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Data Warehousing

Lecture 1 Introduction to Data Warehousing

CITS3401
CITS5504

Zeyi Wen

Computer Science and Software Engineering

School of Maths, Physics and Computing

Acknowledgement: The lecture slides are adopted from online sources.

Outline of Today's Lecture

- Unit Structure and Overview
- A Brief History of Data(base) Technologies
- Storing Data in Databases and Data Warehouses
- What is Data Warehouse
- OLTP vs. OLAP
- Data Mining

Teaching team for CITS3401&5504

- Lecturer and Unit Coordinator
  - **Dr. Zeyi Wen**
    - Email: zeyi.wen@uwa.edu.au
    - Office: CSSE Room 1.16
    - Webpage: https://research-repository.uwa.edu.au/en/persons/zeyi-wen
- Lab Facilitators
  - **Nur Al Hasan Haldar**
    - recent UWA PhD graduate
    - areas of research: databases and data science
  - **Yin Zhong**
    - Awarded UWA Master's degree with Distinction
- Post general questions (which other students are also likely to have) in help3401 or help5504 forums.

CITS3401 and CITS5504

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- Same Lecture Hours and Venue:
  - Time: Thursdays 12:00 – 14:00 pm
  - Venue: ARTS: [G57] Alexander Lecture Theatre
  - All the lectures will be recorded.
  - Lectures will be live-streamed with Microsoft Teams (link here).
- Same Consultation Hour:
  - Thursdays 14:00 – 15:00 pm (no appointment needed)
  - Other times can be arranged too (send an email to book)
  - Zeyi is in CSSE Room 1.16, and will also be on Microsoft Teams (link here).
- Similar Teaching Material
  - Same lecture slides and lab sheets
  - **Similar** projects (e.g. extra challenging tasks for CITS5504 students)
- Different Web Pages on LMS

CITS3401 and CITS5504 Labs

- Different Lab Sessions (from Week 2 onward):

CITS3401 Lab	Mondays	12:00 - 14:00	CSSE: [201] Computer Lab
	Mondays	16:00 - 18:00	Online (Microsoft Teams link)
	Tuesdays	14:00 - 16:00	CSSE: [201] Computer Lab
	Tuesdays	16:00 – 18:00	CSSE: [201] Computer Lab
	Wednesdays	9:00 – 11:00	MATH: [123] Computer Lab

Online sessions

CITS5504 Lab	Wednesdays	12:00 - 14:00	CSSE: [205] Computer Lab
	Wednesdays	14:00 - 16:00	Online (Microsoft Teams link)
	Thursdays	8:00 - 10:00 am	ENCM: [207B] South Civil Computer Room B

Lab sessions

- In **Week 2**, **no Monday lab** sessions due to Labour Day.
  - Affected students can join lab sessions on Tue, Wed and Thu
  - Lab sheets with instructions will be provided—you can complete the Week 2 lab tasks at home.
  - Post questions on help forums.

Same Assessment Structures

- Two Projects: 50%
  - Each project contributes to 25% of this unit.
  - Project specifications will be available on the LMS page.

- Final Examination: 50%

Same Assessment Structures (cont.)

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Two projects worth 50%; each contributes 25%.

- Project 1 submission
  - individual effort
  - (5%) software environment setup evaluation in Week 4
    - during lab time
  - (95%) final submission at the end of Week 6

- Project 2 submission
  - group of 1-2 students
  - final submission at the end of Week 12

- Project 1: analysis of a business scenario through an OLAP (Online Analytical Processing) tool
  - a suite of Microsoft Tools
    - Microsoft SQL Server, and SQL Server Management Studio (SSMS)
    - Visual Studio, and Microsoft SQL Server Data Tools (SSDT)
    - Microsoft PowerBI
- Project 2: analysis of a data mining and exploration problem using Weka.
  - Weka (Waikato Environment for Knowledge Analysis)
  - Weka is a collection of algorithms for data mining tasks.
  - http://www.cs.waikato.ac.nz/ml/weka/

Setting up Software Environment

There are three approaches

1. Install all the software in your **own computer**
   - Recommended approach
   - **Pros**: fast and accessible at any time
   - **Cons**: time to install and fix some tech issues
2. Install OpenVPN and Remote Desktop in your **own computer** to connect to a Virtual Machine (VM) in Azure Cloud
   - **Pros**: easier to setup
   - **Cons**: limited usage **5 hours per week**; slow
3. Use browsers to connect to a VM in Azure Cloud
   - **Pros**: easiest to setup; don't need own computer
   - **Cons**: limited usage **5 hours per week**; **slowest**

Penalty may apply if > 5 hours per week.

- If you use a VM in Azure Cloud, **always backup your work or important data to OneDrive**.
- All your activities on setting the VM are stored in log files, so **use VM for this unit only**.

