Data Mining:
Concepts and Techniques
(3rd ed.)

— Chapter 13 —

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Chapter 13: Data Mining Trends and Research Frontiers

- Mining Complex Types of Data

- Other Methodologies of Data Mining

- Data Mining Applications

- Data Mining and Society

- Data Mining Trends

- Summary

Mining Complex Types of Data

- Mining Sequence Data
  - Mining Time Series
  - Mining Symbolic Sequences
  - Mining Biological Sequences
- Mining Graphs and Networks
- Mining Other Kinds of Data

Mining Sequence Data

- Similarity Search in Time Series Data

  - Subsequence match, dimensionality reduction, query-based similarity search, motif-based similarity search

- Regression and Trend Analysis in Time-Series Data

  - long term + cyclic + seasonal variation + random movements

- Sequential Pattern Mining in Symbolic Sequences

  - GSP, PrefixSpan, constraint-based sequential pattern mining

- Sequence Classification

  - Feature-based vs. sequence-distance-based vs. model-based

- Alignment of Biological Sequences

  - Pair-wise vs. multi-sequence alignment, substitution matirces, BLAST

- Hidden Markov Model for Biological Sequence Analysis

  - Markov chain vs. hidden Markov models, forward vs. Viterbi vs. Baum-Welch algorithms

Mining Graphs and Networks

- Graph Pattern Mining
  - Frequent subgraph patterns, closed graph patterns, gSpan vs. CloseGraph
- Statistical Modeling of Networks
  - Small world phenomenon, power law (log-tail) distribution, densification
- Clustering and Classification of Graphs and Homogeneous Networks
  - Clustering: Fast Modularity vs. SCAN
  - Classification: model vs. pattern-based mining
- Clustering, Ranking and Classification of Heterogeneous Networks
  - RankClus, RankClass, and meta path-based, user-guided methodology
- Role Discovery and Link Prediction in Information Networks
  - PathPredict
- Similarity Search and OLAP in Information Networks: PathSim, GraphCube
- Evolution of Social and Information Networks: EvoNetClus

Mining Other Kinds of Data

- Mining Spatial Data
  - Spatial frequent/co-located patterns, spatial clustering and classification
- Mining Spatiotemporal and Moving Object Data
  - Spatiotemporal data mining, trajectory mining, periodica, swarm, …
- Mining Cyber-Physical System Data
  - Applications: healthcare, air-traffic control, flood simulation
- Mining Multimedia Data
  - Social media data, geo-tagged spatial clustering, periodicity analysis, …
- Mining Text Data
  - Topic modeling, i-topic model, integration with geo- and networked data
- Mining Web Data
  - Web content, web structure, and web usage mining
- Mining Data Streams
  - Dynamics, one-pass, patterns, clustering, classification, outlier detection

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Other Methodologies of Data Mining
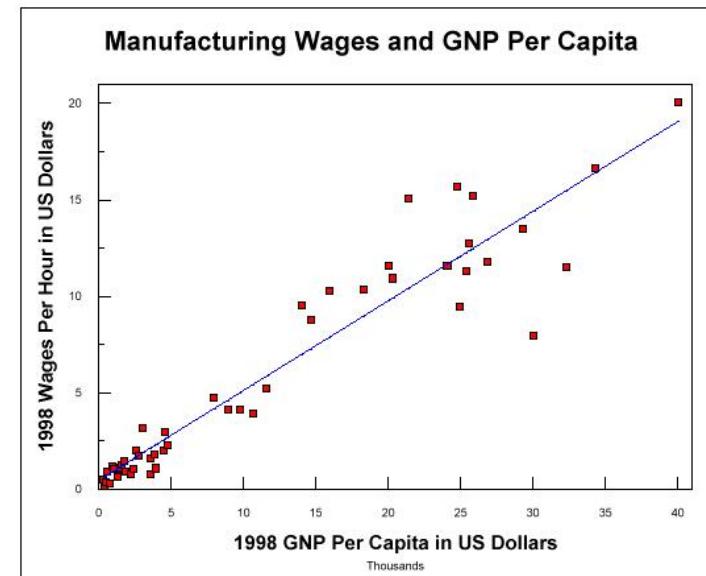
- Statistical Data Mining
- Views on Data Mining Foundations
- Visual and Audio Data Mining

Major Statistical Data Mining Methods

- Regression

- Generalized Linear Model

- Analysis of Variance

- Mixed-Effect Models

- Factor Analysis

- Discriminant Analysis

- Survival Analysis

Statistical Data Mining (1)

- There are many well-established statistical techniques for data analysis, particularly for numeric data
  - applied extensively to data from scientific experiments and data from economics and the social sciences

- **Regression**

  - predict the value of a response (dependent) variable from one or more predictor (independent) variables where the variables are numeric

 - forms of regression: linear, multiple, weighted, polynomial, nonparametric, and robust

Manufacturing Wages and GNP Per Capita
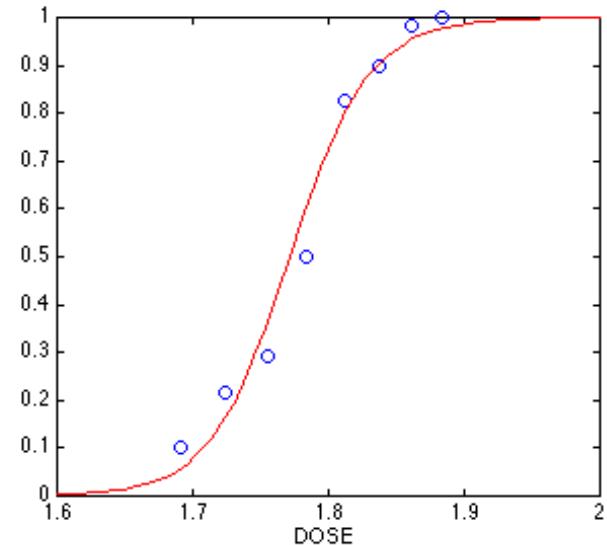
Scientific and Statistical Data Mining (2)

- **Generalized linear models**
  - allow a categorical response variable (or some transformation of it) to be related to a set of predictor variables
  - similar to the modeling of a numeric response variable using linear regression
  - include logistic regression and Poisson regression

