

Data Warehousing & OLAP

**Excerpt from
“Data Mining: Concepts and Techniques”, 3rd Ed.
Jiawei Han, Micheline Kamber, and Jian Pei
Chapter 4**

Outline

- Data Warehouse: Basic Concepts
- Data Warehouse Modeling: Data Cube and OLAP
- Data Warehouse Implementation and Usage
- 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
 - E.g., Hotel price: currency, tax, breakfast covered, etc.
 - 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

- A **physically separate store** of data transformed from the operational environment
- 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*

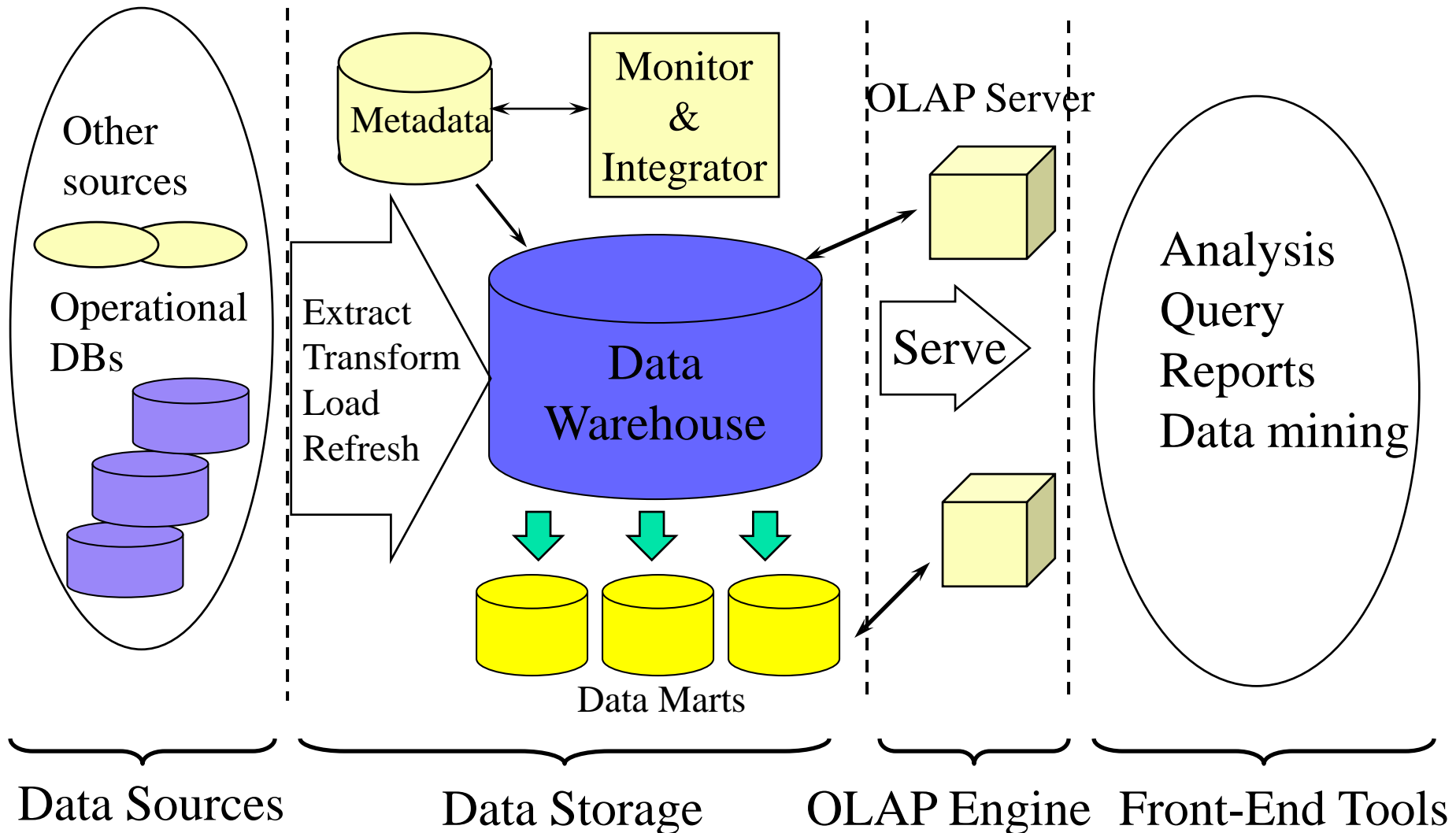
OLTP vs. OLAP

	OLTP	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 quality: different sources typically use inconsistent data representations, codes and formats which have to be reconciled
 - data consolidation: DS requires consolidation (aggregation, summarization) of data from heterogeneous sources
- Note: There are more and more systems which perform OLAP analysis directly on relational databases

Data Warehouse: A Multi-Tiered Architecture



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
- **Business data**
 - business terms and definitions, ownership of data, charging policies

