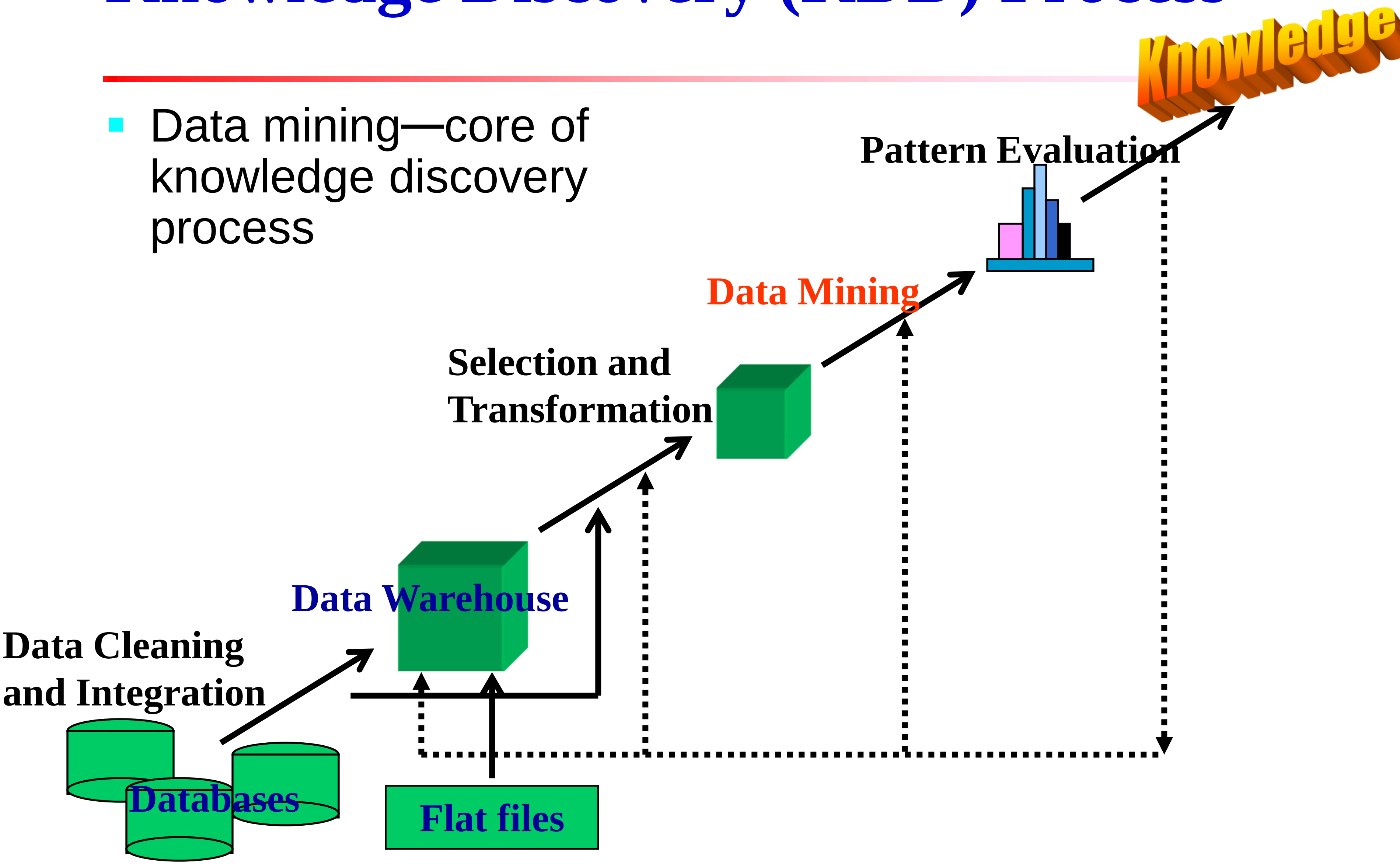
# Data Mining

**刘莹，博士，教授**

中国科学院大学计算机科学与技术学院
中国科学院大学数据挖掘与高性能计算实验室

# Knowledge Discovery (KDD) Process

- Data mining—core of knowledge discovery process



# Data Warehouse

- What is a data warehouse?
- A multi-dimensional data model
- Data warehouse architecture
- From data warehousing to data mining

# What is Data Warehouse?

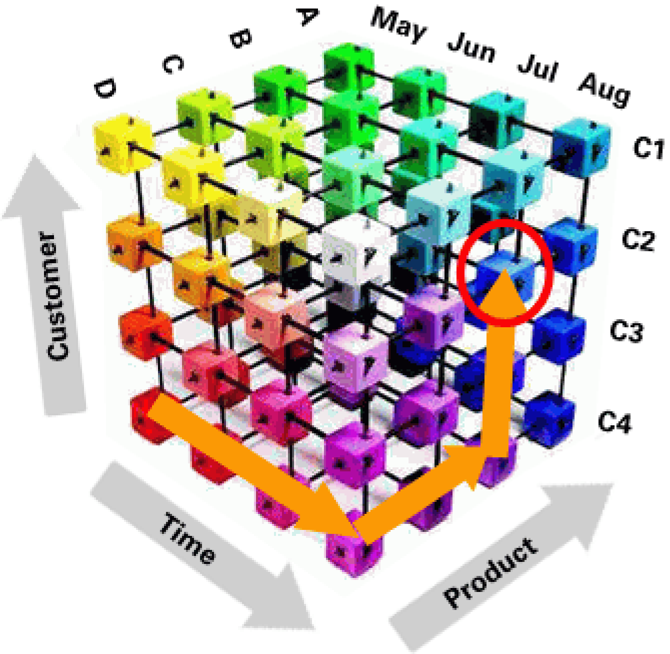
- “A data warehouse is a subject-oriented, integrated, time-variant, and nonvolatile collection of data in support of management’s decision-making process.” — W. H. Inmon
- Defined in many different ways, but not rigorously
  - A decision support database that is maintained separately from the organization’s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

# Data Warehouse

- 数据仓库将分布在企业网络中不同信息岛上的业务数据集成到一起，存储在一个单一的集成关系型数据库中，利用这样的集成信息，可方便用户对信息访问，可使决策人员对一段时间内的历史数据进行分析，研究事务的发展走势—Informix 公司
- 数据仓库是一种管理技术，旨在通过通畅、合理、全面的信息管理，达到有效的决策支持—SAS软件研究所
- 数据仓库是集成信息的存储中心，这些信息可用于查询或分析—Stanford University

# Example

- Customer relationship management



- Banking decision support system
- Insurance decision support system

# Example

- Weather forecasting
  - Air pressure, temperature, longitude/latitude, humidity, time, etc.
  - Slice, drill down, roll up, etc.
  - Query
  - Multi-dimensional visualization

# Data Warehouse—Subject-Oriented

- Organized around major subjects, such as customer, product, sales
- Focus 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
  - 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*

# Data Warehouse vs. Operational DBMS

- OLTP (on-line transaction processing)
  - Major task of traditional relational DBMS
  - Day-to-day operations: e.g. purchasing, inventory, banking, manufacturing, payroll, registration, accounting, etc.
- OLAP (on-line analytical processing)
  - Major task of data warehouse system
  - Data analysis and decision making
- Distinct features (OLTP vs. OLAP):
  - User and system orientation: customer vs. market
  - Data contents: current, detailed vs. historical, consolidated
  - View: current, local vs. evolutionary, integrated
  - Access patterns: update vs. read-only but complex queries

