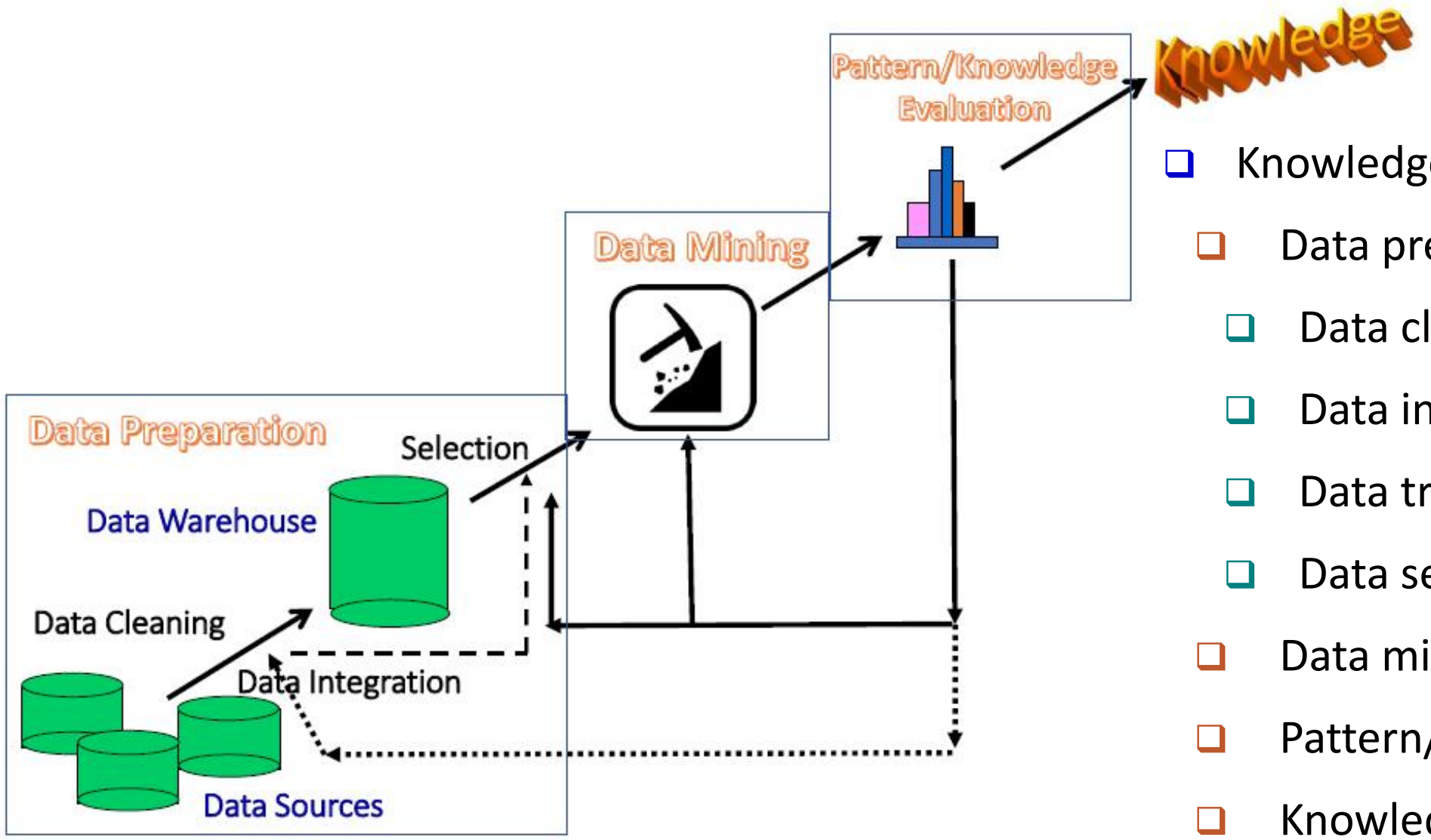
DATA MINING CONCEPTS

Data Mining: An Essential Step in Knowledge Discovery



- Knowledge Discovery Process
  - Data preparation
    - Data cleaning
    - Data integration
    - Data transformation
    - Data selection
  - Data mining
  - Pattern/model evaluation
  - Knowledge presentation

