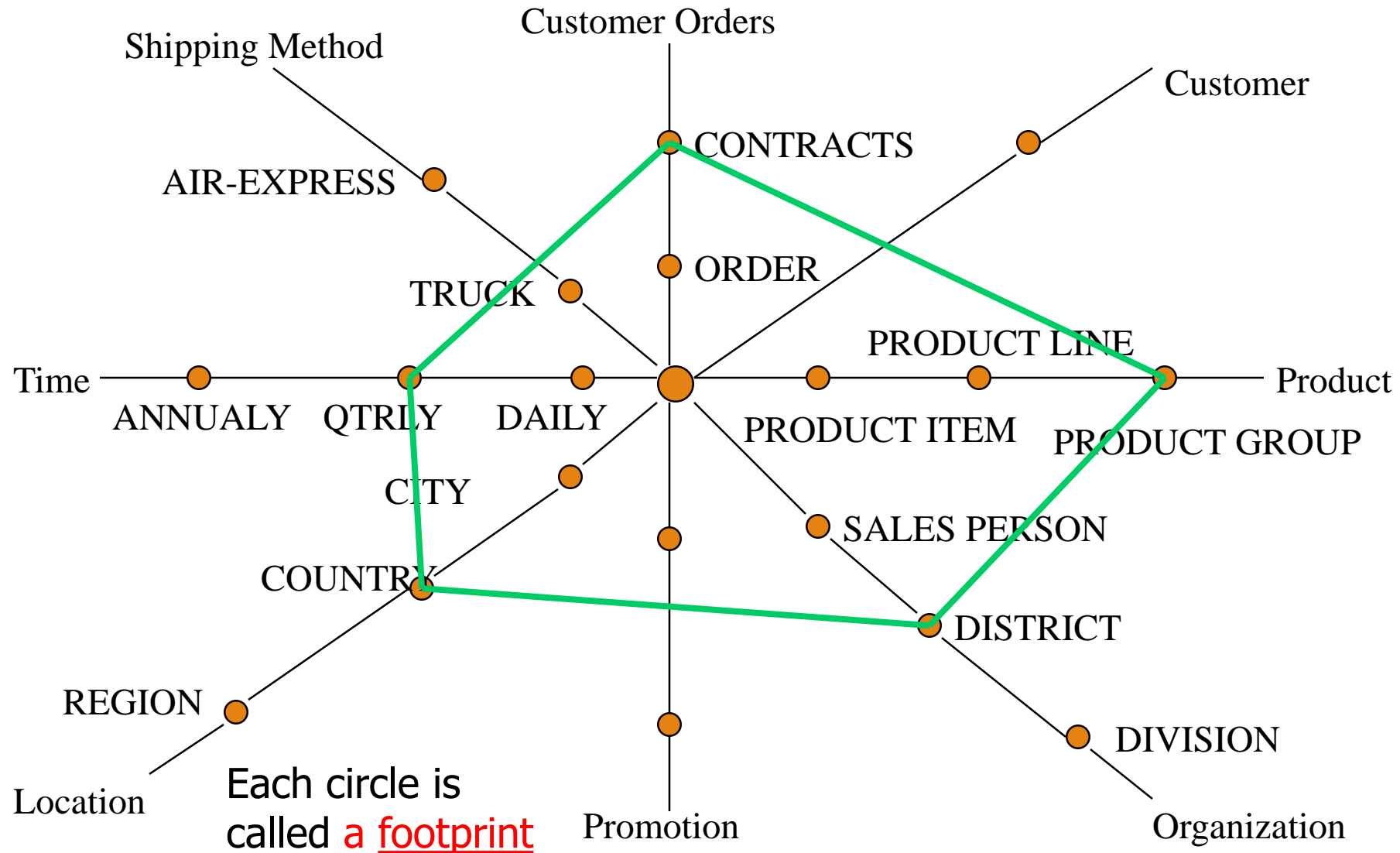
Typical OLAP Operations

- ❑ **Roll up (drill-up):** summarize data
 - ❑ *by climbing up hierarchy or by dimension reduction*
- ❑ **Drill down (roll down):** reverse of roll-up
 - ❑ *from higher level summary to lower level summary or detailed data, or introducing new dimensions*
- ❑ **Slice and dice:** *project and select*
- ❑ **Pivot (rotate):**
 - ❑ *reorient the cube, visualization, 3D to series of 2D planes*
- ❑ **Other operations**
 - ❑ **Drill across:** *involving (across) more than one fact table*
 - ❑ **Drill through:** *through the bottom level of the cube to its back-end relational tables (using SQL)*