Text Books and Recommended Readings

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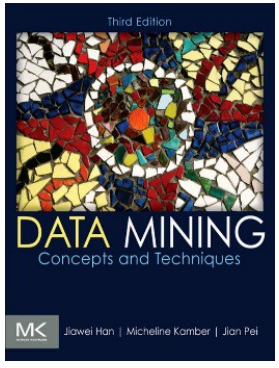
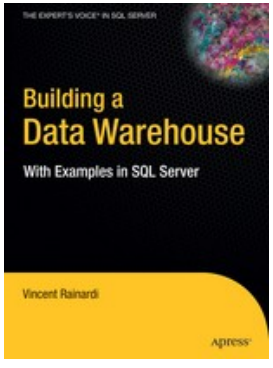
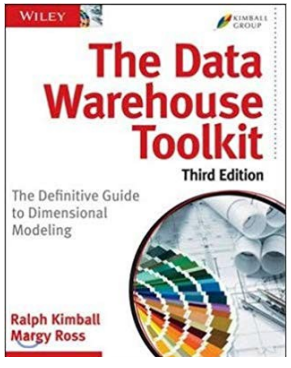
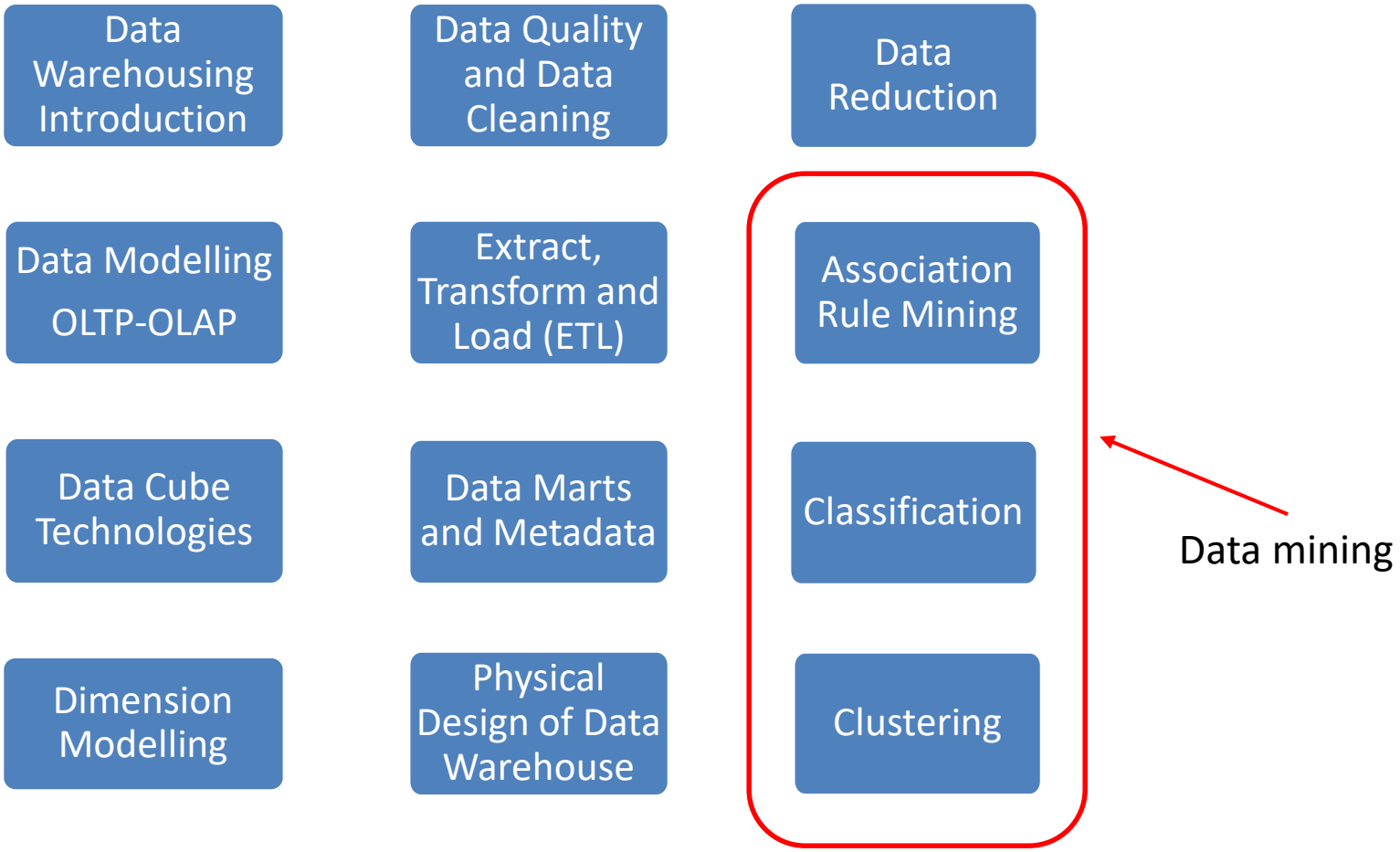
- **Course Text Books:**
  - **Data Mining: Concepts and Techniques**
    - 3rd ed., by J. Han, M. Kamber, and J. Pei. 2011
- **Recommended Readings:**
  - **Building a Data Warehouse with Examples in SQL Server**
    - by Vincent Rainardi. 2008
  - **The Data Warehouse Toolkit, The Definitive Guide to Dimensional Modelling**
    - 3rd ed., by Ralph Kimball and Margy Ross







Unit Overview



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The Evolution of Data Technologies

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- The “dark age”: paper forms in file cabinets
- Computerised systems emerged
  - Initially for big projects like Social Security
  - Same functionality as old paper-based systems
- The “golden age”: databases are everywhere
  - Most activities tracked electronically
  - Stored data provides detailed history of activity
- The next step: use data for decision-making
  - Knowledge discovery from data (a.k.a. Data Mining)
  - One of the enabling technologies: data warehousing

Cambridge Analytica Ltd was founded in 2013.

Evolution of Database Technology

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- **1960s:**
  - (Electronic) Data collection, database creation
  - IMS (database system by IBM) and network DBMS
  - IMS introduced application code should be separated from data.

- **1970s:**
  - Relational data model, relational DBMS implementation
  - The term “relational database” was invented by E. F. Codd at IBM.
  - E. F. Codd won Turing Award in 1981.

- **1980s:**
  - RDBMS, advanced data models (Object Oriented, deductive, etc.)
  - Application-oriented DBMS (spatial, scientific, engineering, etc.)
  - SQL standard adopted by ISO and ANSI.

Microsoft SQL Server was first released in 1989; MySQL in 1995

- **1990s:**
  - Data mining, data warehousing, multimedia DBs, and Web DBs

Google was founded in 1998; Yahoo! in 1994; Baidu and Yandex in 2000

Evolution of Database Technology (cont.)

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- **2000s**
  - Stream data management and mining
  - Data mining and its applications
  - Web tech. (XML, data integration) and geographic info. systems
  - Frequently asked question in job interviews:
    - **Did you work on XML related research?**
- **2010s**

Apache Spark was first released in 2014.

  - NoSQL (Graph Databases, Document Stores)
  - Mining from Varieties of Data:
    - Multimedia Data (Images, Audios, and Videos)
    - Natural Language Processing, Social Network Data
  - Machine (Deep) Learning on various data types (e.g. text, videos)
  - Self-Driving Databases, Autonomous Databases
  - Frequently asked question in job interviews:
    - **Did you work on ML related research?**
- **2020s**
  - Leave this homework to you!