- **Mixed-effect models**
  - For analyzing grouped data, i.e. data that can be classified according to one or more grouping variables
  - Typically describe relationships between a response variable and some covariates in data grouped according to one or more factors
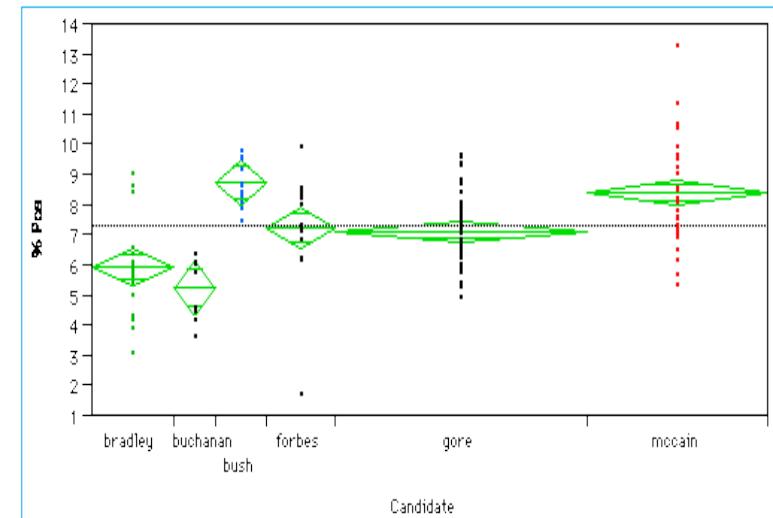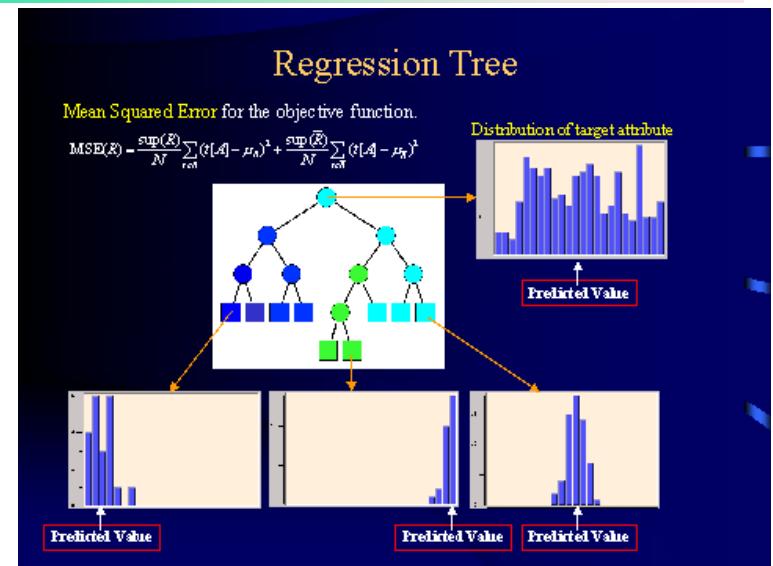
Scientific and Statistical Data Mining (3)

- **Regression trees**
  - Binary trees used for classification and prediction
  - Similar to decision trees: Tests are performed at the internal nodes
  - In a regression tree the mean of the objective attribute is computed and used as the predicted value
- **Analysis of variance**
  - Analyze experimental data for two or more populations described by a numeric response variable and one or more categorical variables (factors)

Statistical Data Mining (4)
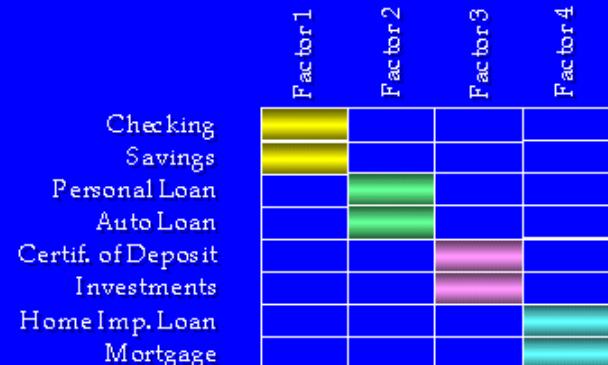
- **Factor analysis**
  - determine which variables are combined to generate a given factor
  - e.g., for many psychiatric data, one can indirectly measure other quantities (such as test scores) that reflect the factor of interest
- **Discriminant analysis**
  - predict a categorical response variable, commonly used in social science
  - Attempts to determine several discriminant functions (linear combinations of the independent variables) that discriminate among the groups defined by the response variable
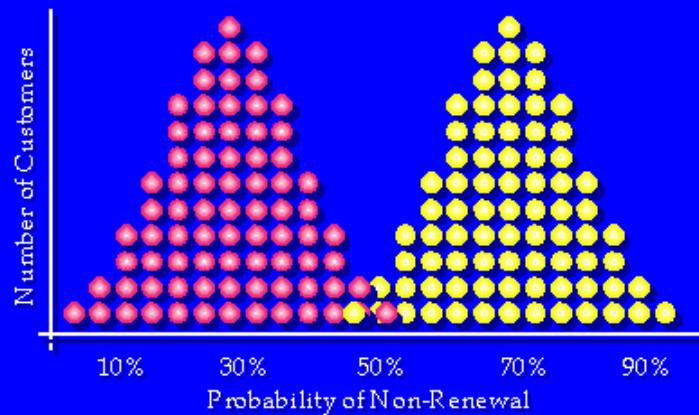
www.spss.com/datamine/factor.htm
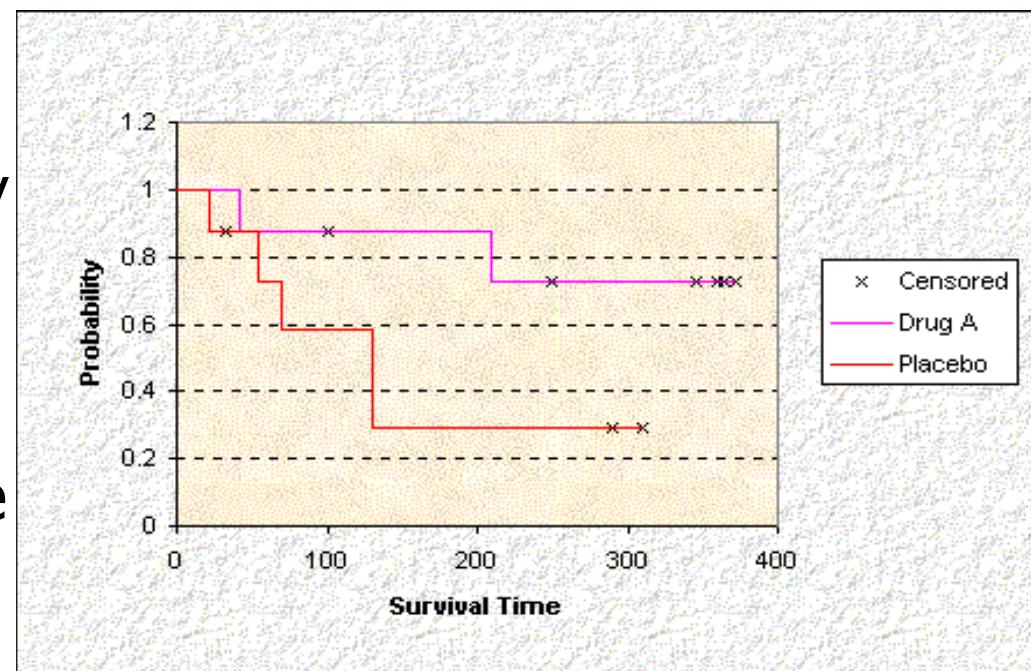
Statistical Data Mining (5)

