Data Mining:

Concepts and Techniques

(3rd ed.)

— Chapter 4 —

Jiawei Han, Micheline Kamber, and Jian Pei
University of Illinois at Urbana-Champaign &
Simon Fraser University

Chapter 4: Data Warehousing and On-line Analytical Processing

- Data Warehouse: Basic Concepts
- Data Warehouse Modeling: Data Cube and OLAP

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*

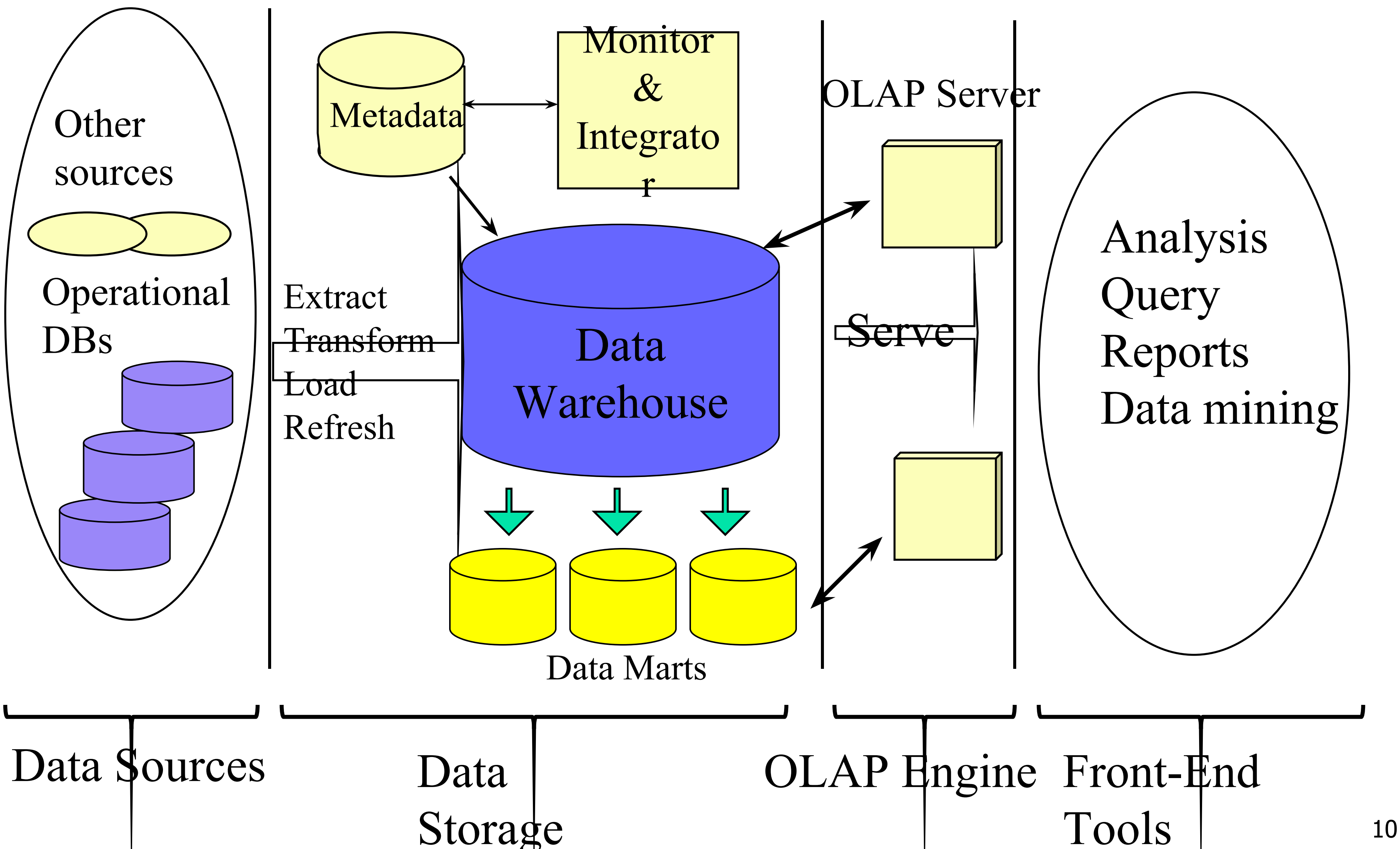
OLTP vs. OLAP

	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

Data Warehouse: A Multi-Tiered Architecture



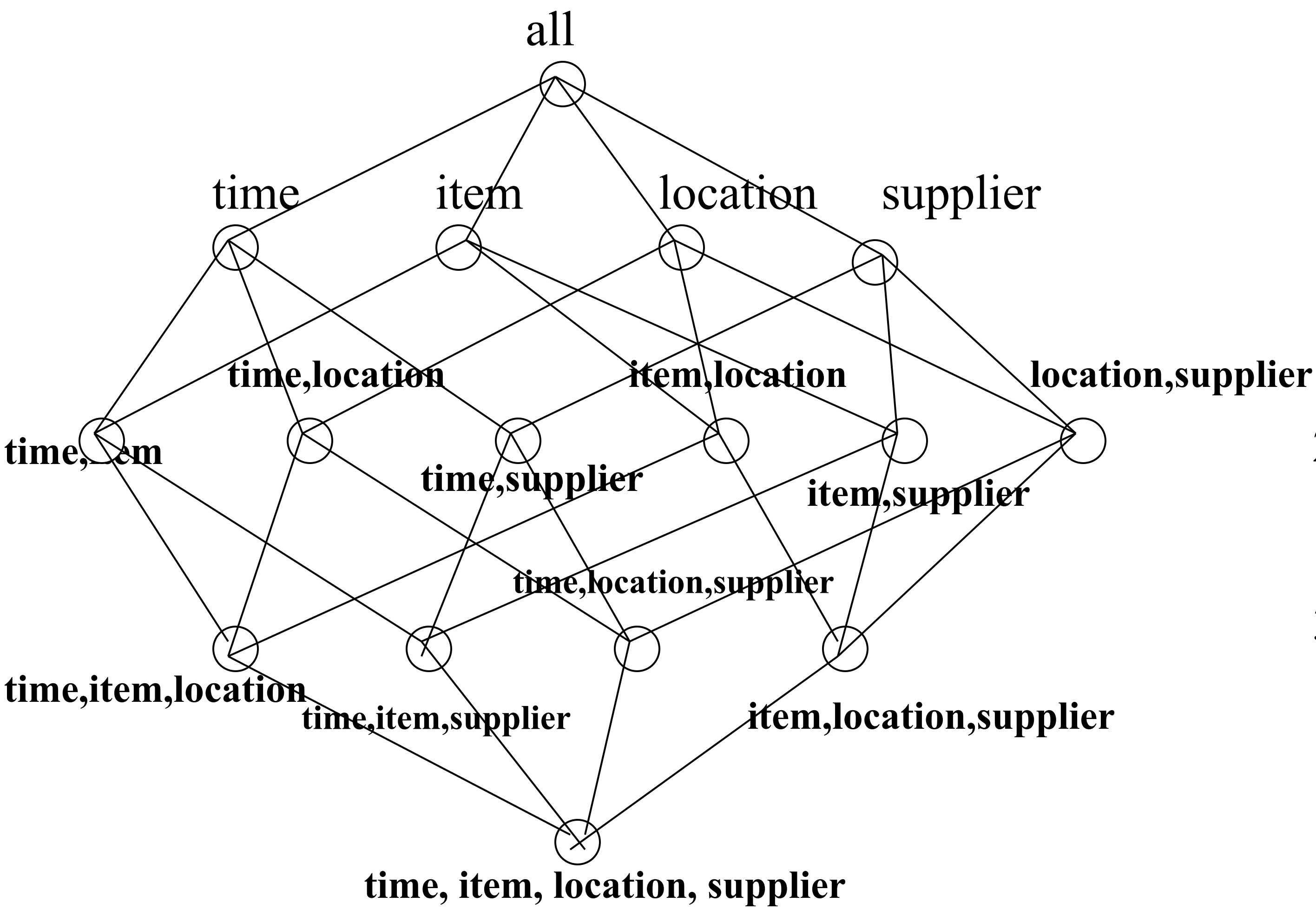
Chapter 4: Data Warehousing and On-line Analytical Processing