From empirical science to data science

- **Before 1600, empirical science**

- **1600-1950s, theoretical science**
  - Each discipline has grown a theoretical component. Theoretical models often motivate experiments and generalise our understanding.

- **1950s-1990s, computational science**
  - Most disciplines have grown a third, *computational* branch
    - e.g. computational ecology, computational physics, comp. linguistics
  - Computational Science traditionally meant simulation. It grew out of our inability to find closed-form solutions for complex mathematical models.

- **1990-now, data science (and data-driven science)**
  - The flood of data from new scientific instruments and simulations
  - The ability to economically store and manage *petabytes* of data online
  - Internet and computing Grid that makes all the data accessible

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Where to Store Data

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Relational Databases

- Support “delete, insert, update, and query”
- Consistency/integrity is crucial
- Queries are often simple
- Data from single department/organisation

Data Warehouses

- Mainly support “query”
- Queries are more complex

Other distributed file systems

- Hadoop Distributed File Systems (HDFS)

Storing Data in Relational Database

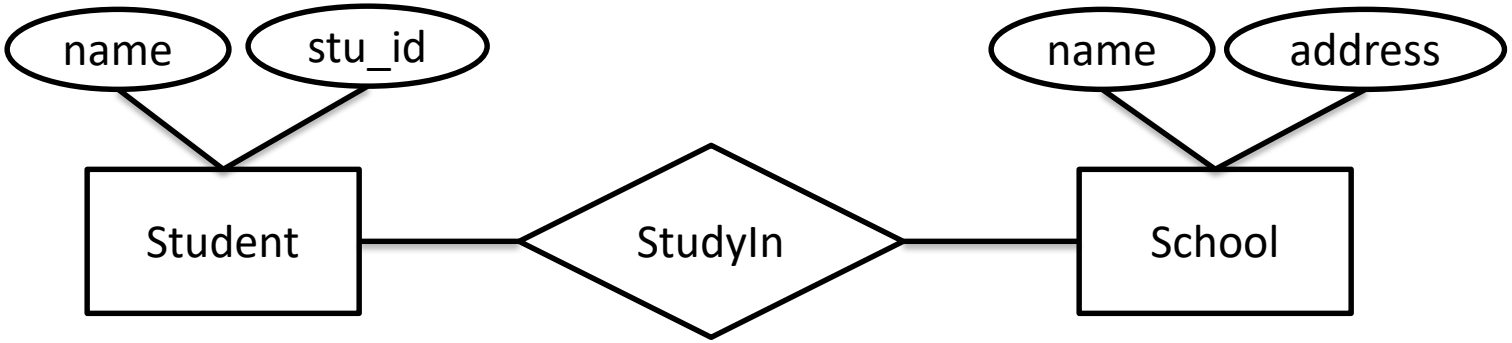
- A relational database is **a collection of tables**, each of which is assigned a unique name.
  - Each table consists of a set of attributes (columns or fields) and usually stores a large set of tuples (records or rows).
  - Each tuple in a relational table represents an object identified by unique key and described by a set of attribute values.

Student_id	Name	Unit_id	School_id	Score
2212201	Jan Smith	CITS3401	006	98
…	…	…	…	….

Storing Data in Relational Database

- A relational database is **a collection of tables**, each of which is assigned a unique name.
  - Each table consists of a set of attributes (columns or fields) and usually stores a large set of tuples (records or rows).
  - Each tuple in a relational table represents an object identified by unique key and described by a set of attribute values.

- A semantic data model, such as the ***Entity Relationship (ER)*** data model, is often constructed for relational databases.
  - An ER data model represents the database as a set of entities and their relationships.



Storing Data in Relational Database (cont.)

- Relational data can be accessed by database queries written in a relational language such as **SQL**.

- A given query is transformed into a set of relational operations such as *join*, *selection* and *projection,* and is then optimised for efficient processing.

- Efficiency of retrieval, efficiency of update and integrity are the key requirements of a good relational database.

An Example - *AllElectronics*

- Four relational tables: *customer*, *item*, *employee* and *branch*.

customer

cust_ID	*name*	*address*	*age*	*income*	*credit_info*	*category*	...
C1	Smith, Sandy	1223 Lake Ave., Chicago, IL	31	$78000	1	3	...
...	...	...	...	...	...	...	...

item

item_ID	*name*	*brand*	*category*	*type*	*price*	*place_made*	*supplier*	*cost*
I3	hi-res-TV	Toshiba	high resolution	TV	$988.00	Japan	NikoX	$600.00
I8	Laptop	Dell	laptop	computer	$1369.00	USA	Dell	$983.00
...	...	...	...	...	...	...	...	...

employee

empl_ID	*name*	*category*	*group*	*salary*	*commission*
E55	Jones, Jane	home entertainment	manager	$118,000	2%
...	...	...	...	...	...

branch

branch_ID	*name*	*address*
B1	City Square	396 Michigan Ave., Chicago, IL
...	...	...

An Example - *AllElectronics*

- Four relational tables: *customer*, *item*, *employee* and *branch*.
- Each relation consists of a set of attributes.

customer

cust_ID	*name*	*address*	*age*	*income*	*credit_info*	*category*	...
C1	Smith, Sandy	1223 Lake Ave., Chicago, IL	31	$78000	1	3	...
...	...	...	...	...	...	...	...

item

item_ID	*name*	*brand*	*category*	*type*	*price*	*place_made*	*supplier*	*cost*
I3	hi-res-TV	Toshiba	high resolution	TV	$988.00	Japan	NikoX	$600.00
I8	Laptop	Dell	laptop	computer	$1369.00	USA	Dell	$983.00
...	...	...	...	...	...	...	...	...

employee

empl_ID	*name*	*category*	*group*	*salary*	*commission*
E55	Jones, Jane	home entertainment	manager	$118,000	2%
...	...	...	...	...	...

branch

branch_ID	*name*	*address*
B1	City Square	396 Michigan Ave., Chicago, IL
...	...	...

purchases

trans_ID	*cust_ID*	*empl_ID*	*date*	*time*	*method_paid*	*amount*
T100	C1	E55	03/21/2005	15:45	Visa	$1357.00
...	...	...	...	...	...	...

items_sold

trans_ID	*item_ID*	*qty*
T100	I3	1
T100	I8	2
...	...	...

works_at

empl_ID	*branch_ID*
E55	B1
...	...