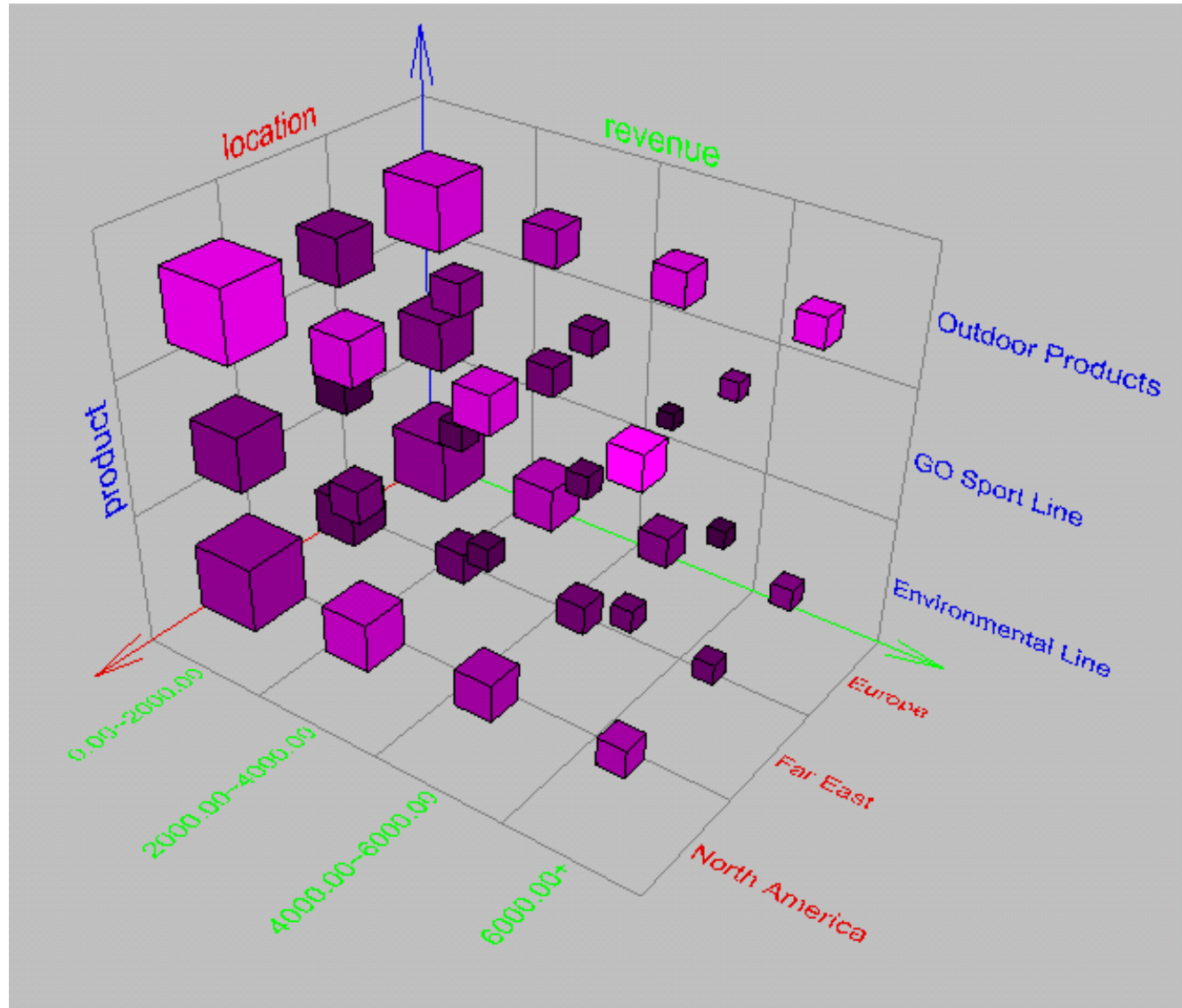
Typical OLAP Operations



A Star-Net Query Model




Browsing a Data Cube



- Visualization
- OLAP capabilities
- Interactive manipulation

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Design of Data Warehouse: A Business Analysis Framework

