DATA MINING

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LECTURE 1

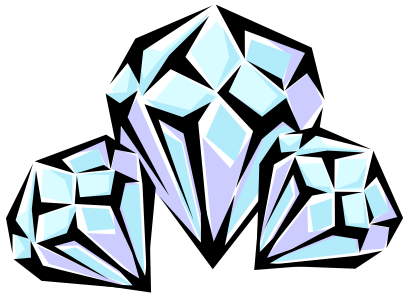
Introduction

What is data mining?

- After years of data mining there is still no unique answer to this question.

- A tentative definition:

Data mining is the use of efficient techniques for the analysis of very large collections of data and the extraction of useful and possibly unexpected patterns in data.



Why do we need data mining?

- Really, really huge amounts of raw data!!
  - In the digital age, TB of data is generated by the second
    - Mobile devices, digital photographs, web documents.
    - Facebook updates, Tweets, Blogs, User-generated content
    - Transactions, sensor data, surveillance data
    - Queries, clicks, browsing
  - Cheap storage has made possible to maintain this data
- Need to analyze the raw data to extract knowledge

Why do we need data mining?

- "The data is the computer"
  - Large amounts of data can be more powerful than complex algorithms and models
    - Google has solved many Natural Language Processing problems, simply by looking at the data
    - Example: misspellings, synonyms
  - Data is power!
    - Today, the collected data is one of the biggest assets of an online company
      - Query logs of Google
      - The friendship and updates of Facebook
      - Tweets and follows of Twitter
      - Amazon transactions
  - We need a way to harness the collective intelligence

The data is also very complex

- Multiple types of data: tables, time series, images, graphs, etc
- Spatial and temporal aspects
- Interconnected data of different types:
  - From the mobile phone we can collect, location of the user, friendship information, check-ins to venues, opinions through twitter, images though cameras, queries to search engines

Example: transaction data

- Billions of real-life customers:
  - WALMART: 20M transactions per day
  - AT&T 300 M calls per day
  - Credit card companies: billions of transactions per day.
- The point cards allow companies to collect information about specific users

Example: document data

- Web as a document repository: estimated 50 billions of web pages
- Wikipedia: 4 million articles (and counting)
- Online news portals: steady stream of 100’s of new articles every day
- Twitter: ~300 million tweets every day

Example: network data

- Web: 50 billion pages linked via hyperlinks
- Facebook: 500 million users
- Twitter: 300 million users
- Instant messenger: ~1billion users
- Blogs: 250 million blogs worldwide, presidential candidates run blogs

Example: genomic sequences

- http://www.1000genomes.org/page.php
- Full sequence of 1000 individuals
- $3*10^9$ nucleotides per person → $3*10^{12}$ nucleotides
- Lots more data in fact: medical history of the persons, gene expression data

Example: environmental data

- Climate data (just an example)

http://www.ncdc.gov/oa/climate/ghcn-monthly/index.php

- “a database of temperature, precipitation and pressure records managed by the National Climatic Data Center, Arizona State University and the Carbon Dioxide Information Analysis Center”

- “6000 temperature stations, 7500 precipitation stations, 2000 pressure stations”
  - Spatiotemporal data

Behavioral data

- Mobile phones today record a large amount of information about the user behavior
  - GPS records position
  - Camera produces images
  - Communication via phone and SMS
  - Text via facebook updates
  - Association with entities via check-ins
- Amazon collects all the items that you browsed, placed into your basket, read reviews about, purchased.
- Google and Bing record all your browsing activity via toolbar plugins. They also record the queries you asked, the pages you saw and the clicks you did.
- Data collected for millions of users on a daily basis

So, what is Data?

- Collection of data objects and their attributes

- An attribute is a property or characteristic of an object
  - Examples: eye color of a person, temperature, etc.
  - Attribute is also known as variable, field, characteristic, or feature
- A collection of attributes describe an object
  - Object is also known as record, point, case, sample, entity, or instance

Attributes

Outcome/ label/class

Objects

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	95K	Yes
6	No	Married	60K	No
7	Yes	Divorced	220K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes

Size: Number of objects
Dimensionality: Number of attributes
Sparsity: Number of populated object-attribute pairs

Types of Attributes

- There are different types of attributes
  - Categorical
    - Examples: eye color, zip codes, words, rankings (e.g, good, fair, bad), height in {tall, medium, short}
    - Nominal (no order or comparison) vs Ordinal (order but not comparable)
  - Numeric
    - Examples: dates, temperature, time, length, value, count.
    - Discrete (counts) vs Continuous (temperature)
    - Special case: Binary attributes (yes/no, exists/not exists)