- **Time series**: many methods such as autoregression, ARIMA (Autoregressive integrated moving-average modeling), long memory time-series modeling

- **Quality control:** displays group summary charts

- **Survival analysis**
  - Predicts the probability that a patient undergoing a medical treatment would survive at least to time t (life span prediction)

Other Methodologies of Data Mining

- Statistical Data Mining

- Views on Data Mining Foundations

- Visual and Audio Data Mining

Views on Data Mining Foundations (I)

- Data reduction
  - Basis of data mining: Reduce data representation
  - Trades accuracy for speed in response
- Data compression
  - Basis of data mining: Compress the given data by encoding in terms of bits, association rules, decision trees, clusters, etc.
- Probability and statistical theory
  - Basis of data mining: Discover joint probability distributions of random variables

Views on Data Mining Foundations (II)
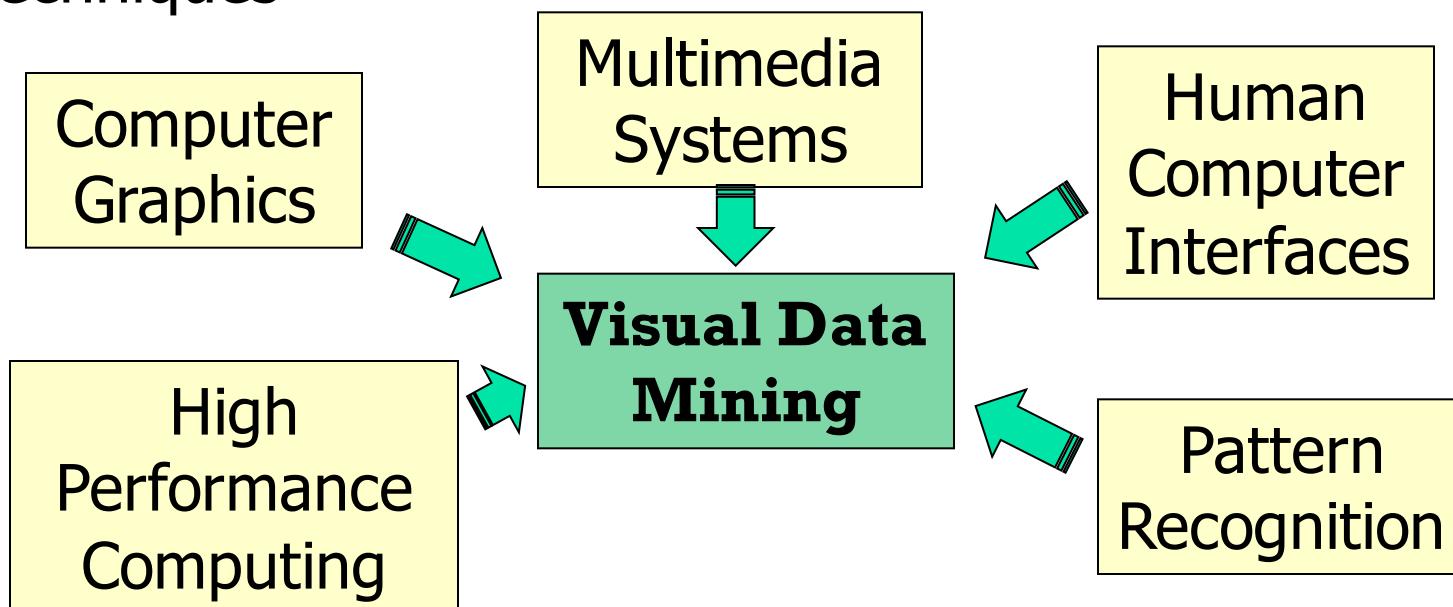
- Microeconomic view

  - A view of utility: Finding patterns that are interesting only to the extent in that they can be used in the decision-making process of some enterprise

- Pattern Discovery and Inductive databases

  - Basis of data mining: Discover patterns occurring in the database, such as associations, classification models, sequential patterns, etc.

  - Data mining is the problem of performing inductive logic on databases

  - The task is to query the data and the theory (i.e., patterns) of the database

  - Popular among many researchers in database systems

Other Methodologies of Data Mining

- Statistical Data Mining

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Visual Data Mining

- Visualization: Use of computer graphics to create visual images which aid in the understanding of complex, often massive representations of data

- Visual Data Mining: discovering implicit but useful knowledge from large data sets using visualization techniques