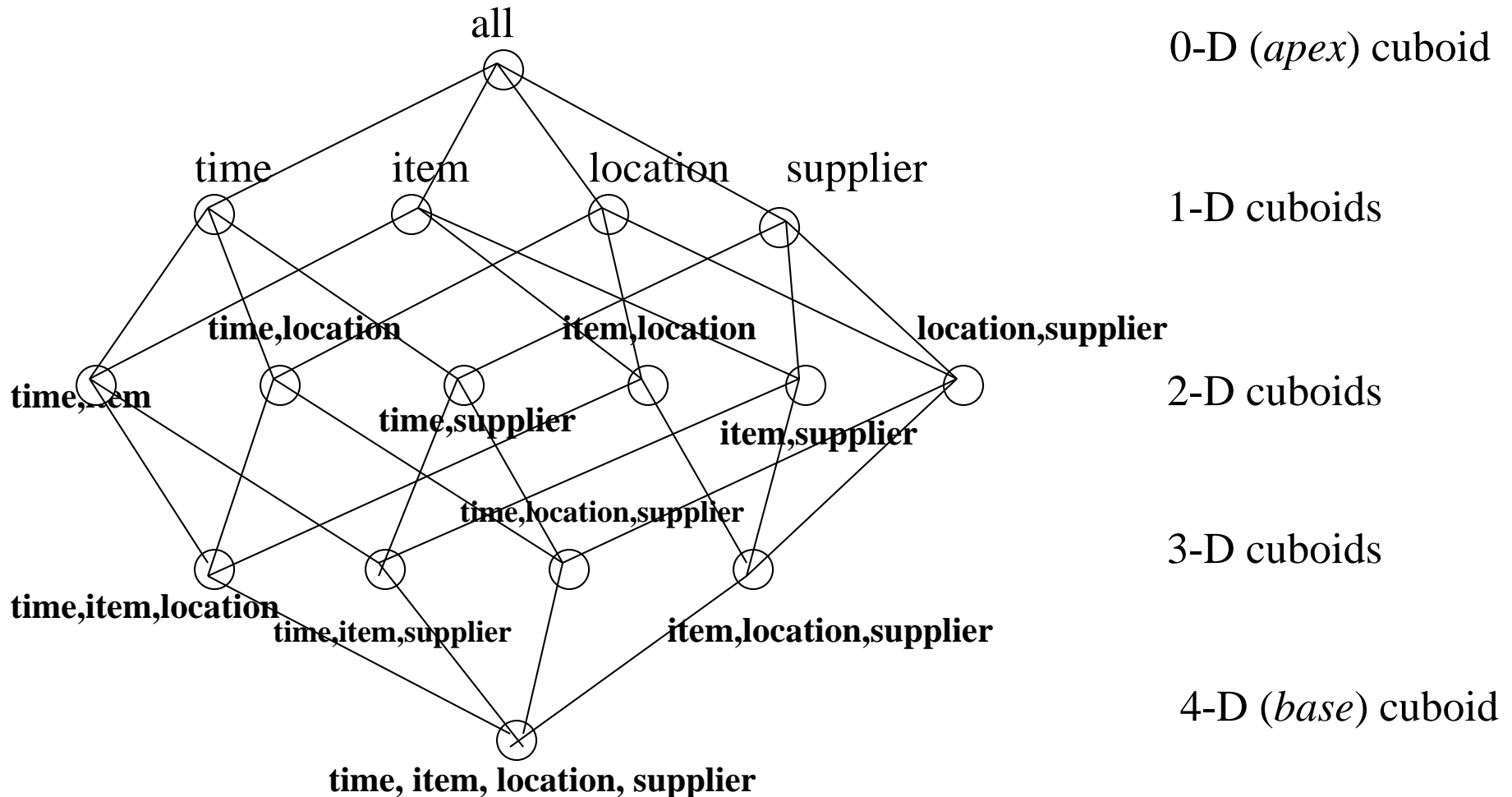
Outline

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

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
- 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**.