# 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<br>detailed, flat relational<br>isolated | historical,<br>summarized, multidimensional<br>integrated, consolidated |
| **usage** | repetitive | ad-hoc |
| **access** | read/write<br>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 |

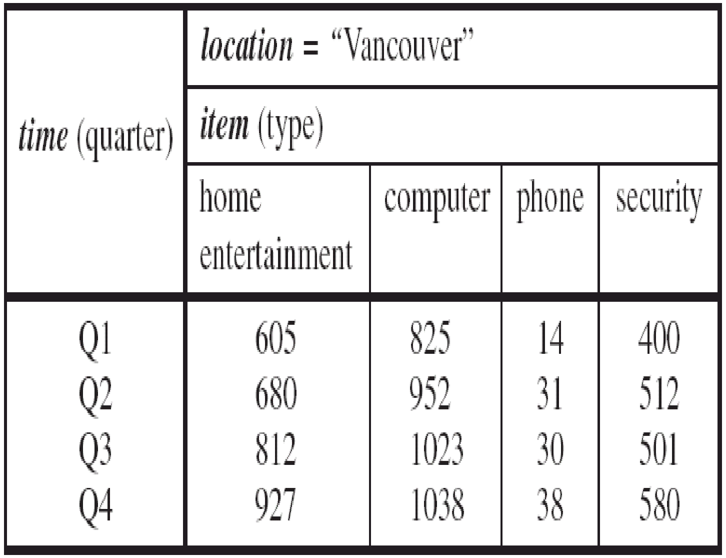
# Data Warehouse

- What is a data warehouse?
- A multi-dimensional data model
- Data warehouse architecture
- From data warehousing to data mining

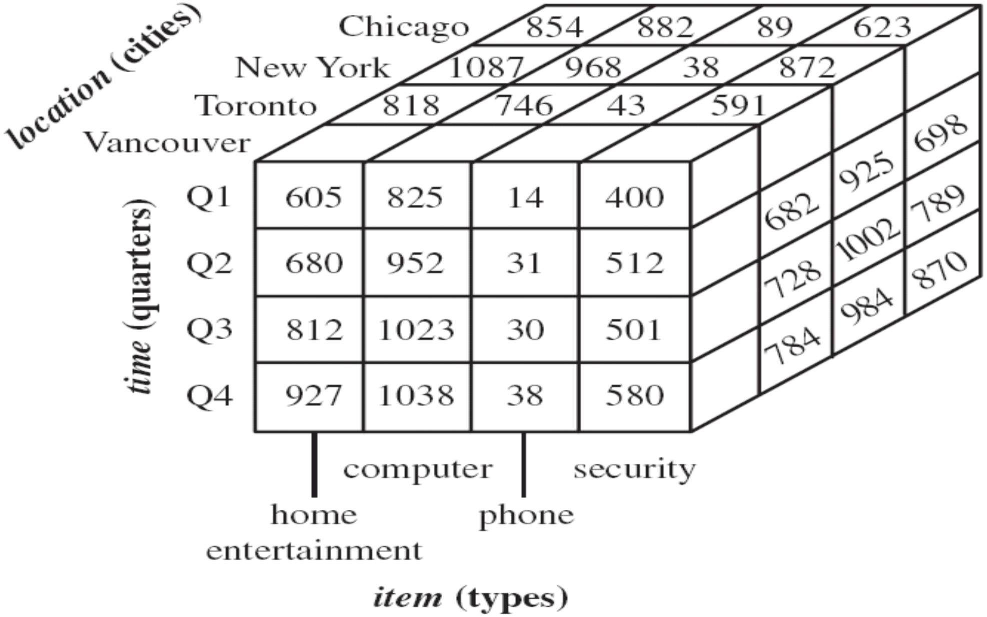
# From Tables and Spreadsheets to Data Cubes

- A data warehouse is based on a multidimensional data model which views data in the form of a data cube
- A data cube 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

# From Tables and Spreadsheets to Data Cubes



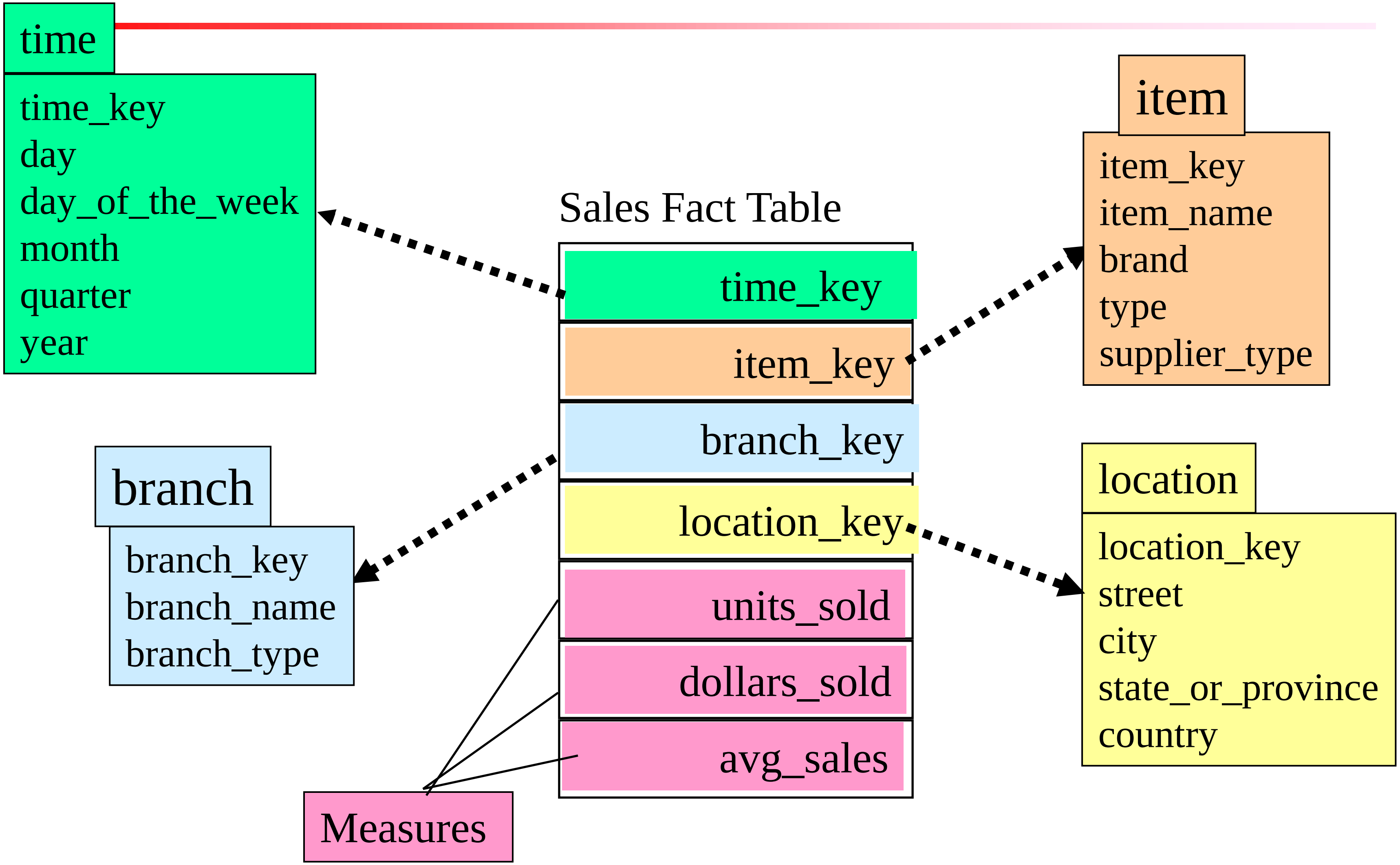
| *time* (quarter) | *location* = "Vancouver" | | | |
|---|---|---|---|---|
| | *item* (type) | | | |
| | home entertainment | computer | phone | security |
| Q1 | 605 | 825 | 14 | 400 |
| Q2 | 680 | 952 | 31 | 512 |
| Q3 | 812 | 1023 | 30 | 501 |
| Q4 | 927 | 1038 | 38 | 580 |