Diversity of Data Types for Data Mining (I)

- **Structured vs. unstructured data**
  - *Structured*: uniform, record- or table-like structures, defined by data dictionaries, with a fixed set of attributes, each with a fixed set of value ranges and semantic meaning
    - Ex. Data stored in *relational databases*, *data cubes*, *data matrices*, and many *data warehouses*
  - *Semi-structured*: allow a data object to contain a set value, a small set of heterogeneous typed values, or nested structures, or to allow the structure of objects or sub-objects to be defined flexibly and dynamically
  - Data having *certain structures* with clearly defined semantic meaning, such as *transactional data set, sequence data set* (e.g., time-series data, gene or protein data, or Weblog data)
  - *Graph or network data:* A more sophisticated type of semi-structured data set
  - *Unstructured data*: text data and multimedia (*e.g.*, audio, image, video) data
- The real-world data can often be a mixture of structured, semi-structured data and unstructured data

Diversity of Data Types for Data Mining (II)

- **Data associated with different applications**
  - Different applications: different data sets and require different data analysis methods
    - Sequence data: *Biological sequences* vs. *shopping transaction sequences*
    - *Time-series:* ordered set of numerical values with equal time interval
    - *Spatial, temporal and spatiotemporal data*
    - Graph and network data: Social networks, computer communication networks, biological networks, and information networks may carry rather different semantics
  - On the same data set, finding different kinds of patterns: require different mining methods
    - Ex. software programs: finding plagiarized modules vs. finding copy-and-paste bugs
- **Stored vs. streaming data**
  - Stored data: Finite, stored in various kinds of large data repositories
  - Streaming data (e.g., video surveillance or remote sensing): Dynamic, constantly coming, infinite, real-time response—posing challenges on effective data mining

Mining Various Kinds of Knowledge

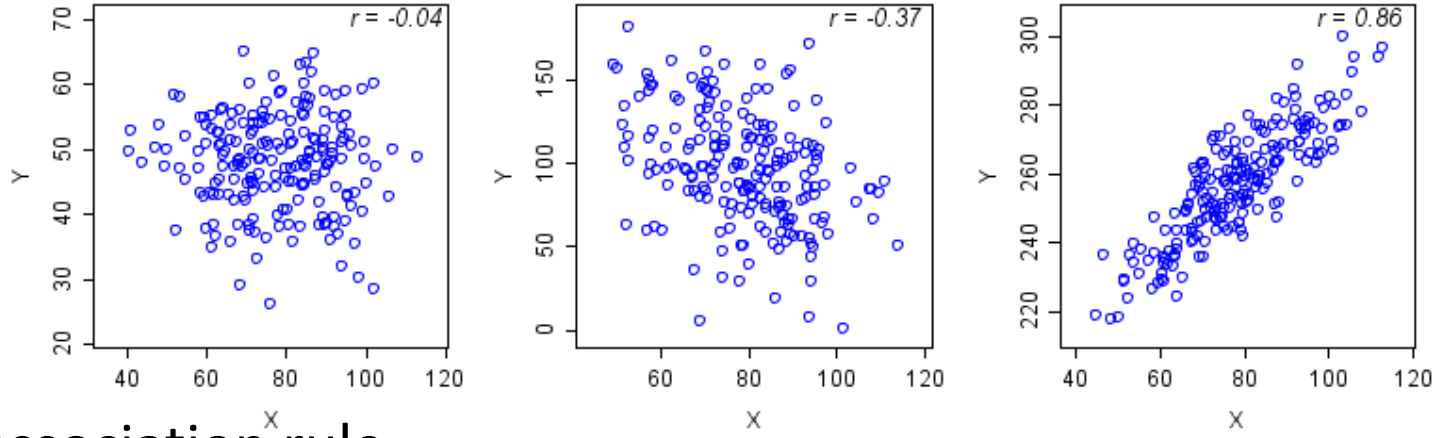
- Multidimensional Data Summarization
- Mining Frequent Patterns, Associations, and Correlations
- Classification and Regression for Predictive Analysis
- Cluster Analysis
- Deep Learning
- Outlier Analysis
- Are All Mining Results Interesting?