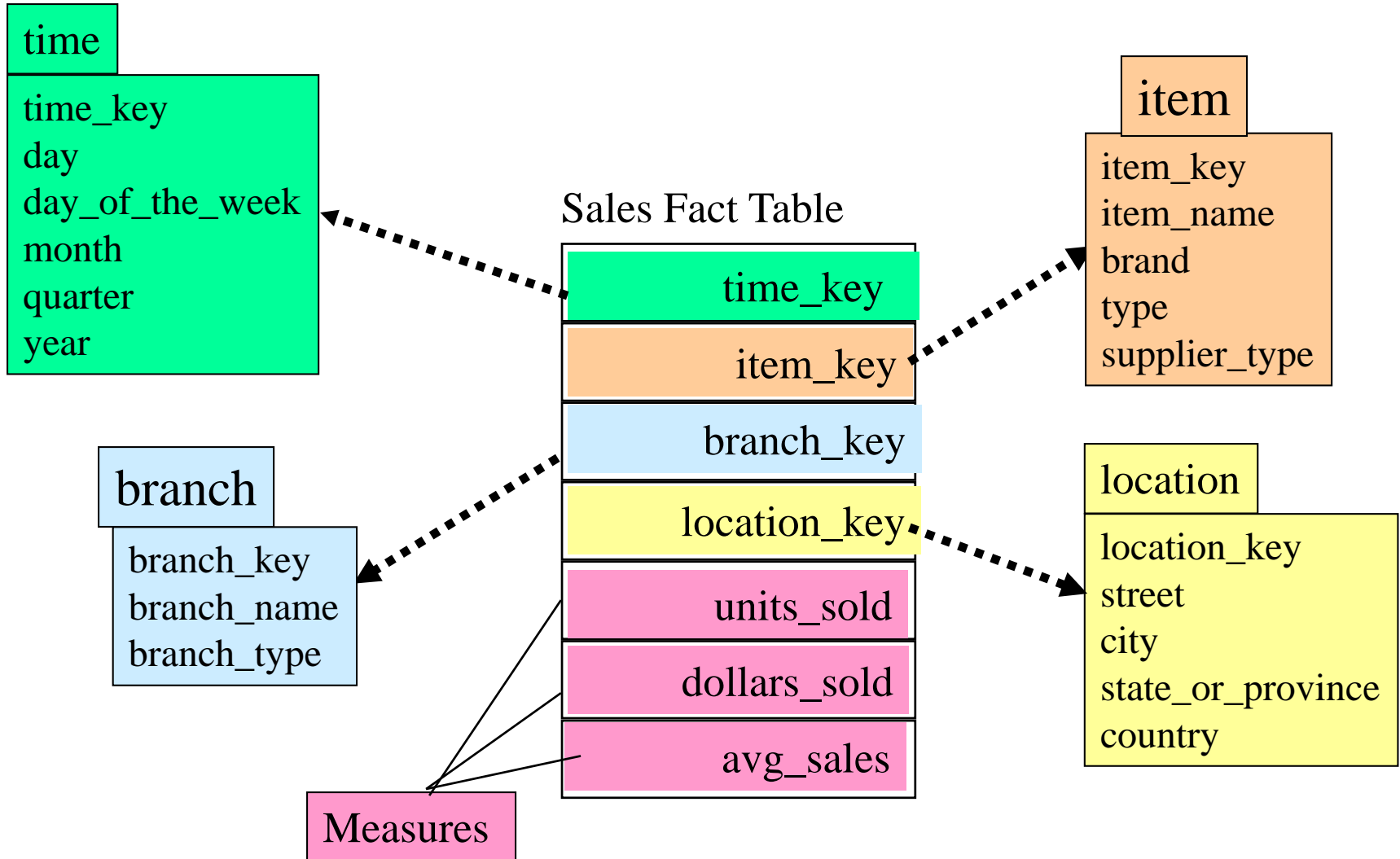
Cube: A Lattice of Cuboids



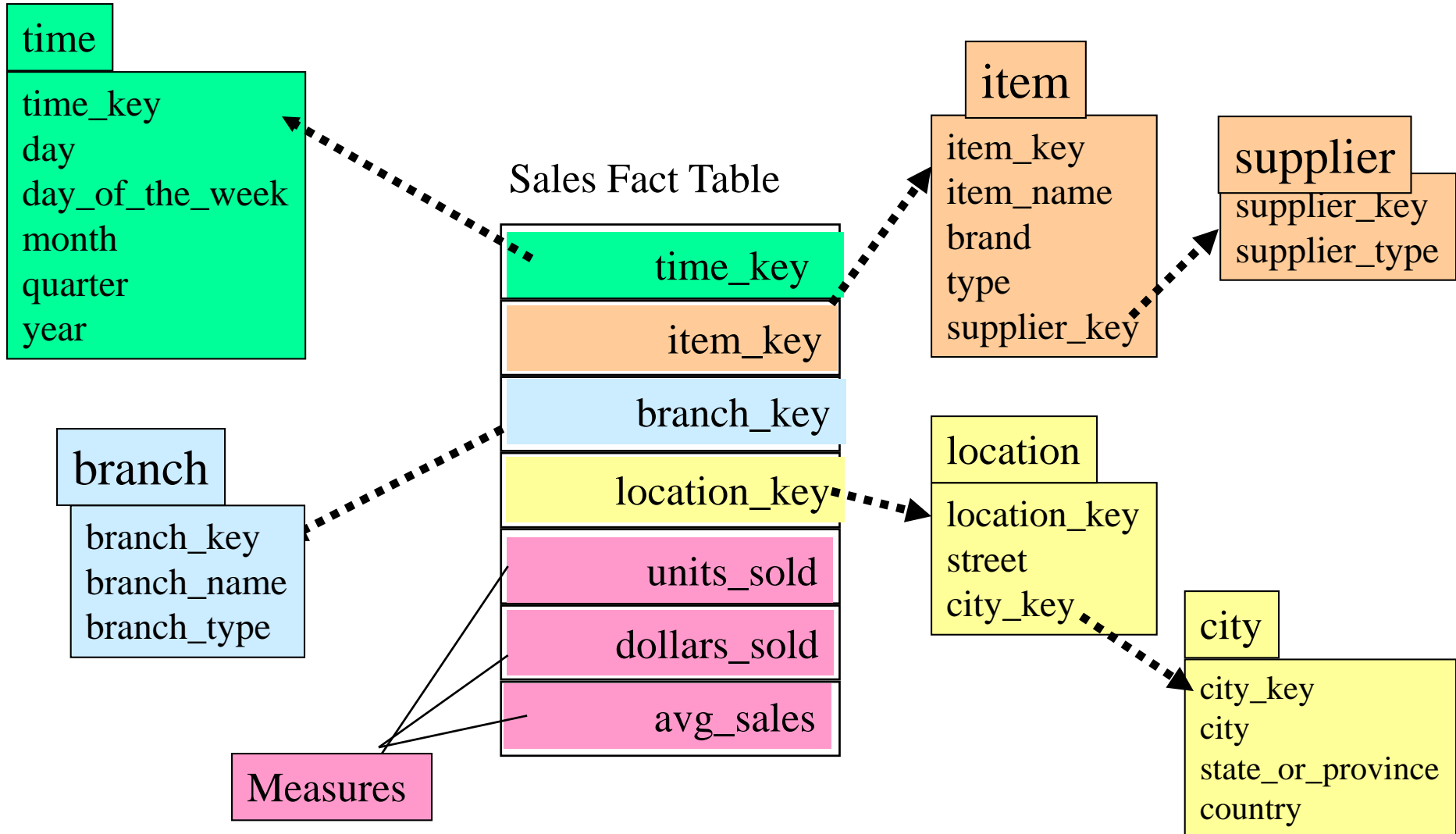
Conceptual Modeling of Data Warehouses

- 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

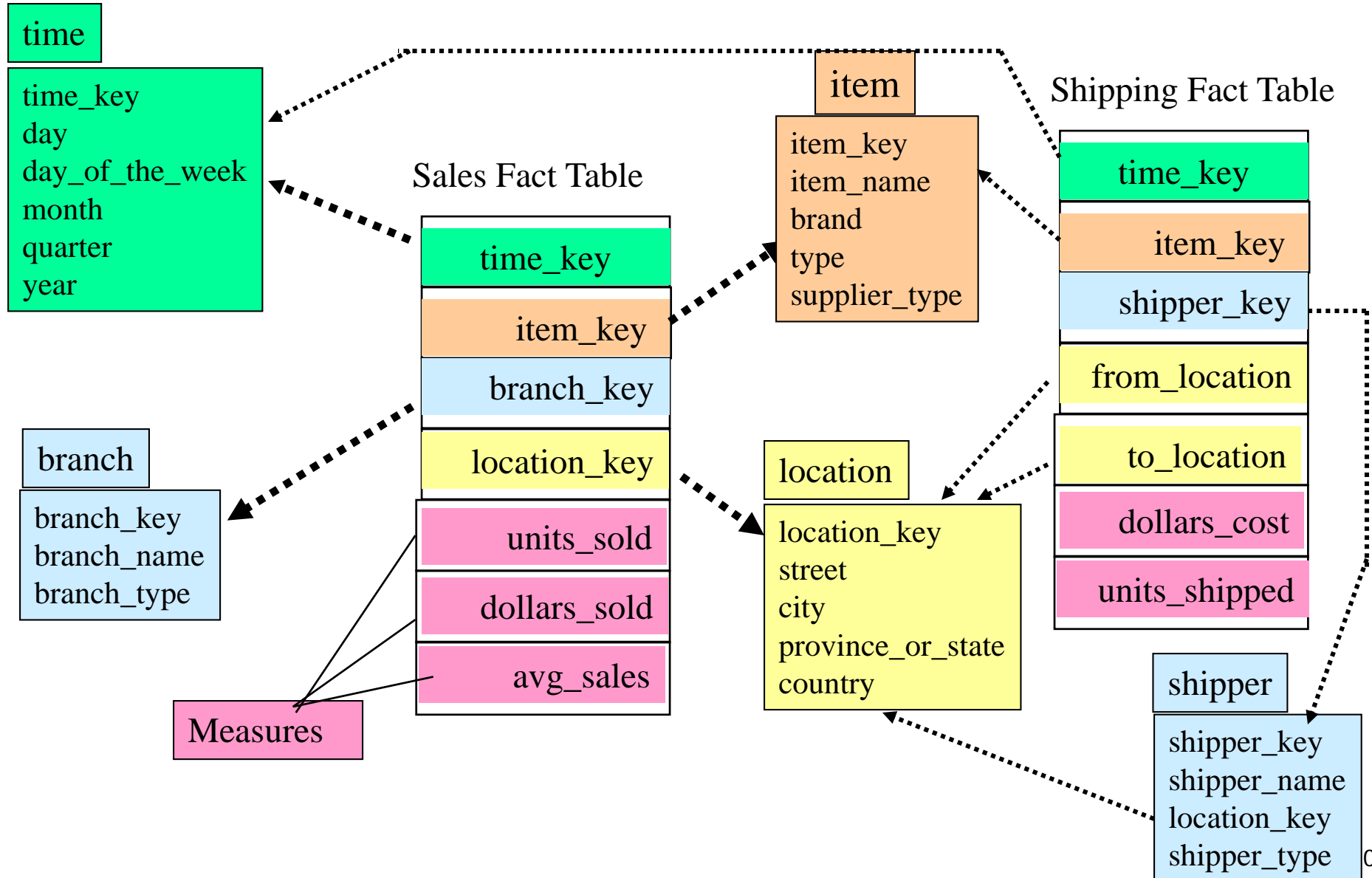
Example of Star Schema