# 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



time

time_key
day
day_of_the_week
month
quarter
year

Sales Fact Table

time_key
item_key
branch_key
location_key
units_sold
dollars_sold
avg_sales

item

item_key
item_name
brand
type
supplier_type

branch

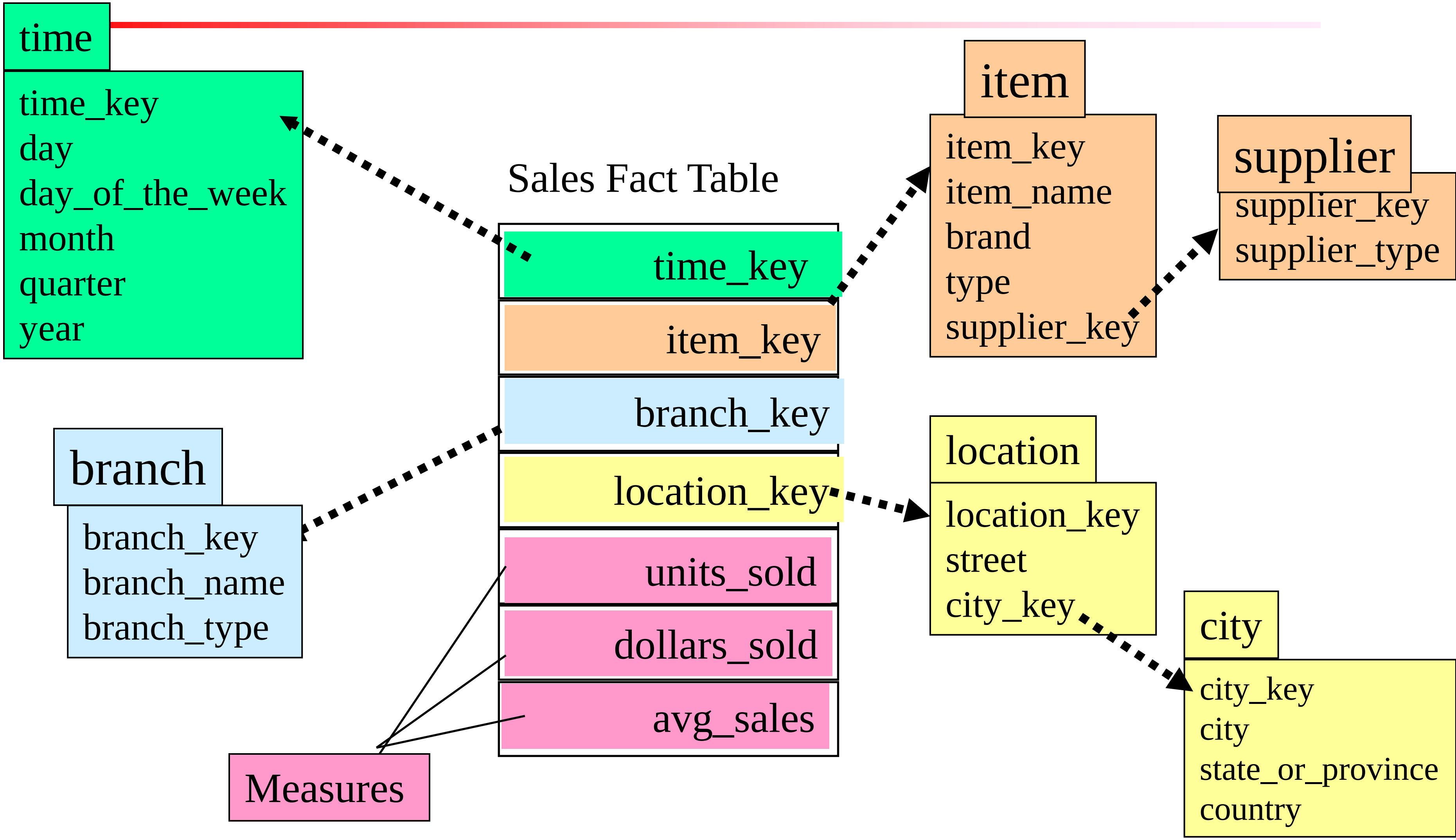
branch_key
branch_name
branch_type

location

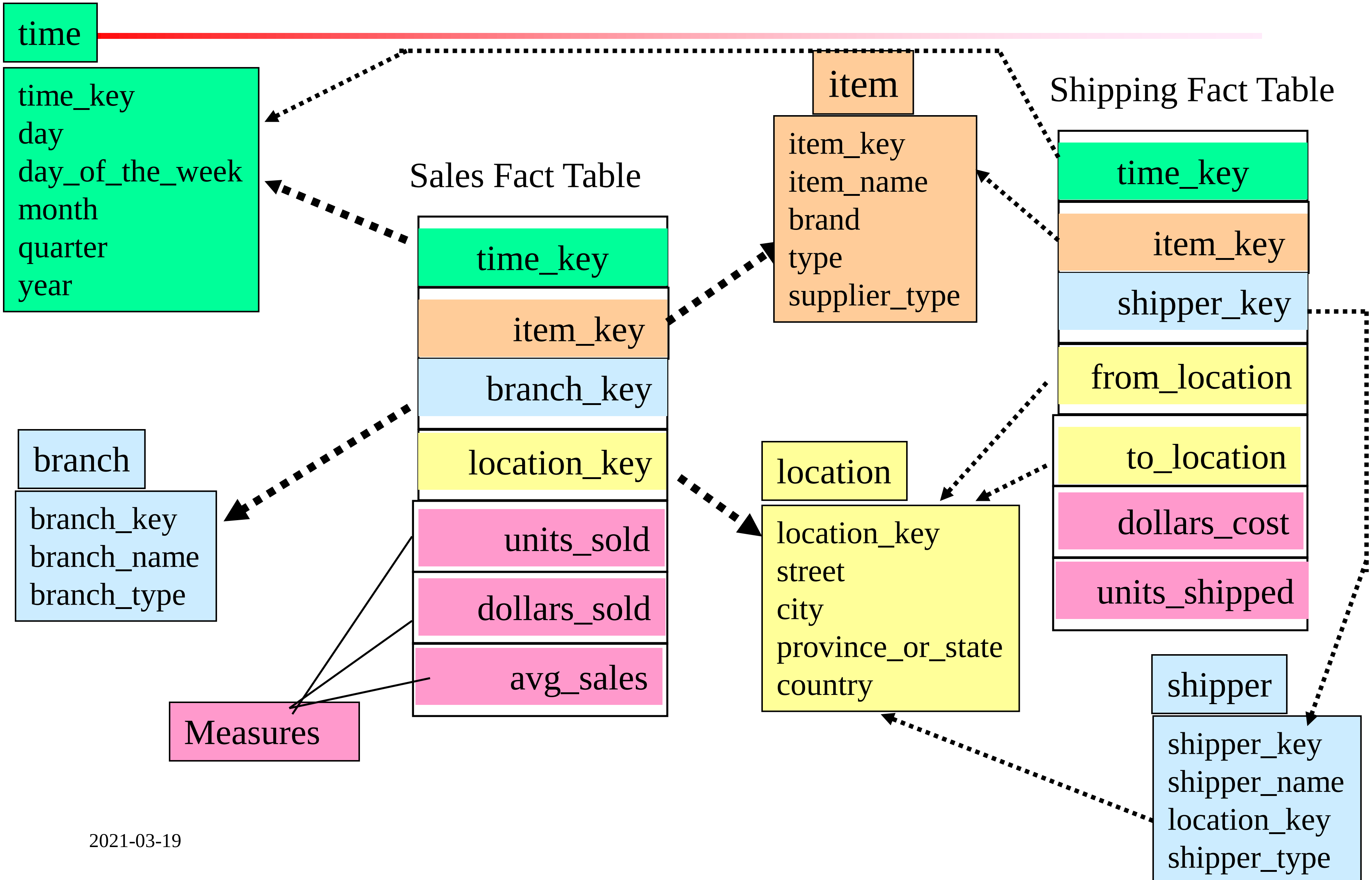
location_key
street
city
state_or_province
country

