MSCIT BD 5002: Knowledge Discovery and Data Mining

Acknowledgement: Slides modified by Dr. Lei Chen based on the slides provided by Jiawei Han, Micheline Kamber, and Jian Pei

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Course Description

- Data Mining and Knowledge Discovery
- Topics:
  - Introduction
  - Getting to Know Your Data
  - Data Preprocessing
  - Data Warehouse and OLAP Technology: An Introduction
  - Advanced Data Cube Technology
  - Mining Frequent Patterns & Association: Basic Concepts
  - Mining Frequent Patterns & Association: Advanced Methods
  - Classification: Basic Concepts
  - Classification: Advanced Methods
  - Cluster Analysis: Basic Concepts
  - Cluster Analysis: Advanced Methods
  - Outlier Analysis:
Important Sites

- **Instructor Web Site**

- **TA:**

- **Assignment Hand-in: online**
- **Course Discussion Site:**
  - Check out the web site
Prerequisites

- Statistics and Probability would help,
  - but not necessary
- Pattern Recognition would help,
  - but not necessary
- Databases
  - Knowledge of SQL and relational algebra
  - But not necessary
- One programming language
  - One of Java, C++, Perl, Matlab, etc.
  - Will need to read Java Library
Grading

- Grade Distribution:
  - Assignments 20%
  - Project 20%
  - Exams 60%
    - Midterm 20%
    - Final 40%
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
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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, ...
    - Science: Remote sensing, bioinformatics, scientific simulation, ...
    - Society and everyone: news, digital cameras, YouTube
- We are drowning in data, but starving for knowledge!
- “Necessity is the mother of invention”—Data mining—Automated analysis of massive data sets
Evolution of Sciences: New Data Science Era

- Before 1600: **Empirical science**
- 1600-1950s: **Theoretical science**
  - Each discipline has grown a *theoretical* component. Theoretical models often motivate experiments and generalize our understanding.
- 1950s-1990s: **Computational science**
  - Over the last 50 years, most disciplines have grown a third, *computational* branch (e.g. empirical, theoretical, and computational ecology, or physics, or linguistics.)
  - Computational Science traditionally meant simulation. It grew out of our inability to find closed-form solutions for complex mathematical models.
- 1990-now: **Data science**
  - The flood of data from new scientific instruments and simulations
  - The ability to economically store and manage petabytes of data online
  - The Internet and computing Grid that makes all these archives universally accessible
  - Scientific info. management, acquisition, organization, query, and visualization tasks scale almost linearly with data volumes
  - **Data mining** is a major new challenge!

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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 view from typical database systems and data warehousing 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

Increasing potential to support business decisions

- Decision Making
- Data Presentation
  - Visualization Techniques
- Data Mining
  - Information Discovery
- Data Exploration
  - Statistical Summary, Querying, and Reporting
- Data Preprocessing/Integration, Data Warehouses
- Data Sources
  - Paper, Files, Web documents, Scientific experiments, Database Systems

End User

Business Analyst

Data Analyst

DBA
KDD Process: A Typical View from ML and Statistics

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

**Input Data** ➔ **Data Pre-Processing** ➔ **Data Mining** ➔ **Post-Processing** ➔ Knowledge

- **Data integration**
- **Normalization**
- **Feature selection**
- **Dimension reduction**

- **Pattern discovery**
- **Association & correlation**
- **Classification**
- **Clustering**
- **Outlier analysis**
- ... … … … …

- **Pattern evaluation**
- **Pattern selection**
- **Pattern interpretation**
- **Pattern visualization**
Which View Do You Prefer?

- 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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Multi-Dimensional View of Data Mining

- **Data to be mined**
  - Database data (extended-relational, object-oriented, heterogeneous, legacy), 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, etc.
  - 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
- 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 multi-linked data
  - Object-relational databases
  - Heterogeneous databases and legacy databases
  - Spatial data and spatiotemporal data
  - Multimedia database
  - Text databases
  - The World-Wide Web
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Data Mining Function: (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 Function: (2) Association and Correlation Analysis

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

- Association, correlation vs. causality
  - A typical association rule
    - Diaper $\rightarrow$ 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 Function: (3) Classification

- Classification and label prediction
  - Construct models (functions) based on some training examples
  - Describe and distinguish classes or concepts for future prediction
    - E.g., classify countries based on (climate), or 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 Function: (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 Function: (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
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., first buy digital camera, then buy large SD 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
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” and knowledge
- 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

- Machine Learning
- Pattern Recognition
- Statistics
- Applications
- Visualization
- Algorithm
- Database Technology
- High-Performance Computing

Data Mining
Why Confluence of Multiple Disciplines?

- Tremendous amount of data
  - Algorithms must be highly scalable to handle such as tera-bytes of 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 networks and multi-linked data
  - Heterogeneous databases and legacy databases
  - Spatial, spatiotemporal, multimedia, text and Web data
  - Software programs, scientific simulations
- New and sophisticated applications
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Applications of Data Mining

- Web page analysis: from web page classification, clustering to PageRank & HITS algorithms
- Collaborative analysis & recommender systems
- Basket data analysis to targeted marketing
- Biological and medical data analysis: classification, cluster analysis (microarray data analysis), biological sequence analysis, biological network analysis
- Data mining and software engineering (e.g., IEEE Computer, Aug. 2009 issue)
- From major dedicated data mining systems/tools (e.g., SAS, MS SQL-Server Analysis Manager, Oracle Data Mining Tools) to invisible data mining
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Major Issues 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 Issues 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 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
- ACM Transactions on KDD (2007)
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, NIPS
- PR conferences: CVPR,

Journals
- Data Mining and Knowledge Discovery (DAMI or DMKD)
- IEEE Trans. On Knowledge and Data Eng. (TKDE)
- KDD Explorations
- ACM Trans. on KDD
Where to Find References? DBLP, CiteSeer, Google

- **Data mining and KDD (SIGKDD: CDROM)**
  - Conferences: ACM-SIGKDD, IEEE-ICDM, SIAM-DM, PKDD, PAKDD, etc.
  - Journal: Data Mining and Knowledge Discovery, KDD Explorations, ACM TKDD

- **Database systems (SIGMOD: ACM SIGMOD Anthology—CD ROM)**
  - Conferences: ACM-SIGMOD, ACM-PODS, VLDB, IEEE-ICDE, EDBT, ICDT, DASFAA

- **AI & Machine Learning**
  - Conferences: Machine learning (ML), AAAI, IJCAI, COLT (Learning Theory), CVPR, NIPS, 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.
Recommended Reference Books

- U. Fayyad, G. Grinstein, and A. Wierse. *Information Visualization in Data Mining and Knowledge Discovery*, Morgan Kaufmann, 2001
- Y. Sun and J. Han. *Mining Heterogeneous Information Networks*, Morgan & Claypool, 2012
- P.-N. Tan, M. Steinbach and V. Kumar. *Introduction to Data Mining*, Wiley, 2005
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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