Data management and visualization

Introduction
Why data management?

• Nowadays, the amount of data available grows exponentially, and at the same time their heterogeneity increases.

• To extract useful insights from such data collections, there is the need of tools to collect, prepare and store data in a suitable repository, to subsequently proceed to their analysis through Business Intelligence and Data Analytics methodologies.
Type of Information processing

• Transaction processing
• Analytical processing
Transaction processing

- On Line Transaction Processing (OLTP)
  - Traditional DBMS usage
- Characterized by
  - snapshot of current data values
  - detailed data, relational representation
  - structured, repetitive operations
  - read/write access to few records
  - short transactions
  - isolation, reliability, and integrity are critical (ACID)
  - database size \( \approx 100\text{MB-GB} \)
Analytical processing

• On Line Analytical Processing (OLAP)
  – Decision support applications

• Characterized by
  – “historical” data
  – consolidated, integrated data
  – ad hoc applications
  – read access to millions of records
  – complex queries
  – consistency before and after periodical loads
  – database size \(\approx 100\text{GB-TB}\)
Data warehouse
Introduction
Decision support systems

• Huge operational databases are available in most companies
  ⇒ these databases may provide a large wealth of useful information

• Decision support systems provide means for
  ⇒ in depth analysis of a company’s business
  ⇒ faster and better decisions
Strategic decision support

- Demand evolution analysis and forecast
- Critical business areas identification
- Budgeting and management transparency
  - reporting, practices against frauds and money laundering
- Identification and implementation of winning strategies
  - cost reduction and profit increase
Business Intelligence

• BI provides support to strategic decision support in companies

• Objective: transforming company data into actionable information
  – at different detail levels
  – for analysis applications

• Users may have heterogeneous needs

• BI requires an appropriate hardware and software infrastructure
Applications

• Manufacturing companies: order management, client support
• Distribution: user profile, stock management
• Financial services: buyer behavior (credit cards)
• Insurance: claim analysis, fraud detection
• Telecommunication: call analysis, churning, fraud detection
• Public service: usage analysis
• Health: service analysis and evaluation
Business intelligence at a glance

Data sources

(External) data sources

Data storage

Data warehouse

Data marts

Data analysis

OLAP Analysis

Data mining

Result

Data visualization

Decision

Knowledge management
Data warehouse

• Database devoted to decision support, which is kept *separate* from company operational databases

• Data which is
  – devoted to a specific subject
  – Integrated and consistent
  – time dependent, non volatile

  used for decision support in a company

  *W. H. Inmon, Building the data warehouse, 1992*
Why separate data?

- **Performance**
  - complex queries reduce performance of operational transaction management
  - different access methods at the physical level

- **Data management**
  - missing information (e.g., history)
  - data consolidation
  - data quality (inconsistency problems)
Data model
Multidimensional representation

- Data are represented as an (hyper)cube with three or more dimensions
- Measures on which analysis is performed: cells at dimension intersection
- Data warehouse for tracking sales in a supermarket chain:
  - dimensions: product, shop, time
  - measures: sold quantity, sold amount, ...
Multidimensional representation

From Golfarelli, Rizzi, "Data warehouse, teoria e pratica della progettazione", McGraw Hill 2006
Relational representation: star model

- Numerical measures stored in the *fact table*
  - attribute domain is numeric
- *Dimensions* describe the context of each measure in the fact table
  - characterized by many descriptive attributes
Example

Data warehouse for tracking sales in a supermarket chain

Shop  \---\ Sale  \---\ Product
      |        |          
      v        v          
      Date
Data warehouse size

- Time dimension: 2 years x 365 days
- Shop dimension: 300 shops
- Product dimension: 30,000 products, of which 3,000 sold every day in every shop
- Number of rows in the fact table:
  \[ 730 \times 300 \times 3000 = 657 \text{ millions} \]

\[ \text{Size of the fact table} \approx 21\text{GB} \]
NOSQL data representation

- A database is a set of collections
- Each collection contains a set of documents
- Each document is described by a list of key-value fields and each field can hold any data type
- Documents from the same collection can be heterogeneous
- Since the data representation is schema-less it not required to define the schema of the documents a-priori and objects of the same collections can be characterized by different fields

<table>
<thead>
<tr>
<th>Relational database</th>
<th>NOSQL database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table</td>
<td>Collection</td>
</tr>
<tr>
<td>Row</td>
<td>Document</td>
</tr>
<tr>
<td>Column</td>
<td>Field</td>
</tr>
</tbody>
</table>
Example of Document Data

- Records are stored into Documents
  - field-value pairs
  - similar to JSON objects
  - may be nested

```json
{
  _id: <ObjectId>,
  username: "123xyz",
  contact: {
    phone: "123-456-7890",
    email: "xyz@example.com"
  },
  access: {
    level: 5,
    group: "dev"
  }
}
```
Example of Document Data

- Relations among documents are inefficient, and leads to de-normalization
  - Object(ID) reference, with no native join
Types of NoSQL databases

Key-Value

Column-Family

Graph

Document
Data analysis
Data analysis tools

• OLAP analysis: complex aggregate function computation
  – support to different types of aggregate functions (e.g., moving average, top ten)
• Data analysis by means of data mining techniques
  – various analysis types
  – significant algorithmic contribution
Key Performance Indicator (KPI)

