CS 412 Intro. to Data Mining

Chapter 1. Introduction

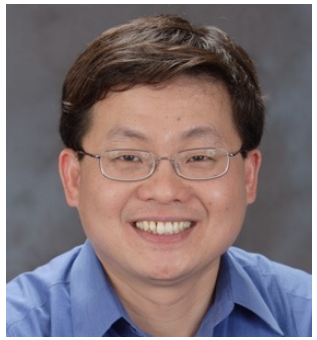
Arindam Banerjee, Computer Science, UIUC, Fall 2021

Data and Information Systems (DAIS)

- Database Systems
- Data Mining
- Text Information Systems
- Networks

Jiawei Han

Hanghang Tong



Kevin Chang

Hari Sundaram

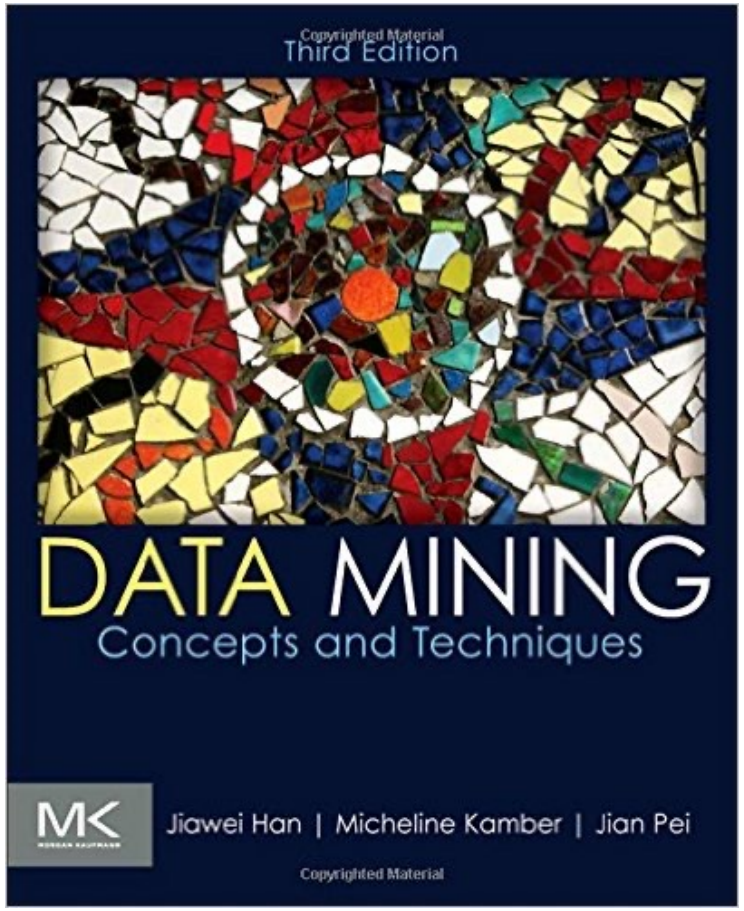
ChengXiang Zhai

Yongjoo Park

Data and Information Systems (DAIS:) Course Structures at CS/UIUC

- Coverage: Database, data mining, text information systems, Web and bioinformatics
- Data mining
  - Intro. to Data Mining (CS 412)
  - Data Mining Principles (CS 512)
- Database Systems:
  - Database systems (CS 411)
  - Advanced Data Management (CS 511)
- Text information systems
  - Text Information System (CS 410)
  - Advanced Information Retrieval (CS 510)

CS 412. Course Page & Class Schedule



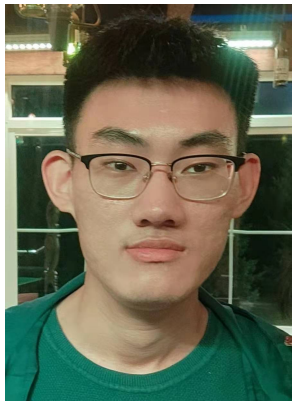
- Textbook
  - Jiawei Han, Micheline Kamber, Jian Pei, Hanghang Tong, *Data Mining: Concepts and Techniques (4rh ed)*, 2021
- Class Homepage: Fall, 2021
  https://canvas.illinois.edu/courses/13790
- **Class Schedule: Tue, Thu 09:30 am-10:45 pm**
  - **3039 Campus Instructional Facility**
- Office hours: Tue, Thu 6:00-7:00 pm @zoom

CS 412. Fall 2021. Teaching Assistants

Yikun Ban

Dongqi Fu

Zhe Xu



Hang Zhang

- TA office hours:
  - Yikun: Tue, Thu 4 – 5 pm
  - Dongqi: Fri, 4 – 6 pm
  - Zhe: Mon, Wed 4 – 5 pm
  - Hang: Mon, Thu 11 am – 12 noon
- Wait list -- No wait list at this time, keep attending the class

CS 412. Course Work and Grading

- Assignments, Programming Assignments, and Exams
  - Written Assignments: 30% (three homework assignments expected)
  - Programming assignments: 30% (two programming assignments expected)
  - Midterm exam (take home): 20%
  - Final exam (take home): 20%
- For students taking 4th credit
  - For students registering 4 credits: 25%, overall scores to be scaled proportionally
  - Group project: 2-3 members
- Slides, Chapters, homeworks/exams, your scores & grades: **Canvas**
- Need help and/or discussions?
  - Canvas discussions
  - Slack

Key Dates

- Assignments
  - A1: Tue, Sept 7 out, Thu, **Sept 23** due (16 days)
  - A2: Thu, Sept 23 out, Mon, **Oct 11** due (18 days)
  - A3 (programming): Mon, Oct 11 out, Mon, **Nov 08** due (28 days)
  - A4 (programming): Mon, Nov 08 out, Fri, **Dec 03** due (25 days)
  - A5: Mon, Nov 15 out, Mon, **Dec 06** due (21 days)
- Take-Home Exams
  - Mid-term: Thu, **Oct 14**, 6 pm, 24 hours
  - Final: Fri, **Dec 10**, 6 pm, 24 hours