Numeric Record Data

- If data objects have the same fixed set of numeric attributes, then the data objects can be thought of as points in a multi-dimensional space, where each dimension represents a distinct attribute

- Such data set can be represented by an n-by-d data matrix, where there are n rows, one for each object, and d columns, one for each attribute

Projection of x Load	Projection of y load	Distance	Load	Thickness
10.23	5.27	15.22	2.7	1.2
12.65	6.25	16.22	2.2	1.1

Categorical Data

- Data that consists of a collection of records, each of which consists of a fixed set of categorical attributes

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	High	No
2	No	Married	Medium	No
3	No	Single	Low	No
4	Yes	Married	High	No
5	No	Divorced	Medium	Yes
6	No	Married	Low	No
7	Yes	Divorced	High	No
8	No	Single	Medium	Yes
9	No	Married	Medium	No
10	No	Single	Medium	Yes

Document Data

- Each document becomes a `term' vector,
  - each term is a component (attribute) of the vector,
  - the value of each component is the number of times the corresponding term occurs in the document.
  - Bag-of-words representation – no ordering

	team	coach	play	ball	score	game	win	lost	timeout	season
Document 1	3	0	5	0	2	6	0	2	0	2
Document 2	0	7	0	2	1	0	0	3	0	0
Document 3	0	1	0	0	1	2	2	0	3	0

Transaction Data

- Each record (transaction) is a set of items.

TID	*Items*
1	Bread, Coke, Milk
2	Beer, Bread
3	Beer, Coke, Diaper, Milk
4	Beer, Bread, Diaper, Milk
5	Coke, Diaper, Milk

- A set of items can also be represented as a binary vector, where each attribute is an item.
- A document can also be represented as a set of words (no counts)

Sparsity: average number of products bought by a customer

Ordered Data

- Genomic sequence data

```
GGTTCCGCCTTCAGCCCCGCGCC
CGCAGGGCCCGCCCCGCGCCGTC
GAGAAGGGCCCGCCTGGCGGGCG
GGGGGAGGCGGGGCCGCCCGAGC
CCAACCGAGTCCGACCAGGTGCC
CCCTCTGCTCGGCCTAGACCTGA
GCTCATTAGGCGGCAGCGGACAG
GCCAAGTAGAACACGCGAAGCGC
TGGGCTGCCTGCTGCGACCAGGG
```

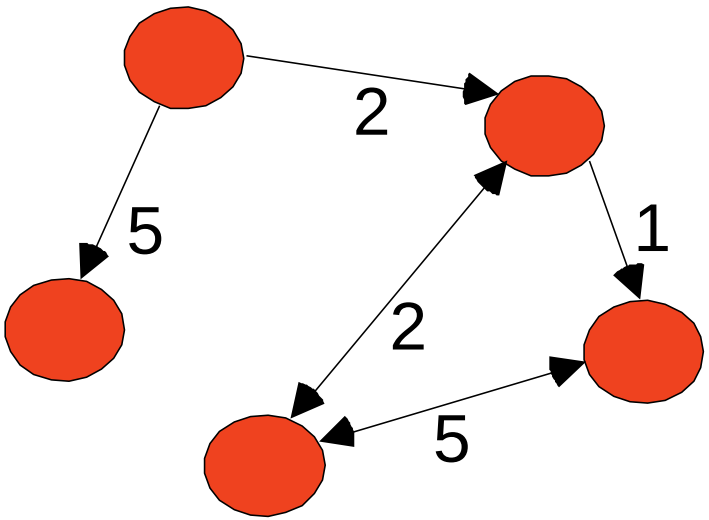
- Data is a long ordered string

Ordered Data

- Time series
  - Sequence of ordered (over “time”) numeric values.

Graph Data

- Examples: Web graph and HTML Links



Data Mining

Graph Partitioning

Parallel Solution of Sparse Linear System of Equations

<a href="papers/papers.html#ffff">
N-Body Computation and Dense Linear System Solvers

Types of data

- Numeric data: Each object is a point in a multidimensional space
- Categorical data: Each object is a vector of categorical values
- Set data: Each object is a set of values (with or without counts)
  - Sets can also be represented as binary vectors, or vectors of counts
- Ordered sequences: Each object is an ordered sequence of values.
- Graph data

What can you do with the data?