Example of Snowflake Schema



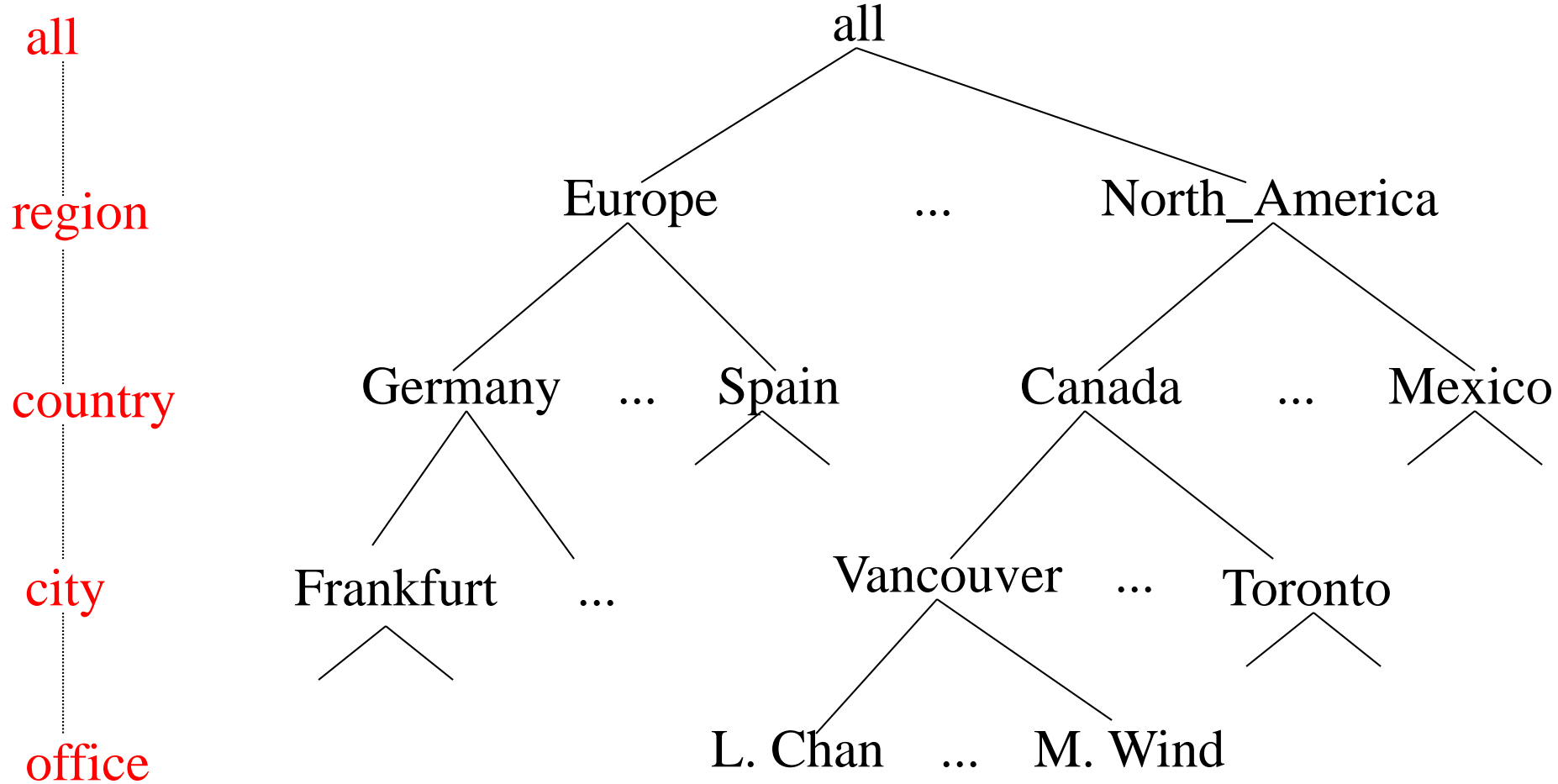
Example of Fact Constellation



Data Cube Measures: Three Categories

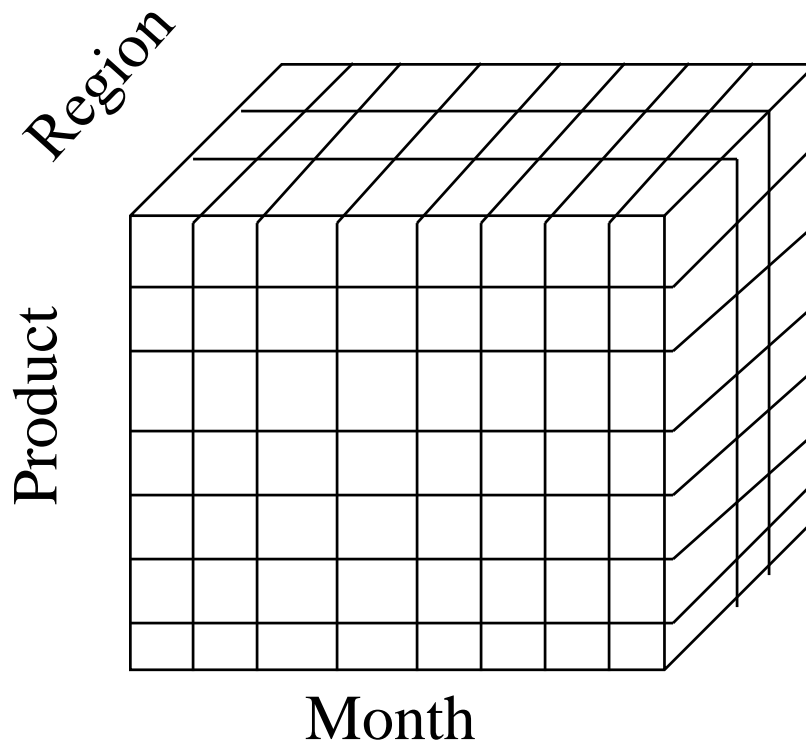
- Distributive: if the result derived by applying the function to n aggregate values is the same as that derived by applying the function on all the data without partitioning
 - E.g., `count()`, `sum()`, `min()`, `max()`
- Algebraic: if it can be computed by an algebraic function with M arguments (where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

A Concept Hierarchy: Dimension (location)