Please Mark Your Calendars **Start Early**

4-Credit Projects

- Research project: Join a competition or propose your own project
  - Example: https://www.kaggle.com/competitions

- Important Dates
  - Project teams due: Mon, Sept 20
  - Project proposal due: Mon, Oct 04, 1 page + references
  - Mid-term report due: Wed, Nov 03, 4 pages + references
  - Final report due: Wed, Dec 08, 8 pages + references

- Reports need to be in 11-pt, single column, 1-inch margins

CS 412. Grades

- Following cutoffs represent what will likely be used to generate letter grades:

A+ >= 98%	A >=94% & < 98%	A- >=90% & < 94%
B+ >= 85% & < 90%	B >=80% & < 85%	B- >=77% & < 80%
C+ >= 74% & < 77%	C >=70% & < 74%	C- >=67% & <70%
D >= 60%& <67%	F < 60%	

- The above cutoffs are tentative and may be adjusted slightly; if there is any adjustment to the above cutoffs, we will NOT curve down your letter grades

- However, there will be no general curve-fitting in assigning the final grades

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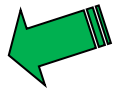

- Why Data Mining?
- What Is Data Mining?
- A Multi-Dimensional View of Data Mining
- What Kinds of Data Can Be Mined?
- What Kinds of Patterns Can Be Mined?
- What Kinds of Technologies Are Used?
- What Kinds of Applications Are Targeted?
- Major Issues in Data Mining
- A Brief History of Data Mining and Data Mining Society
- Summary

Why Data Mining?

- The Explosive Growth of Data: from terabytes to petabytes
  - Data collection and data availability
    - Automated data collection tools, database systems, Web, computerized society
  - Major sources of abundant data
    - Business: Web, e-commerce, transactions, stocks, transportation, …
    - Science: Remote sensing, bioinformatics, climate science, agriculture, water, …
    - Society and everyone: news, events, social networks, …
- We are drowning in data, but starving for knowledge!
- "Necessity is the mother of invention"—Data mining—Automated analysis of massive data sets

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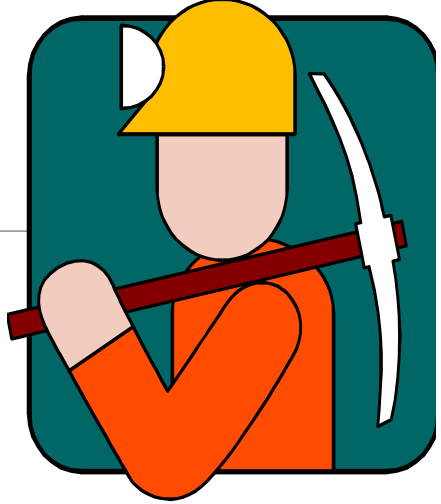
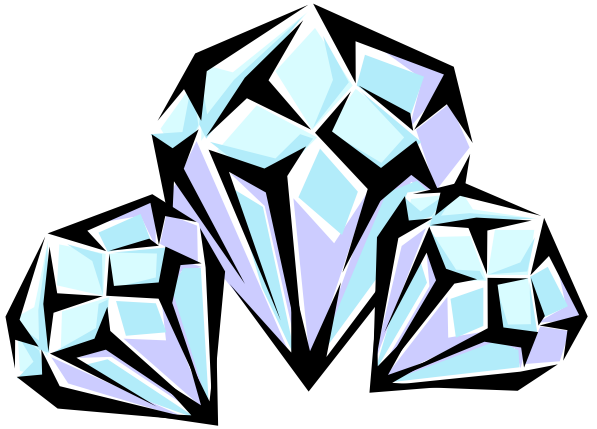
What Is Data Mining?