- Data Warehouse: Basic Concepts
- Data Warehouse Modeling: Data Cube and OLAP

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



0-D (*apex*) cuboid

1-D cuboids

2-D cuboids

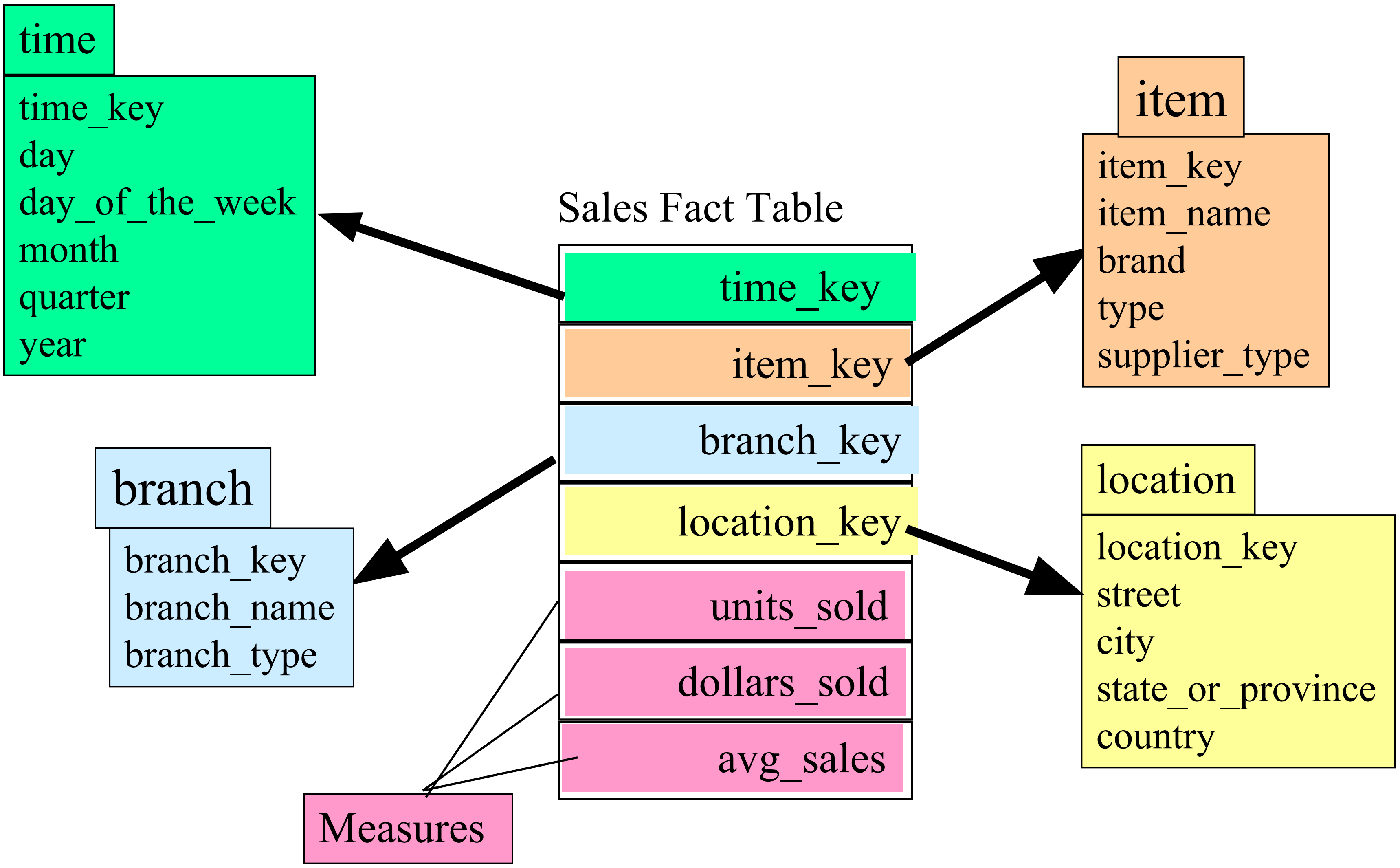
3-D cuboids