- ❑ Four views regarding the design of a data warehouse
 - ❑ Top-down view
 - ❑ allows selection of the relevant information necessary for the data warehouse
 - ❑ Data source view
 - ❑ exposes the information being captured, stored, and managed by operational systems
 - ❑ Data warehouse view
 - ❑ consists of fact tables and dimension tables
 - ❑ Business query view
 - ❑ sees the perspectives of data in the warehouse from the view of end-user

Data Warehouse Design Process

- ❑ **Top-down, bottom-up approaches or a combination of both**
 - ❑ Top-down: Starts with overall design and planning (mature)
 - ❑ Bottom-up: Starts with experiments and prototypes (rapid)
- ❑ **From software engineering point of view**
 - ❑ Waterfall: structured and systematic analysis at each step before proceeding to the next
 - ❑ Spiral: rapid generation of increasingly functional systems, short turn around time, quick turn around
- ❑ **Typical data warehouse design process**
 - ❑ Choose a business process to model, e.g., orders, invoices, etc.
 - ❑ Choose the grain (*atomic level of data*) of the business process
 - ❑ Choose the dimensions that will apply to each fact table record
 - ❑ Choose the measure that will populate each fact table record


Data Warehouse Usage

- ❑ Three kinds of data warehouse applications
 - ❑ **Information processing**
 - ❑ supports querying, basic statistical analysis, and reporting using crosstabs, tables, charts and graphs
 - ❑ **Analytical processing**
 - ❑ multidimensional analysis of data warehouse data
 - ❑ supports basic OLAP operations, slice-dice, drilling, pivoting
 - ❑ **Data mining**
 - ❑ knowledge discovery from hidden patterns
 - ❑ supports associations, constructing analytical models, performing classification and prediction, and presenting the mining results using visualization tools

From On-Line Analytical Processing (OLAP) to On Line Analytical Mining (OLAM)

- ❑ Why online analytical mining?
 - ❑ High quality of data in data warehouses
 - ❑ DW contains integrated, consistent, cleaned data
 - ❑ Available information processing structure surrounding data warehouses
 - ❑ ODBC, OLEDB, Web accessing, service facilities, reporting and OLAP tools
 - ❑ OLAP-based exploratory data analysis
 - ❑ Mining with drilling, dicing, pivoting, etc.
 - ❑ On-line selection of data mining functions
 - ❑ Integration and swapping of multiple mining functions, algorithms, and tasks

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Efficient Data Cube Computation

- Data cube can be viewed as a lattice of cuboids

- The bottom-most cuboid is the base cuboid

- The top-most cuboid (apex) contains only one cell

- How many cuboids in an n-dimensional cube with L levels?

Why this formula?

$$T = \prod_{i=1}^n (L_i + 1)$$

- Materialization of data cube

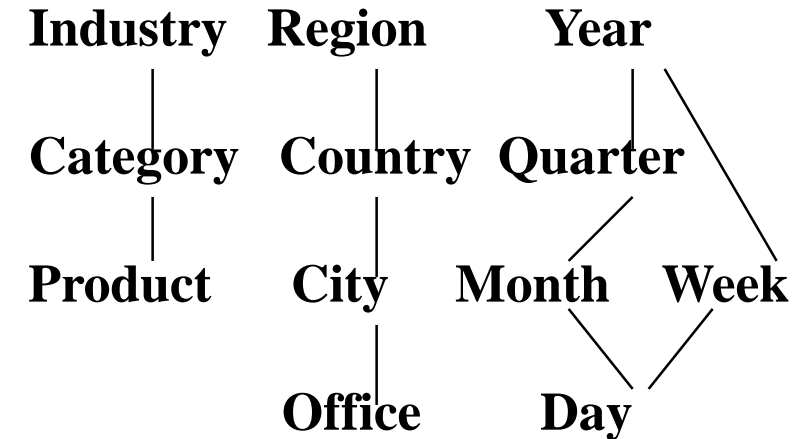
- **Full materialization:** Materialize every (cuboid)

- **No materialization:** Materialize none (cuboid)

- **Partial materialization:** Materialize some cuboids

- Which cuboids to materialize?