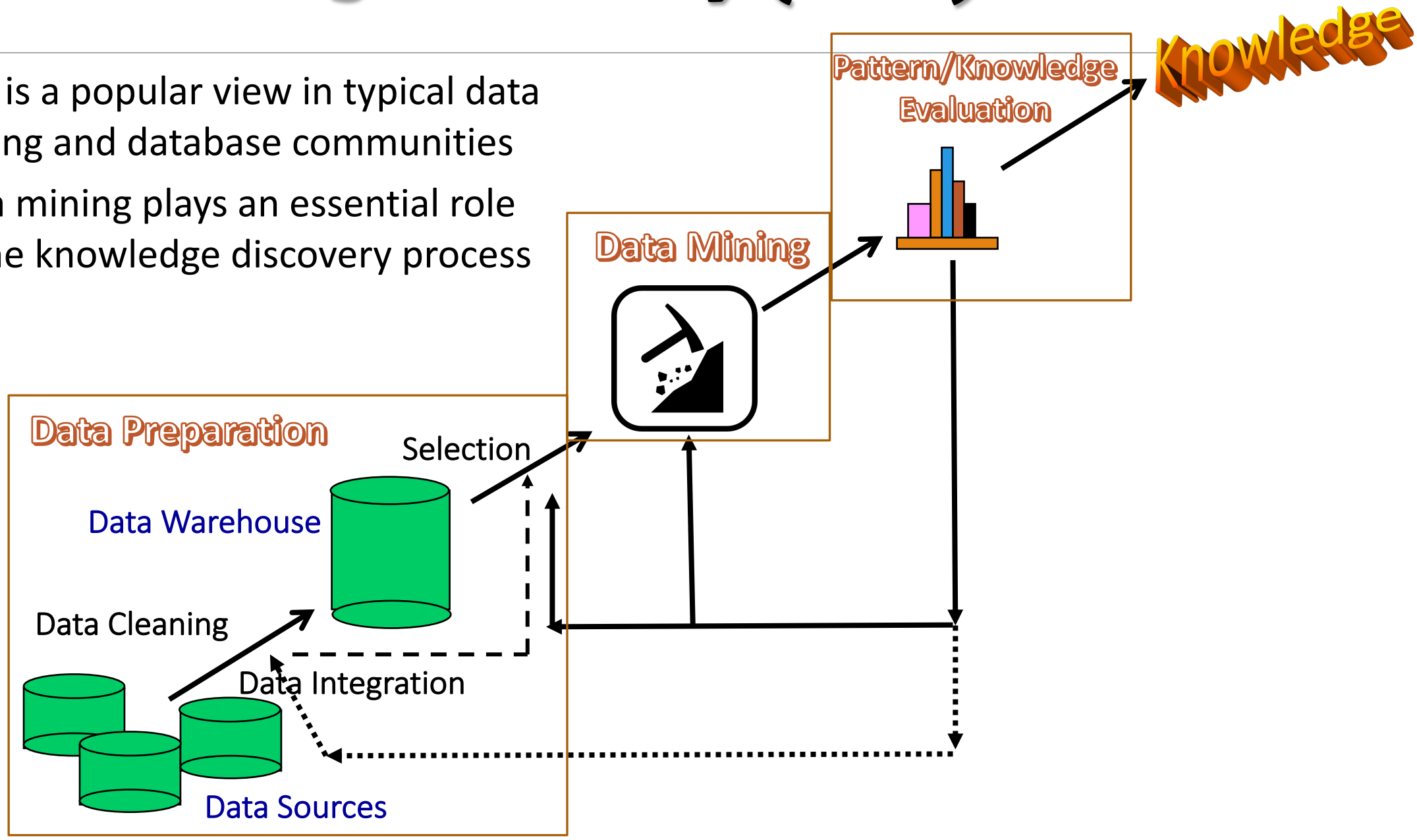


- Data mining (knowledge discovery from data)
  - Extraction of interesting (non-trivial, implicit, previously unknown and potentially useful) patterns or knowledge from huge amount of data
  - Data mining: a misnomer?
- Alternative names
  - Knowledge discovery (mining) in databases (KDD), knowledge extraction, data/pattern analysis, data archeology, data dredging, information harvesting, business intelligence, etc.
- Watch out: Is everything "data mining"?
  - Simple search and query processing
  - (Deductive) expert systems



Knowledge Discovery (KDD) Process

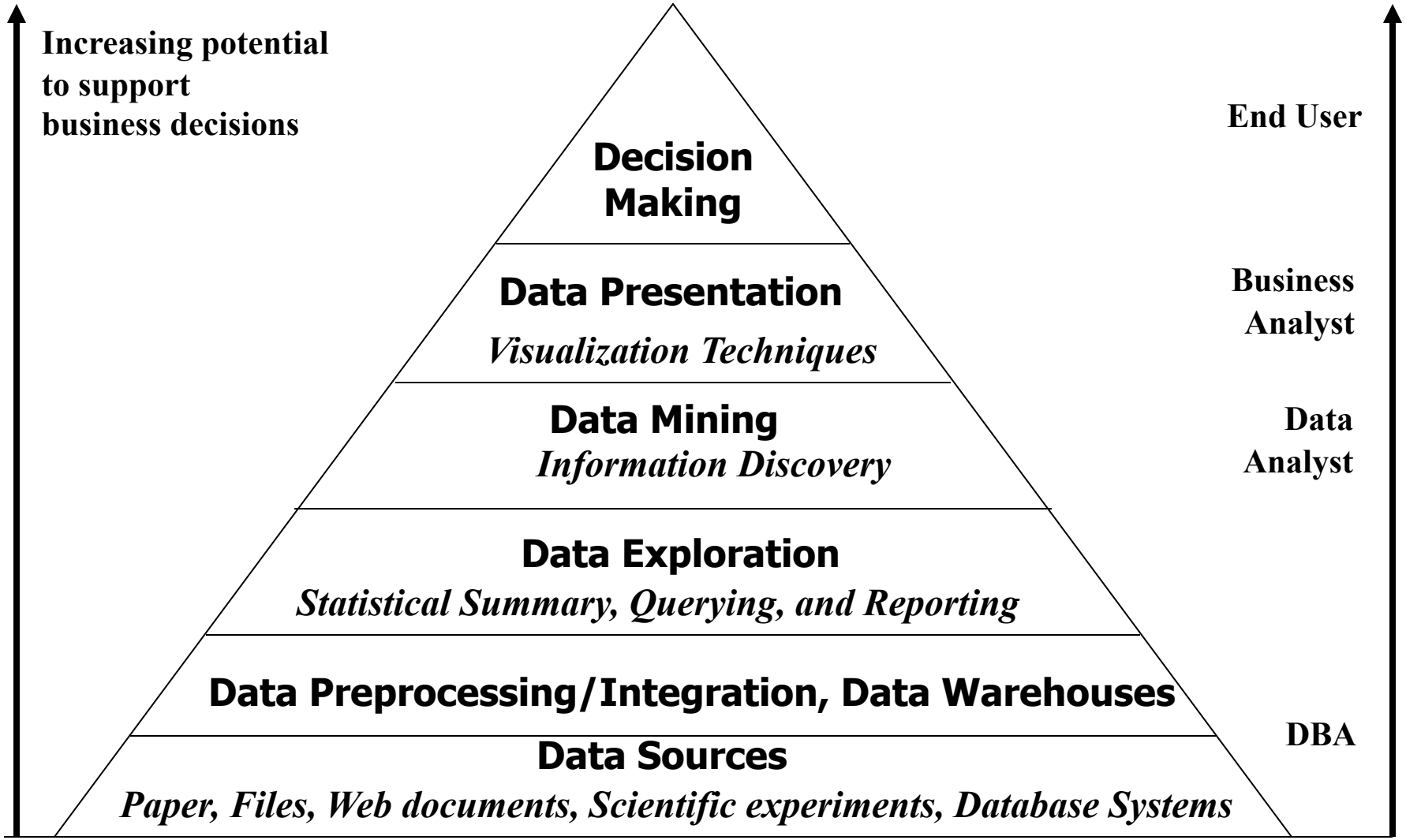
- This is a popular view in typical data mining and database communities
- Data mining plays an essential role in the knowledge discovery process



