

Data Mining



Data Mining: An Introduction

Outline

- **Introduction: Data Flood**
- Data Mining Application Examples
- Data Mining & Knowledge Discovery
- Data Mining Techniques

Big Data

- Lots and lots of data:
 - Bank, telecom, business transactions (online and offline), ...
 - Scientific data: astronomy, climate, biology, medicine, chemistry, etc
 - Web, text, and e-commerce
 - Etc.



Big Data

- The characteristics of Big Data:
 - Volume
 - Variety
 - Velocity
 - Veracity

Zeta bytes = 10^{21} bytes

Exabytes = Quintillion = 10^{18} bytes

Petabytes = 10^{15} bytes

Tera = 10^{12} bytes

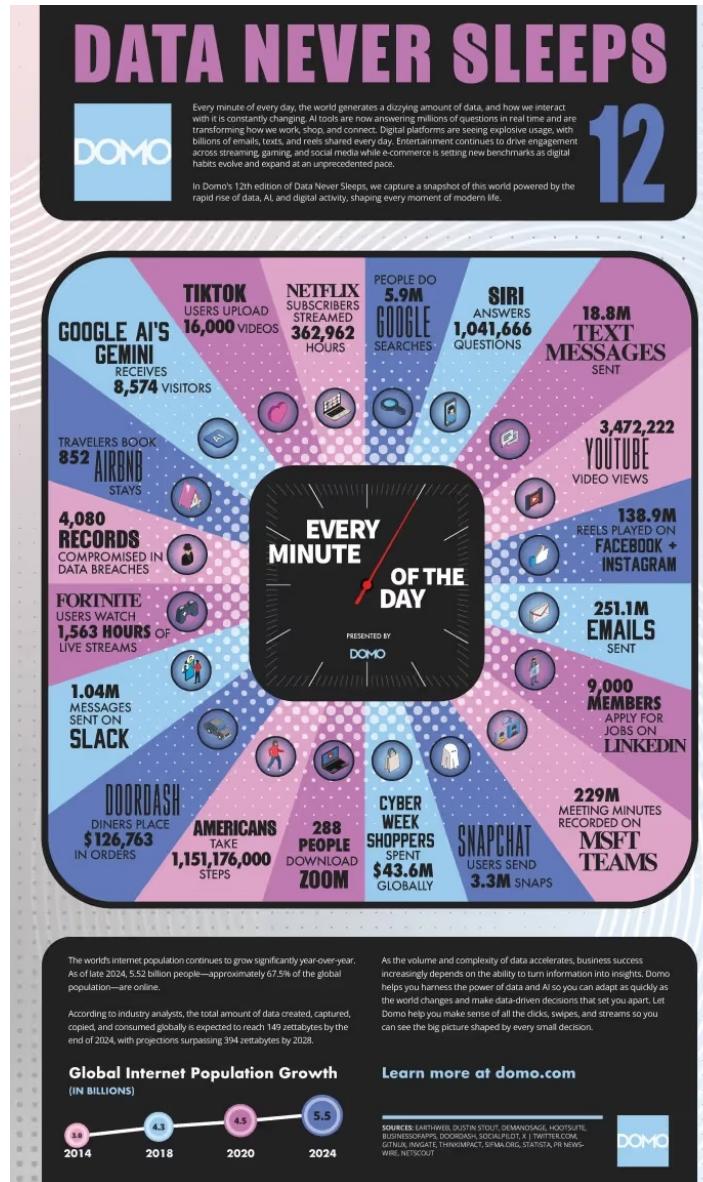
Giga bytes = 10^9 bytes

Mega bytes = 10^6 bytes



Big Data

2024 Data



Market Growth

- The global **big data analytics market** was valued at **USD 307.52 billion in 2023** and is projected to grow from **USD 348.21 billion in 2024** to **USD 961.89 billion by 2032**, showing strong growth for the **forecast period**.

Large Data Sets

- Society For Science
 - <https://www.societyforscience.org/research-at-home/large-data-sets/>

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SCIENCE COMPETITIONS JOURNALISM OUTREACH & EQUITY GET INVOLVED

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Research at Home: Large Data Sets

Mountains of data are at your fingertips and can be analyzed in new ways for your at-home research project

Locate a data set that interests you, see how others students have used large data sets in their research, and learn about current scientific studies fueled by big data.



Sources of Large Data Sets

US Government
Here you will find data, tools, and resources to conduct research, develop web and mobile applications, design data visualizations, and more.

[US GOVERNMENT OPEN DATA](#)

US Census Bureau
The vision for data.census.gov is to make data available from one centralized place so that data users spend less time searching for data and content, and more time using it.

[CENTRAL DATA REPOSITORY](#)

Amazon Web Services
This registry exists to help people discover and share datasets that are available via AWS resources.

[REGISTRY OF OPEN DATA ON AWS](#)

U.S. Geological Survey
The USGS Science Data Catalog provides seamless access to USGS research and monitoring data from across the nation. Users have the ability to search, browse, or use a map-based interface to discover data.

[USGS SCIENCE DATA CATALOG](#)

National Oceanic and Atmosphere Administration (NOAA)
NCEI is responsible for preserving, monitoring, assessing, and providing public access to the Nation's treasure of climate and historical weather data and information.

[NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION \(NCEI\)](#)

NASA Infrared Processing and Analysis Center
IRSA's holdings consist of data products from NASA's infrared and submillimeter projects and missions, as well as contributed data sets. These holdings include all-sky surveys in 20 bands, 88 billion rows of catalog data, 100 million images, and over 100,000 spectra.