- Selection based on size, sharing, access frequency, etc.



The “Compute Cube” Operator

- ❑ Cube definition and computation in DMQL

```
define cube sales [item, city, year]: sum (sales_in_dollars)
```

```
compute cube sales
```

- ❑ Transform it into a SQL-like language (with a new operator **cube by**, introduced by Gray et al.'96)

```
SELECT item, city, year, SUM (amount)
```

```
FROM SALES
```

```
CUBE BY item, city, year
```

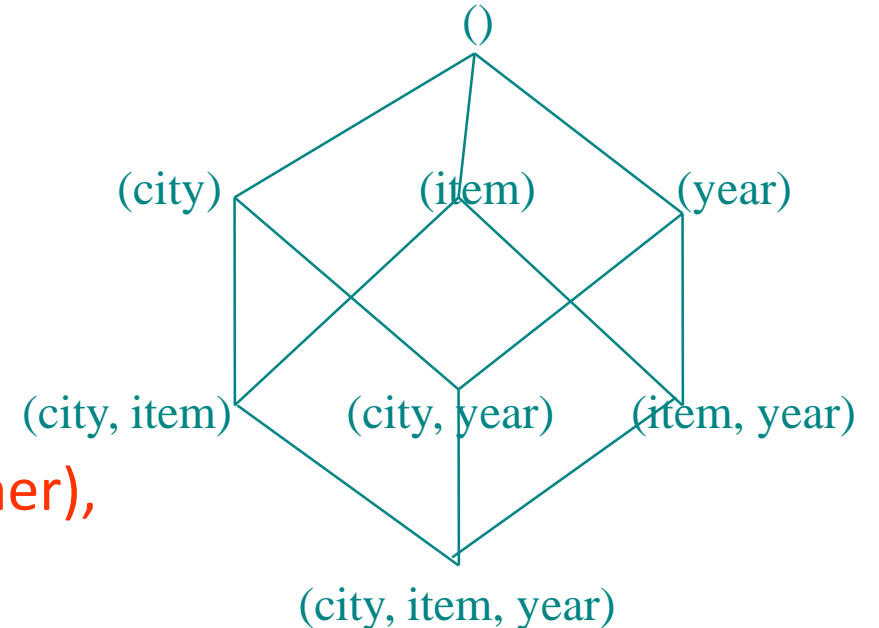
- ❑ Need compute the following Group-Bys

```
(date, product, customer),
```

```
(date, product),(date, customer), (product, customer),
```

```
(date), (product), (customer)
```

```
()
```



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
 - not suitable for high cardinality domains
- A recent bit compression technique, Word-Aligned Hybrid (WAH), makes it work for high cardinality domain as well [Wu, et al. TODS'06]

Base table

Cust	Region	Type
C1	Asia	Retail
C2	Europe	Dealer
C3	Asia	Dealer
C4	America	Retail
C5	Europe	Dealer