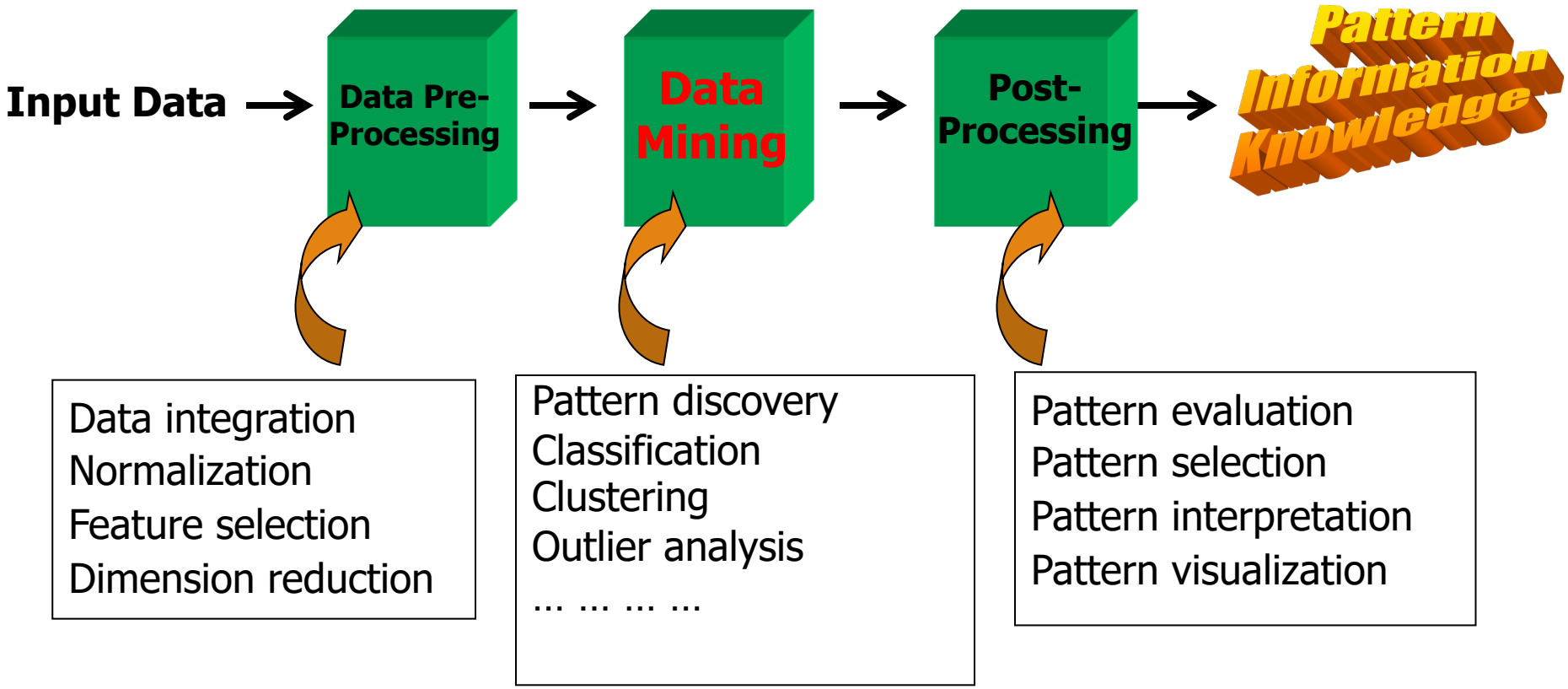
Example: A Web Mining Framework

- Web mining usually involves
  - Data cleaning
  - Data integration from multiple sources
  - Warehousing the data
  - Data cube construction
  - Data selection for data mining
  - Data mining
  - Presentation of the mining results
  - Patterns and knowledge to be used or stored into knowledge-base

Data Mining in Business Intelligence



KDD Process: A View from ML and Statistics



- This is a view from typical machine learning and statistics communities

Data Mining vs. Data Exploration

- Which view do you prefer?
  - KDD vs. ML/Stat. vs. Business Intelligence
  - Depending on the data, applications, and your focus

- Data Mining vs. Data Exploration
  - Business intelligence view
    - Warehouse, data cube, reporting but not much mining
  - Business objects vs. data mining tools
  - Supply chain example: mining vs. OLAP vs. presentation tools
  - Data presentation vs. data exploration

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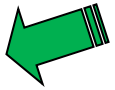
- A Multi-Dimensional View of Data Mining 
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Multi-Dimensional View of Data Mining

- **Data to be mined**
  - Database data (extended-relational, object-oriented, heterogeneous), data warehouse, transactional data, stream, spatiotemporal, time-series, sequence, text and web, multi-media, graphs & social and information networks
- **Knowledge to be mined (or: Data mining functions)**
  - Characterization, discrimination, association, classification, clustering, trend/deviation, outlier analysis, …
  - Descriptive vs. predictive data mining
  - Multiple/integrated functions and mining at multiple levels
- **Techniques utilized**
  - Data-intensive, data warehouse (OLAP), machine learning, statistics, pattern recognition, visualization, high-performance, etc.
- **Applications adapted**
  - Retail, telecommunication, banking, fraud analysis, bio-data mining, stock market analysis, text mining, Web mining, etc.

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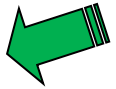

Data Mining: On What Kinds of Data?

