

# Machine Learning and Data Mining

Academic Year 2023 – 2024  
Alma Mater Studiorum · University of Bologna

# Contents

<b>1</b>	<b>Introduction</b>	<b>2</b>
1.1	Data . . . . .	2
1.1.1	Data sources . . . . .	2
1.1.2	Software . . . . .	2
1.1.3	Insight . . . . .	2
<b>2</b>	<b>Business Intelligence</b>	<b>4</b>
2.1	Online Analytical Processing (Online Analytical Processing (OLAP)) . . . .	4
2.1.1	Operators . . . . .	4
2.2	Extraction, Transformation, Loading (Extraction, Transformation, Loading (ETL)) . . . . .	5
2.2.1	Extraction . . . . .	5
2.2.2	Cleaning . . . . .	5
2.2.3	Transformation . . . . .	6
2.2.4	Loading . . . . .	6
2.3	Data warehouse architectures . . . . .	6
2.3.1	Single-layer architecture . . . . .	7
2.3.2	Two-layer architecture . . . . .	7
2.3.3	Three-layer architecture . . . . .	7
2.4	Conceptual modeling . . . . .	8
2.4.1	Aggregation operators . . . . .	9
2.4.2	Logical design . . . . .	9

# Acronyms

**BI** Business Intelligence

**DFM** Dimensional Fact Model

**DM** Data Mart

**DSS** Decision Support System

**DWH** Data Warehouse

**EIS** Executive Information System

**ERP** Enterprise Resource Planning

**ETL** Extraction, Transformation, Loading

**MIS** Management Information System

**OLAP** Online Analytical Processing

**OLTP** Online Transaction Processing

# 1 Introduction

## 1.1 Data

**Data** Collection of raw values.

Data

**Information** Organized data (e.g. relationships, context, ...).

Information

**Knowledge** Understanding information.

Knowledge

### 1.1.1 Data sources

**Transaction** Business event that generates or modifies data in an information system (e.g. database).

Transaction

**Signal** Measure produced by a sensor.

Signal

### External subjects

### 1.1.2 Software

**Online Transaction Processing (OLTP)** Class of programs to support transaction oriented applications and data storage. Suitable for real-time applications.

Online Transaction Processing

**Enterprise Resource Planning (ERP)** Integrated system to manage all the processes of a business. Uses a shared database for all applications. Suitable for real-time applications.

Enterprise Resource Planning

### 1.1.3 Insight

Decision can be classified as:

**Structured** Established and well understood situations. What is needed is known.

Structured decision

**Unstructured** Unplanned and unclear situations. What is needed for the decision is unknown.

Unstructured decision

Different levels of insight can be extracted by:

**Management Information System (MIS)** Standardized reporting system built on existing OLTP. Used for structured decisions.

Management Information System

**Decision Support System (DSS)** Analytical system to provide support for unstructured decisions.

Decision Support System

**Executive Information System (EIS)** Formulate high level decisions that impact the organization.

Executive Information System

**Online Analytical Processing (OLAP)** Grouped analysis of multidimensional data. Involves large amount of data.

Online Analytical Processing

**Business Intelligence (BI)** Applications, infrastructure, tools and best practices to analyze information. Business Intelligence

**Big data** Large and/or complex and/or fast changing collection of data that traditional DBMSs are unable to process. Big data