Multidimensional Data Summarization

- Information integration and data warehouse construction
  - Data cleaning, transformation, integration, and multidimensional data model
- Data cube technology
  - Scalable methods for computing (i.e., materializing) multidimensional aggregates
  - OLAP (online analytical processing)
- Multidimensional concept description: Characterization and discrimination
  - Generalize, summarize, and contrast data characteristics, e.g., dry vs. wet region

Pattern Discovery: Mining Frequent Patterns, Associations, and Correlations

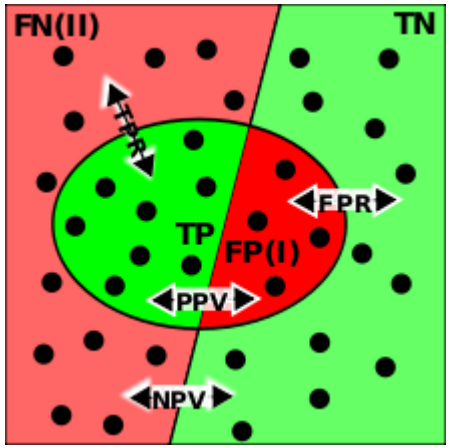
- Frequent patterns (or frequent itemsets)
  - What items are frequently purchased together in your Walmart?
- Association and Correlation Analysis



- A typical association rule
  - Diaper → Beer [0.5%, 75%] (support, confidence)
  - Are strongly associated items also strongly correlated?
- How to mine such patterns and rules efficiently in large datasets?
- How to use such patterns for classification, clustering, and other applications?

Classification and Regression for Predictive Analysis

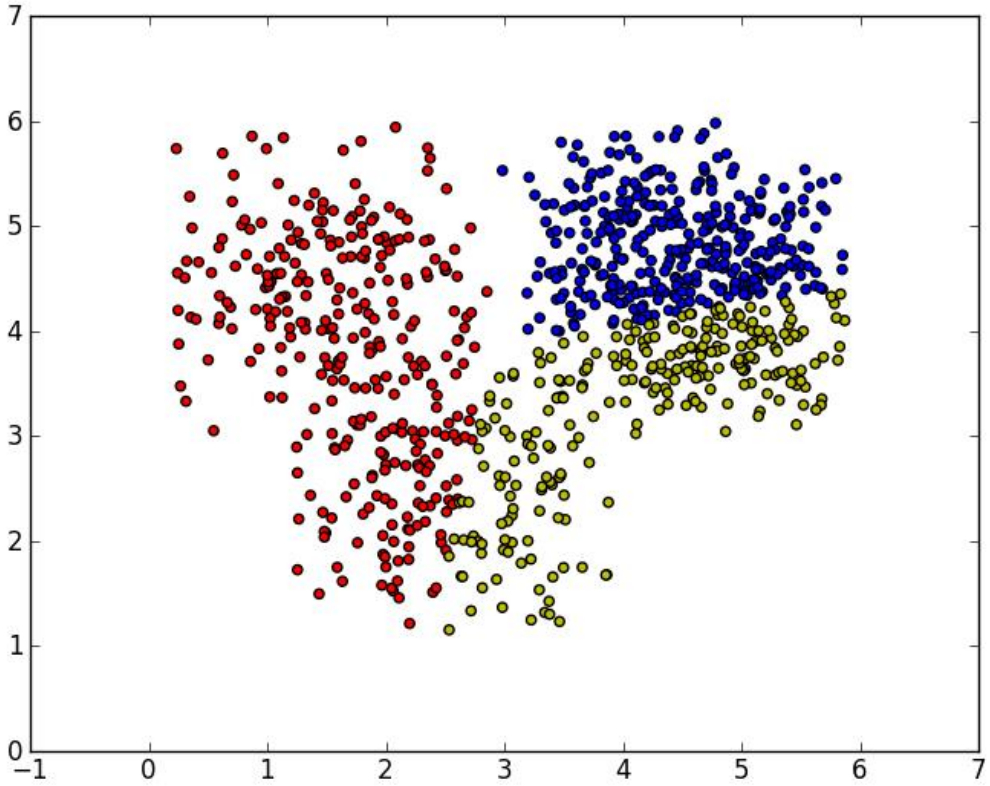
- Classification and label prediction
  - Construct models (functions) based on some training examples
  - Describe and distinguish classes or concepts for future prediction
    - Ex. 1. Classify countries based on (climate)
    - Ex. 2. Classify cars based on (gas mileage)
  - Predict some unknown class labels