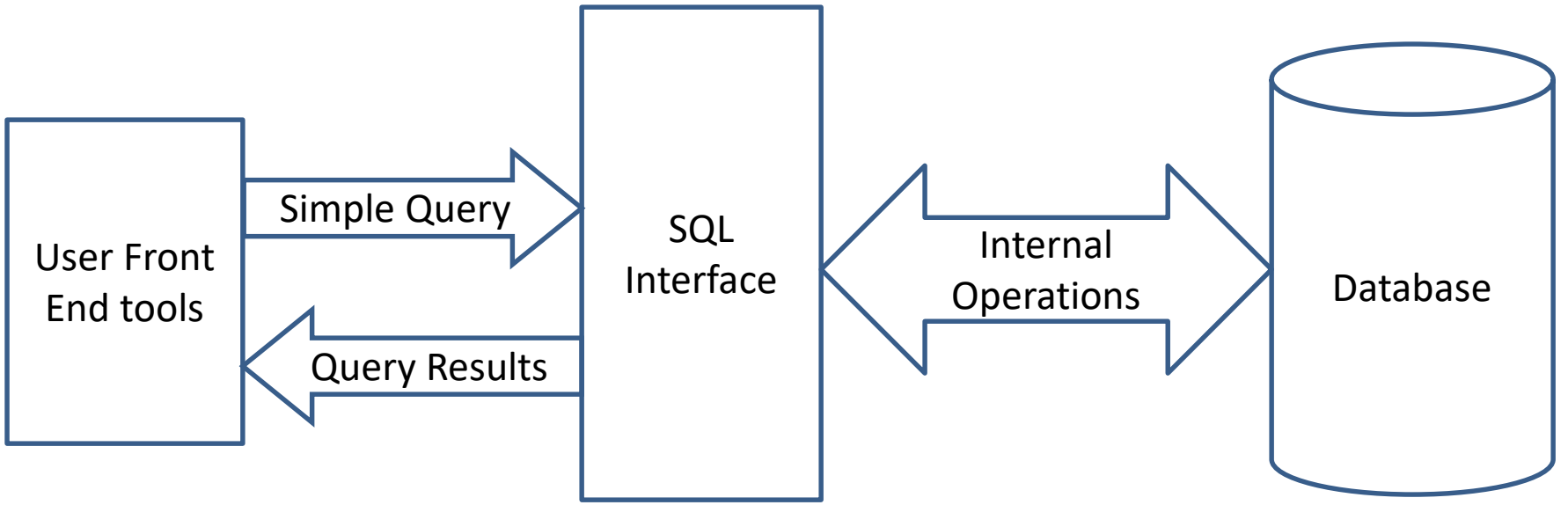
Purpose of Relational Database

- The main purpose of a relational database is to store data **correctly** and retrieve data **on demand**.

- This type of data processing is sometime called Online Transaction Processing (OLTP).

- Relational databases are passive data repositories in the sense that a query only shows you what is stored in the database, but cannot tell you much about the **meaning or trend** of the data.

Query Answering in Relational Database

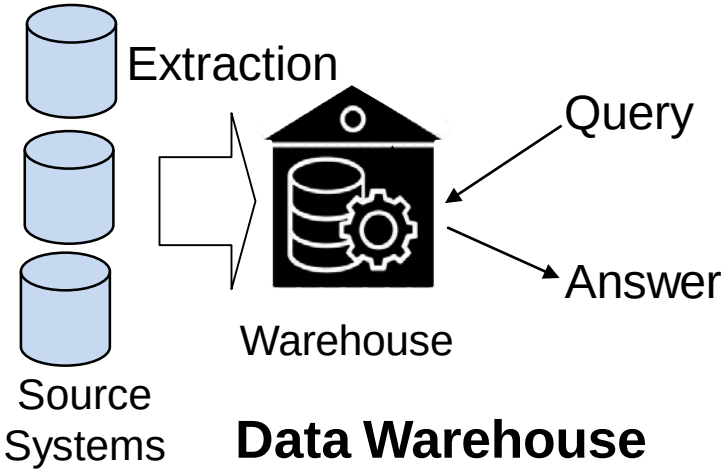


Transactional Database

- A transactional database consists of a file where each record represents a transaction.
- Supports nested relation
- Transaction id: Items, customer name, date…
- Sample Queries**:**
  - Show me all the items purchased by ‘X’
  - How many transactions include item number ‘Y’?
  - market basket data analysis: Which items sold well together? **(Frequent item set)**

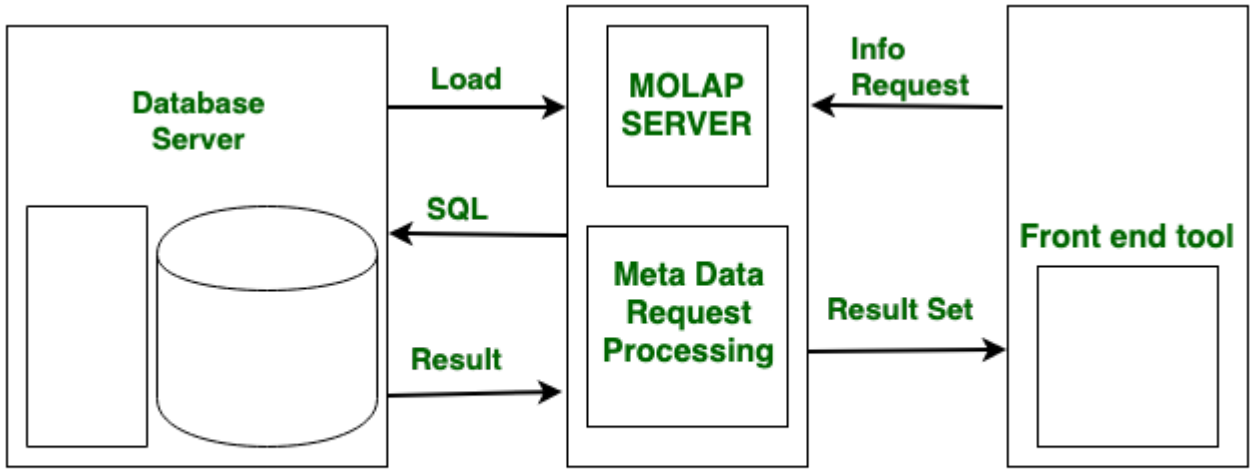
Storing Data in Data Warehouses

- Data are from multiple data sources
  - Relational DB systems, flat files, .csv files, …
- Data are integrated into a data warehouse
- Data are stored in DBMS using tables.