Measures

# Example of Snowflake Schema



# Example of Fact Constellation



time

time_key
day
day_of_the_week
month
quarter
year

Sales Fact Table

time_key
item_key
branch_key
location_key
units_sold
dollars_sold
avg_sales

Measures

item

item_key
item_name
brand
type
supplier_type

branch

branch_key
branch_name
branch_type

location

location_key
street
city
province_or_state
country

Shipping Fact Table

time_key
item_key
shipper_key
from_location
to_location
dollars_cost
units_shipped

shipper

shipper_key
shipper_name
location_key
shipper_type

# Cube Definition Syntax in DMQL

- Cube Definition (Fact Table)

  define cube <cube_name> [<dimension_list>]: <measure_list>

- Dimension Definition (Dimension Table)

  define dimension <dimension_name> as (<attribute_or_subdimension_list>)

- Special Case (Shared Dimension Tables)
  - First time as "cube definition"
  - define dimension <dimension_name> as <dimension_name_first_time> in cube <cube_name_first_time>

# Defining Star Schema in DMQL

define cube sales_star [time, item, branch, location]:

dollars_sold, avg_sales, units_sold

define dimension time as (time_key, day, day_of_week, month, quarter, year)

define dimension item as (item_key, item_name, brand, type, supplier_type)

define dimension branch as (branch_key, branch_name, branch_type)

define dimension location as (location_key, street, city, province_or_state, country)

# Defining Snowflake Schema in DMQL

define cube sales_snowflake [time, item, branch, location]:

dollars_sold, avg_sales, units_sold

define dimension time as (time_key, day, day_of_week, month, quarter, year)

define dimension item as (item_key, item_name, brand, type, supplier(supplier_key, supplier_type))

define dimension branch as (branch_key, branch_name, branch_type)

define dimension location as (location_key, street, city(city_key, province_or_state, country))

# Defining Fact Constellation in DMQL

```
define cube sales [time, item, branch, location]:
            dollars_sold, avg_sales, units_sold
define dimension time as (time_key, day, day_of_week, month, quarter,
    year)
define dimension item as (item_key, item_name, brand, type,
    supplier_type)
define dimension branch as (branch_key, branch_name, branch_type)
define dimension location as (location_key, street, city, province_or_state,
    country)
define cube shipping [time, item, shipper, from_location, to_location]:
            dollar_cost, unit_shipped
define dimension time as time in cube sales
define dimension item as item in cube sales
define dimension shipper as (shipper_key, shipper_name, location as
    location in cube sales, shipper_type)
define dimension from_location as location in cube sales
define dimension to_location as location in cube sales
```

# Exercise

1. Suppose that a data warehouse consists of three dimensions *time, doctor, and patient*, and two measures *count* and *charge*, where *charge* is the fee that a doctor charges a patient for a visit.

(1) Draw a schema diagram for the data warehouse.

# How to Generate a Specified Data Cube?

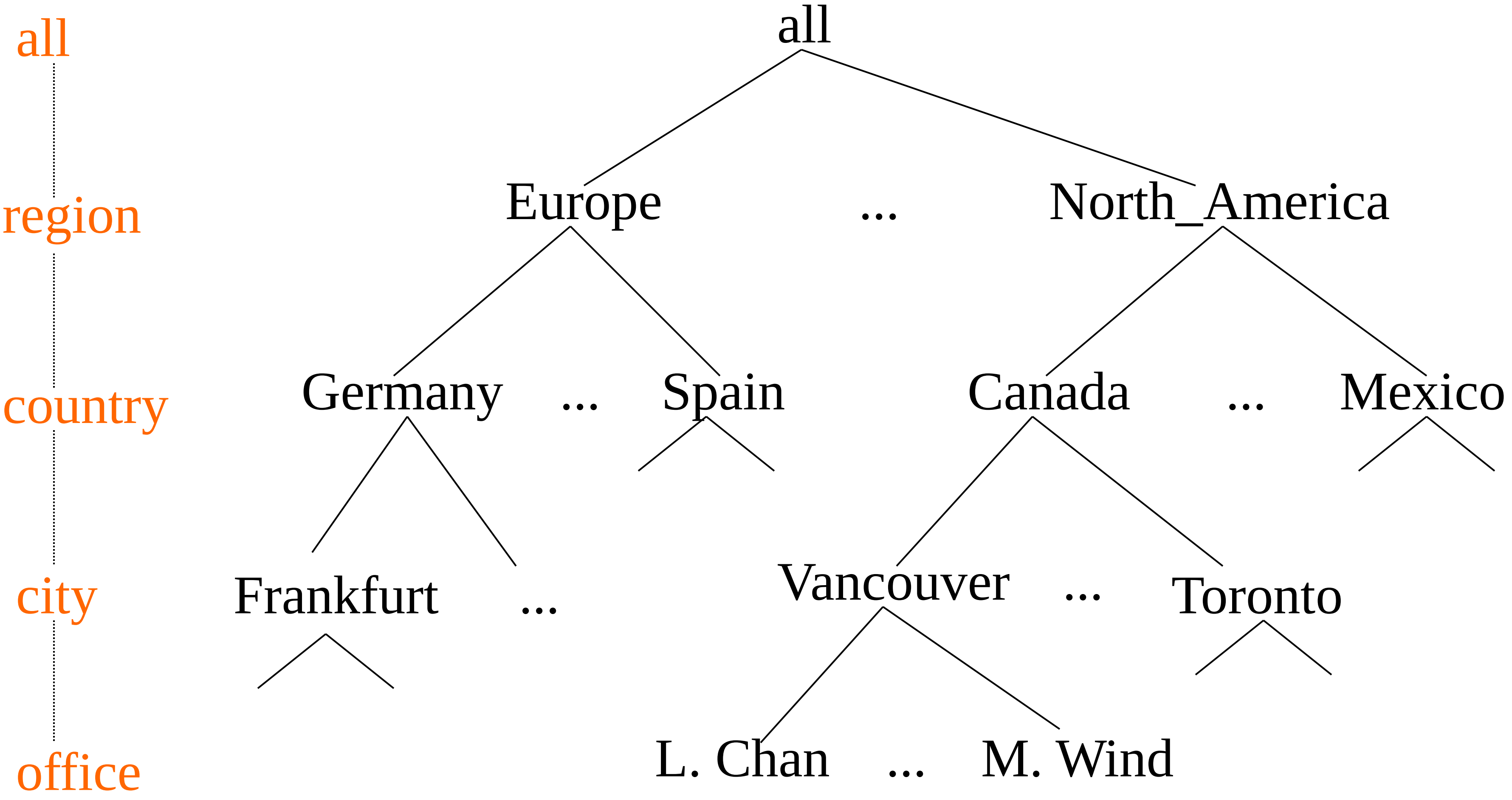
- DMQL specification is translated into SQL query

```
define cube sales_star [time, item, branch, location]:
        dollars_sold, units_sold, units_sold
```