- Typical methods
  - Decision trees, naïve Bayesian classification, support vector machines, neural networks, rule-based classification, pattern-based classification, logistic regression, …
- Typical applications:
  - Credit card fraud detection, direct marketing, classifying stars, diseases, web-pages, …

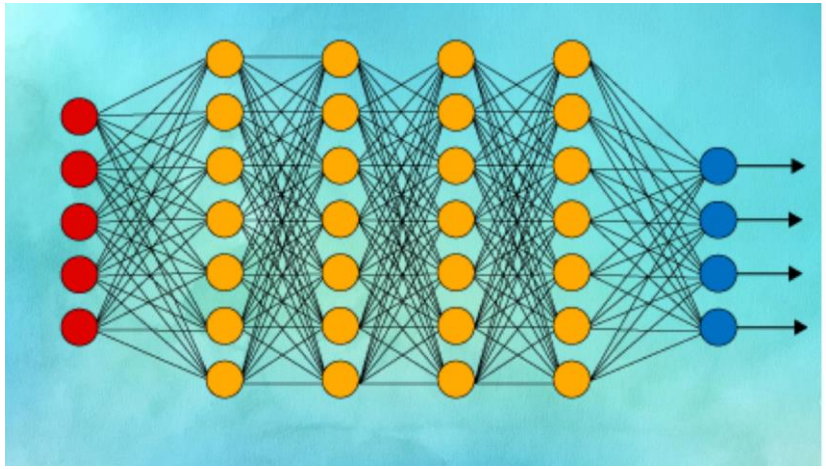
Cluster Analysis

- Unsupervised learning (i.e., Class label is unknown)
- Group data to form new categories (i.e., clusters), e.g., cluster houses to find distribution patterns
- Principle: Maximizing intra-class similarity & minimizing interclass similarity
- Many methods and applications



Deep Learning

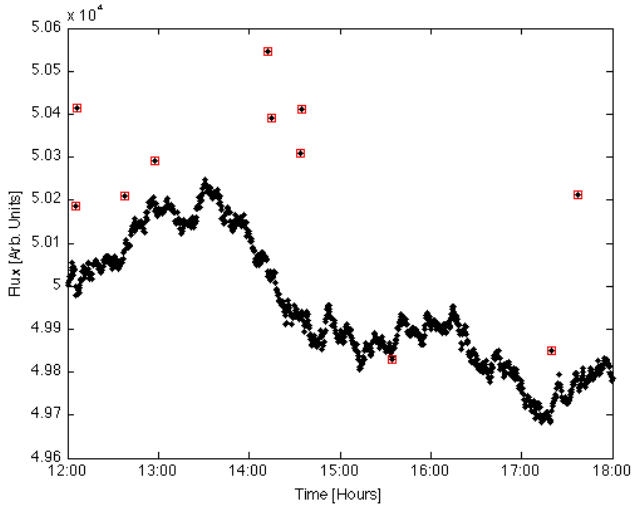
- Deep learning: A fast expanding dynamic frontier in machine learning
- Deep learning has developed various *neural network architectures*
  - Feed-forward neural networks
  - Convolutional neural networks
  - Recurrent neural networks
  - Graph neural networks
  - Transformer