- Database-oriented data sets and applications
  - Relational database, data warehouse, transactional database
  - Object-relational databases, Heterogeneous databases and legacy databases
- Advanced data sets and advanced applications
  - Data streams and sensor data
  - Time-series data, temporal data, sequence data (incl. bio-sequences)
  - Structure data, graphs, social networks and information networks
  - Spatial data and spatiotemporal data
  - Multimedia database
  - Text databases
  - The World-Wide Web

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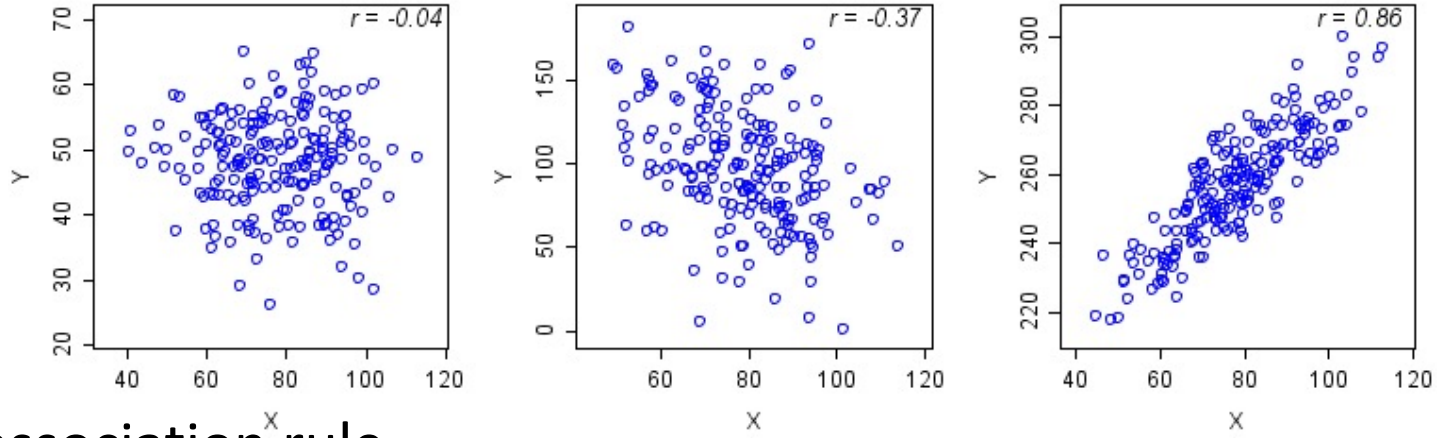
Data Mining Functions: (1) Generalization

- 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

Data Mining Functions: (2) Pattern Discovery

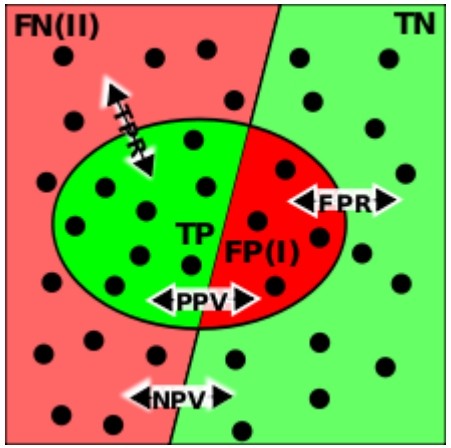
- Frequent patterns (or frequent itemsets)
  - What items are frequently purchased together in your Walmart?
- Association and Correlation Analysis



- 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?

Data Mining Functions: (3) Classification

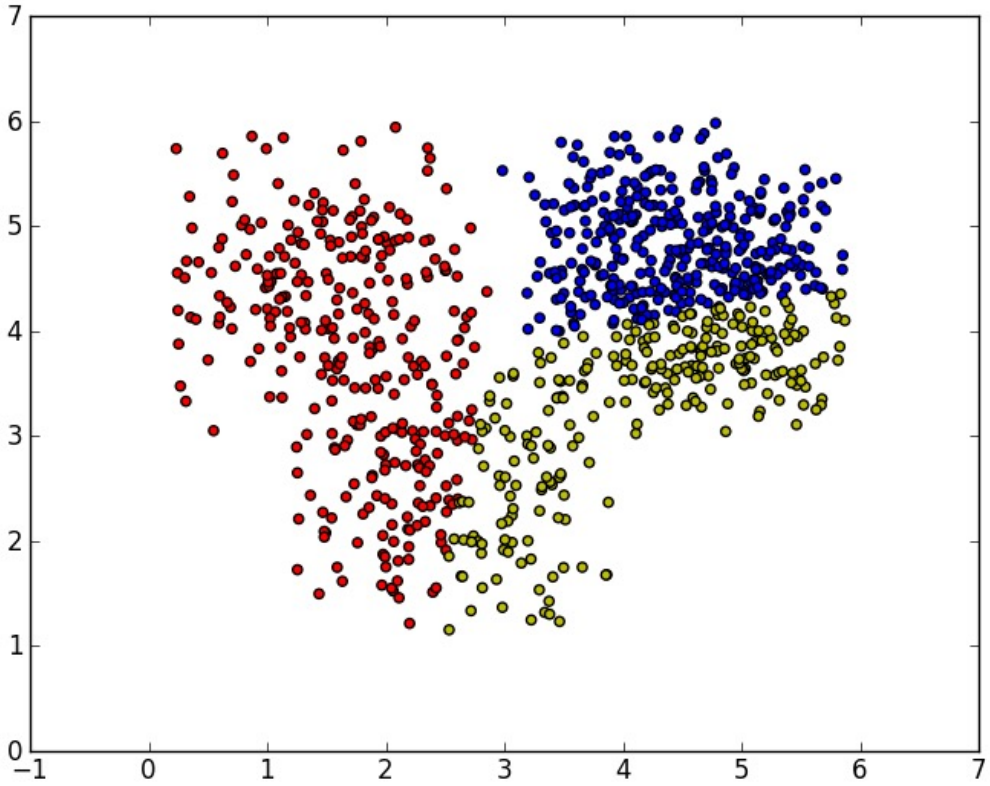
- Classification and label prediction
  - Construct models (functions) based on some training examples
  - Describe and distinguish classes or concepts for future prediction
    - Ex. 1. Classify countries based on (climate)
    - Ex. 2. Classify cars based on (gas mileage)
  - Predict some unknown class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