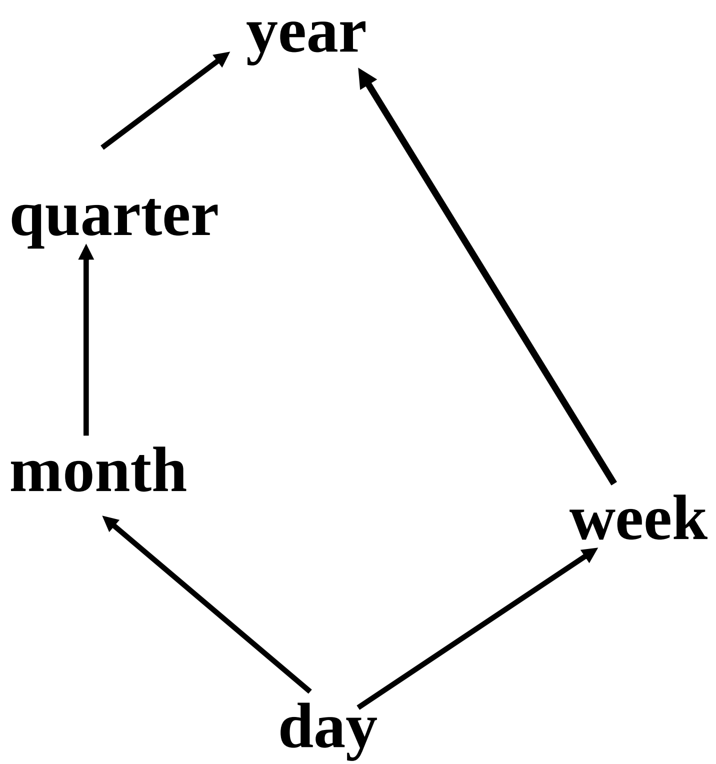
***translator*** ⬇

```
select s.time_key, s.item_key, s.branch_key, s.location_key,
    sum(s.number_of_units_sold*s.price), sum(s.number_of_units_sold)
from time t, item i, branch b, location l, sales s,
where s.time_key = t.time_key and s.item_key = i.item_key
    and s.branch_key = b.branch_key and s.location_key = l.location_key
group by s.time_key, s.item_key, s.branch_key, s.location_key
```

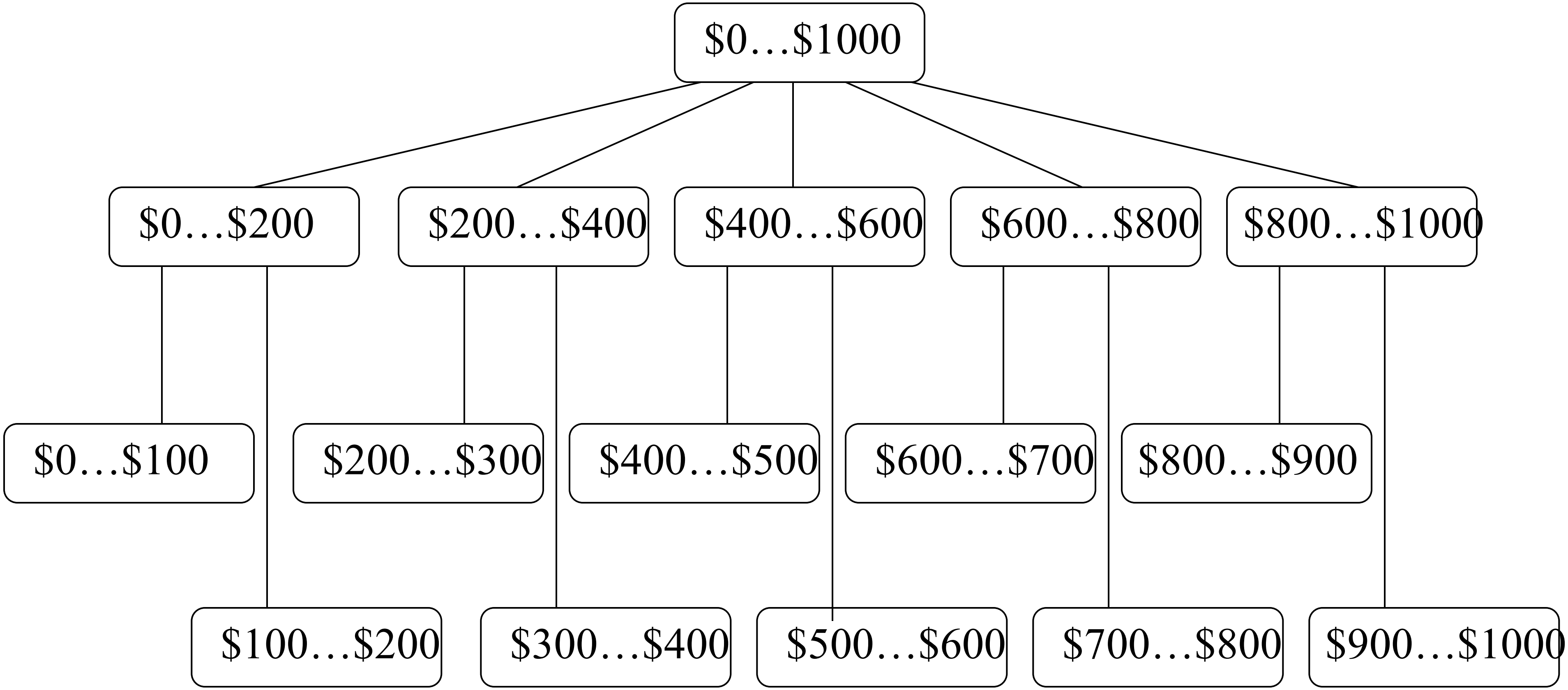
# A Concept Hierarchy: Dimension (location)