4-D (*base*) cuboid

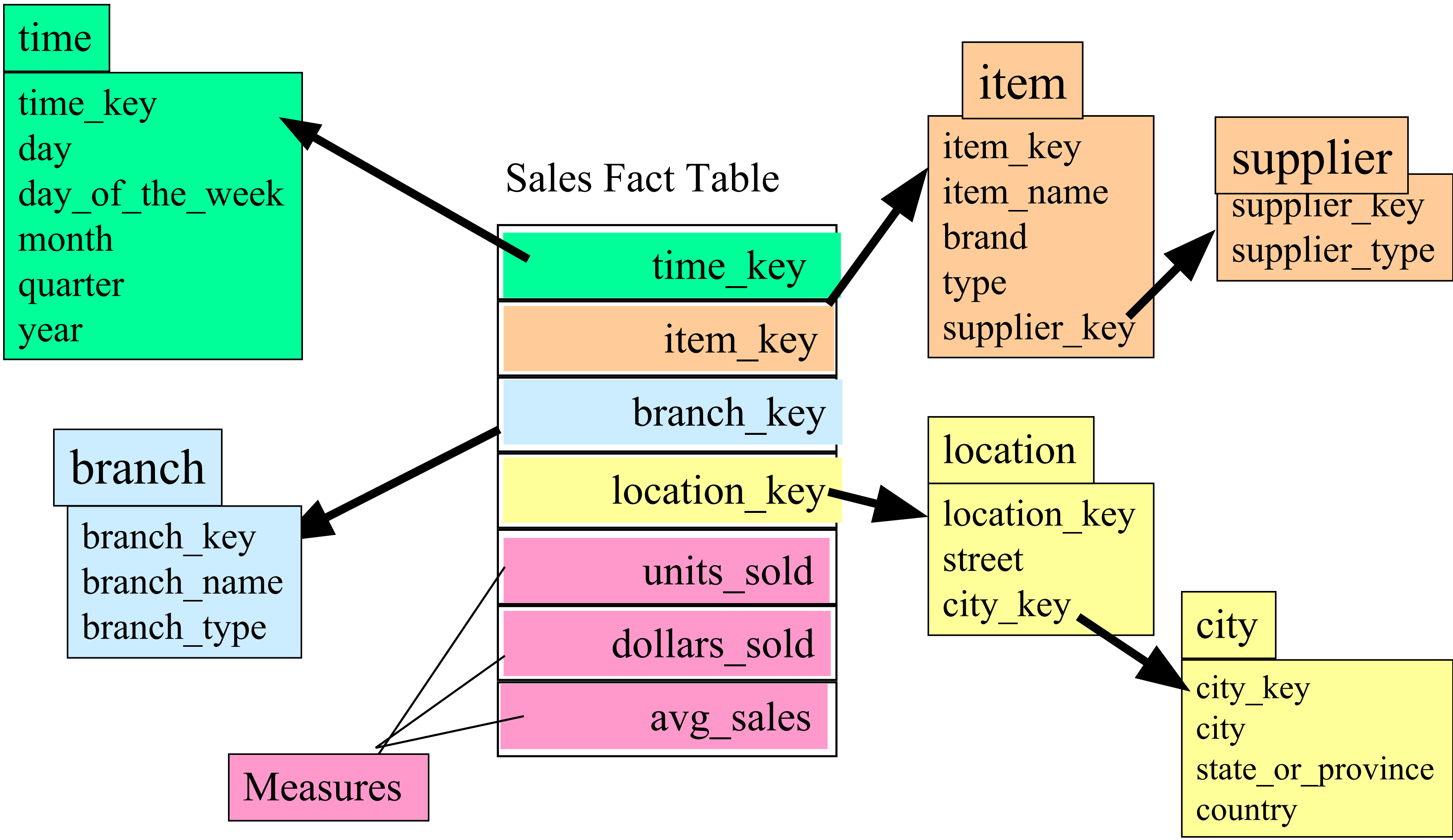
Conceptual Modeling of Data Warehouses

- 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

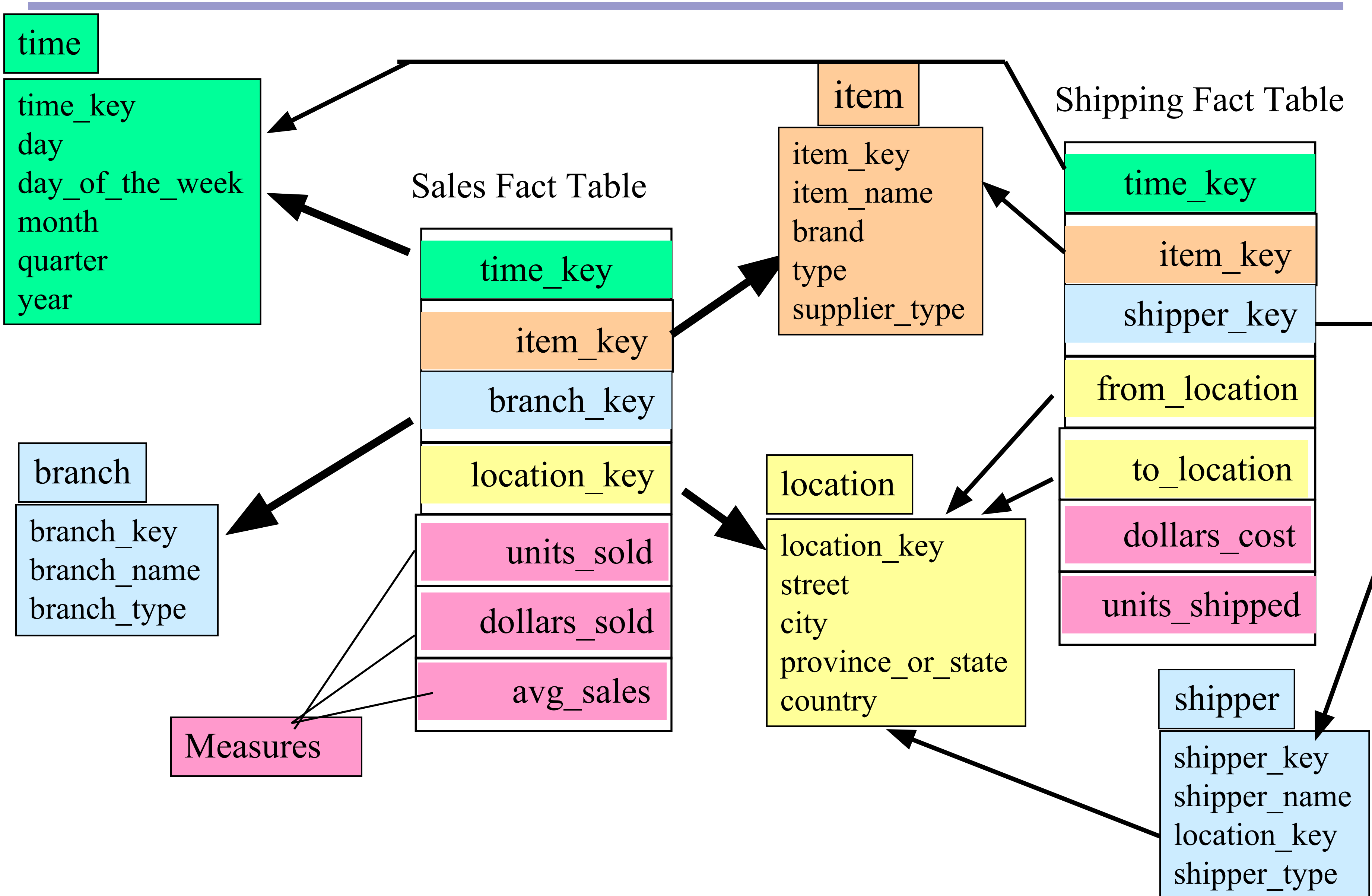
Example of **Star Schema**



Example of Snowflake Schema