[INFRARED ASTRONOMY DATA - IPAC](#)

National Aeronautics and Space Administration (NASA)
DATA.NASA.GOV is NASA's clearinghouse site for open-data provided to the public.

[DATA.NASA.GOV](#)

Centers for Disease Control and Prevention
CDC is one of the major operating components of the Department of Health and Human Services.

[CDC DATA CATALOG](#)

Large Databases

- Astronomy
 - Sloan Digital Sky Survey (SDSS) (<https://www.sdss5.org>)
- Biology/Medicine
 - National Center for Biotechnology Information (NCBI)
(<https://www.ncbi.nlm.nih.gov/>)
 - PubMed has over 33 million records (2021)
(<https://www.ncbi.nlm.nih.gov/pubmed/>)
- Earth / Climate / Satellite Big Data
 - Data discovery portal: <https://www.earthdata.nasa.gov/data>
 - Earthdata Search tool: <https://search.earthdata.nasa.gov/>
- NOAA Climate data
 - <https://www.ncei.noaa.gov/access/search/index>
 - <https://www.ncei.noaa.gov/cdo-web/>

Large Databases

- Finance / Business / Markets
 - SEC EDGAR filings (text mining +financial analytics)
<https://www.sec.gov/search-filings/edgar-application-programming-interfaces>
 - World Bank Open Data <https://data.worldbank.org/>
 - IMF Data <https://www.imf.org/en/data>
- Transportation / Mobility Datasets
 - NYC Taxi Trip Record Data
<https://www.nyc.gov/site/tlc/about/tlc-trip-record-data.page>
 - OpenStreetMap (global geospatial dataset)
<https://planet.openstreetmap.org/>

Data Sets For Data Mining Research

- OpenML
 - <https://www.openml.org/>
 - Papers with code: <https://paperswithcode.com/datasets>
- UCI Machine Learning Repository
 - <https://archive.ics.uci.edu/ml/index.php>
- Kaggle Data Sets: <https://www.kaggle.com/datasets>
- Recommender Systems / Personalization
 - MovieLens: <https://grouplens.org/datasets/movielens/>
 - Amazon Reviews / Product Data
https://cseweb.ucsd.edu/~jmcauley/datasets/amazon_v2/

Data Sets For Data Mining Research

- Computer Vision / Multimedia Mining
 - COCO dataset <https://cocodataset.org/>
 - ImageNet <https://www.image-net.org/>
- Graph Mining / Network Science
 - SNAP (Stanford Network Analysis Project) <https://snap.stanford.edu/data/>
- Cybersecurity / Anomaly Detection
 - CIC datasets (Canadian Institute for Cybersecurity)
<https://www.unb.ca/cic/datasets/>
- Google BigQuery Public Datasets
 - <https://cloud.google.com/bigquery/public-data>

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Data Mining Applications

- Science and Engineering
 - Data from sensor networks and data from moving objects
 - Wireless sensor networks
 - fault detection, environmental monitoring, predictive maintenance, energy-efficient system optimization
 - RFID tagged moving objects
 - tracking & trajectory mining, supply chain optimization, bottleneck detection, demand forecasting, behavior pattern mining (movement/flow)

Data Mining Applications

- Science and Engineering
 - Spatial, temporal, spatiotemporal, and multimedia data
 - Images: Satellite images, medical images, images from various science fields (Astronomy(e.g., Galaxy Zoo project), chemistry, biology, physics, etc.)
 - *object detection/classification (tumors, land use, galaxies), segmentation, change detection over time, automated labeling, pattern discovery*
 - Spatial: data with geographic location info
 - hotspot detection, clustering regions, spatial correlations (nearby effects), route optimization, site selection/planning (stores, hospitals, facilities)
 - Time series data: use sequences of recorded values (e.g. physics, finance, medicine and music) for prediction
 - forecasting/prediction, anomaly detection (fraud, faults), trend/seasonality discovery, signal classification, early warning systems
 - Etc.

Data Mining Applications

- Business
 - CRM (Customer Relationship management) Tasks:
 - attrition prediction: *identify customers likely to leave, trigger retention campaigns, improve satisfaction/loyalty, reduce revenue loss*
 - targeted marketing:
 - cross-sell/up-sell: recommend additional products/services, increase basket size
 - customer acquisition: identify high-value prospects, look-alike modeling, predict conversion likelihood
 - credit-risk: predict default probability, optimize loan approval and pricing, assign credit scores, reduce losses
 - fraud detection: detect suspicious patterns/transactions in real time, reduce fraud losses, identify abnormal behavior, support investigation

Data Mining Applications

- Business (cont.)
 - Industries
 - Banking: credit scoring, Anti-Money Laundering/fraud detection, customer segmentation, risk management
 - e-commerce: recommendation systems, dynamic pricing, customer targeting, churn prediction
 - retail sales: market basket analysis, demand forecasting, inventory optimization, store/site analytics

Data Mining Applications

- Health Science
 - Predictive medicine
 - Predict outbreaks of health problems
 - early detection of epidemics, outbreak forecasting, identifying hotspots, supporting public health interventions (vaccination, isolation, resource allocation)
 - Precision medicine using genomic data
 - identify genetic risk factors, predict patient-specific disease susceptibility, select personalized treatments, reduce adverse drug reactions, improve outcomes
 - Management of healthcare and measuring the effectiveness of treatments
 - Compare and contrast symptoms, causes and treatment outcomes
 - find the most effective treatment plan for a condition, improve clinical decision support, optimize care pathways, identify best practices using real-world evidence
 - Measure effectiveness of outcome
 - evaluate which therapies work best for which patient groups, monitor side effects, support evidence-based medicine