Visualization

- Purpose of Visualization
  - Gain insight into an information space by mapping data onto graphical primitives
  - Provide qualitative overview of large data sets
  - Search for patterns, trends, structure, irregularities, relationships among data.
  - Help find interesting regions and suitable parameters for further quantitative analysis.
  - Provide a visual proof of computer representations derived
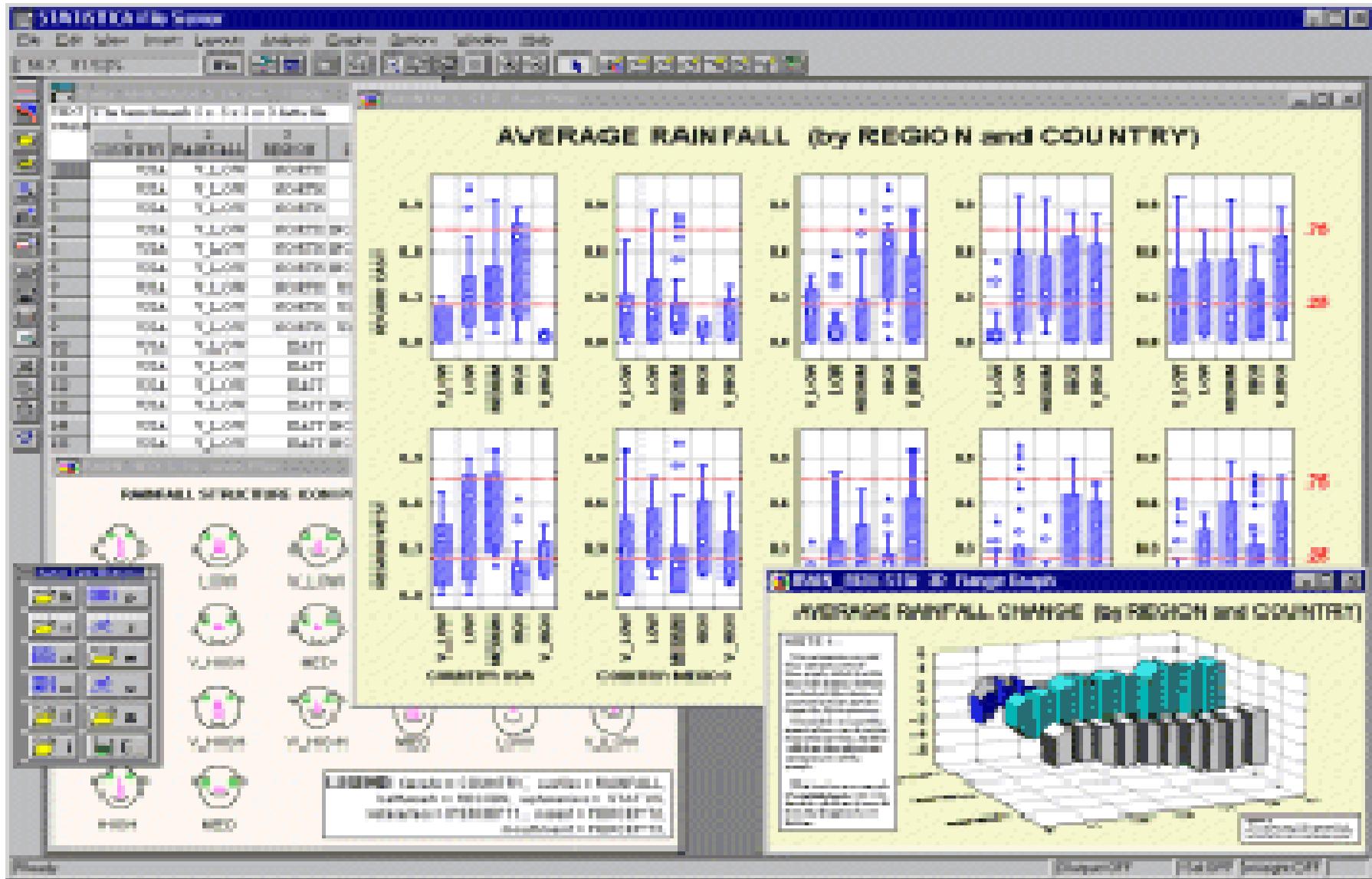
Visual Data Mining & Data Visualization

- Integration of visualization and data mining
  - data visualization
  - data mining result visualization
  - data mining process visualization
  - interactive visual data mining
- Data visualization
  - Data in a database or data warehouse can be viewed
    - at different levels of abstraction
    - as different combinations of attributes or dimensions
  - Data can be presented in various visual forms
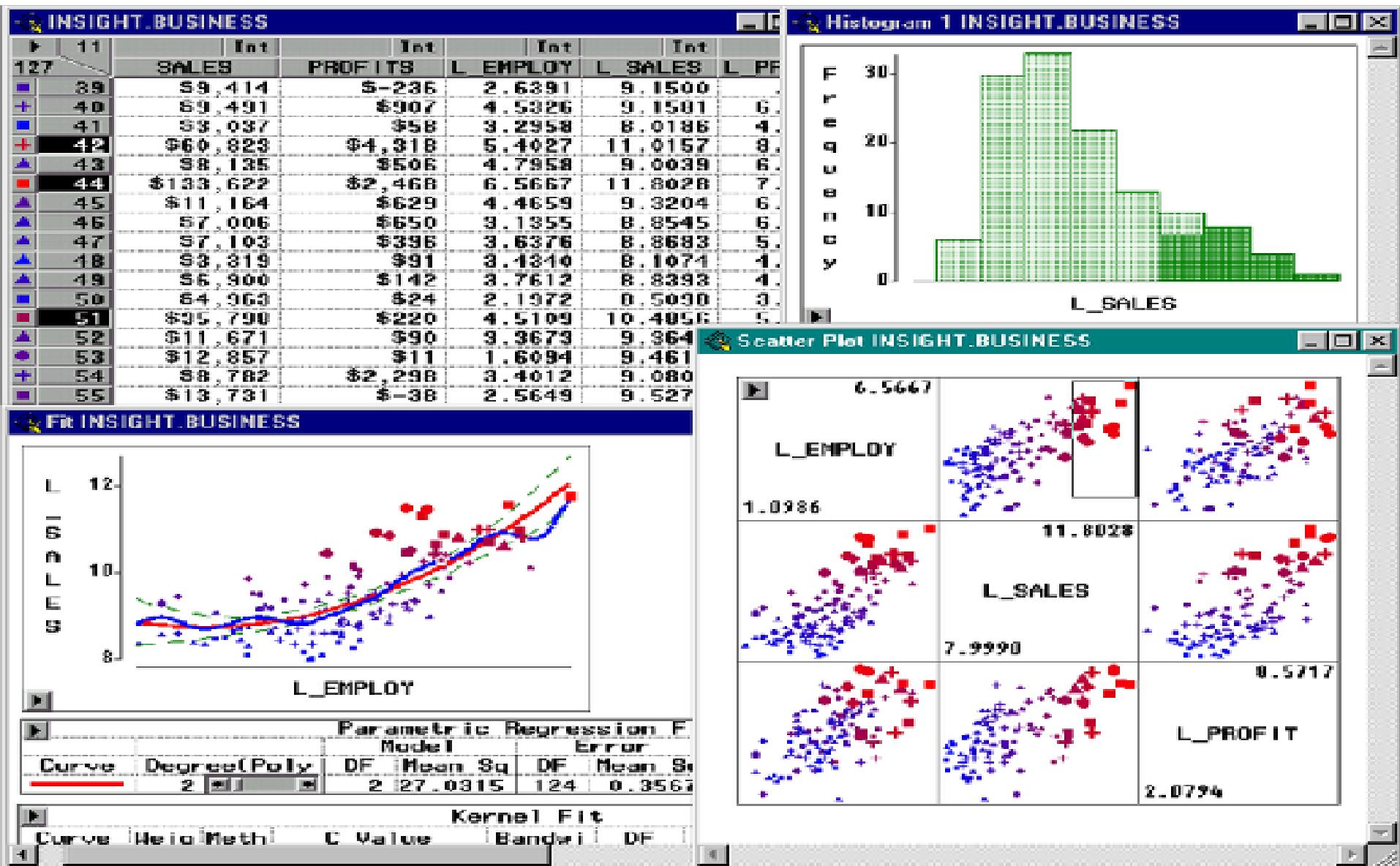
Data Mining Result Visualization

- Presentation of the results or knowledge obtained from data mining in visual forms