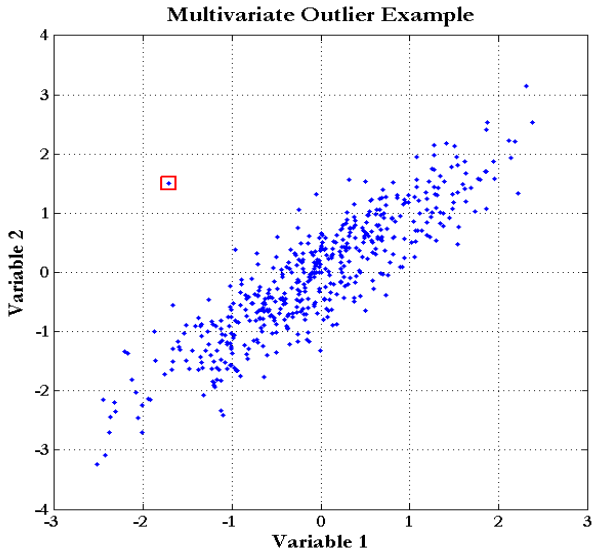


- Deep learning has broad applications in computer vision, natural language processing, machine translation, social network analysis, and so on
- Deep learning has been reshaping a variety of data mining tasks
  - Ex. classification, clustering, outlier detection, and reinforcement learning

Outlier Analysis

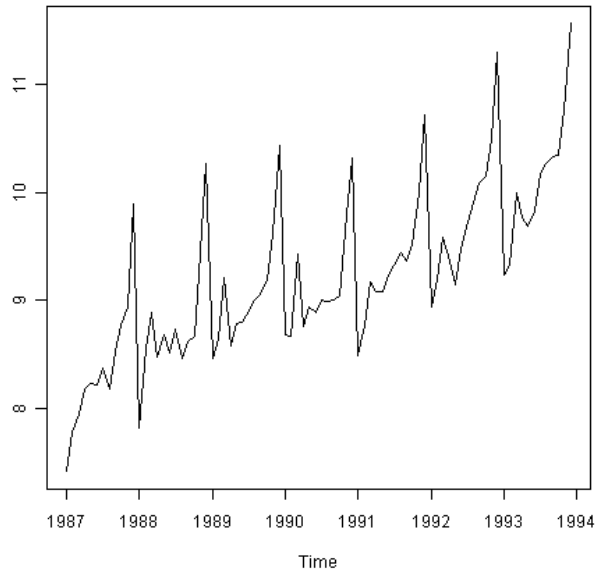
- Outlier analysis
  - Outlier: A data object that does not comply with the general behavior of the data
  - Noise or exception?—One person's garbage could be another person's treasure
  - Methods: by product of clustering or regression analysis, …
  - Useful in fraud detection, rare events analysis





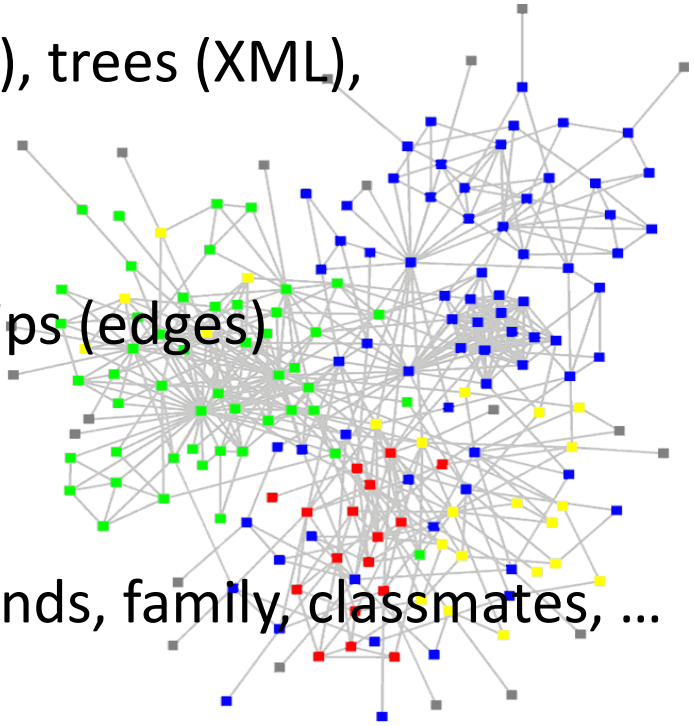
Other Data Mining Functions: Time and Ordering: Sequential Pattern, Trend and Evolution Analysis