Data Mining Applications

- Health Science (cont.)
 - Drug development and design.
 - Design/Determine chemical compounds for effective treatment
 - predict drug-target interactions, identify promising molecules, virtual screening, optimize drug properties (toxicity, efficacy), prioritize compounds for clinical trials
 - Detection of health insurance fraud and abuse
 - The Texas Medicaid Fraud and Abuse Detection System
 - detect abnormal billing patterns, identify suspicious claims/providers, reduce waste/abuse, support investigation and enforcement
 - **Example: Texas Medicaid Fraud and Abuse Detection System**
→ use large-scale claims + provider billing data to automatically flag suspicious patterns for investigation

Data Mining Applications

- Education:
 - Predict student success and attrition
- Government:
 - Video surveillance
 - Face recognition
 - Crime prediction, detection, and prevention
 - profiling tax cheaters, predict regions which have high prob for crime occurrence and can visualize crime prone area ...
- Sports:
 - Soccer, Football
 - Predict player injuries by analyzing data from workouts over a period of time (European soccer club AC Milan)
 - Predict future physical performance based on physical aptitude test data (e.g. NFL Combine)
- Web:
 - Search engines, targeted advertising, web and text mining, ...

Customer Attrition: Case Study

- Situation: Attrition rate for mobile phone customers is around 25-30% a year!
- With this in mind, what is a data mining task?
 - Assume we have customer information for the past N months.

Customer Attrition: Case Study

- Task:
 - Predict who is likely to attrite next month.
 - Estimate customer value and what is the cost-effective offer to make to this customer.

Customer Attrition Results

- Verizon Wireless built a customer data warehouse
- Identified potential attritors
- Developed multiple regional models
- Targeted customers with high inclination to accept the offer
- Reduced attrition rate from over 2%/month to under 1.5%/month (huge impact, with >30 M subscribers)

Assessing Credit Risk: Case Study

- Situation: Person applies for a loan
- Task: Should a bank approve the loan?
- Note: People who have the best credit often don't need the loans, and people with worst credit are not likely to repay. Bank's best customers are in the middle.

Credit Risk - Results

- Banks develop credit models using variety of machine learning methods.
- Mortgage and credit card proliferation are the results of being able to successfully predict if a person is likely to default on a loan
- Widely deployed in many countries

e-Commerce

- A person buys a book (or a product) from a vendor at Amazon

What is the data mining task from the Amazon vendor's stand?

Successful e-commerce – Case Study

- Task: Recommend other books (products) this person is likely to buy
- Amazon does clustering based on books bought:
 - customers who bought “**Advances in Knowledge Discovery and Data Mining**”, also bought “**Data Mining: Practical Machine Learning Tools and Techniques with Java Implementations**”
- Recommendation program is quite successful
 - Short video recommendation – TikTok, Youtube
 - Movie recommendation

Other Examples

- Fraud Detection
 - Credit card fraud detection
 - Detection of money laundering
 - US Treasury
 - Securities fraud
 - NASDAQ KDD system, NASD Regulation Advanced-Detection System (ADS)
 - Healthcare fraud
 - Phone fraud
 - AT&T, Bell Atlantic, British Telecom/MCI

Genomic Microarrays – Case Study

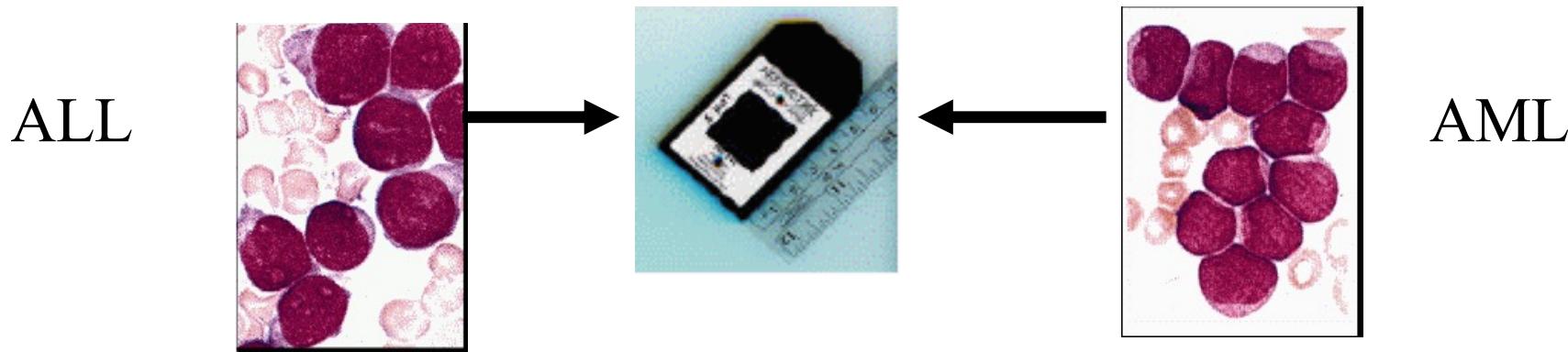
DNA microarray data is used by the scientists to measure the expression levels of large numbers of genes simultaneously or to find the genetic constitution of multiple regions of a genome.

Given DNA microarray data for a number of samples (patients), can we

- Accurately diagnose the disease?
- Predict outcome for given treatment?
- Recommend best treatment?