- Examples
    - Scatter plots and boxplots (obtained from descriptive data mining)
    - Decision trees
    - Association rules
    - Clusters
    - Outliers
    - Generalized rules
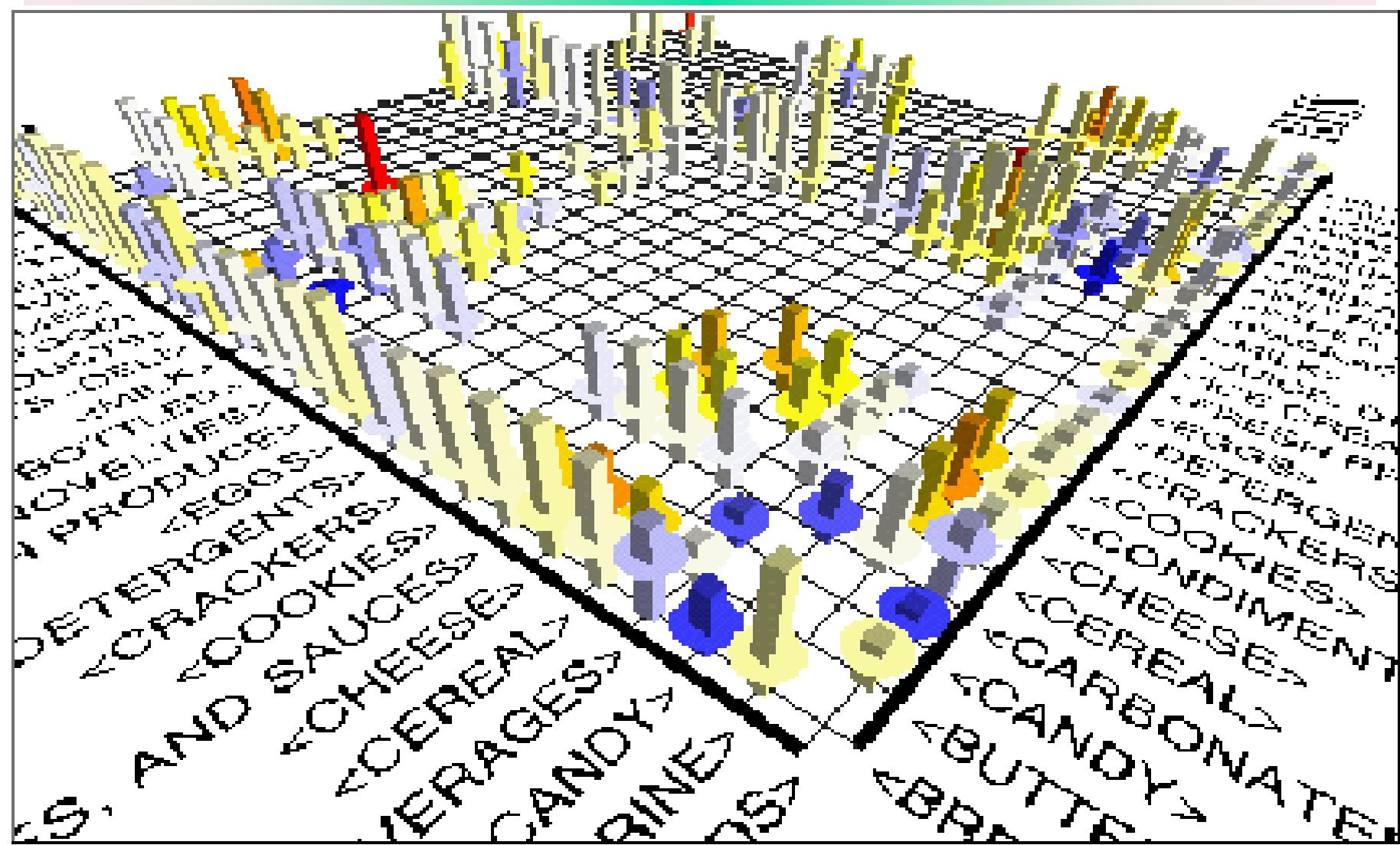
Boxplots from Statsoft: Multiple Variable Combinations
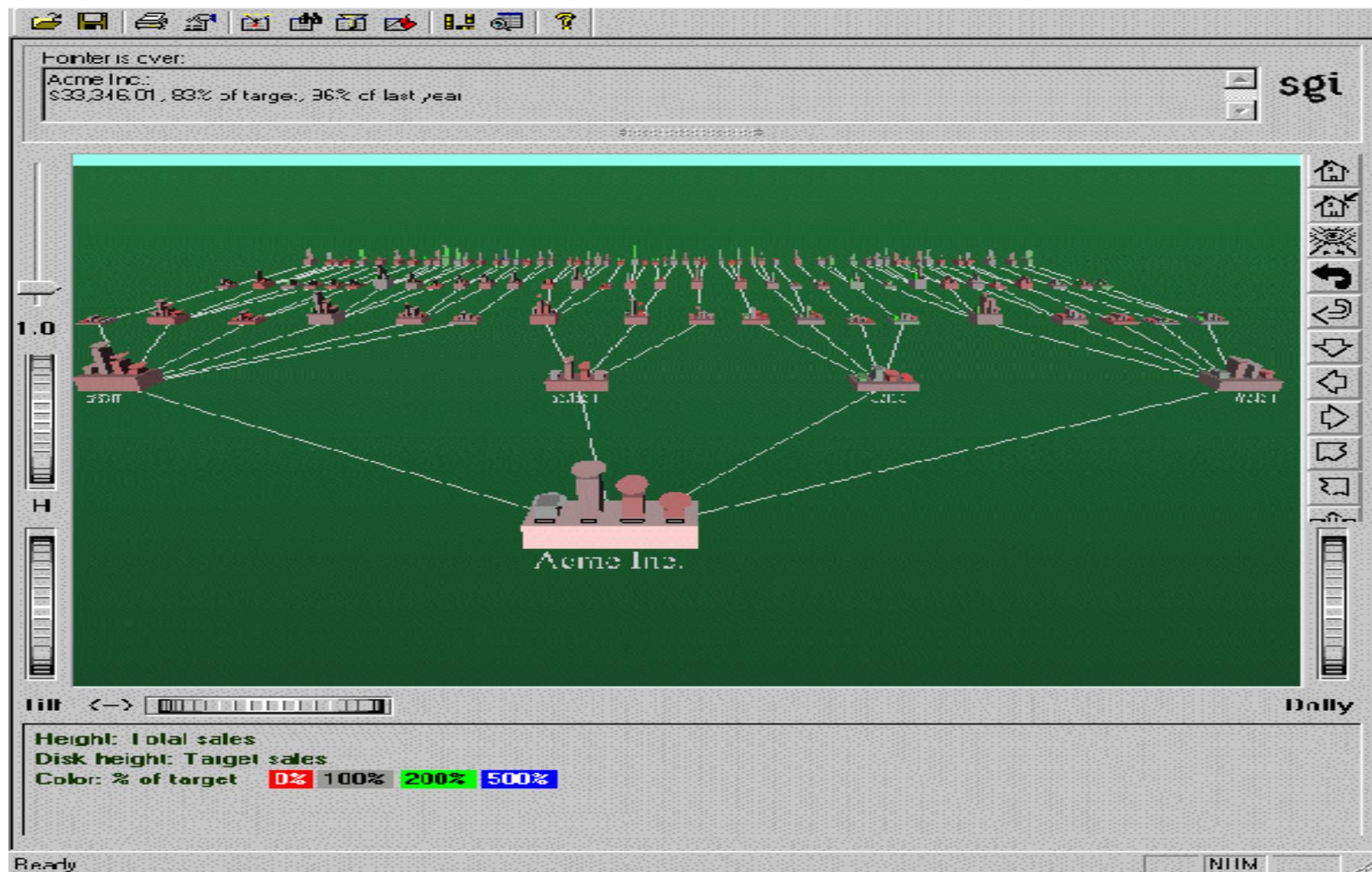
Visualization of Data Mining Results in SAS Enterprise Miner: Scatter Plots
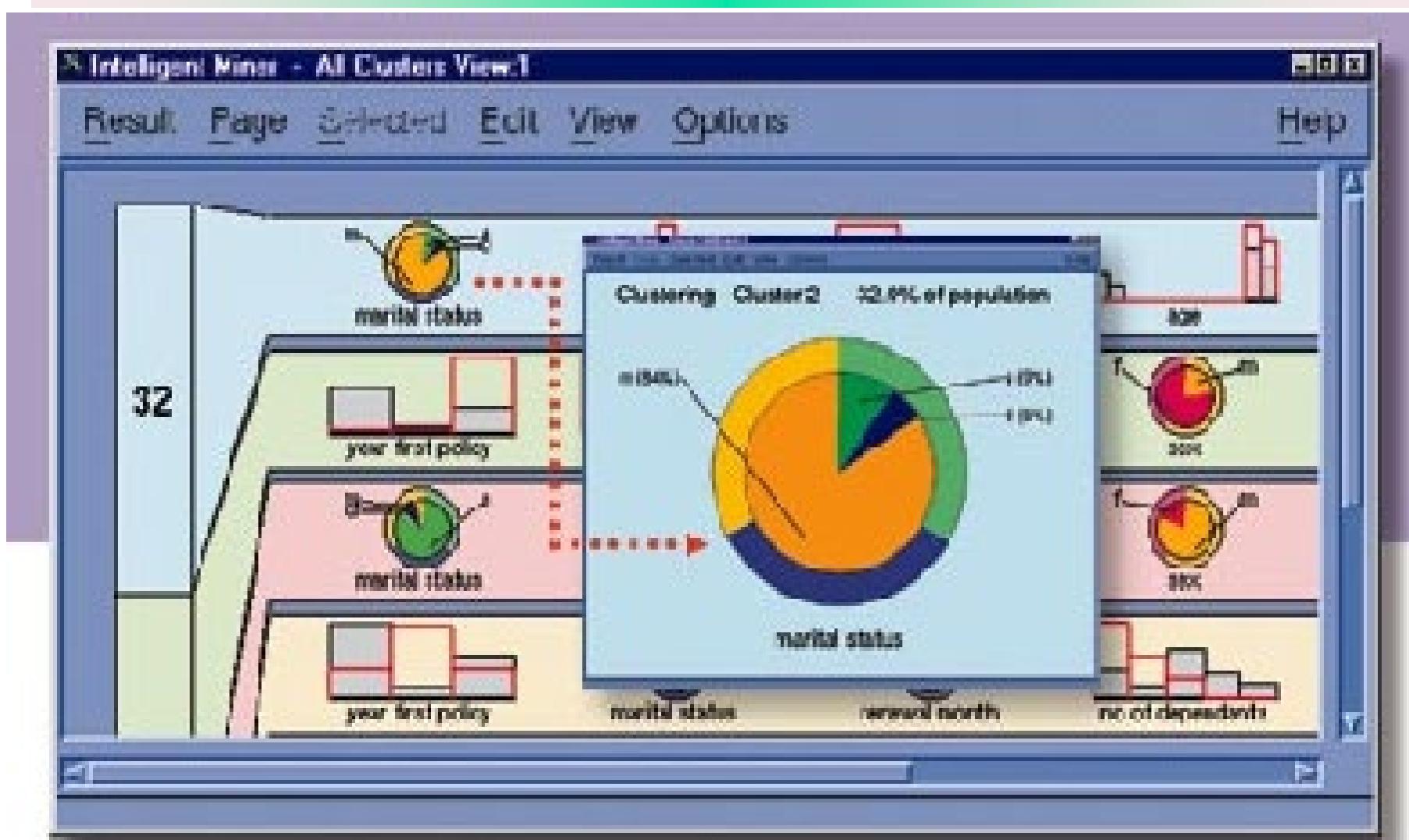
Visualization of Association Rules in SGI/MineSet 3.0