Index on Region

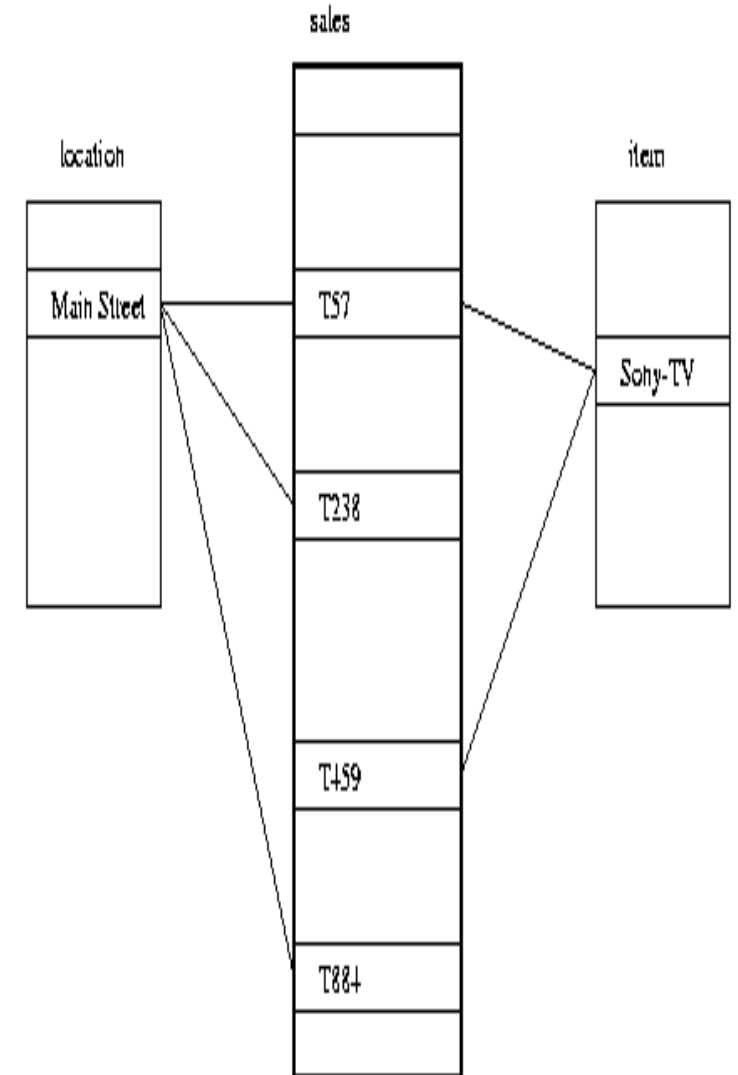
RecID	Asia	Europe	America
1	1	0	0
2	0	1	0
3	1	0	0
4	0	0	1
5	0	1	0

Index on Type

RecID	Retail	Dealer
1	1	0
2	0	1
3	0	1
4	1	0
5	0	1

Indexing OLAP Data: Join Indices

- ❑ Join index: $JI(R-id, S-id)$ where $R(R-id, ...) \triangleright \triangleleft S(S-id, ...)$
- ❑ Traditional indices map the values to a list of record ids
 - ❑ It materializes relational join in JI file and speeds up relational join
- ❑ In data warehouses, join index relates the values of the dimensions of a star 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



Efficient Processing OLAP Queries

- ❑ **Determine which operations** should be performed on the available cuboids
 - ❑ Transform drill, roll, etc. into corresponding SQL and/or OLAP operations, e.g.,
dice = selection + projection
- ❑ **Determine which materialized cuboid(s)** should be selected for OLAP op.
 - ❑ Let the query to be processed be on $\{brand, province_or_state\}$ with the condition “ $year = 2004$ ”, and there are 4 materialized cuboids available:
 - 1) $\{year, item_name, city\}$
 - 2) $\{year, brand, country\}$
 - 3) $\{year, brand, province_or_state\}$
 - 4) $\{item_name, province_or_state\}$ where $year = 2004$Which should be selected to process the query?
- ❑ Explore indexing structures and compressed vs. dense array structs in MOLAP

OLAP Server Architectures

❑ Relational OLAP (ROLAP)

- ❑ Use relational or extended-relational DBMS to store and manage warehouse data and OLAP middle ware
- ❑ Include optimization of DBMS backend, implementation of aggregation navigation logic, and additional tools and services
- ❑ Greater scalability

❑ Multidimensional OLAP (MOLAP)

- ❑ Sparse array-based multidimensional storage engine
- ❑ Fast indexing to pre-computed summarized data


❑ Hybrid OLAP (HOLAP) (e.g., Microsoft SQLServer)

- ❑ Flexibility, e.g., low level: relational, high-level: array

❑ Specialized SQL servers (e.g., Redbricks)

- ❑ Specialized support for SQL queries over star/snowflake schemas

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Summary

- ❑ Data warehousing: A multi-dimensional model of a data warehouse
 - ❑ A data cube consists of *dimensions & measures*
 - ❑ Star schema, snowflake schema, fact constellations
 - ❑ OLAP operations: drilling, rolling, slicing, dicing and pivoting
- ❑ Data Warehouse Architecture, Design, and Usage
 - ❑ Multi-tiered architecture
 - ❑ Business analysis design framework
 - ❑ Information processing, analytical processing, data mining, OLAM
- ❑ Implementation: Efficient computation of data cubes
 - ❑ Partial vs. full vs. no materialization
 - ❑ Indexing OLAP data: Bitmap index and join index
 - ❑ OLAP query processing
 - ❑ OLAP servers: ROLAP, MOLAP, HOLAP

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