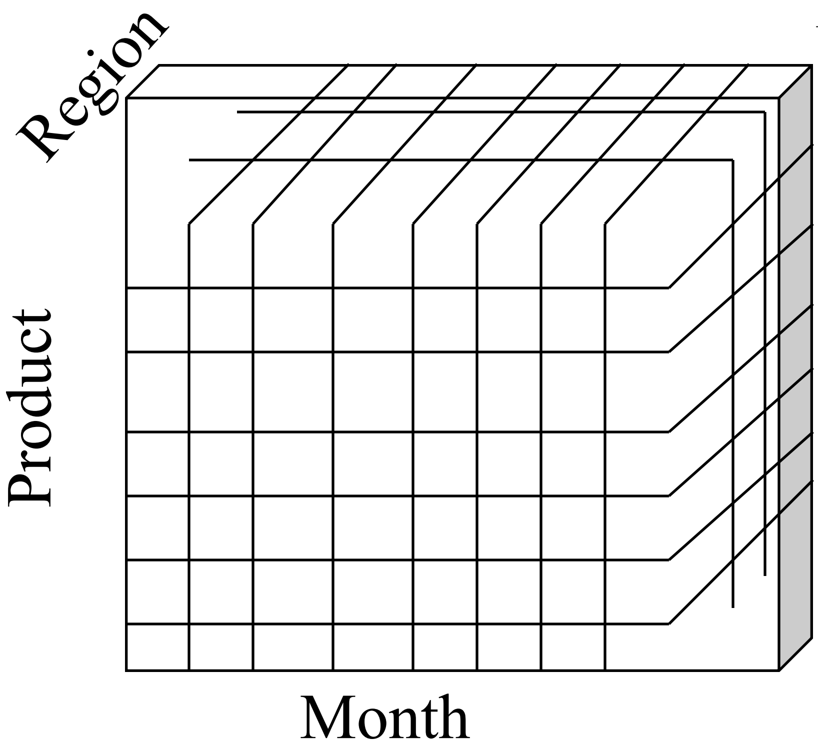


Example of **Fact Constellation**

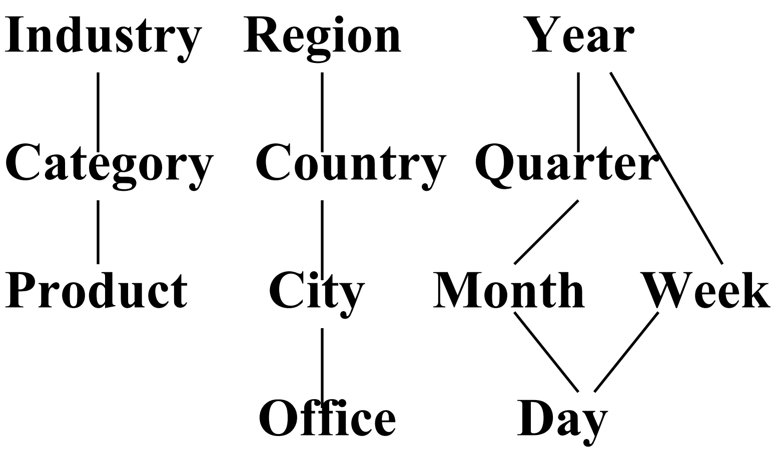


Multidimensional Data

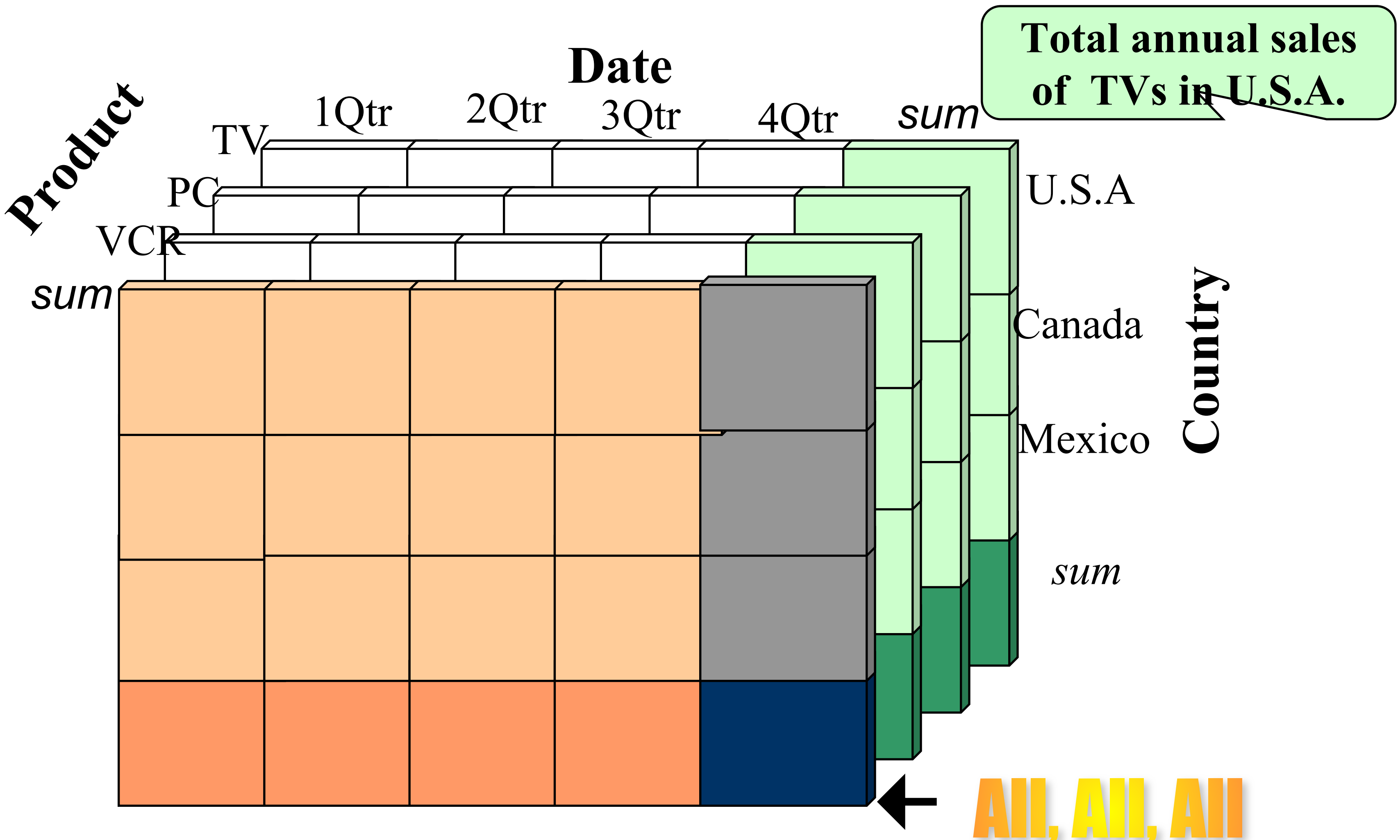
- Sales volume as a function of product, month, and region