Example: ALL/AML data

- 38 training cases, 34 test, ~ 7,000 genes
- 2 Classes: Acute Lymphoblastic Leukemia (ALL) vs Acute Myeloid Leukemia (AML)
- Use train data to build diagnostic model



Results on test data:
33/34 correct, 1 error may be mislabeled

Data Mining and Privacy

- Privacy considerations important if personal data is involved
 - The Facebook–Cambridge Analytica data breach was a data leak in early 2018
 - The data sharing agreement between DeepMind health and the Royal Free NHS Foundation Trust (2016)
 - Google’s “Project Nightingale” (2019)
 - Ascension
 - HIPPA rule

Data Mining and Privacy

- In 2006, NSA (National Security Agency) was reported to be mining years of call info, to identify terrorism networks
- Social network analysis has a potential to find networks
- Invasion of privacy – do you mind if your call information is in a gov database?
- What if NSA program finds one real suspect for 1,000 false leads ? 1,000,000 false leads?

Class Discussion

- What data are you interested in mining?
- What applications are you interested in developing data mining tasks for?

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- Data Mining Tasks

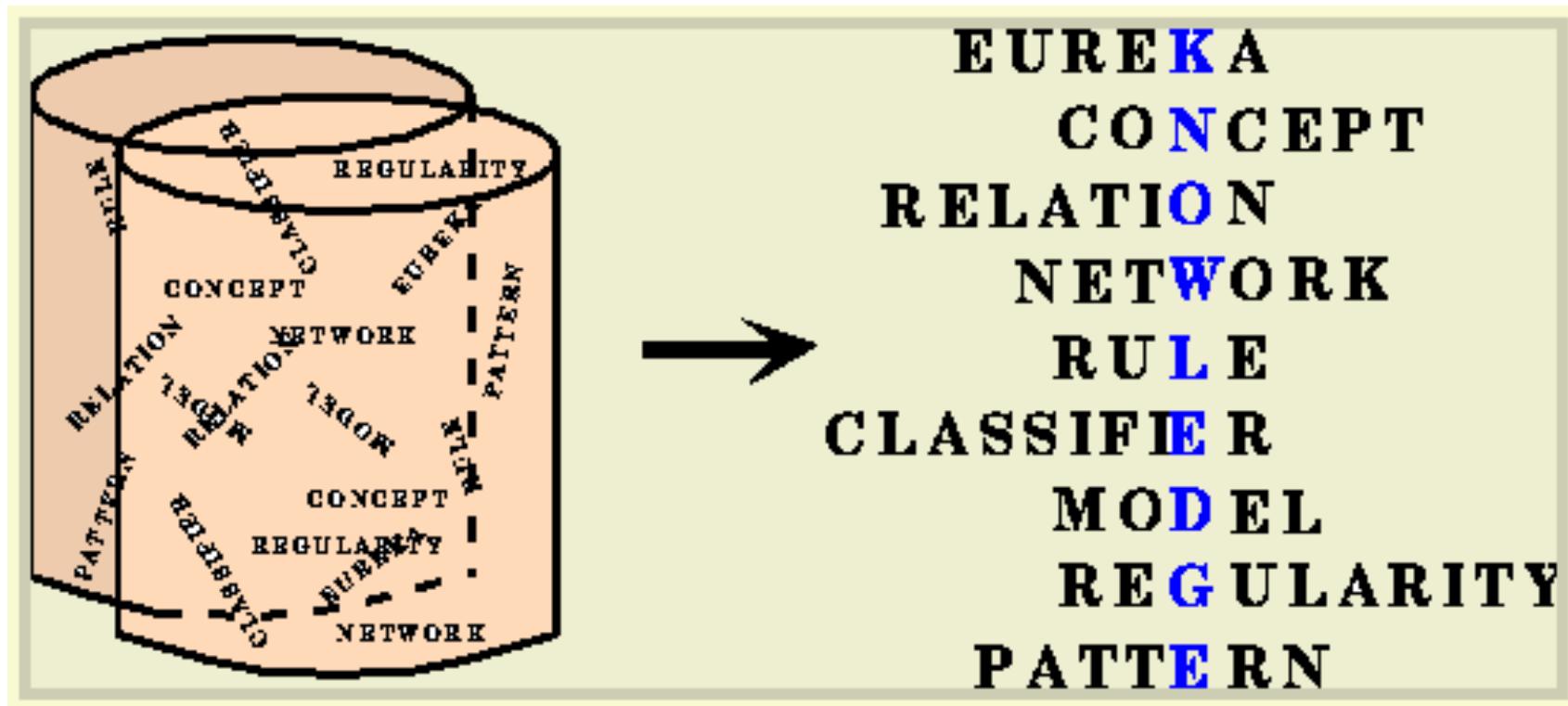
Knowledge Discovery

Knowledge Discovery in Data is the
non-trivial process of identifying

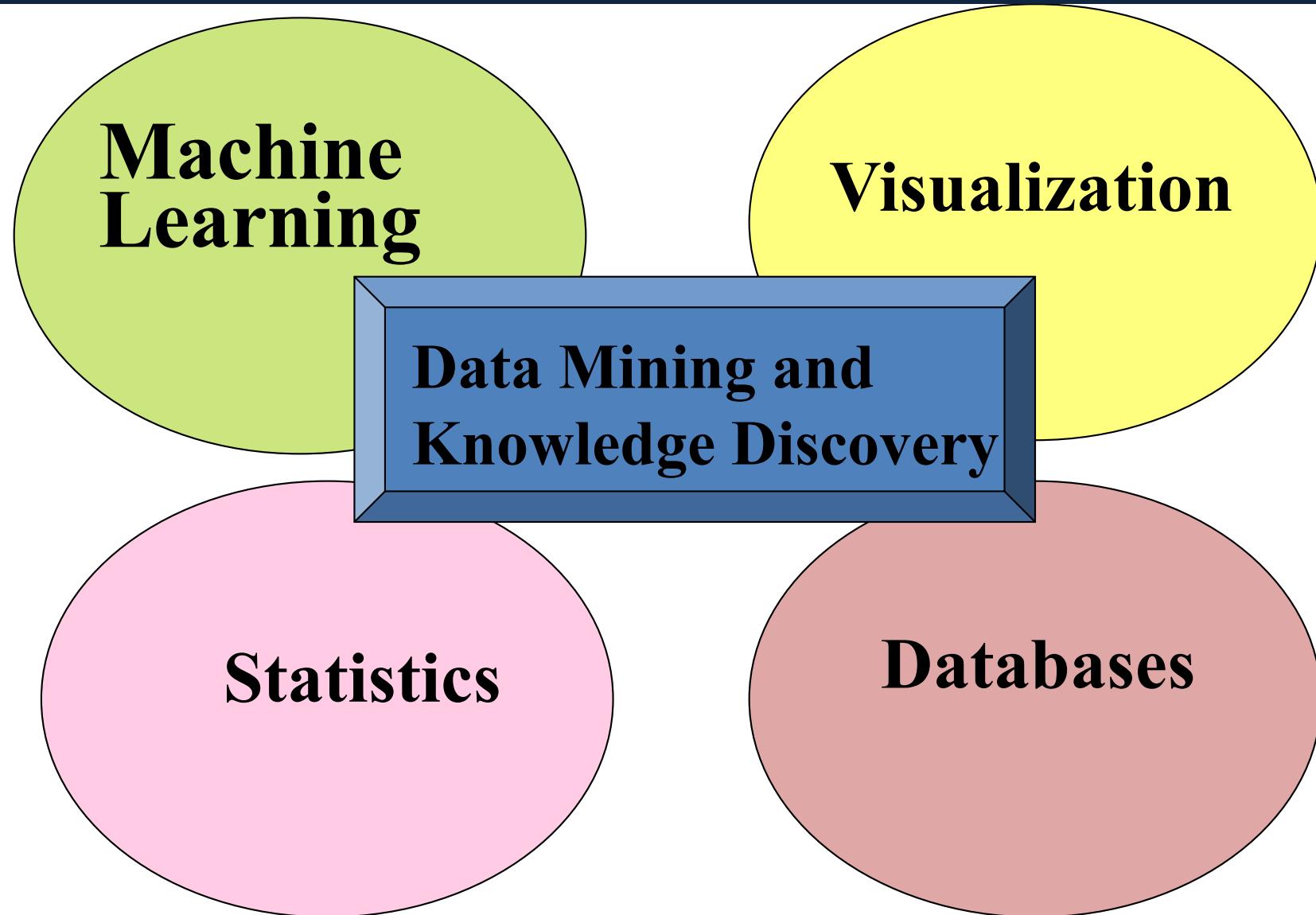
- *valid*
- *novel*
- *potentially useful*
- and ultimately *understandable patterns* in data.

from *Advances in Knowledge Discovery and Data Mining*, Fayyad, Piatetsky-Shapiro, Smyth, and Uthurusamy, (Chapter 1), AAAI/MIT Press 1996