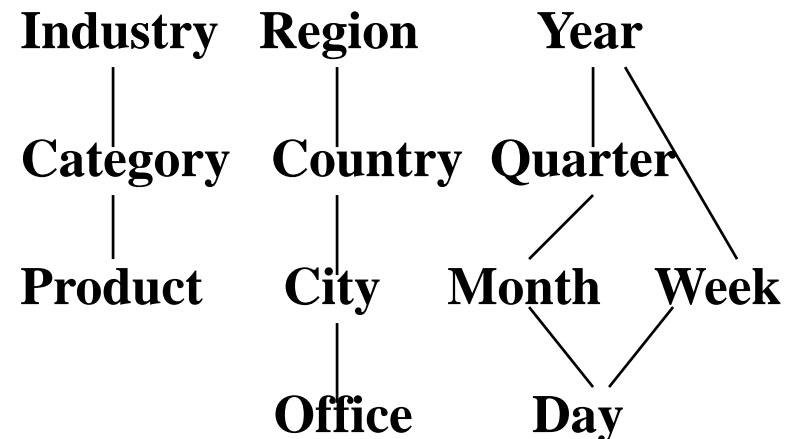


Multidimensional Data

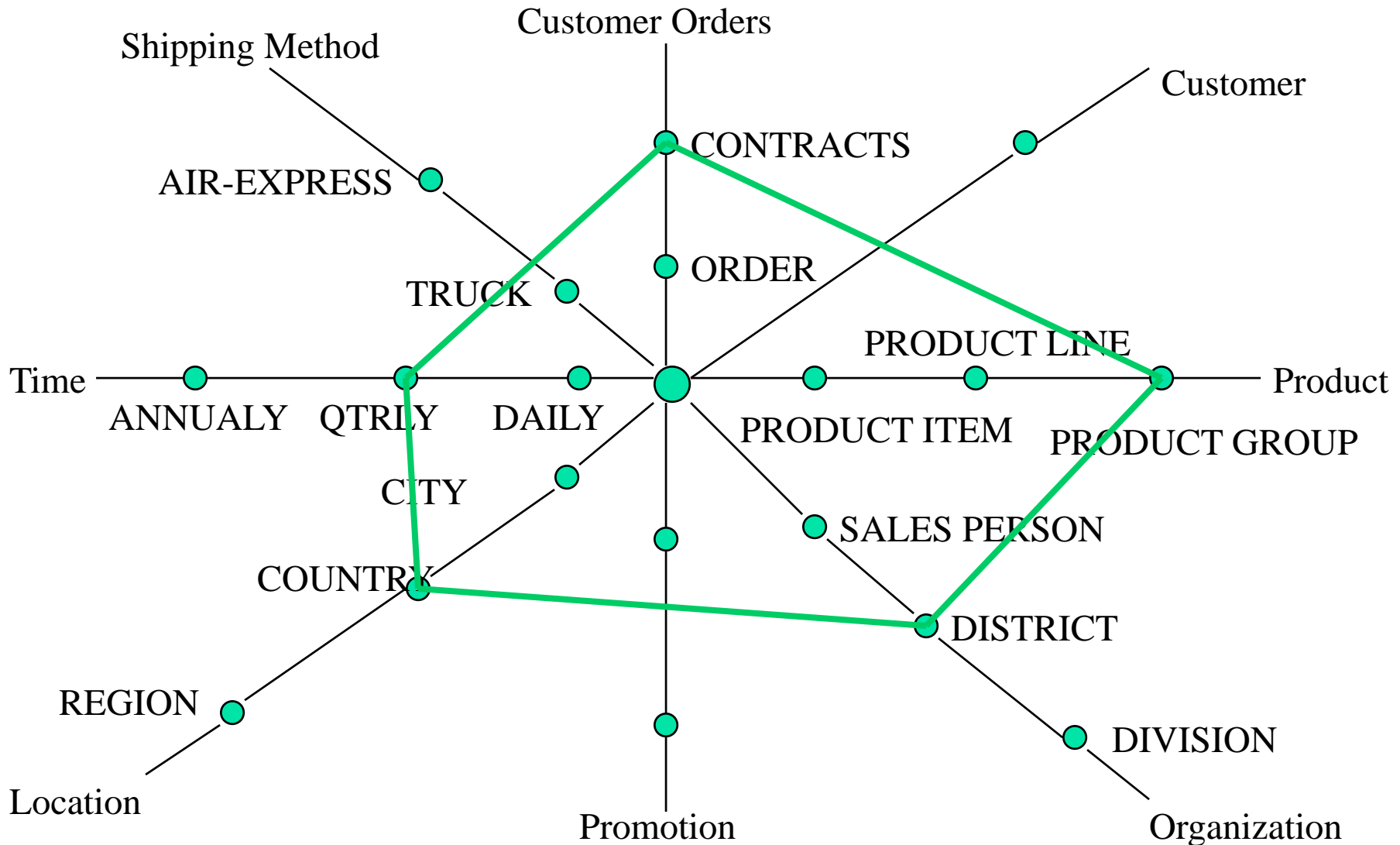
- Sales volume as a function of product, month, and region



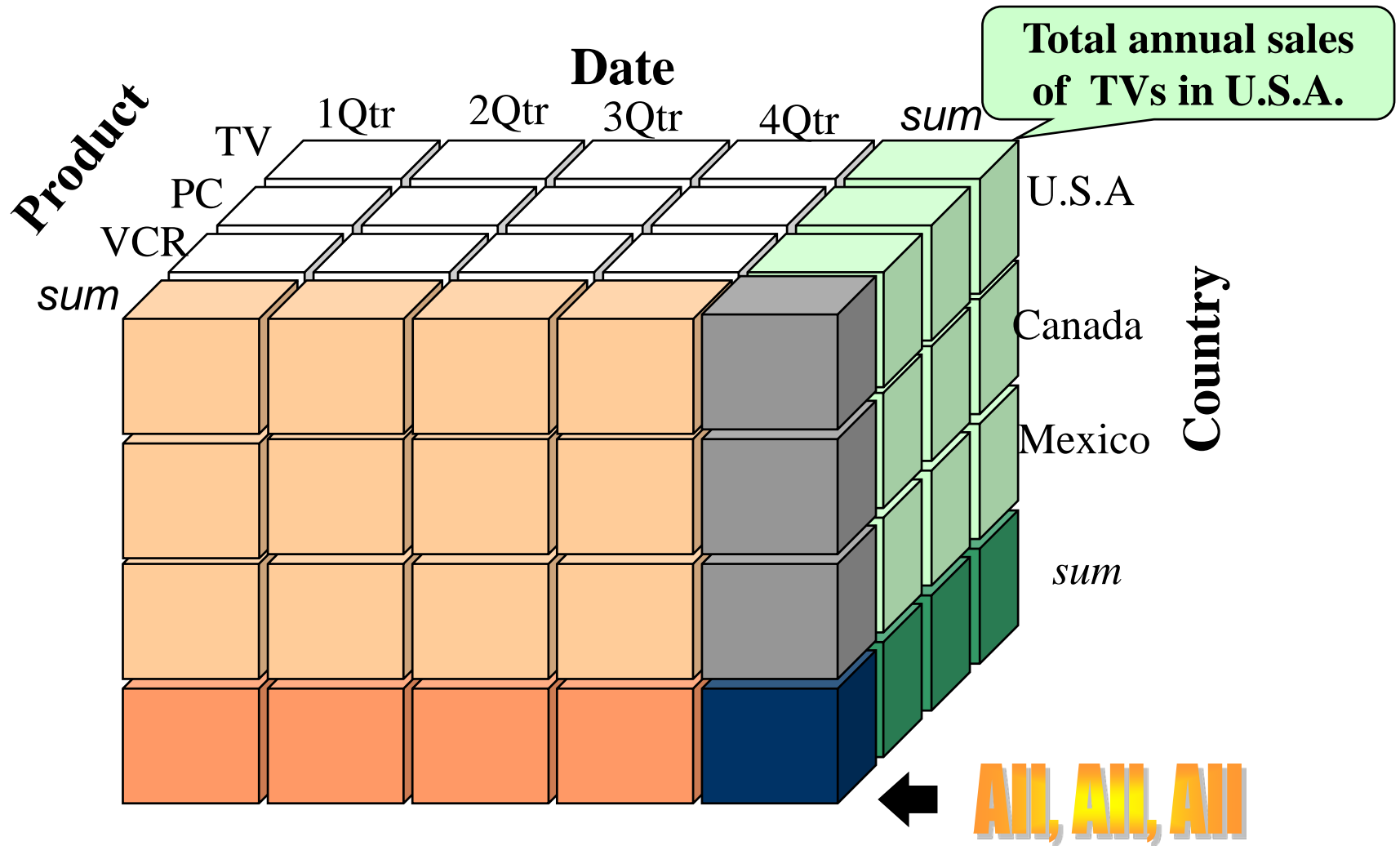
Dimensions: *Product, Location, Time*
Hierarchical summarization paths