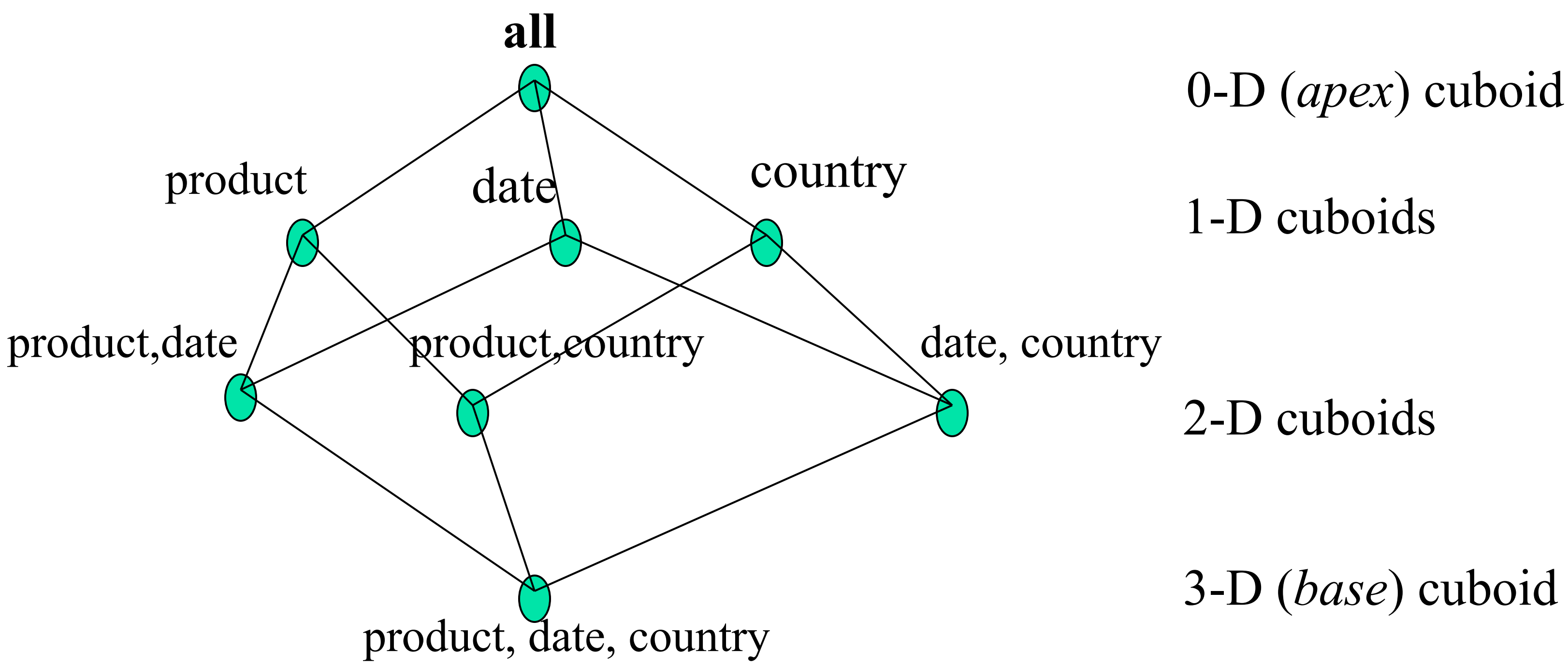
Dimensions: *Product, Location, Time*
Hierarchical summarization paths