Storing Data in Data Warehouses

- Data are from multiple data sources
  - Relational DB systems, flat files, .csv files, …
- Data are integrated into a data warehouse
- Data are stored in DBMS using tables.
- Query answering process is more complex.



MOLAP Architecture

Query Answering Comparison

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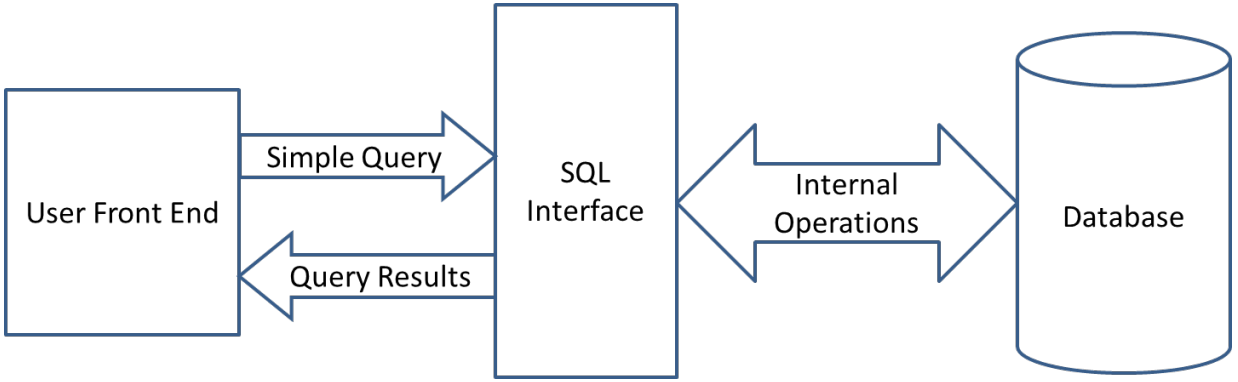
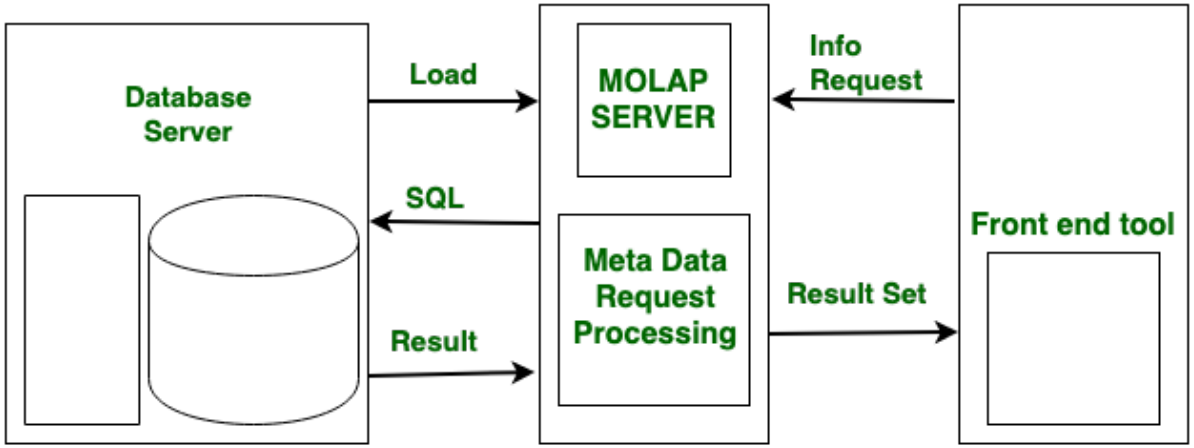
Query answering in Relational Databases



Query answering in Data Warehouses



MOLAP Architecture

Examples of More Complex Queries

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- Show a list of all items that were sold in the last quarter
- Show the total sales of the last month, grouped by branch
- Which sales person has the highest amount of sales?
- How many sales transactions occurred in September?

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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.

Data Warehouse – Subject Oriented

- Organised around major subjects, such as customer, supplier, product, sales, time.

- 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 making 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

Data Warehouse – Integrated (cont.)

Data Integration is hard.

- Data warehouses combine data from multiple sources
- Data must be translated into a consistent format

- Data integration represents ~80% of effort for a typical data warehouse project!

- Some reasons why it's hard:
  - Metadata is poor or non-existent
  - Data quality is often bad
    - Missing or default values
    - Multiple spellings of the same thing (UWA vs. Uni. of WA. vs. University of Western Australia)
  - Inconsistent semantics
    - Marks across different universities?

Data Warehouse – Time Variant

- The time horizon for the data warehouse is significantly longer than that of operational DB 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

Data Warehouse – Non-Volatile

- 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 :
    - *initial loading of data* and *access of data*.

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Key operations of Data Warehouses

Key operations of RDBMS

Data Warehouse (OLAP) vs. Operational DBMS (OLTP)

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- OLTP (on-line transaction processing)
  - Major task of traditional relational DBMS
  - Day-to-day operations: purchasing, inventory, banking, manufacturing, payroll, registration, accounting, etc.