Visualization of a **Decision Tree** in SGI/MineSet 3.0

Visualization of Cluster Grouping in IBM Intelligent Miner
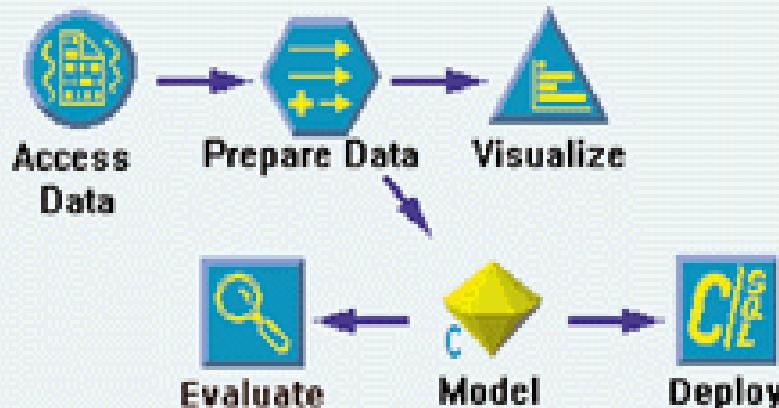
Data Mining Process Visualization

- Presentation of the various processes of data mining in visual forms so that users can see