**Structured** e.g. relational tables.

**Unstructured** e.g. videos.

**Semi-structured** e.g. JSON.

**Anaylitics** Structured decision driven by data. Anaylitics

**Data mining** Discovery process for unstructured decisions. Data mining

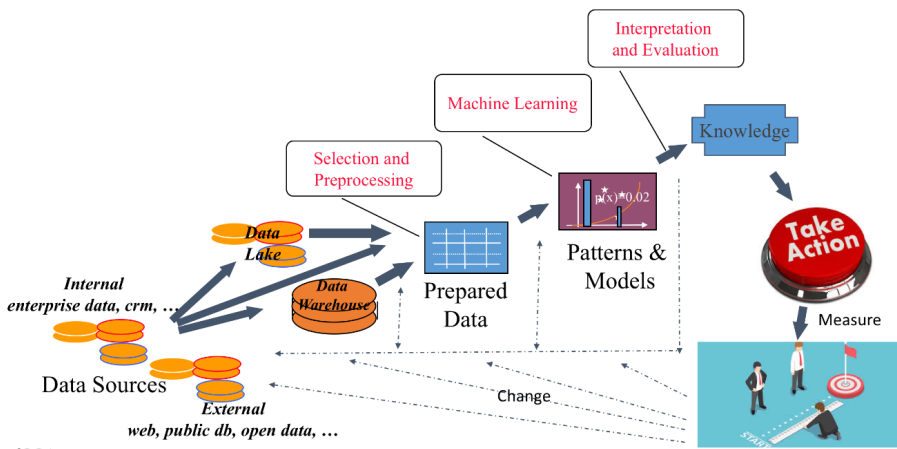


Figure 1.1: Data mining process

**Machine learning** Learning models and algorithms that allow to extract patterns from data. Machine learning

## 2 Business Intelligence

**Business Intelligence** Transform raw data into information. Deliver the right information to the right people at the right time through the right channel. Business Intelligence

**Data Warehouse (DWH)** Optimized repository that stores information for decision making processes. DWHs are a specific type of DSS. Data Warehouse

Features:

- Subject-oriented: focused on enterprise specific concepts.
- Integrates data from different sources and provides an unified view.
- Non-volatile storage with change tracking.

**Data Mart (DM)** Subset of the primary DWH with information relevant to a specific business area. Data Mart

### 2.1 Online Analytical Processing (OLAP)

**OLAP analyses** Able to interactively navigate the information in a data warehouse. Allows to visualize different levels of aggregation. Online Analytical Processing (OLAP)

**OLAP session** Navigation path created by the operations that a user applied.

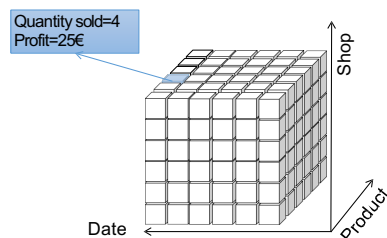
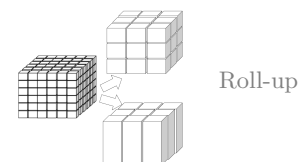


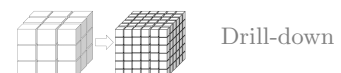
Figure 2.1: OLAP data cube

#### 2.1.1 Operators

**Roll-up** Increases the level of aggregation (i.e. GROUP BY in SQL). Some details are collapsed together.



**Drill-down** Reduces the level of aggregation. Some details are reintroduced.



The diagram illustrates the process of measuring volume by slicing. On the left is a large cube representing 1000 unit cubes (10x10x10). An arrow points to a single 10x10 slice, labeled 'slice'. Another arrow points from the slice to a 1x1 unit cube, labeled 'dice'.

The dice operator reduces the number of data being analyzed (i.e. LIMIT in SQL).

Changes the layout of the data, to analyze it from a different viewpoint.

## Drill-through

Order ID	Order Date	Ship Date	Ship Mode	Customer Name	Segment	City	State	Country
17-0129-128000	15/01/2017	17/01/2017	Same Day	Gunga Industries	Corporate	Mumbai	India-France	France
15-0124-026907	17/01/2016	17/01/2016	Second Day	Sara Garcia	Corporate	Houston	India-France	France
15-0124-026908	16/01/2016	16/01/2016	First Day	Vanessa	Corporate	London	India-France	France
15-0124-0468009	16/01/2016	16/01/2016	Standard Class	Vanessa	Corporate	Huygheboon	Germany	Germany
15-0124-0468010	16/01/2016	16/01/2016	Standard Class	Vanessa	Corporate	Huygheboon	Germany	Germany
15-0124-0468021	17/01/2016	17/01/2016	Standard Class	Vanessa	Corporate	Waller (Dach)	North-West-Germany	Germany
15-0124-0468022	17/01/2016	17/01/2016	Standard Class	Vanessa	Corporate	Waller (Dach)	North-West-Germany	Germany
15-0124-0468023	17/01/2016	17/01/2016	Standard Class	Vanessa	Corporate	Waller (Dach)	North-West-Germany	Germany

The ETL process extracts, integrates and cleans operational data that will be loaded into a data warehouse.