# A Concept Hierarchy: Dimension (time)

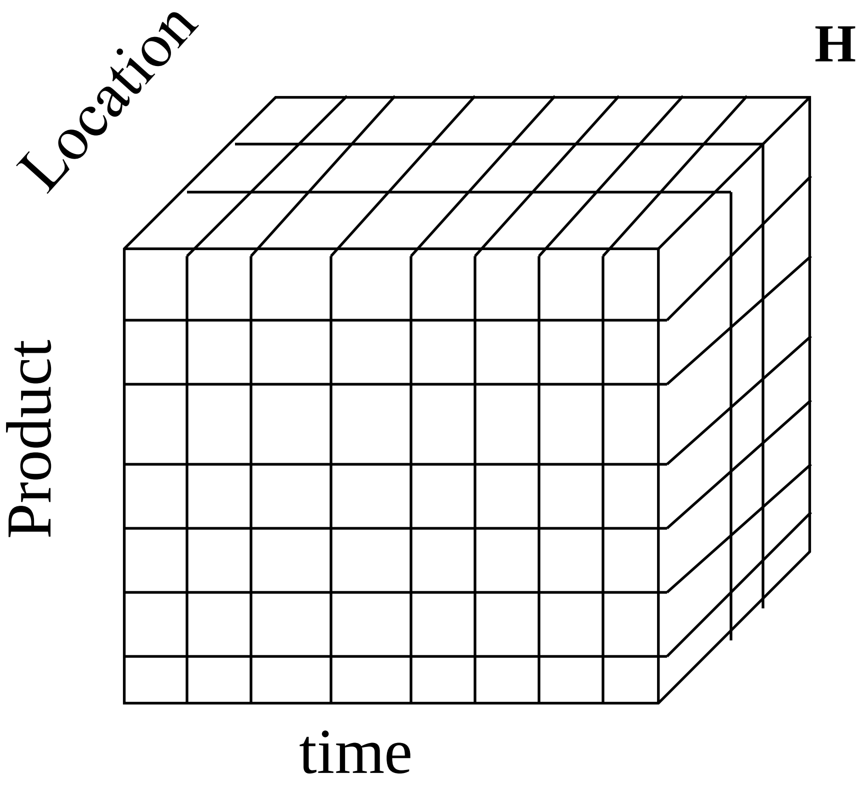


# A Concept Hierarchy for Numeric Values

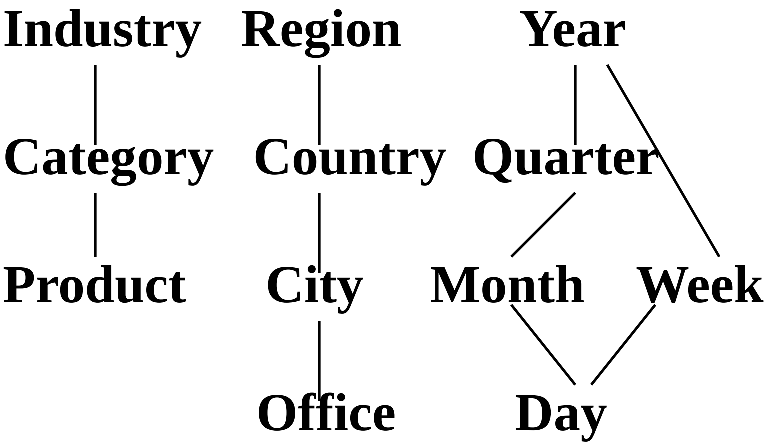


# Multidimensional Data

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



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


Industry
Category
Product

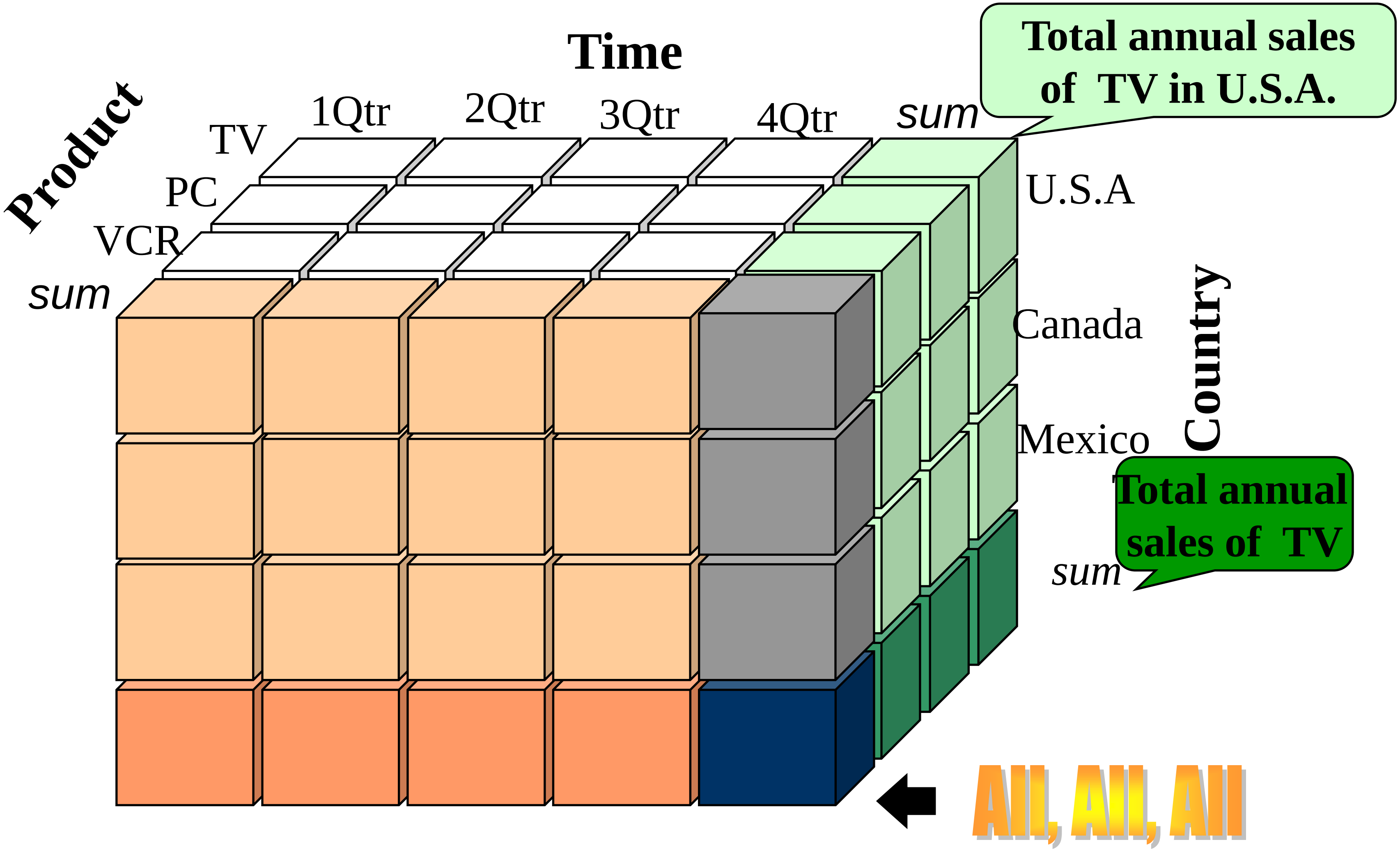
Region
Country
City
Office

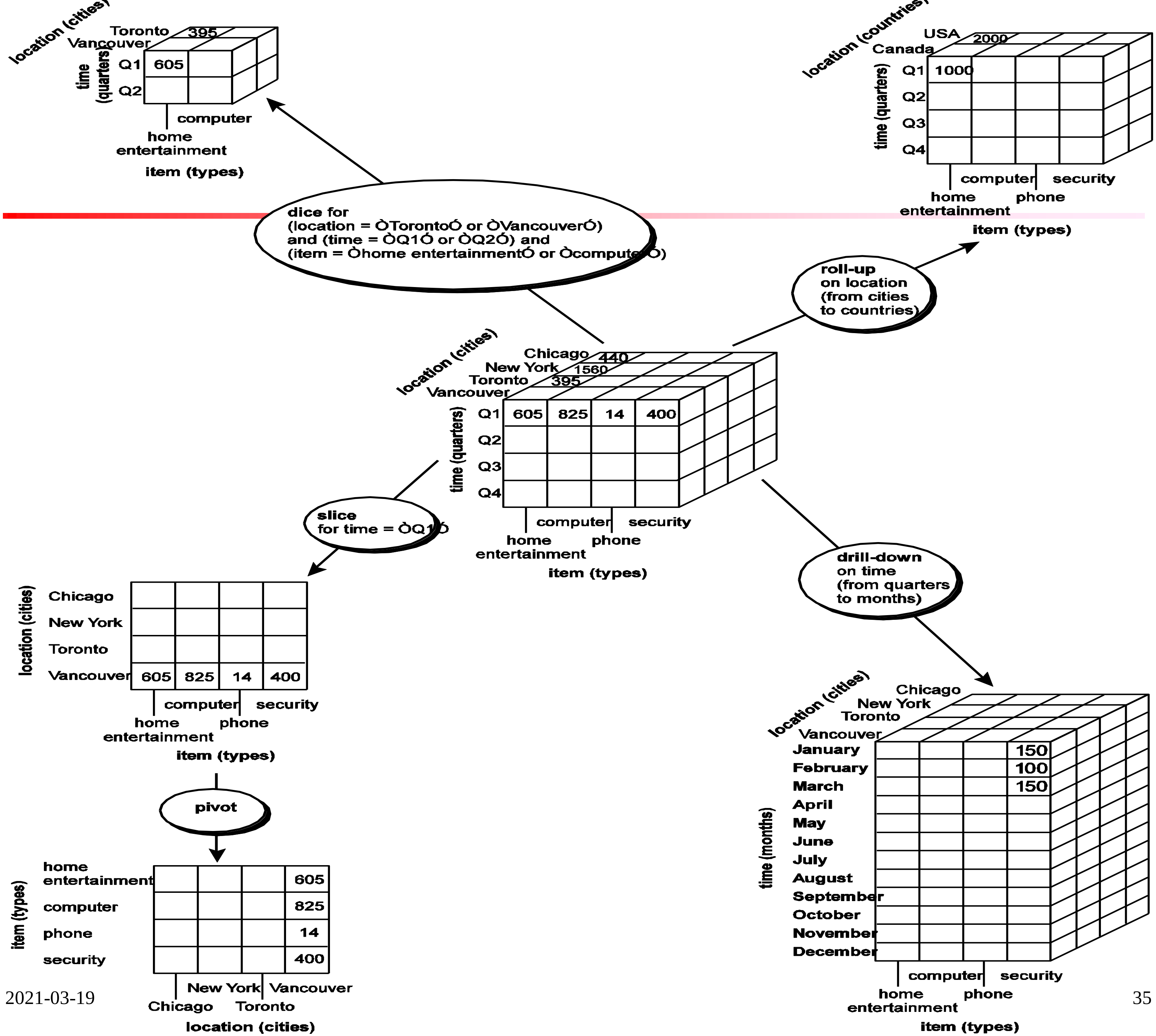
Year
Quarter
Month
Week
Day

# 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*

# A Sample Data Cube





| location (cities) | home entertainment | computer | phone | security |
|---|---|---|---|---|
| Chicago | | | | |