- OLAP (on-line analytical processing)
  - Major task of data warehouse system
  - Data analysis and decision making
  - Can organise and present data in various forms and combinations

Data Warehouse (OLAP) vs. Operational DBMS (OLTP)

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- **On-Line Transaction Processing (OLTP)**
  - Many short transactions (queries + updates)
  - Examples:
    - Update account balance
    - Enroll in course
    - Add book to shopping cart
  - Queries touch small amounts of data (e.g. a few records)
  - Updates are frequent
  - Concurrency is biggest performance concern

- **On-Line Analytical Processing (OLAP)**
  - Long transactions, complex queries
  - Examples:
    - Report total sales for each department in each month
    - Identify top-selling books
    - Count classes with < 10 students
  - Queries touch large amounts of data
  - Updates are infrequent
  - Individual queries can require lots of resources

Why OLAP & OLTP don't mix (1)

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- **Transaction processing (OLTP):**
  - Fast response time important (< 1 second)
  - Data must be up-to-date, consistent at all times
- **Data analysis (OLAP):**
  - Queries can consume lots of resources
  - Can saturate CPUs and disk bandwidth
  - Operating on static "snapshot" of data usually OK
- **OLAP can "crowd out" OLTP transactions**
  - Transactions are slow → unhappy users
- **Example:**
  - Analysis query asks for sum of all sales
  - Acquires lock on sales table for consistency
  - New sales transaction is blocked

Different performance requirements

Why OLAP & OLTP don't mix (2)

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- **Transaction processing (OLTP):**
  - Normalised schema for consistency
  - Complex data models, many tables
  - Limited number of standardised queries and updates

- **Data analysis (OLAP):**
  - Simplicity of data model is important
    - Allow semi-technical users to formulate ad hoc queries
  - De-normalised schemas are common
    - Fewer joins → improved query performance
    - Fewer tables → schema is easier to understand

Different data modeling requirements

Why OLAP & OLTP don't mix (3)

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- **An OLTP system targets one specific process**
  - For example: ordering from an online store
- **OLAP integrates data from different processes**
  - Combine sales, inventory, and purchasing data
  - Analyse experiments conducted by different labs
- **OLAP often makes use of historical data**
  - Identify long-term patterns
  - Notice changes in behavior over time
- **Terminology, schemas vary across data sources**
  - Integrating data from disparate sources is a challenge

Analysis requires data from many sources

Why separate data warehouse?

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- Doing OLTP and OLAP in the same database system is often impractical
  - Different performance requirements
  - Different data modelling requirements
  - Analysis queries require data from many sources

- Different functions and different data:
  - missing data: Decision support requires historical data which operational DBs do not typically maintain
  - data consolidation: DW requires consolidation (aggregation, summarisation) of data from heterogeneous sources
  - data quality: different sources typically use inconsistent data representations, codes and formats which have to be reconciled

Comparison of OLTP and OLAP

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Table 4.1 Comparison of OLTP and OLAP Systems

Feature	*OLTP*	*OLAP*
Characteristic	operational processing	informational processing
Orientation	transaction	analysis
User	clerk, DBA, database professional	knowledge worker (e.g., manager, executive, analyst)
Function	day-to-day operations	long-term informational requirements decision support
DB design	ER-based, application-oriented	star/snowflake, subject-oriented
Data	current, guaranteed up-to-date	historic, accuracy maintained over time
Summarization	primitive, highly detailed	summarized, consolidated
View	detailed, flat relational	summarized, multidimensional
Unit of work	short, simple transaction	complex query
Access	read/write	mostly read
Focus	data in	information out
Operations	index/hash on primary key	lots of scans
Number of records accessed	tens	millions
Number of users	thousands	hundreds
DB size	GB to high-order GB	≥ TB
Priority	high performance, high availability	high flexibility, end-user autonomy
Metric	transaction throughput	query throughput, response time

Note: Table is partially based on Chaudhuri and Dayal [CD97].

Building a Data Warehouse along with OLTP Systems

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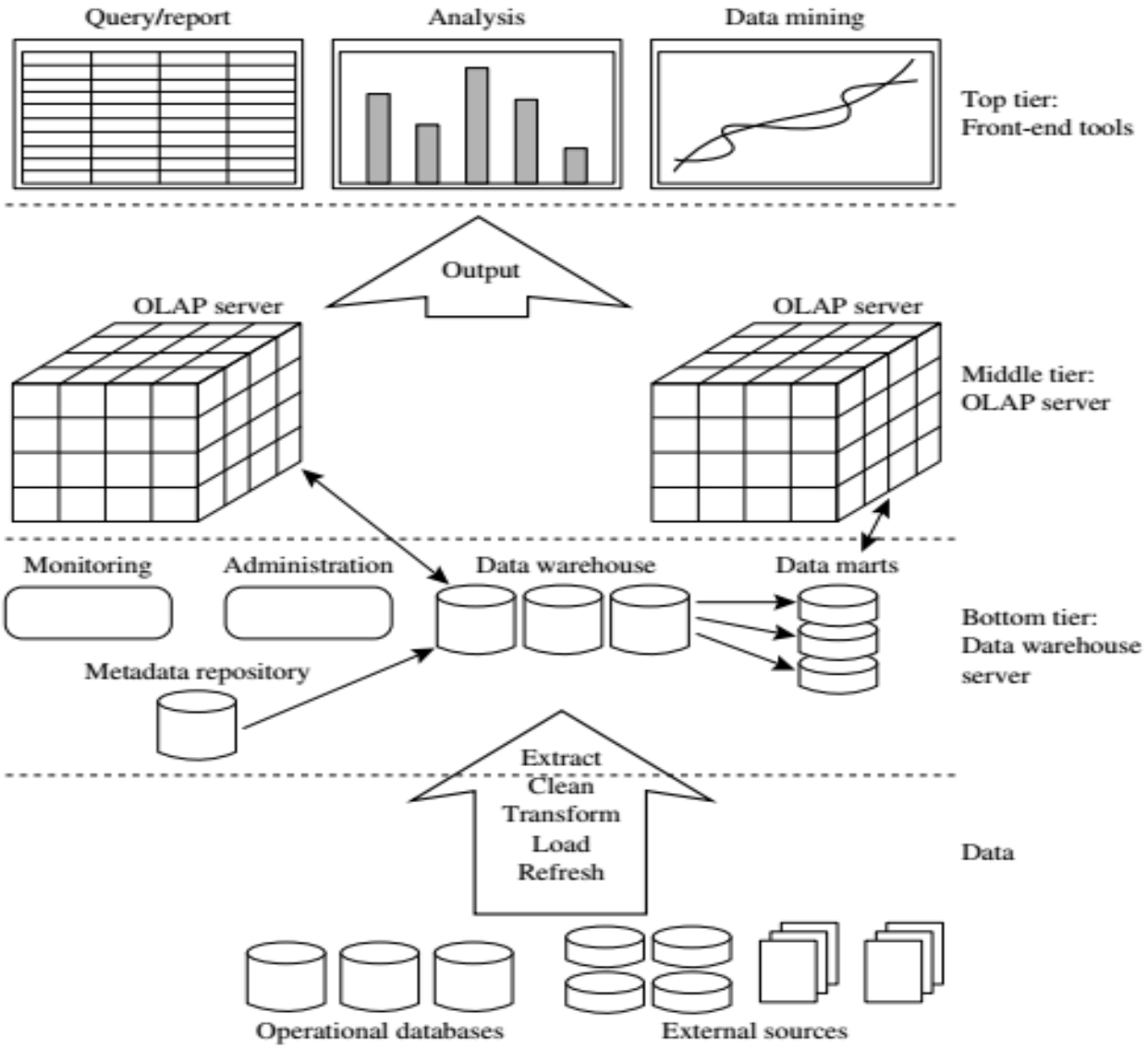
- Solution: Build a “data warehouse”
  - Copy data from various OLTP systems
  - Optimise data organisation, system tuning for OLAP
  - Transactions aren’t slowed by big analysis queries
  - Periodically refresh the data in the warehouse