  - Data extraction process

  - Where the data is extracted

  - How the data is cleaned, integrated, preprocessed, and mined

  - Method selected for data mining

  - Where the results are stored

  - How they may be viewed
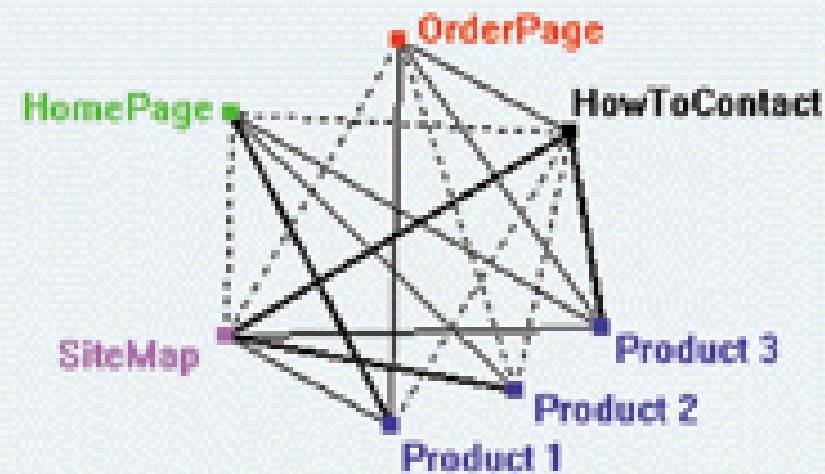
Visualization of Data Mining Processes by Clementine

See your solution discovery process clearly
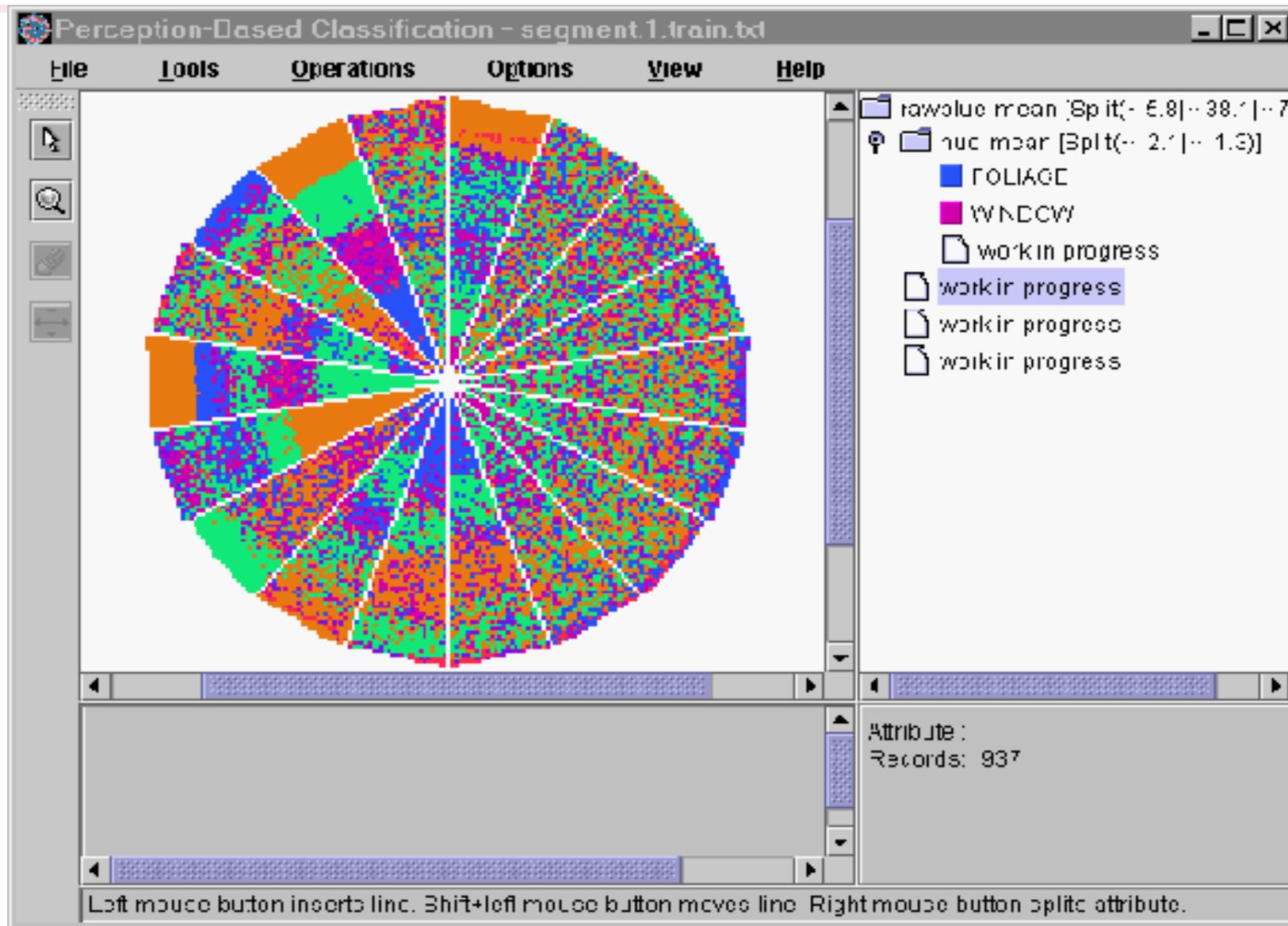
Understand variations with visualized data

Interactive Visual Data Mining

- Using visualization tools in the data mining process to help users make smart data mining decisions

- Example

  - Display the data distribution in a set of attributes using colored sectors or columns (depending on whether the whole space is represented by either a circle or a set of columns)

  - Use the display to which sector should first be selected for classification and where a good split point for this sector may be

Interactive Visual Mining by Perception-Based Classification (PBC)

Audio Data Mining

- Uses audio signals to indicate the patterns of data or the features of data mining results

- An interesting alternative to visual mining

- An inverse task of mining audio (such as music) databases which is to find patterns from audio data

- Visual data mining may disclose interesting patterns using graphical displays, but requires users to concentrate on watching patterns

- Instead, transform patterns into sound and music and listen to pitches, rhythms, tune, and melody in order to identify anything interesting or unusual

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Data Mining Applications

- Data mining: A young discipline with broad and diverse applications
  - There still exists a nontrivial gap between generic data mining methods and effective and scalable data mining tools for domain-specific applications
- Some application domains (briefly discussed here)
  - Data Mining for Financial data analysis
  - Data Mining for Retail and Telecommunication Industries
  - Data Mining in Science and Engineering
  - Data Mining for Intrusion Detection and Prevention
  - Data Mining and Recommender Systems

Data Mining for Financial Data Analysis (I)

- Financial data collected in banks and financial institutions are often relatively complete, reliable, and of high quality

- Design and construction of data warehouses for multidimensional data analysis and data mining
  - View the debt and revenue changes by month, by region, by sector, and by other factors
  - Access statistical information such as max, min, total, average, trend, etc.