| New York | | | | |
| Toronto | | | | |
| Vancouver | 605 | 825 | 14 | 400 |

| item (types) | Chicago | New York | Toronto | Vancouver |
|---|---|---|---|---|
| home entertainment | | | | 605 |
| computer | | | | 825 |
| phone | | | | 14 |
| security | | | | 400 |

# OLAP Operations

- 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)*
  - *rank top N* or *bottom N items in lists*
  - *Compute average, variance, deviation*

# Exercise

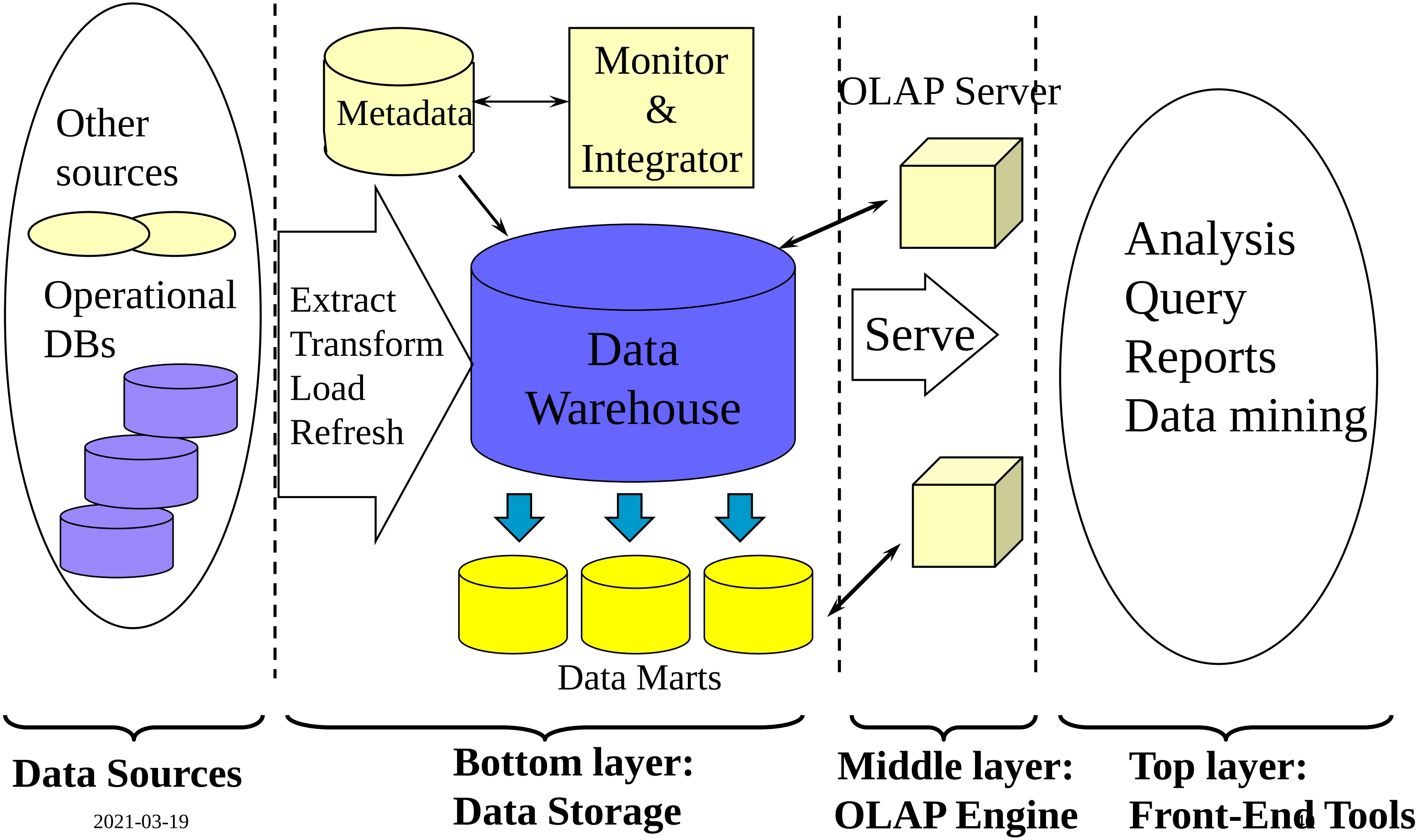
1. Suppose that a data warehouse consists of three dimensions *time, doctor, and patient*, and two measures count and charge, there charge is the fee that a doctor charges a patient for a visit.