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)*

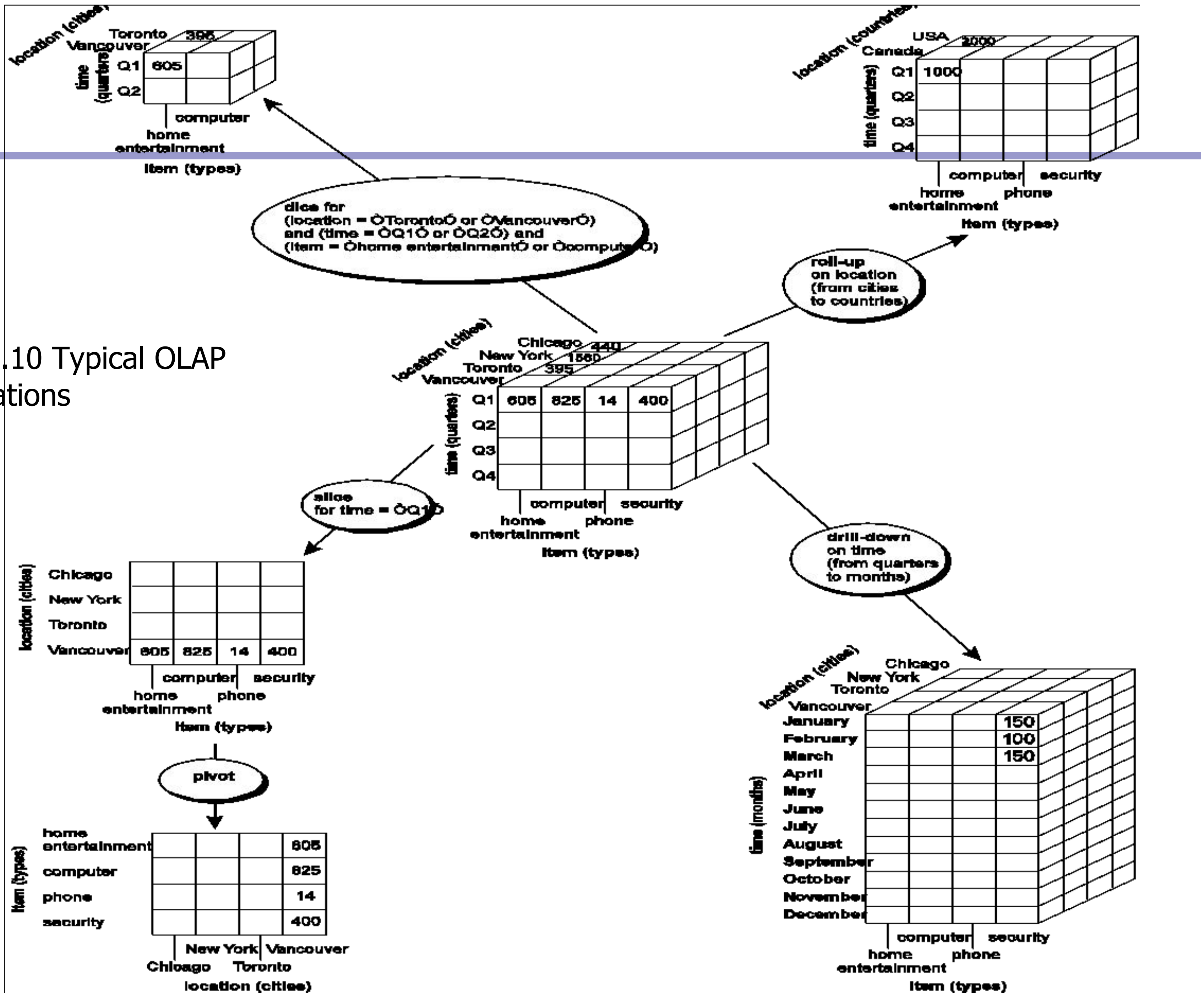


Fig. 3.10 Typical OLAP Operations

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
- Mapping the Data Warehouse to a Multiprocessor Architecture

Mapping the Data Warehouse to a Multiprocessor Architecture

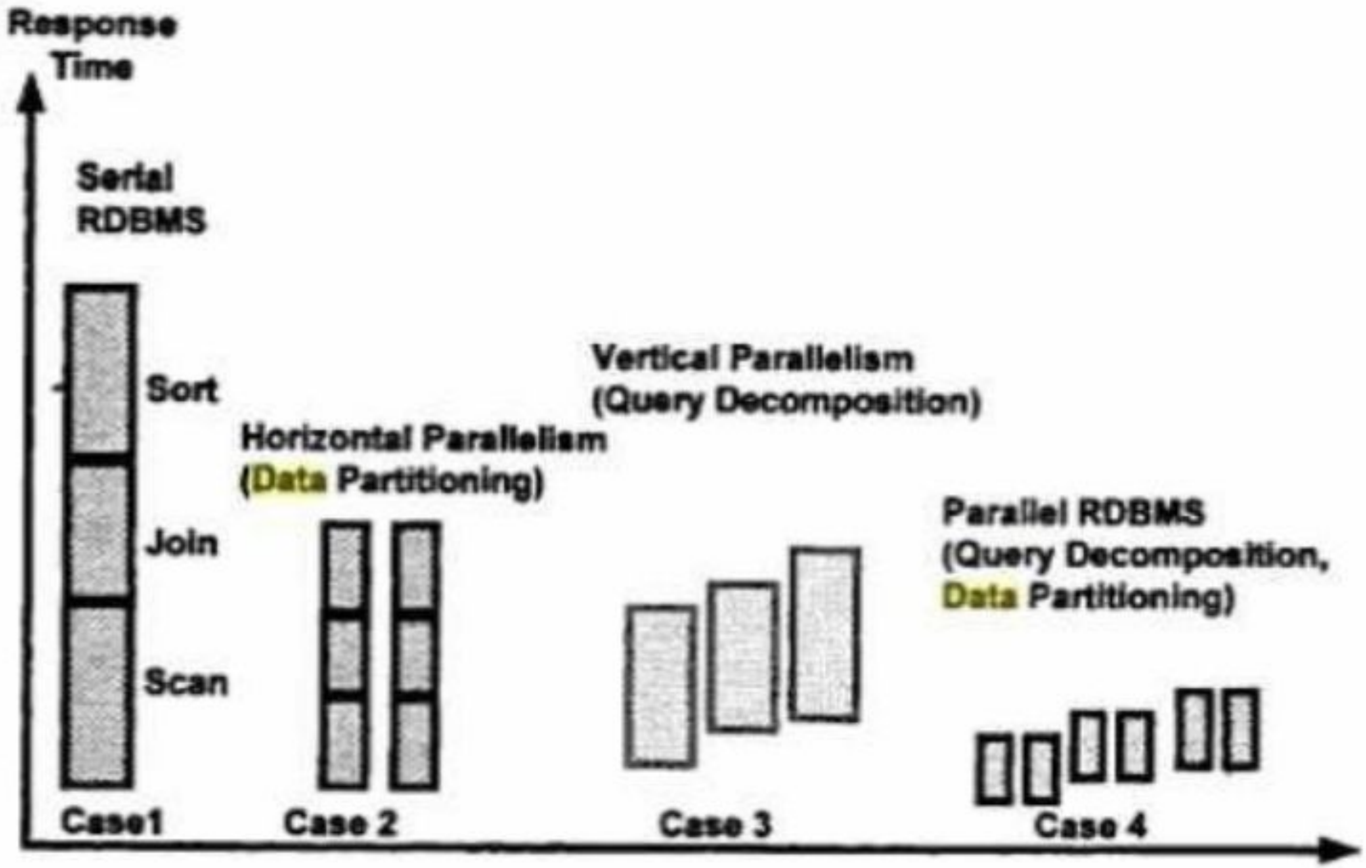
- **Relational data base technology for data warehouse**

- *Linear Speed up:* refers the ability to increase the number of processor to reduce response time
- *Linear Scale up:* refers the ability to provide same performance on the same requests as the database size increases

- ***Types of parallelism***

- *Inter query Parallelism:* In which different server threads or processes handle multiple requests at the same time.
- *Intra query Parallelism:* This form of parallelism decomposes the serial SQL query into lower level operations such as scan, join, sort etc. Then these lower level operations are executed concurrently in parallel.

- Intra query parallelism can be done in either of two ways:
  - *Horizontal parallelism:* which means that the data base is partitioned across multiple disks and parallel processing occurs within a specific task that is performed concurrently on different processors against different set of data
  - *Vertical parallelism:* This occurs among different tasks. All query components such as scan, join, sort etc are executed in parallel in a pipelined fashion. In other words, an output from one task becomes an input into another task



Types of DBMS parallelism.