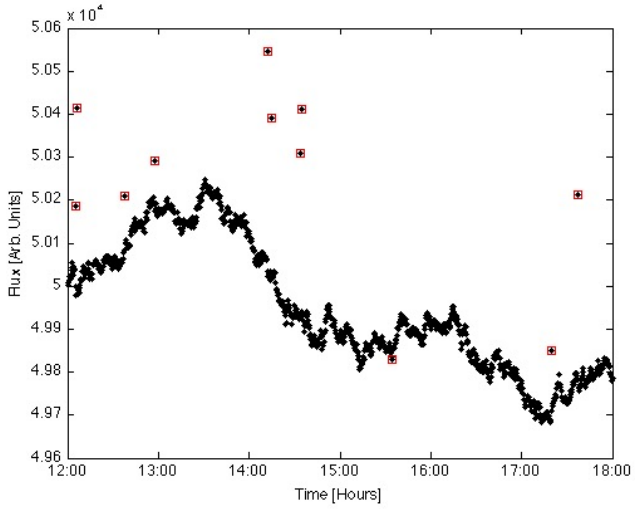
Data Mining Functions: (4) Cluster Analysis

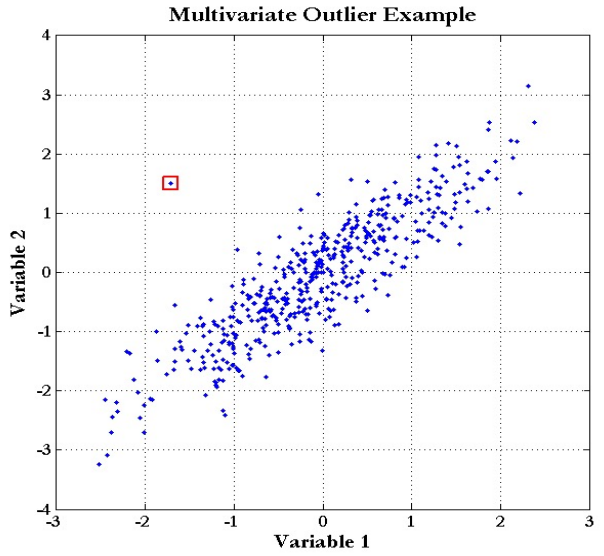
- Unsupervised learning (i.e., Class label is unknown)
- Group data to form new categories (i.e., clusters), e.g., cluster houses to find distribution patterns
- Principle: Maximizing intra-class similarity & minimizing interclass similarity
- Many methods and applications



Data Mining Functions: (5) Outlier Analysis

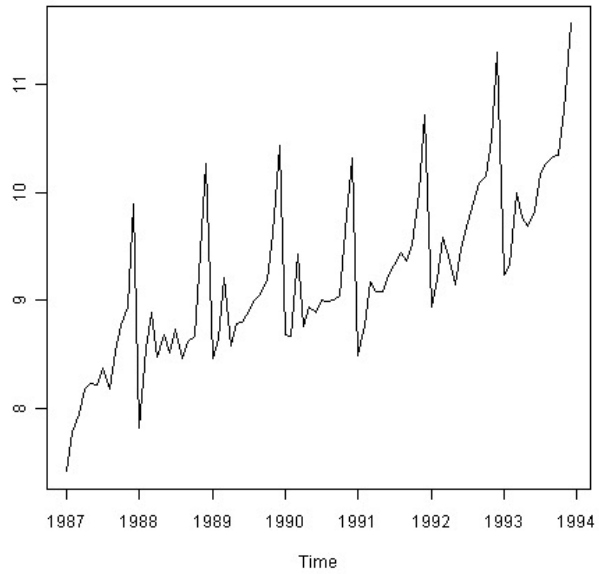
- Outlier analysis
  - Outlier: A data object that does not comply with the general behavior of the data
  - Noise or exception?—One person's garbage could be another person's treasure
  - Methods: by product of clustering or regression analysis, …
  - Useful in fraud detection, rare events analysis





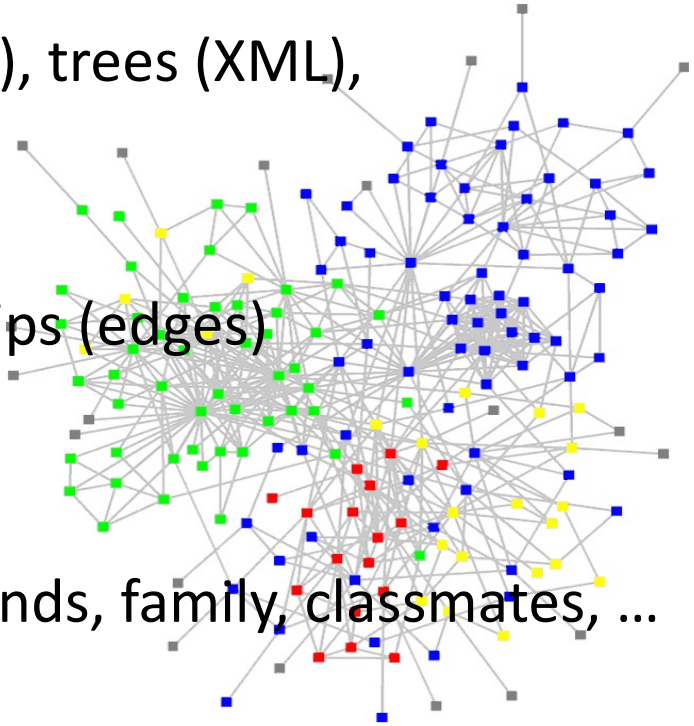
Data Mining Functions: (6) Time and Ordering: Sequential Pattern, Trend and Evolution Analysis