- Sequence, trend and evolution analysis
  - Trend, time-series, and deviation analysis
    - e.g., regression and value prediction
  - Sequential pattern mining
    - e.g., buy digital camera, then buy large memory cards
  - Periodicity analysis
  - Motifs and biological sequence analysis
    - Approximate and consecutive motifs
  - Similarity-based analysis
- Mining data streams
  - Ordered, time-varying, potentially infinite, data streams



Other Data Mining Functions: Structure and Network Analysis

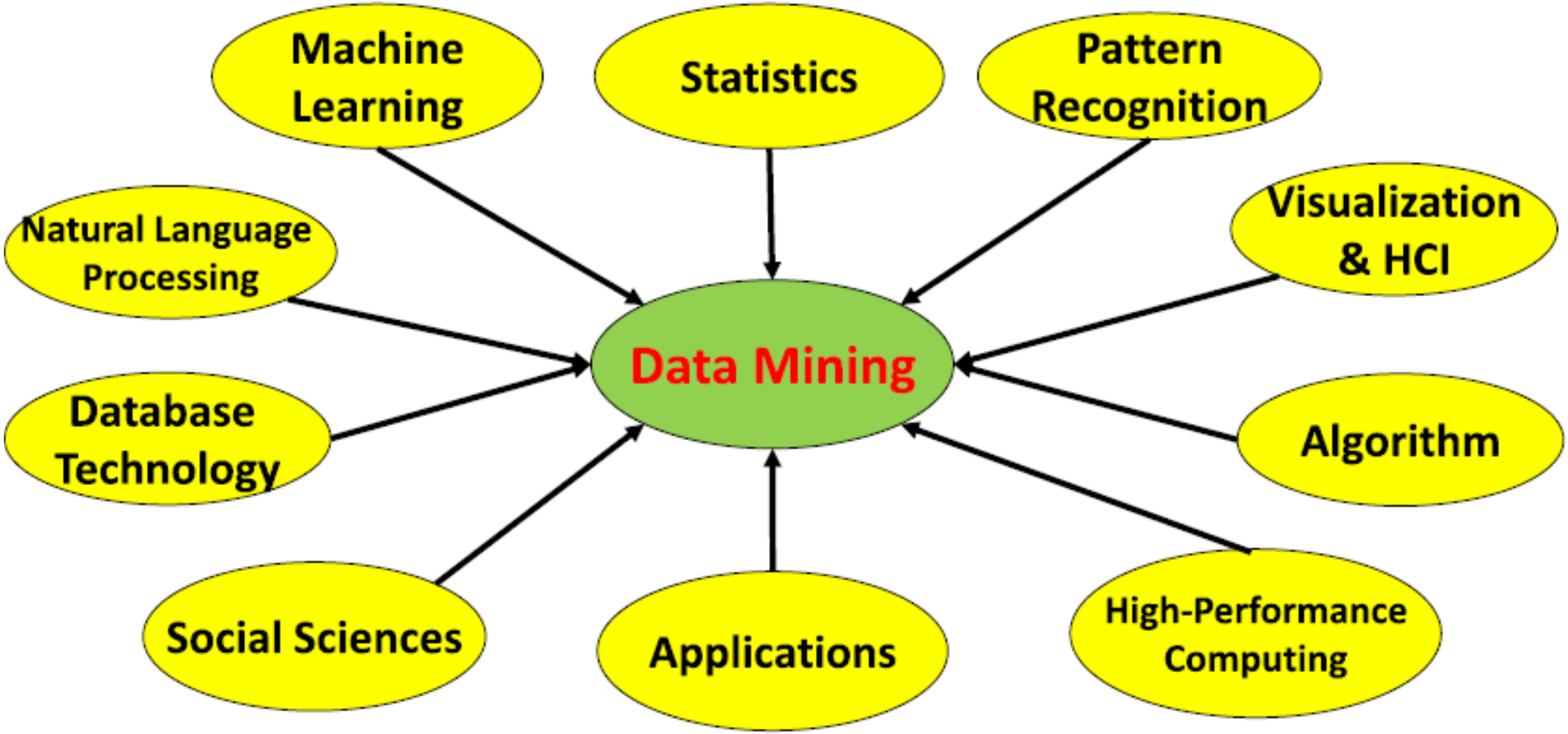
- Graph mining
  - Finding frequent subgraphs (e.g., chemical compounds), trees (XML), substructures (web fragments)
- Information network analysis
  - Social networks: actors (objects, nodes) and relationships (edges)
    - e.g., author networks in CS, terrorist networks
  - Multiple heterogeneous networks
    - A person could be multiple information networks: friends, family, classmates, …
  - Links carry a lot of semantic information: Link mining
- Web mining
  - Web is a big information network: from PageRank to Google
  - Analysis of Web information networks
    - Web community discovery, opinion mining, usage mining, …