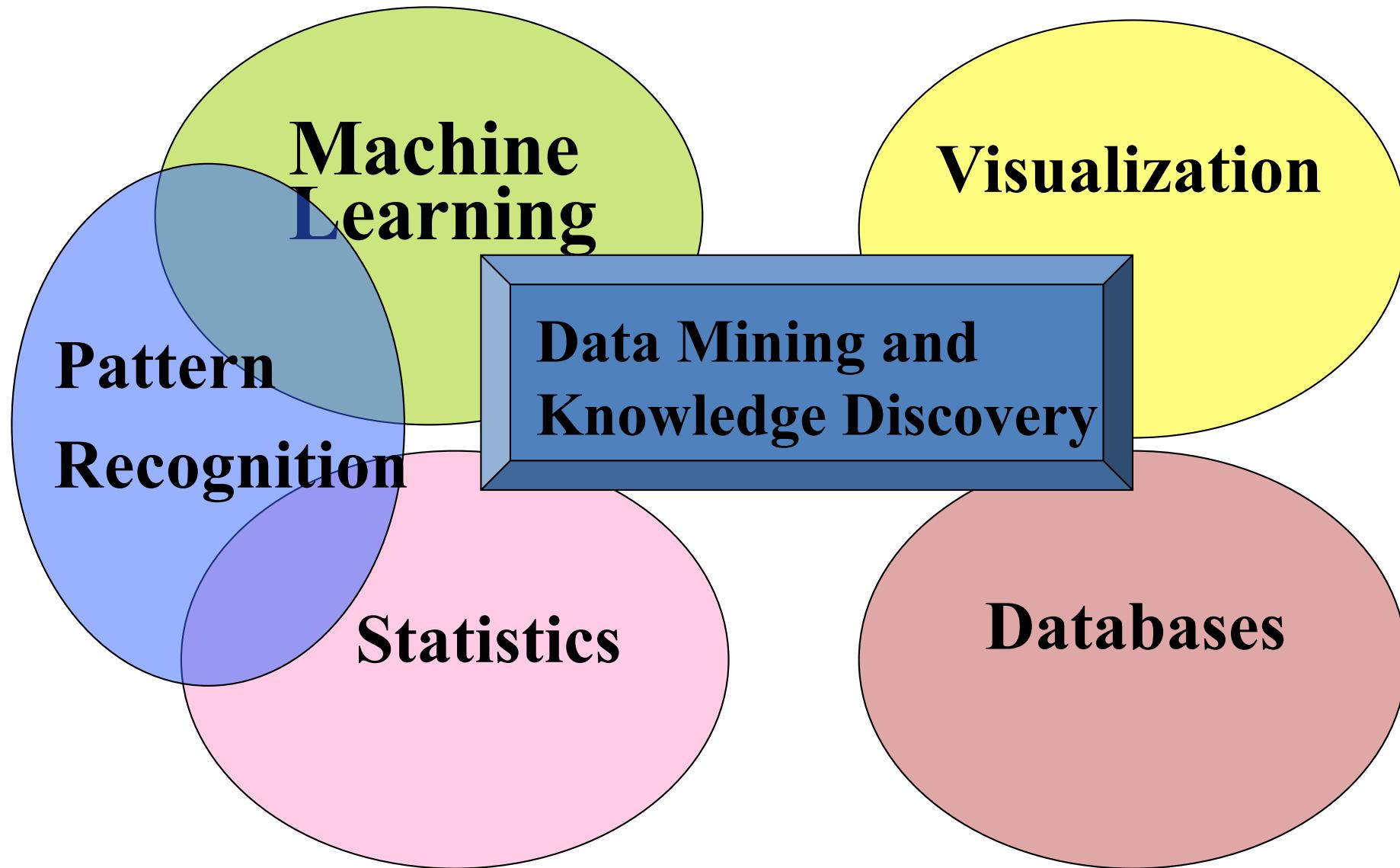
My early interpretation of Data Mining



Related Disciplines



Related Disciplines

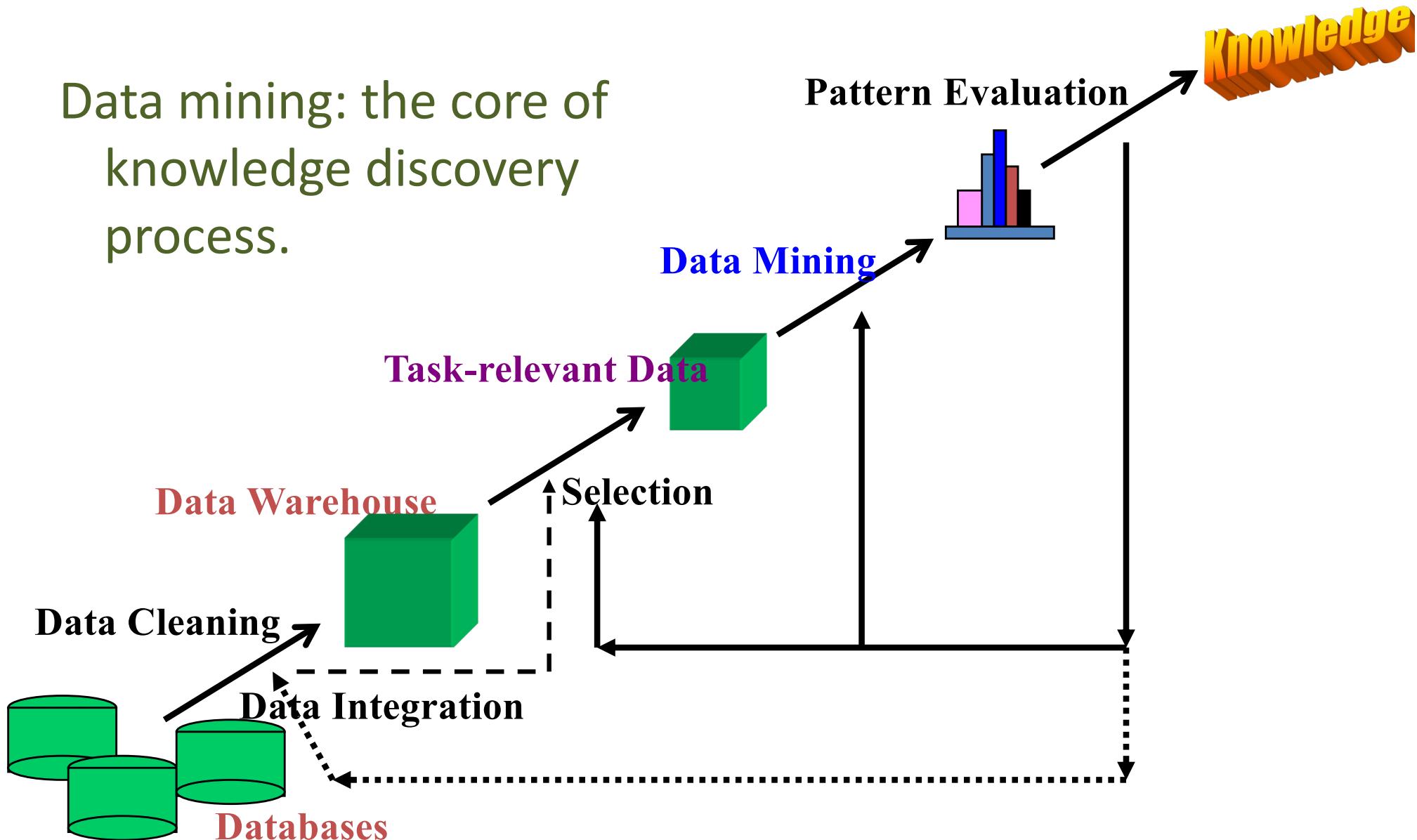


Statistics, Machine Learning, Data Mining

- Statistics:
 - more theory-based
 - more focused on testing hypotheses
- Machine learning
 - more heuristic
 - focused on improving performance of a learning agent
 - also looks at real-time learning and robotics – areas not part of data mining
- Data Mining and Knowledge Discovery
 - integrates theory and heuristics
 - focus on the entire process of knowledge discovery, including data cleaning, learning, and integration and visualization of results
- Distinctions are fuzzy

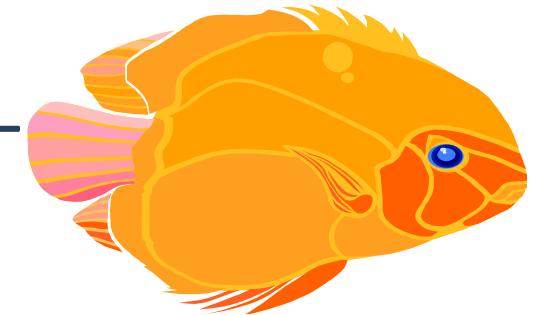
Knowledge discovery process flow

Data mining: the core of knowledge discovery process.