- 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



Data Mining Functions: (7) 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 mine only interesting knowledge?
  - Descriptive vs. predictive
  - Coverage
  - Typicality vs. novelty
  - Accuracy
  - Timeliness
  - …

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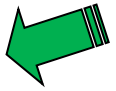
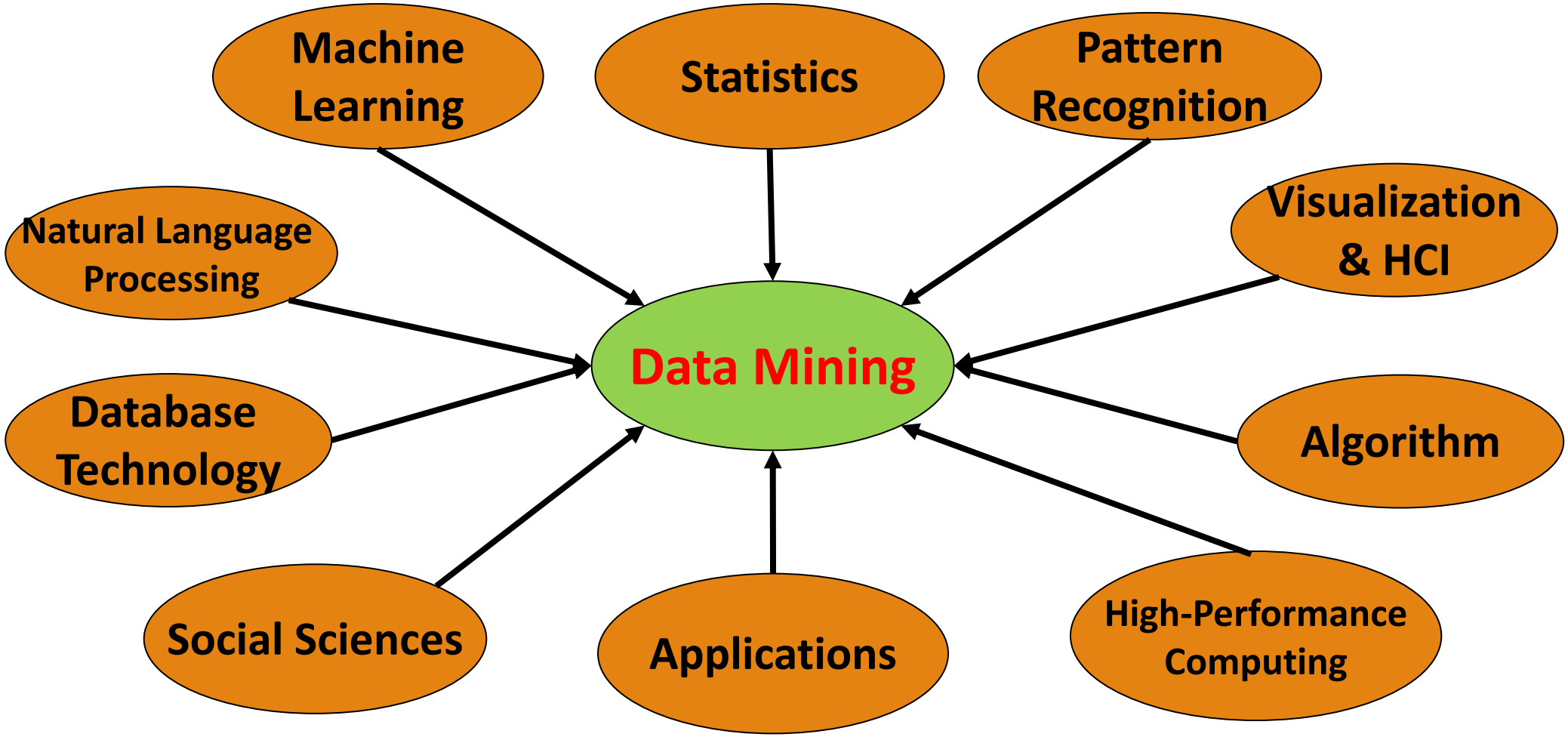


Data Mining: Confluence of Multiple Disciplines



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

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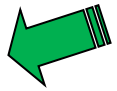
- What Kinds of Applications Are Targeted? 
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Applications of Data Mining

- 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, MS, Yahoo!, Linked, Facebook, …
- Major dedicated data mining systems/tools
  - SAS, MS SQL-Server Analysis Manager, Oracle Data Mining Tools

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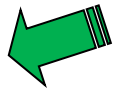
- Major Challenges in Data Mining 
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Major Challenges in Data Mining (1)

- Mining Methodology
  - Mining various and new kinds of knowledge
  - Mining knowledge in multi-dimensional space
  - Data mining: An interdisciplinary effort
  - Boosting the power of discovery in a networked environment
  - Handling noise, uncertainty, and incompleteness of data
  - Pattern evaluation and pattern- or constraint-guided mining
- User Interaction
  - Interactive mining
  - Incorporation of background knowledge
  - Presentation and visualization of data mining results

Major Challenges in Data Mining (2)

- Efficiency and Scalability
  - Efficiency and scalability of data mining algorithms
  - Parallel, distributed, stream, and incremental mining methods
- Diversity of data types
  - Handling complex types of data
  - Mining dynamic, networked, and global data repositories
- Data mining and society
  - Social impacts of data mining
  - Privacy-preserving data mining
  - Invisible data mining