- 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.

A three-tier data warehousing architecture



Data Warehouse Models

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- **Enterprise warehouse:**
  - An enterprise warehouse collects all of the information about subjects spanning the entire organisation.
  - Contains both detailed and summerised data

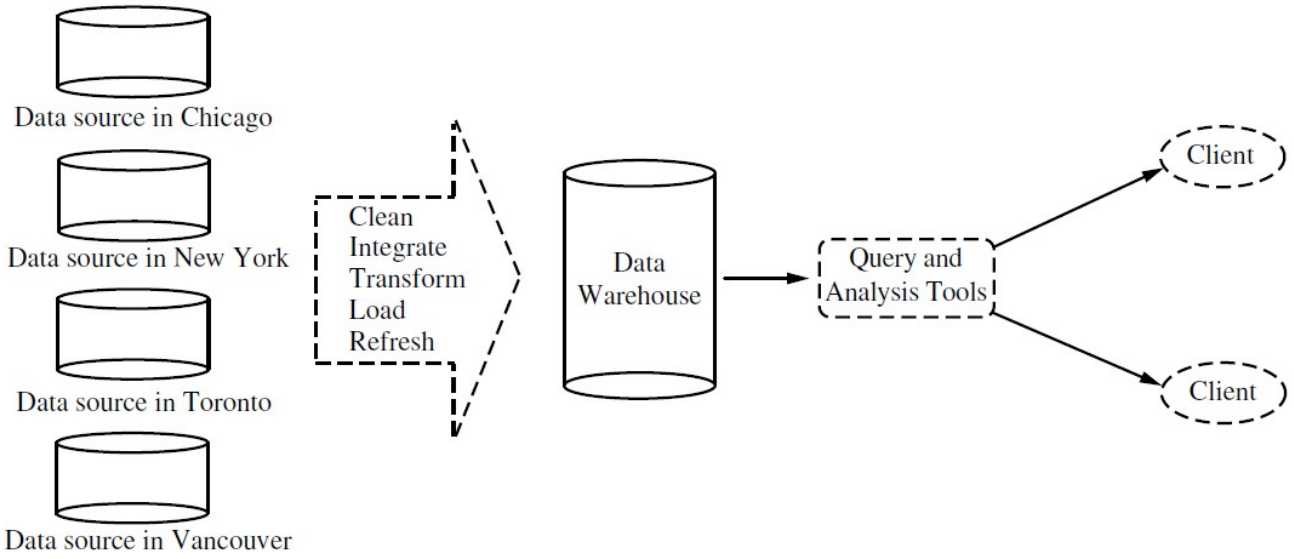
- **Data Mart**
  - A data mart contains a subset of corporate-wide data that is of value to a *specific group of users*.
  - The scope is confined to specific selected subjects, e.g. marketing data mart (customer, item, and sales)
  - Summerised (sometimes due to privacy concerns)

- **Virtual warehouse:**
  - A virtual warehouse is a set of views over operational databases.
  - For efficient query processing, only some of the possible summary views may be materialised.