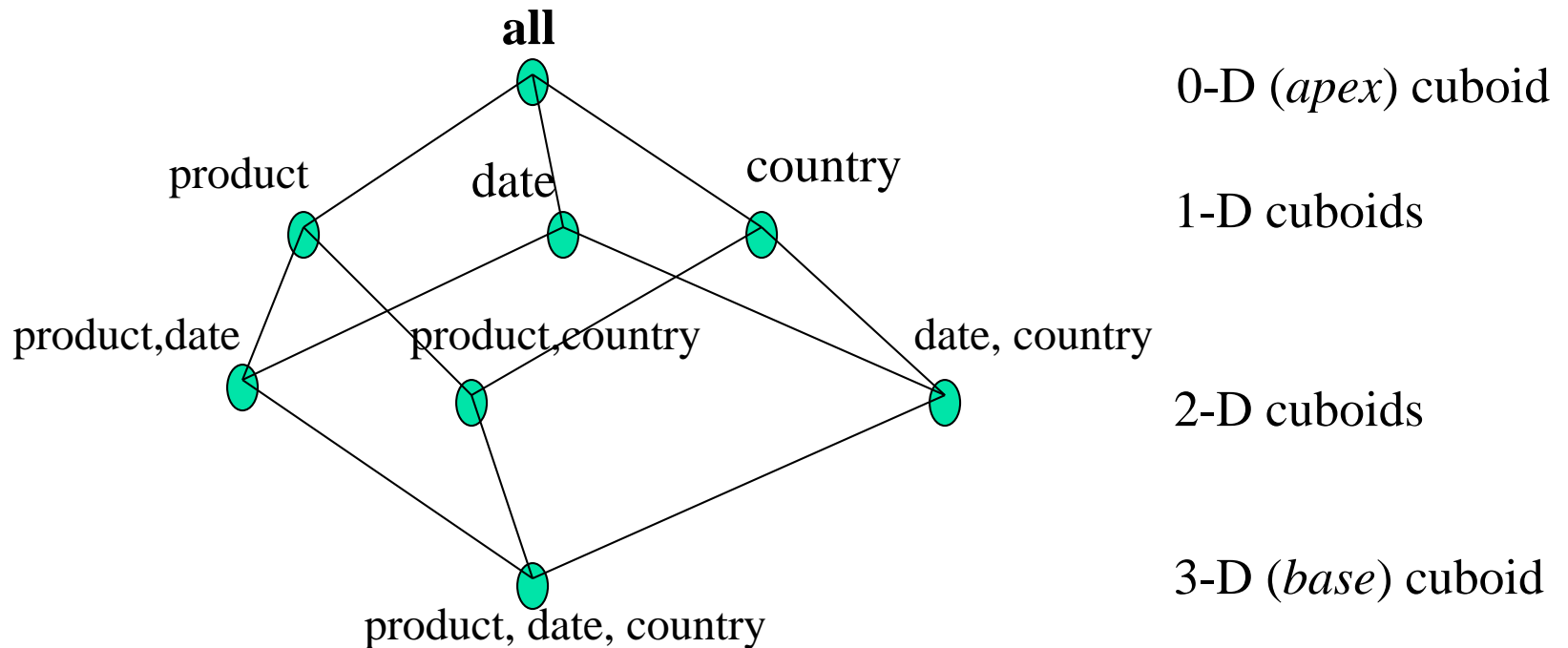
A Star-Net Query Model



A Sample Data Cube



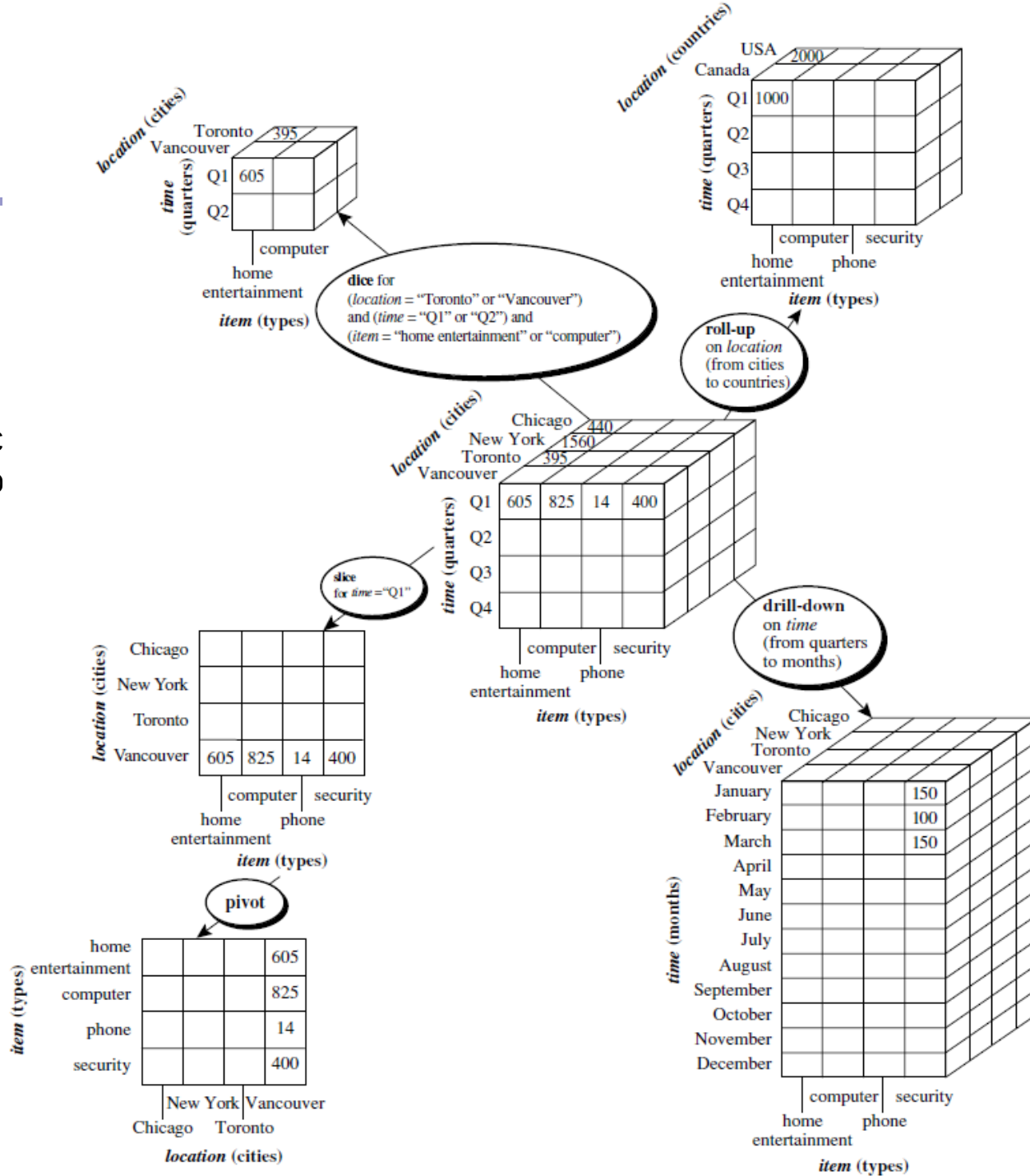
Cuboids Corresponding to the Cube



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: *select and project*
- 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)*

Fig. 4.12 Typic
OLAP Operatio



Outline

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

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?

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

- Materialization of data cube
 - Materialize every (cuboid) (**full materialization**), none (**no materialization**), or some (**partial materialization**)
 - Selection of which cuboids to materialize
 - Based on size, sharing, access frequency, etc.

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?

OLAP Server Architectures

- Relational OLAP (ROLAP)
 - Use relational or extended-relational DBMS to store and manage warehouse data and OLAP middleware
 - 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

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

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
- **Implementation**: Efficient computation of data cubes
 - Partial vs. full vs. no materialization
 - OLAP query processing
 - OLAP servers: ROLAP, MOLAP, HOLAP

References (I)

- S. Agarwal, R. Agrawal, P. M. Deshpande, A. Gupta, J. F. Naughton, R. Ramakrishnan, and S. Sarawagi. On the computation of multidimensional aggregates. VLDB'96
- D. Agrawal, A. E. Abbadi, A. Singh, and T. Yurek. Efficient view maintenance in data warehouses. SIGMOD'97
- R. Agrawal, A. Gupta, and S. Sarawagi. Modeling multidimensional databases. ICDE'97
- S. Chaudhuri and U. Dayal. An overview of data warehousing and OLAP technology. *ACM SIGMOD Record*, 26:65-74, 1997