- ***Data partitioning:***

  Data partitioning is the key component for effective parallel execution of data base operations. Partition can be done randomly or intelligently.

- *Random portioning:*
  - Includes random data striping across multiple disks on a single server.
- *Intelligent partitioning:*

  Assumes that DBMS knows where a specific record is located and does not waste time searching for it across all disks. The various intelligent partitioning include:

  - *Hash partitioning:* A hash algorithm is used to calculate the partition number based on the value of the partitioning key for each row

  - *Key range partitioning:* Rows are placed and located in the partitions according to the value of the partitioning key. That is all the rows with the key value from A to K are in partition 1, L to T are in partition 2 and so on.

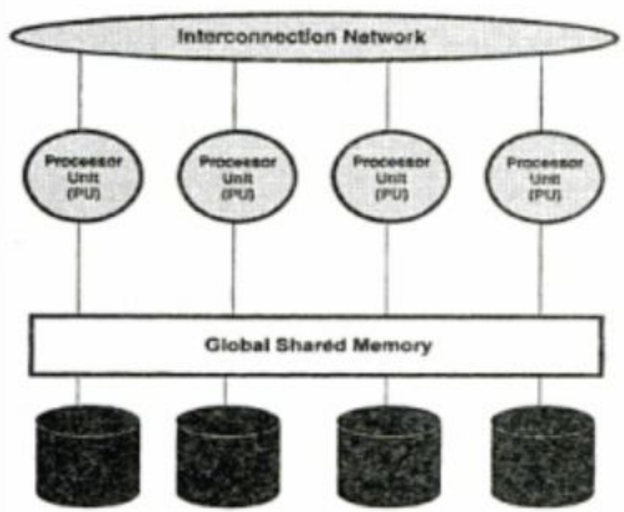
- *Schema portioning:* an entire table is placed on one disk; another table is placed on different disk etc. This is useful for small reference tables.
- *User defined portioning:* It allows a table to be partitioned on the basis of a user defined expression.

Data base architectures of parallel processing

- There are three DBMS software architecture styles for parallel processing:
  - Shared memory or shared everything Architecture
  - Shared disk architecture
  - Shred nothing architecture

SHARED MEMORY ARCHITECTURE

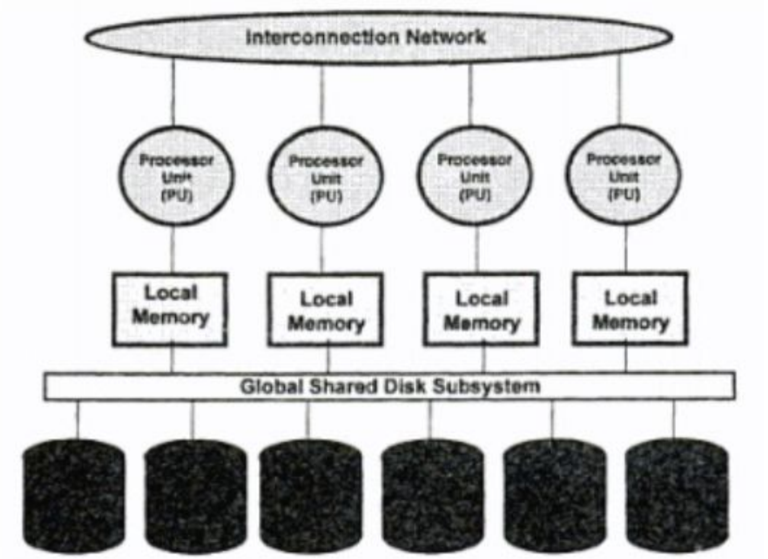
- Tightly coupled shared memory systems.
- Multiple PUs share memory.
- Each PU has full access to all shared memory through a common bus.
- Communication between nodes occurs via shared memory.
- Performance is limited by the bandwidth of the memory bus.



Shared-memory architecture.

SHARED DISK ARCHITECTURE

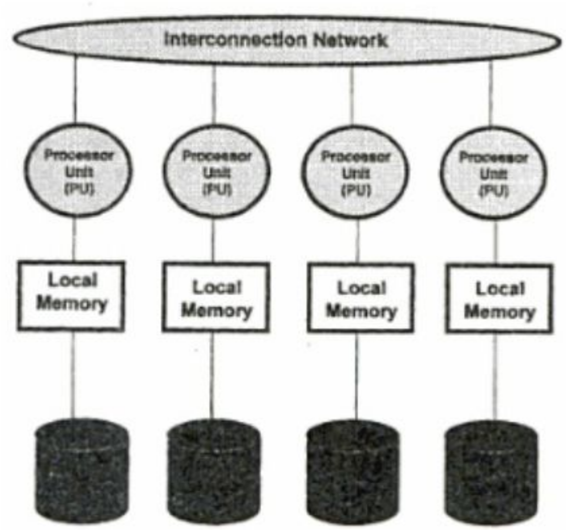
- Shared disk systems are typically loosely coupled. Such systems have the following characteristics:
- Each node consists of one or more PUs and associated memory.
- Memory is not shared between nodes.
- Communication occurs over a common high-speed bus.
- Each node has access to the same disks and other resources.
- Bandwidth of the high-speed bus limits the number of nodes (scalability) of the system.
- The Distributed Lock Manager (DLM) is required.



shared-disk architecture.

SHARED NOTHING ARCHITECTURE

- Shared nothing systems are typically loosely coupled. In shared nothing systems only one CPU is connected to a given disk. If a table or database is located on that disk
- Shared nothing systems are concerned with access to disks, not access to memory.
- Adding more PUs and disks can improve scale up.



Distributed memory architecture.