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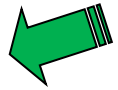
- A Brief History of Data Mining and Data Mining Society 
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A Brief History of Data Mining Society

- 1989 IJCAI Workshop on Knowledge Discovery in Databases
  - Knowledge Discovery in Databases (G. Piatetsky-Shapiro and W. Frawley, 1991)
- 1991-1994 Workshops on Knowledge Discovery in Databases
  - Advances in Knowledge Discovery and Data Mining (U. Fayyad, G. Piatetsky-Shapiro, P. Smyth, and R. Uthurusamy, 1996)
- 1995-1998 International Conferences on Knowledge Discovery in Databases and Data Mining (KDD'95-98)
  - Journal of Data Mining and Knowledge Discovery (1997)
- ACM SIGKDD conferences since 1998 and SIGKDD Explorations
- More conferences on data mining
  - SDM (2001), (IEEE) ICDM (2001), WSDM (2008), PKDD (1997), PAKDD (1997), etc.
- ACM Transactions on KDD (2007), IEEE Transactions on KDE (1989)

Conferences and Journals on Data Mining

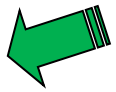
- KDD Conferences
  - ACM SIGKDD Int. Conf. on Knowledge Discovery in Databases and Data Mining (KDD)
  - SIAM Data Mining Conf. (SDM)
  - (IEEE) Int. Conf. on Data Mining (ICDM)
  - European Conf. on Machine Learning and Principles and practices of Knowledge Discovery and Data Mining (ECML-PKDD)
  - Pacific-Asia Conf. on Knowledge Discovery and Data Mining (PAKDD)
  - Int. Conf. on Web Search and Data Mining (WSDM)
- Other related conferences
  - DB conferences: ACM SIGMOD, VLDB, ICDE, EDBT, ICDT, …
  - Web and IR conferences: WWW, SIGIR, WSDM
  - ML conferences: ICML, NeurIPS, AISTATS, COLT, UAI, …
  - Vision/Language conferences: CVPR, ICCV,ACL, EMNLP, …
- Journals
  - Data Mining and Knowledge Discovery (DAMI or DMKD)
  - IEEE Trans. On Knowledge and Data Eng. (TKDE)
  - KDD Explorations
  - ACM Trans. on KDD

References? DBLP, Google, arXiv, CiteSeer

- Data mining and KDD (SIGKDD)
  - Conferences: ACM-SIGKDD, IEEE-ICDM, SIAM-DM, PKDD, PAKDD, etc.
  - Journal: Data Mining and Knowledge Discovery, KDD Explorations, ACM TKDD
- Database systems (SIGMOD)
  - Conferences: ACM-SIGMOD, ACM-PODS, VLDB, IEEE-ICDE, EDBT, ICDT, DASFAA
  - Journals: IEEE-TKDE, ACM-TODS/TOIS, JIIS, J. ACM, VLDB J., Info. Sys., etc.
- AI & Machine Learning
  - Conferences: NeurIPS, ICML, ICLR, AAAI, AISTATS, IJCAI, COLT, CVPR, ICCV, UAI, etc.
  - Journals: Machine Learning, Artificial Intelligence, Knowledge and Information Systems, IEEE-PAMI, etc.
- Web and IR
  - Conferences: SIGIR, WWW, CIKM, etc.
  - Journals: WWW: Internet and Web Information Systems,
- Statistics
  - Conferences: Joint Stat. Meeting, etc.
  - Journals: Annals of statistics, etc.
- Visualization
  - Conference proceedings: CHI, ACM-SIGGraph, etc.
  - Journals: IEEE Trans. visualization and computer graphics, etc.

Chapter 1. Introduction

- Why Data Mining?
- What Is Data Mining?
- A Multi-Dimensional View of Data Mining
- What Kinds of Data Can Be Mined?
- What Kinds of Patterns Can Be Mined?
- What Kinds of Technologies Are Used?
- What Kinds of Applications Are Targeted?
- Major Issues in Data Mining
- A Brief History of Data Mining and Data Mining Society
- Summary



Summary

- Data mining: Discovering interesting patterns and knowledge from massive amount of data
- A natural evolution of science and information technology, in great demand, with wide applications
- A KDD process includes data cleaning, data integration, data selection, transformation, data mining, pattern evaluation, and knowledge presentation
- Mining can be performed in a variety of data
- Data mining functionalities: characterization, discrimination, association, classification, clustering, trend and outlier analysis, etc.
- Data mining technologies and applications
- Major issues in data mining

Recommended Reference Books

- Charu C. Aggarwal, Data Mining: The Textbook, Springer, 2015
- E. Alpaydin. Introduction to Machine Learning, 2nd ed., MIT Press, 2011
- R. O. Duda, P. E. Hart, and D. G. Stork, Pattern Classification, 2ed., Wiley-Interscience, 2000
- U. Fayyad, G. Grinstein, and A. Wierse, Information Visualization in Data Mining and Knowledge Discovery, Morgan Kaufmann, 2001
- J. Han, M. Kamber, and J. Pei, Data Mining: Concepts and Techniques. Morgan Kaufmann, 3rd ed. , 2011
- T. Hastie, R. Tibshirani, and J. Friedman, The Elements of Statistical Learning: Data Mining, Inference, and Prediction, 2nd ed., Springer, 2009
- T. M. Mitchell, Machine Learning, McGraw Hill, 1997
- P.-N. Tan, M. Steinbach and V. Kumar, Introduction to Data Mining, Wiley, 2005 (2nd ed. 2016)
- I. H. Witten and E. Frank, Data Mining: Practical Machine Learning Tools and Techniques with Java Implementations, Morgan Kaufmann, 2nd ed. 2005
- Mohammed J. Zaki and Wagner Meira Jr., Data Mining and Analysis: Fundamental Concepts and Algorithms, Cambridge University Press, 2014