Extraction,  
Transformation,  
Loading (ETL)

Extracted operational data can be:

## Strucured data

Unstructured data

**Static** The entirety of the operational data are extracted to populate the data warehouse for the first time.

## Static extraction

## Incremental extraction

Operational data may contain:

## Missing data

**Wrong values** (e.g. 30th of February)

5

## Typos

Methods to clean and increase the quality of the data are:

<b>Dictionary-based techniques</b>	Lookup tables to substitute abbreviations, synonyms or typos. Applicable if the domain is known and limited.	Dictionary-based cleaning
<b>Approximate merging</b>	Merging data that do not have a common key.	Approximate merging
<b>Approximate join</b>	Use non-key attributes to join two tables (e.g. using the name and surname instead of a unique identifier).	
<b>Similarity approach</b>	Use similarity functions (e.g. edit distance) to merge multiple instances of the same information (e.g. typo in customer surname).	
<b>Ad-hoc algorithms</b>		Ad-hoc algorithms

### 2.2.3 Transformation

Data are transformed to respect the format of the data warehouse:

<b>Conversion</b>	Modifications of types and formats (e.g. date format)	Conversion
<b>Enrichment</b>	Creating new information by using existing attributes (e.g. compute profit from receipts and expenses)	Enrichment
<b>Separation and concatenation</b>	Denormalization of the data: introduces redundances (i.e. breaks normal form <sup>1</sup> ) to speed up operations.	Separation and concatenation

### 2.2.4 Loading

Adding data into a data warehouse:

<b>Refresh</b>	The entire DWH is rewritten.	Refresh loading
<b>Update</b>	Only the changes are added to the DWH. Old data are not modified.	Update loading

## 2.3 Data warehouse architectures

The architecture of a data warehouse should meet the following requirements:

<b>Separation</b>	Separate the analytical and transactional workflows.
<b>Scalability</b>	Hardware and software should be easily upgradable.
<b>Extensibility</b>	Capability to host new applications and technologies without the need to redesign the system.
<b>Security</b>	Access control.
<b>Administrability</b>	Easily manageable.

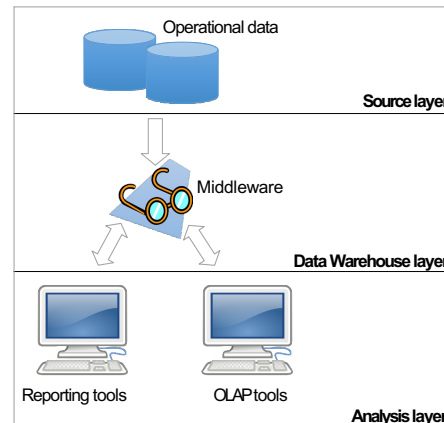
---

<sup>1</sup>[https://en.wikipedia.org/wiki/Database\\_normalization](https://en.wikipedia.org/wiki/Database_normalization)



### 2.3.1 Single-layer architecture

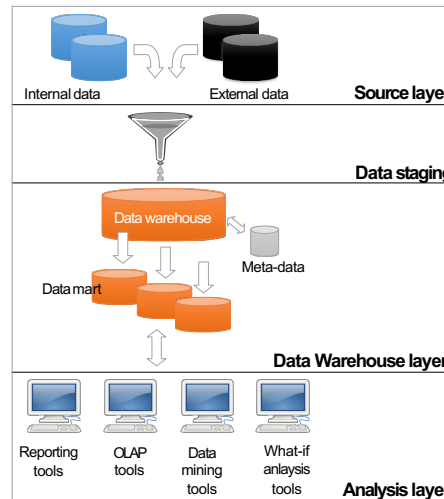
- Minimizes the amount of data stored (i.e. no redundances).
- The source layer is the only physical layer (i.e. no separation).
- A middleware provides the DWH features.