Evaluation of Knowledge

- Are all mined knowledge interesting?
  - One can mine tremendous amount of "patterns"
  - Some may fit only certain dimension space (time, location, …)
  - Some may not be representative, may be transient, …
- Evaluation of mined knowledge → directly mining only interesting knowledge?
  - Descriptive vs. predictive
  - Coverage
  - Typicality vs. novelty
  - Accuracy
  - Timeliness
  - …

Data Mining: Confluence of Multiple Disciplines



Why Confluence of Multiple Disciplines?

- Tremendous amount of data
  - Algorithms must be scalable to handle big data
- High-dimensionality of data
  - Micro-array may have tens of thousands of dimensions
- High complexity of data
  - Data streams and sensor data
  - Time-series data, temporal data, sequence data
  - Structure data, graphs, social and information networks
  - Spatial, spatiotemporal, multimedia, text and Web data
  - Software programs, scientific simulations
- New and sophisticated applications

Data Mining and Applications

- Web page analysis: classification, clustering, ranking
- Collaborative analysis & recommender systems
- Basket data analysis to targeted marketing
- Biological and medical data analysis
- Data mining and software engineering
- Data mining and text analysis
- Data mining and social and information network analysis
- Built-in (invisible data mining) functions in Google, Microsoft, LinkedIn, Meta, …
- Major dedicated data mining systems/tools
  - SAS, MS SQL-Server Analysis Manager, Oracle Data Mining Tools)

Data Mining and Society

- Data mining technology may benefit society
  - Ex.: Help scientific discovery, business management, economy recovery, and security protection (*e.g.*, the real-time discovery of intruders and cyberattacks)
- Need to guard against the misuse of data mining
  - Data mining also poses the risk of unintentionally disclosing some confidential business or government information and disclosing an individual's personal information
- Studies on data security in data mining and privacy-preserving data publishing and data mining are important, ongoing research theme
  - The philosophy is to observe data sensitivity and preserve data security and people's privacy while performing successful data mining
- These and other related issues will be discussed throughout the book

Summary

- Data mining: Discovering interesting patterns and knowledge from massive amounts of data
- A KDD process includes data cleaning, data integration, data selection, transformation, data mining, pattern evaluation, and knowledge presentation
- Different data mining method on a wide variety of data
- Data mining functionalities: summarization, pattern discovery, classification, clustering, deep learning, outlier analysis, trend and outlier analysis, …
- Data mining is a confluence of multiple disciplines
- Data mining has broad applications
- Promote secure data mining to benefit society