- Loan payment prediction/consumer credit policy analysis
  - feature selection and attribute relevance ranking
  - Loan payment performance
  - Consumer credit rating

Data Mining for Financial Data Analysis (II)

- Classification and clustering of customers for targeted marketing
  - multidimensional segmentation by nearest-neighbor, classification, decision trees, etc. to identify customer groups or associate a new customer to an appropriate customer group
- Detection of money laundering and other financial crimes
  - integration of from multiple DBs (e.g., bank transactions, federal/state crime history DBs)
  - Tools: data visualization, linkage analysis, classification, clustering tools, outlier analysis, and sequential pattern analysis tools (find unusual access sequences)

Data Mining for Retail & Telcomm. Industries (I)

- Retail industry: huge amounts of data on sales, customer shopping history, e-commerce, etc.

- Applications of retail data mining
  - Identify customer buying behaviors
  - Discover customer shopping patterns and trends
  - Improve the quality of customer service
  - Achieve better customer retention and satisfaction
  - Enhance goods consumption ratios
  - Design more effective goods transportation and distribution policies

- Telcomm. and many other industries: Share many similar goals and expectations of retail data mining

Data Mining Practice for Retail Industry

- Design and construction of data warehouses

- Multidimensional analysis of sales, customers, products, time, and region

- Analysis of the effectiveness of sales campaigns

- Customer retention: Analysis of customer loyalty

  - Use customer loyalty card information to register sequences of purchases of particular customers

  - Use sequential pattern mining to investigate changes in customer consumption or loyalty

  - Suggest adjustments on the pricing and variety of goods

- Product recommendation and cross-reference of items

- Fraudulent analysis and the identification of usual patterns

- Use of visualization tools in data analysis

Data Mining in Science and Engineering

- Data warehouses and data preprocessing

  - Resolving inconsistencies or incompatible data collected in diverse environments and different periods (e.g. eco-system studies)

- Mining complex data types

  - Spatiotemporal, biological, diverse semantics and relationships

- Graph-based and network-based mining

  - Links, relationships, data flow, etc.

- Visualization tools and domain-specific knowledge

- Other issues

  - Data mining in social sciences and social studies: text and social media

  - Data mining in computer science: monitoring systems, software bugs, network intrusion

Data Mining for Intrusion Detection and Prevention

- Majority of intrusion detection and prevention systems use

  - Signature-based detection: use signatures, attack patterns that are preconfigured and predetermined by domain experts

  - Anomaly-based detection: build profiles (models of normal behavior) and detect those that are substantially deviate from the profiles

- What data mining can help

  - New data mining algorithms for intrusion detection

  - Association, correlation, and discriminative pattern analysis help select and build discriminative classifiers

  - Analysis of stream data: outlier detection, clustering, model shifting

  - Distributed data mining

  - Visualization and querying tools

Data Mining and Recommender Systems

- Recommender systems: Personalization, making product recommendations that are likely to be of interest to a user
- Approaches: Content-based, collaborative, or their hybrid
  - Content-based: Recommends items that are similar to items the user preferred or queried in the past
  - Collaborative filtering: Consider a user's social environment, opinions of other customers who have similar tastes or preferences
- Data mining and recommender systems
  - Users C $\times$ items S: extract from known to unknown ratings to predict user-item combinations
  - Memory-based method often uses k-nearest neighbor approach
  - Model-based method uses a collection of ratings to learn a model (e.g., probabilistic models, clustering, Bayesian networks, etc.)
  - Hybrid approaches integrate both to improve performance (e.g., using ensemble)

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Ubiquitous and Invisible Data Mining

- Ubiquitous Data Mining

    - Data mining is used everywhere, e.g., online shopping

    - Ex. Customer relationship management (CRM)

- Invisible Data Mining

    - Invisible: Data mining functions are built in daily life operations

    - Ex. Google search: Users may be unaware that they are examining results returned by data

    - Invisible data mining is highly desirable

    - Invisible mining needs to consider efficiency and scalability, user interaction, incorporation of background knowledge and visualization techniques, finding interesting patterns, real-time, …

    - Further work: Integration of data mining into existing business and scientific technologies to provide domain-specific data mining tools

Privacy, Security and Social Impacts of Data Mining

- Many data mining applications do not touch personal data
  - E.g., meteorology, astronomy, geography, geology, biology, and other scientific and engineering data
- Many DM studies are on developing scalable algorithms to find general or statistically significant patterns, not touching individuals
- The real privacy concern: unconstrained access of individual records, especially privacy-sensitive information
- Method 1: Removing sensitive IDs associated with the data
- Method 2: Data security-enhancing methods
  - Multi-level security model: permit to access to only authorized level
  - Encryption: e.g., *blind signatures*, *biometric encryption*, and *anonymous databases* (personal information is encrypted and stored at different locations)
- Method 3: Privacy-preserving data mining methods

Privacy-Preserving Data Mining

- Privacy-preserving (privacy-enhanced or privacy-sensitive) mining:
  - Obtaining valid mining results without disclosing the underlying sensitive data values
  - Often needs trade-off between information loss and privacy
- Privacy-preserving data mining methods:
  - Randomization (e.g., perturbation): Add noise to the data in order to mask some attribute values of records
  - K-anonymity and l-diversity: Alter individual records so that they cannot be uniquely identified
    - k-anonymity: Any given record maps onto at least k other records
    - l-diversity: enforcing intra-group diversity of sensitive values
  - Distributed privacy preservation: Data partitioned and distributed either horizontally, vertically, or a combination of both
  - Downgrading the effectiveness of data mining: The output of data mining may violate privacy
    - Modify data or mining results, e.g., hiding some association rules or slightly distorting some classification models

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Trends of Data Mining

- Application exploration: Dealing with application-specific problems

- Scalable and interactive data mining methods

- Integration of data mining with Web search engines, database systems, data warehouse systems and cloud computing systems

- Mining social and information networks

- Mining spatiotemporal, moving objects and cyber-physical systems

- Mining multimedia, text and web data

- Mining biological and biomedical data

- Data mining with software engineering and system engineering

- Visual and audio data mining

- Distributed data mining and real-time data stream mining

- Privacy protection and information security in data mining

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Summary

- We present a high-level overview of mining complex data types

- Statistical data mining methods, such as regression, generalized linear models, analysis of variance, etc., are popularly adopted

- Researchers also try to build theoretical foundations for data mining

- Visual/audio data mining has been popular and effective

- Application-based mining integrates domain-specific knowledge with data analysis techniques and provide mission-specific solutions

- Ubiquitous data mining and invisible data mining are penetrating our data lives

- Privacy and data security are importance issues in data mining, and privacy-preserving data mining has been developed recently

- Our discussion on trends in data mining shows that data mining is a promising, young field, with great, strategic importance

References and Further Reading

❖ The books lists a lot of references for further reading. Here we only list a few books

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