Data Warehouse of AllElectronics

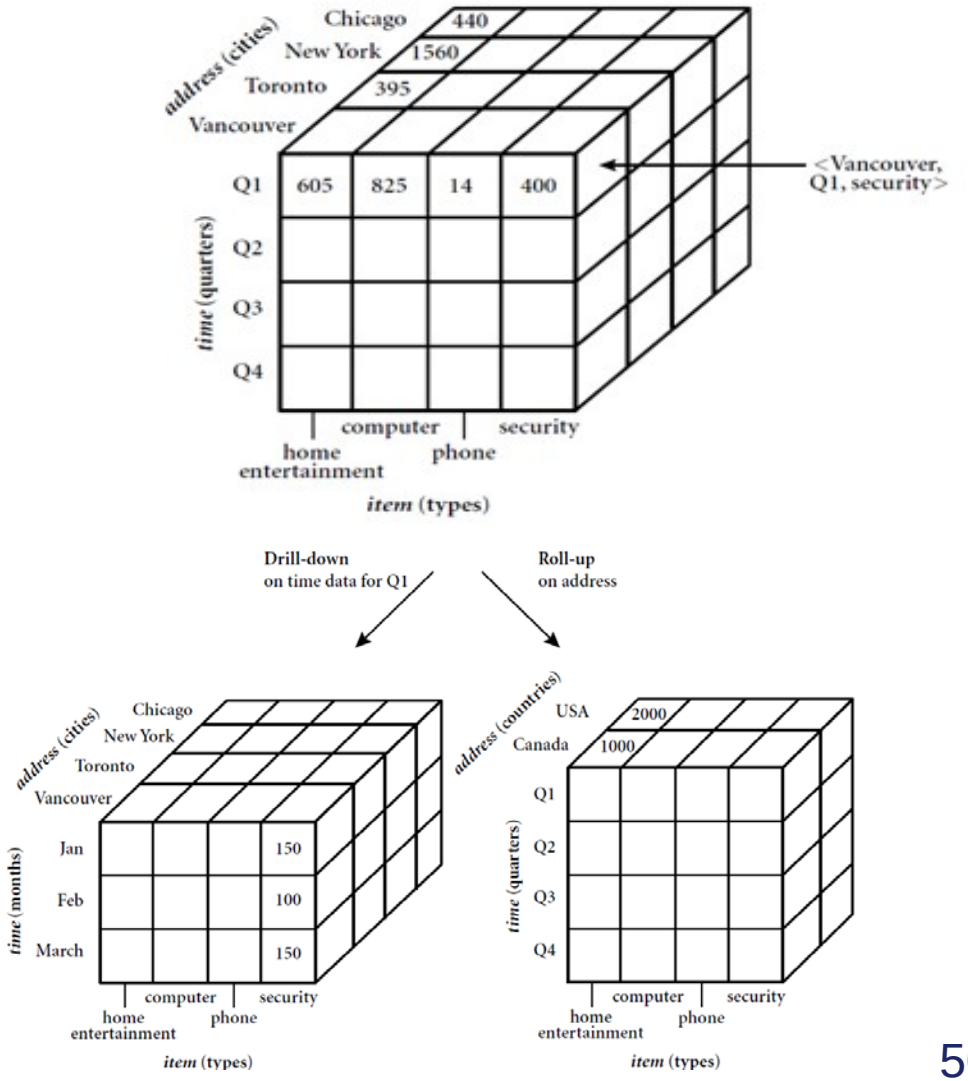
- A data warehouse is a ***repository*** of information collected from multiple sources, stored under a ***unified schema***, and that usually resides at a single site.

- The need is to provide an analysis of the company's sales per item type per branch for a specified period.



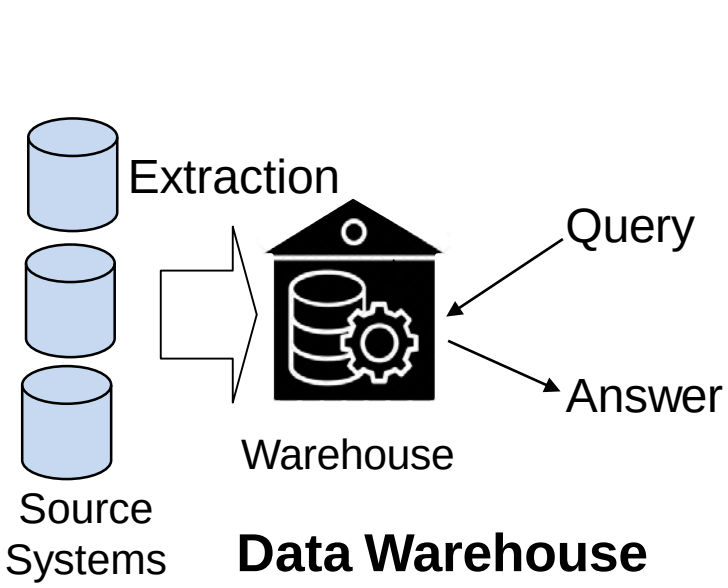
Data Warehouse

- The data warehouse may store a summary of the transactions per item type for each store or, summarised to a higher level, for each sales region.

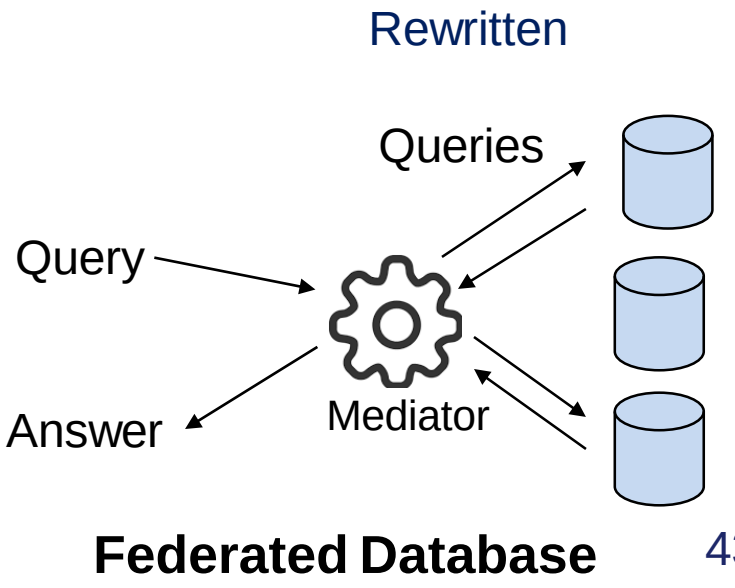


Federated Databases

- An alternative to data warehouses
- Data warehouse
  - Create a copy of all the data
  - Execute queries against the copy
- Federated database
  - Pull data from source systems as needed to answer queries
- “lazy” vs. “eager” data integration



Data Warehouse



Federated Database

Warehouse vs. Federation

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- Advantages of federated databases:
  - No redundant copying of data
  - Queries see “real-time” view of evolving data
  - More flexible security policy
- Disadvantages of federated databases:
  - Analysis queries place extra load on transactional systems
  - Query optimisation is hard to do well
  - Historical data may not be available
  - Complex “wrappers” needed to mediate between analysis server and source systems
- Data warehouses are much more common in practice
  - Better performance
  - Lower complexity
  - Slightly out-of-date data is acceptable

3 kinds of data warehouse applications

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- **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 visualisation tools.

References

- Some slides are adapted from
  - http://web.stanford.edu/class/cs345/
  - https://hanj.cs.illinois.edu/bk3/bk3_slidesindex.htm

- Readings
  - Chapter 1.1, 1.2 and 4.1 of Han et al.'s book
  - Evolution of Sciences (page 4 to 8).
  - Relational DB v.s. Transational DB

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