(2) Starting with the base cuboid [day, doctor, patient], what OLAP operations should be performed in order to list the total fee collected by each doctor in 1999?

# Data Warehouse

- What is a data warehouse?
- A multi-dimensional data model
- Data warehouse architecture
- From data warehousing to data mining

# Data Warehouse: A Three-Layer Architecture



# Data Warehouse Back-End Tools and Utilities

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

# Three Data Warehouse Models

- Enterprise warehouse
  - collect 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 group 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

# Data Mart

- Credit scoring

| C_id | sex | age | income | edu | # credit cards | Payment ratio per month | # loans | Payment ratio per month | … |
|---|---|---|---|---|---|---|---|---|---|
| 12 | 0 | 34 | 50K | BS. | 1 | 100% | 1 | 100% | … |
| 14 | 1 | 29 | 60K | BS. | 2 | 20% | 1 | 50% | … |
| 135 | 1 | 46 | 100K | MS. | 4 | 100% | 2 | 100% | … |
| … | … | … | … | … | … | … | … | … | … |

- Utility mining

| C_id | T_id | A | Profit(A) | B | Profit(B) | C | Profit(C) | D | Profit(D) | … |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 01 | 0 | 0 | 4 | 5.2 | 1 | 0.9 | 3 | 5.7 | … |
| 14 | 123 | 3 | 6.0 | 0 | 0 | 1 | 0.9 | 2 | 3.8 | … |
| 135 | 12 | 1 | 2.0 | 1 | 1.3 | 2 | 1.8 | 1 | 1.9 | … |
| … | … | … | … | … | … | … | … | … | … | … |

# Metadata Repository

- Meta data is data about data. It contains:
  - Description of the structure of the data warehouse
    - schema, view, dimensions, hierarchies, derived data definition, 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)

# Metadata Repository

- 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

# 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
  - Use parallel computing, bitmap indexing, etc.

# OLAP Server Architectures

- Multidimensional OLAP (MOLAP)
  - **Sparse array**-based multidimensional storage engine
  - **Fast indexing** to pre-computed summarized data
  - **Sparse matrix compression** technique
- Hybrid OLAP (HOLAP) (e.g., Microsoft SQLServer)
  - Flexibility, e.g., low level: relational, high-level: array

# Data Warehouse

- What is a data warehouse?
- A multi-dimensional data model
- Data warehouse architecture
- From data warehousing to data mining

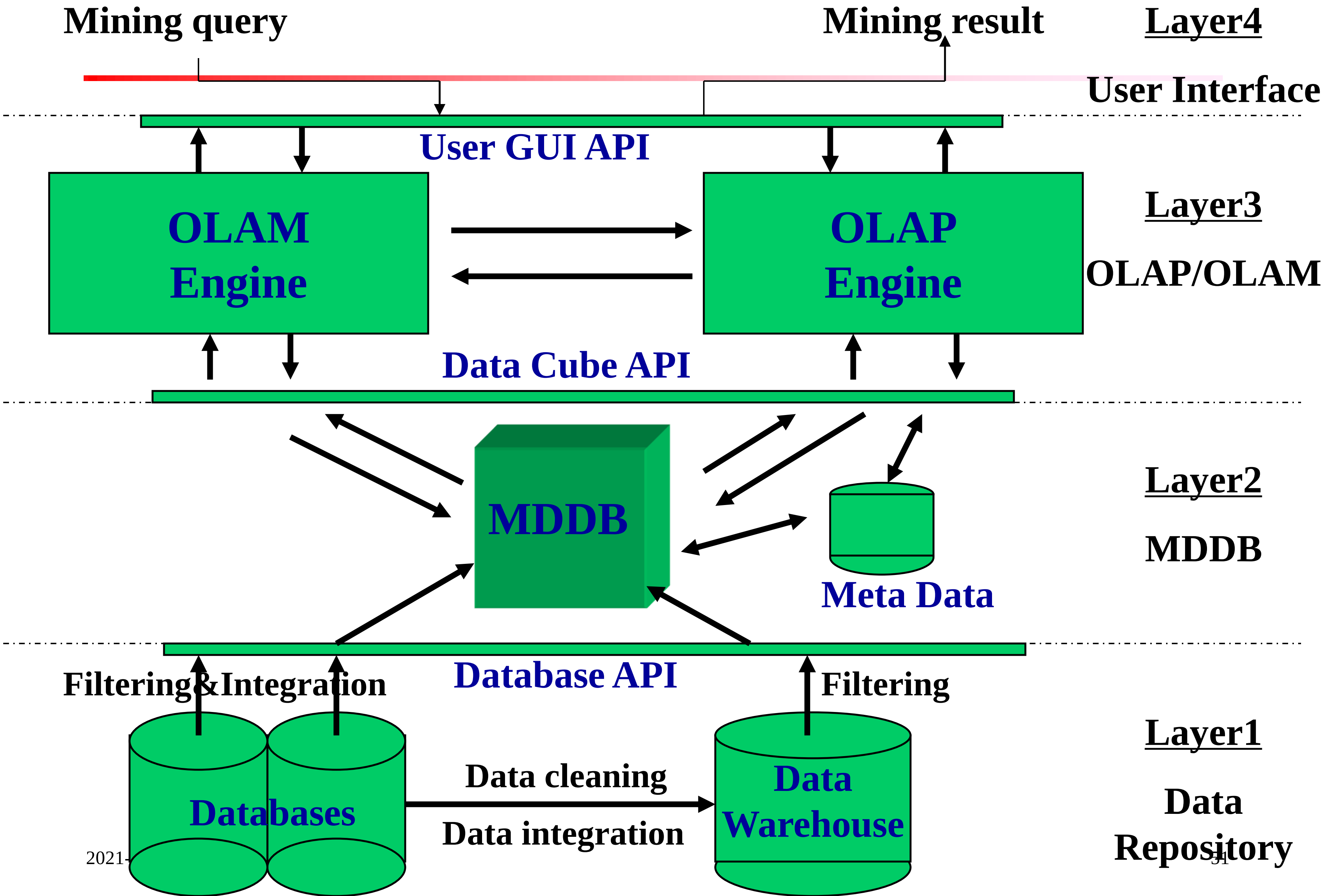
# Data Warehouse Usage

- Three kinds of data warehouse applications
  - Information processing
    - supports querying, basic statistical analysis, and reporting using crosstabs, tables, charts and graphs
  - Analytical processing
    - 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

# An OLAM System Architecture



# Summary

- Why data warehousing?
- A multi-dimensional model of a data warehouse
  - Star schema, snowflake schema, fact constellations
  - A data cube consists of dimensions & measures
- OLAP operations: drilling, rolling, slicing, dicing and pivoting
- Data warehouse architecture
- OLAP servers: ROLAP, MOLAP, HOLAP
- From OLAP to OLAM (on-line analytical mining)