- E. F. Codd, S. B. Codd, and C. T. Salley. Beyond decision support. *Computer World*, 27, July 1993.
- J. Gray, et al. Data cube: A relational aggregation operator generalizing group-by, cross-tab and sub-totals. *Data Mining and Knowledge Discovery*, 1:29-54, 1997.
- A. Gupta and I. S. Mumick. *Materialized Views: Techniques, Implementations, and Applications*. MIT Press, 1999.
- J. Han. Towards on-line analytical mining in large databases. *ACM SIGMOD Record*, 27:97-107, 1998.
- V. Harinarayan, A. Rajaraman, and J. D. Ullman. Implementing data cubes efficiently. SIGMOD'96
- J. Hellerstein, P. Haas, and H. Wang. Online aggregation. SIGMOD'97

References (II)

- C. Imhoff, N. Galemme, and J. G. Geiger. Mastering Data Warehouse Design: Relational and Dimensional Techniques. John Wiley, 2003
- W. H. Inmon. Building the Data Warehouse. John Wiley, 1996
- R. Kimball and M. Ross. The Data Warehouse Toolkit: The Complete Guide to Dimensional Modeling. 2ed. John Wiley, 2002
- P. O'Neil and G. Graefe. Multi-table joins through bitmapped join indices. *SIGMOD Record*, 24:8–11, Sept. 1995.
- P. O'Neil and D. Quass. Improved query performance with variant indexes. SIGMOD'97
- Microsoft. OLEDB for OLAP programmer's reference version 1.0. In <http://www.microsoft.com/data/oledb/olap>, 1998
- S. Sarawagi and M. Stonebraker. Efficient organization of large multidimensional arrays. ICDE'94
- A. Shoshani. OLAP and statistical databases: Similarities and differences. PODS'00.
- D. Srivastava, S. Dar, H. V. Jagadish, and A. V. Levy. Answering queries with aggregation using views. *VLDB'96*
- P. Valduriez. Join indices. *ACM Trans. Database Systems*, 12:218-246, 1987.
- J. Widom. Research problems in data warehousing. CIKM'95
- K. Wu, E. Otoo, and A. Shoshani, Optimal Bitmap Indices with Efficient Compression, *ACM Trans. on Database Systems (TODS)*, 31(1): 1-38, 2006