Other Names

- Data Fishing, Data Dredging: 1960-
 - used by Statistician (as bad name)
- Data Mining :1990 --
 - used DB, business
 - in 2003 – bad image because of Total Information Awareness (TIA), DARPA
- Knowledge Discovery in Databases (1989-)
 - used by AI, Machine Learning Community
- Also Data Archaeology, Information Harvesting, Information Discovery, Knowledge Extraction, ...
- Now - Data Science, Big Data



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Data Mining Techniques

- **Classification:** predicting the class for an item
- **Regression:** predicting a continuous value
- **Clustering:** finding clusters in data
- **Association:** e.g. A & B & C occur frequently
- **Recommendation:** find personalized recommendations
- **Summarization:** describing a group
- **Deviation Detection:** finding changes
- **Link Analysis:** finding relationships
- **Visualization:** to facilitate human discovery

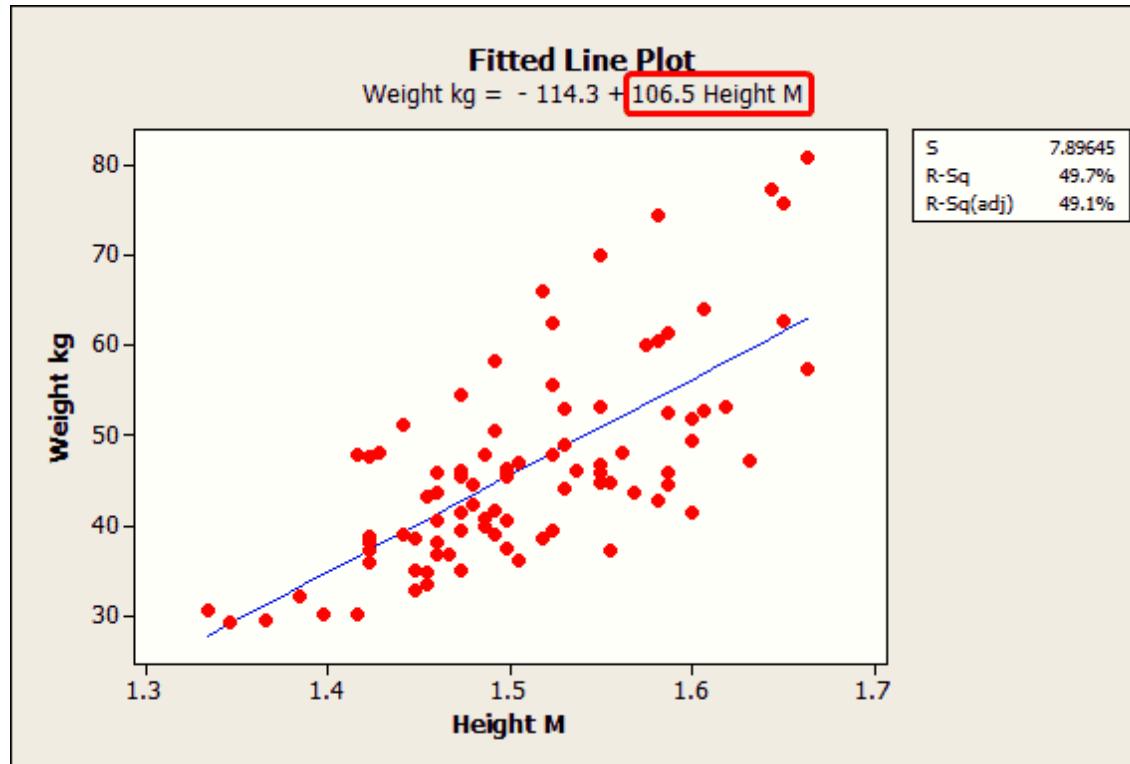
Data Mining Techniques (1)

- Regression and Classification
 - Regression: Predict some unknown or missing numerical values
 - E.g., predict stock price, predict the amount of sale, ...
 - Finding models (functions) that describe and distinguish classes or concepts for future prediction
 - E.g., classify countries based on climate, classify cars based on gas mileage and other data, ...
 - Approaches: regression models, decision-tree, SVM, Artificial Neural Networks, ...