Single-layer architecture

### 2.3.2 Two-layer architecture

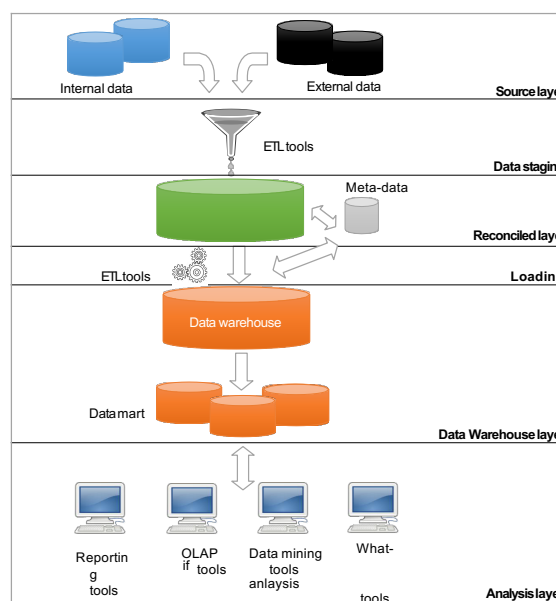
- Source data (source layer) are physically separated from the DWH (data warehouse layer).
- A staging layer applies ETL procedures before populating the DWH.
- The DWH is a centralized repository from which data marts can be created. Metadata repositories store information on sources, staging and data marts schematics.



Two-layer architecture

### 2.3.3 Three-layer architecture

- A reconciled layer enhances the cleaned data coming from the staging step by adding enterprise-level details (i.e. adds more redundancy before populating the DWH).



Three-layer architecture

## 2.4 Conceptual modeling

**Dimensional Fact Model (DFM)** Conceptual model to support the design of data marts.

The main concepts are:

**Fact** Concept relevant to decision-making processes (e.g. sales).

**Measure** Numerical property to describe a fact (e.g. profit).

**Dimension** Property of a fact with a finite domain (e.g. date).

**Dimensional attribute** Property of a dimension (e.g. month).

**Hierarchy** A tree where the root is a dimension and nodes are dimensional attributes (e.g. date  $\rightarrow$  month).

**Primary event** Occurrence of a fact. It is described by a tuple with a value for each dimension and each measure.

**Secondary event** Aggregation of primary events. Measures of primary events are aggregated if they have the same (preselected) dimensional attributes.

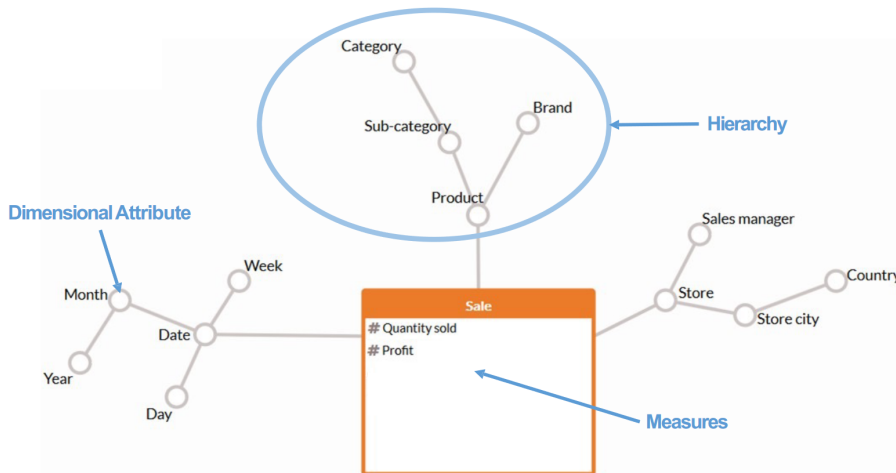


Figure 2.2: Example of DFM

Primary events				
Date	Store	Product	Qty sold	Profit
01/03/15	Central store	Milk	20	60
01/03/15	Central store	Coke	25	50
02/03/15	Central store	Bread	40	70
10/03/15	Central store	Wine	15	150

Secondary event				
Month	Store	Category	Qty sold	Profit
March 2015	Central store	Food and Beverages	100	330