- KPIs are measurable values that demonstrates how effectively a company is achieving key business objectives.
- They are used to periodically assess at multiple levels the performance of organizations and their success at reaching targets
  - high-level KPIs may focus on the overall performance of the business
  - low-level KPIs may focus on processes in specifics areas/departments (e.g, sales, marketing, HR).
- One of the most important aspects of KPIs is that they are a form of communication.
- Example KPIs: Days to deliver an order, number of new customers acquired, employee satisfaction, …
Data analysis tools

• Presentation
  – separate activity: data returned by a query may be rendered by means of different presentation tools

• Motivation search
  – Data exploration by means of progressive, “incremental” refinements (e.g., drill down)
Data visualization
Informative Dashboard

• A dashboard is a user interface that organizes and presents information in a way that is easy to read.
• It is a visual display of the most important information needed to achieve one or more objectives
• Dashboard are small and concise to allow monitoring relevant phenomena at a glance
• Visual Business Intelligence for enlightening analysis and communication
Why Visualization

• Information retrieval
  – After 3 days, correct recall with text alone ~10%, with text + visuals ~65%

• Information density
  – In principle any single pixel on a screen (1024x768) could encode a datum ~ 1 M pixels ~ 1 M characters ~ 250 pages

• Information context
  – Visualization compares multiple values and puts the information into context. A single number means nothing.
Visualization Pipeline

Knowledge → Decisions

- Information Understanding
  Visual Patterns, Trends, Exceptions

- Quantitative Reasoning
  Quantitative Relationship & Comparison

- Visual Perception
  Visual Properties & Objects

Data → Representation/Encoding
Data warehouse architectures
Data warehouse architectures

• Separation between transactional computing and data analysis
  – avoid one level architectures

• Architectures characterized by two or more levels
  – separate to a different extent data incoming into the data warehouse from analyzed data
  – more scalable
Data warehouse: architecture

- Metadata
- (External) data sources
- DW management
- ETL tools
- Data warehouse
- Data marts
- OLAP servers
- Analysis tools
- Data Analysis
**Data warehouse and data mart**

*Company data warehouse:* it contains *all* the information on the company business

- extensive functional modelling process
- design and implementation require a long time

*Data mart:* departimental information subset focused on a given subject

- two architectures
  - dependent, fed by the company data warehouse
  - independent, fed directly by the sources
- faster implementation
- requires careful design, to avoid subsequent data mart integration problems
Servers for Data Warehouses

- ROLAP (Relational OLAP) server
  - extended relational DBMS
    - compact representation for sparse data
  - SQL extensions for aggregate computation
  - specialized access methods which implement efficient OLAP data access
- MOLAP (Multidimensional OLAP) server
  - data represented in proprietary (multidimensional) matrix format
    - sparse data require compression
  - special OLAP primitives
- HOLAP (Hybrid OLAP) server
- NOSQL architectures
Extraction, Transformation and Loading (ETL)

- Prepares data to be loaded into the data warehouse
  - data extraction from (OLTP and external) sources
  - data cleaning
  - data transformation
  - data loading

- Performed
  - when the DW is first loaded
  - during periodical DW refresh
ETL process

• **Data extraction**: data acquisition from sources
• **Data cleaning**: techniques for improving data quality (correctness and consistency)
• **Data transformation**: data conversion from operational format to data warehouse format
• **Data loading**: update propagation to the data warehouse
Metadata

metadata = data about data

• Different types of metadata:
  – for data transformation and loading: describe data sources and needed transformation operations
    • Useful using a common notation to represent data sources and data after transformation
    • CWMI (Common Warehouse Metadata Initiative): standard proposed by OMG to exchange data between DW tools and repository of metadata in heterogenous and distributed environments
  – for data management: describe the structure of the data in the data warehouse
    • also for materialized view
  – for query management: data on query structure and to monitor query execution
    - SQL code for the query
    - execution plan
    - memory and CPU usage
Two level architecture

Data warehouse

Source level

Data sources (operational and external)

ETL tools

Metadata

DW management

OLAP servers

Analysis tools

Data warehouse level

Data warehouse

Data marts

Data analysis

From Golfarelli, Rizzi, "Data warehouse, teoria e pratica della progettazione", McGraw Hill 2006
Two level architecture features

• Decoupling between source and DW data
  – management of external (not OLTP) data sources (e.g., text files)
  – data modelling suited for OLAP analysis
  – physical design tailored for OLAP load

• Easy management of different temporal granularity of operational and analytical data

• Partitioning between transactional and analytical load

• “On the fly” data transformation and cleaning (ETL)
Three level architecture

Source level

- Data sources (operational and external)
- ETL level
- ETL tools

Staging area

- Loading

ETL level

Data warehouse level

- Data warehouse
- Data marts
- OLAP servers
- DW management
- Data analysis
- Analysis tools
- Metadata

From Golfarelli, Rizzi, "Data warehouse, teoria e pratica della progettazione", McGraw Hill 2006

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INTRODUCTION - 48
Three level architecture features

• *Staging area*: buffer area allowing the separation between ET management and data warehouse loading
  – complex transformation and cleaning operations are eased
  – provides an integrated model of business data, still close to OLTP representation
  – sometime denoted as Operational Data Store (ODS)

• Introduces further redundancy
  – more disk space is required for data storage