Regression

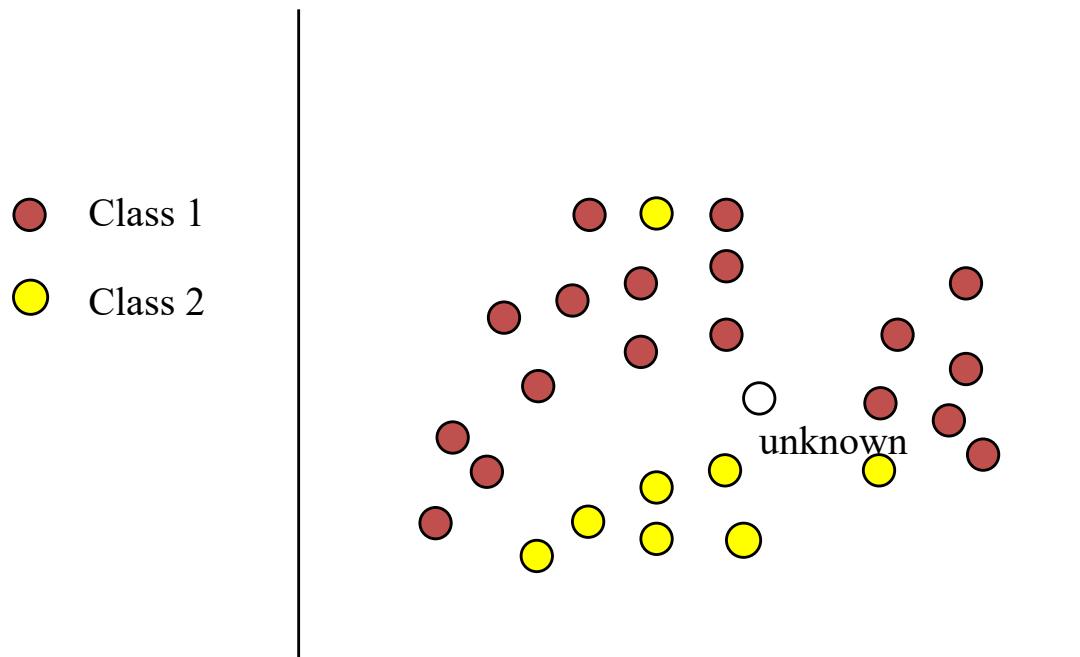
Learn a method for predicting the target value from pre-labeled (classified) instances

The value to be predicted is numeric type



Classification

Learn a method for predicting the instance class from pre-labeled (classified) instances

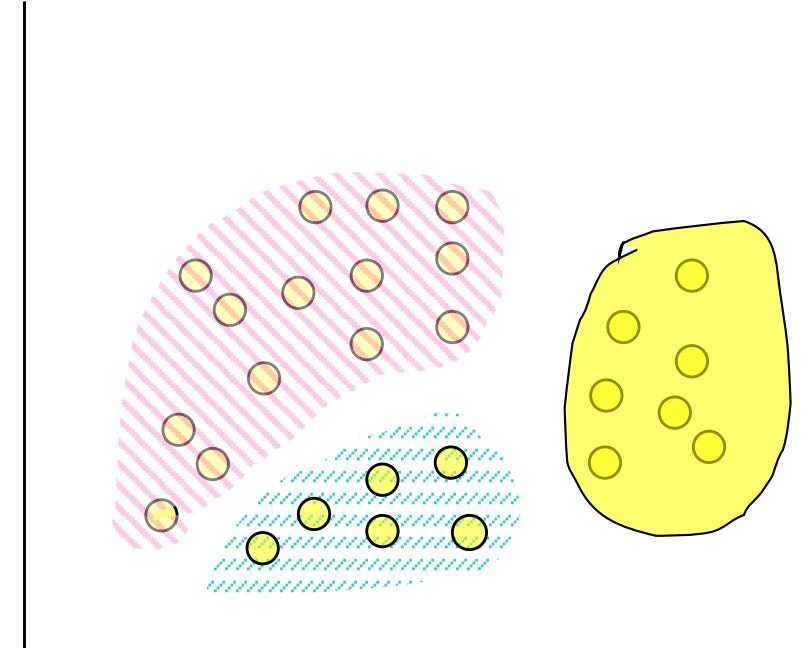


Many approaches:
Statistics,
Logistic regression,
Decision Trees,
SVM, Neural
Networks,
...

Data Mining Techniques (2): Clustering

- Cluster analysis
 - Class label is unknown:
Group data to form new classes, e.g., cluster houses to find distribution patterns
 - Clustering based on the principle: maximizing the intra-class similarity and minimizing the interclass similarity

Find “natural” grouping of instances given un-labeled data



Data Mining Techniques (3)

- Concept description: Characterization and discrimination
 - Generalize, summarize, and contrast data characteristics, e.g., dry vs. wet regions
- Association (correlation and causality)
 - Multi-dimensional vs. single-dimensional association
 - $\text{age}(X, "20..29") \wedge \text{income}(X, "20..29K") \rightarrow \text{buys}(X, "PC")$ [support = 2%, confidence = 60%]
 - $\text{contains}(T, "computer") \rightarrow \text{contains}(x, "software")$ [1%, 75%]

Data Mining Techniques (4)

- Outlier analysis
 - Outlier: a data object that does not comply with the general behavior of the data
 - It can be considered as noise or exception but is quite useful in fraud detection, rare events analysis
- Trend and evolution analysis
 - Trend and deviation: regression analysis
 - Sequential pattern mining, periodicity analysis
 - Similarity-based analysis
- Other pattern-directed or statistical analyses

Are All the “Discovered” Patterns Interesting?

- A data mining system/query may generate thousands of patterns, not all of them are interesting.
 - Suggested approach: Human-centered, query-based, focused mining
- **Interestingness measures:** A pattern is interesting if it is easily understood by humans, valid on new or test data with some degree of certainty, potentially useful, novel, or validates some hypothesis that a user seeks to confirm

Are All the “Discovered” Patterns Interesting?

- Objective vs. subjective interestingness measures:
 - Objective: based on statistics and structures of patterns, e.g., support, confidence, etc.
 - Subjective: based on user’s belief in the data, e.g., unexpectedness, novelty, actionability, etc.

Summary

- Technology trends lead to data flood
 - data mining is needed to make sense of data
- Data Mining has many applications
- Knowledge Discovery Process
- Data Mining Techniques
 - classification, regression, clustering, association rule analysis, outlier detection, recommendation, ...