SUM      SUM

Figure 2.3: Example of primary and secondary events

## 2.4.1 Aggregation operators

Measures can be classified as:

- Flow measures** Evaluated cumulatively with respect to a time interval (e.g. quantity sold). Flow measures
- Level measures** Evaluated at a particular time (e.g. number of products in inventory). Level measures
- Unit measures** Evaluated at a particular time but expressed in relative terms (e.g. unit price). Unit measures

Aggregation operators can be classified as:

- Distributive** Able to calculate aggregates from partial aggregates (e.g. SUM, MIN, MAX). Distributive operators
- Algebraic** Requires a finite number of support measures to compute the result (e.g. AVG). Algebraic operators
- Holistic** Requires an infinite number of support measures to compute the result (e.g. RANK). Holistic operators
- Additivity** A measure is additive along a dimension if an aggregation operator can be applied. Additive measure

	Temporal hierarchies	Non-temporal hierarchies
Flow measures	SUM, AVG, MIN, MAX	SUM, AVG, MIN, MAX
Level measures	AVG, MIN, MAX	SUM, AVG, MIN, MAX
Unit measures	AVG, MIN, MAX	AVG, MIN, MAX

Table 2.1: Allowed operators for each measure type

## 2.4.2 Logical design

Defining the data structures (e.g. tables and relationships) according to a conceptual model. There are mainly two strategies:

- Star schema** A fact table that contains all the measures and linked to dimensional tables. Star schema

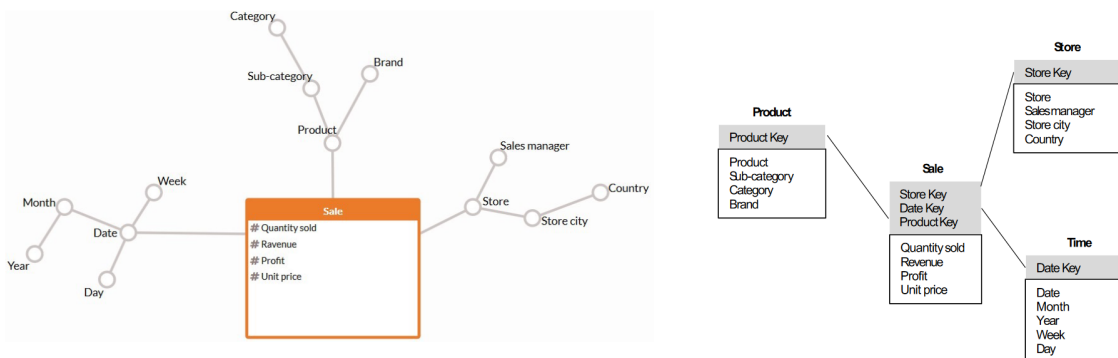


Figure 2.4: Example of star schema

- Snowflake schema** A star schema variant with partially normalized dimension tables. Snowflake schema

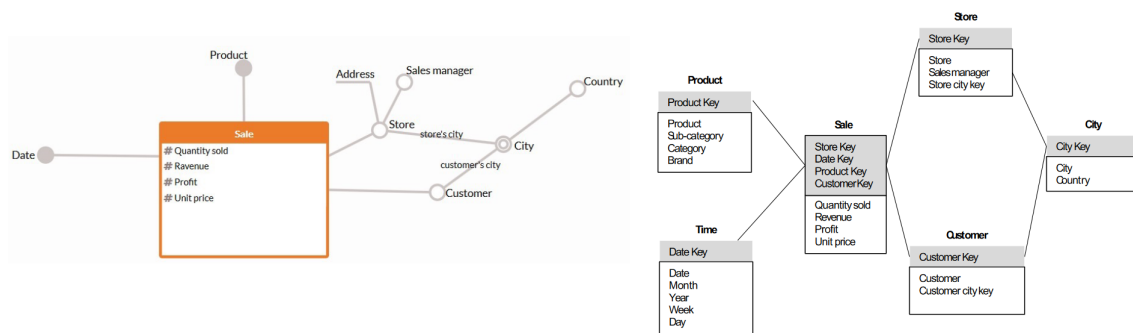


Figure 2.5: Example of snowflake schema