- Suppose that you are the owner of a supermarket and you have collected billions of market basket data. What information would you extract from it and how would you use it?

TID	*Items*
1	Bread, Coke, Milk
2	Beer, Bread
3	Beer, Coke, Diaper, Milk
4	Beer, Bread, Diaper, Milk
5	Coke, Diaper, Milk

Product placement

Catalog creation

Recommendations

- What if this was an online store?

What can you do with the data?

- Suppose you are a search engine and you have a toolbar log consisting of
  - pages browsed,
  - queries,
  - pages clicked,
  - ads clicked

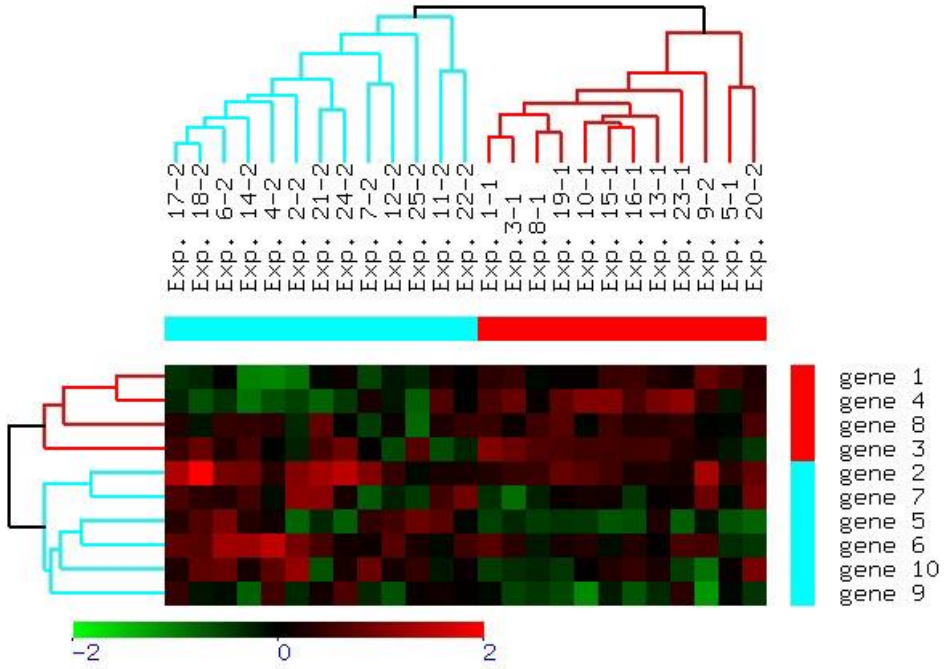
Ad click prediction

Query reformulations

each with a user id and a timestamp. What information would you like to get our of the data?

What can you do with the data?

- Suppose you are biologist who has microarray expression data: thousands of genes, and their expression values over thousands of different settings (e.g. tissues). What information would you like to get out of your data?



Groups of genes and tissues

What can you do with the data?

- Suppose you are a stock broker and you observe the fluctuations of multiple stocks over time. What information would you like to get our of your data?

What can you do with the data?

- You are the owner of a social network, and you have full access to the social graph, what kind of information do you want to get out of your graph?

- Who is the most important node in the graph?
- What is the shortest path between two nodes?
- How many friends two nodes have in common?
- How does information spread on the network?

Why data mining?

- Commercial point of view
  - Data has become the key competitive advantage of companies
    - Examples: Facebook, Google, Amazon
  - Being able to extract useful information out of the data is key for exploiting them commercially.
- Scientific point of view
  - Scientists are at an unprecedented position where they can collect TB of information
    - Examples: Sensor data, astronomy data, social network data, gene data
  - We need the tools to analyze such data to get a better understanding of the world and advance science
- Scale (in data size and feature dimension)
  - Why not use traditional analytic methods?
  - Enormity of data, curse of dimensionality
  - The amount and the complexity of data does not allow for manual processing of the data. We need automated techniques.

What is Data Mining again?

- "Data mining is the analysis of (often large) observational data sets to find unsuspected relationships and to summarize the data in novel ways that are both understandable and useful to the data analyst" (Hand, Mannila, Smyth)

- "Data mining is the discovery of models for data" (Rajaraman, Ullman)
  - We can have the following types of models
    - Models that explain the data (e.g., a single function)
    - Models that predict the future data instances.
    - Models that summarize the data
    - Models the extract the most prominent features of the data.

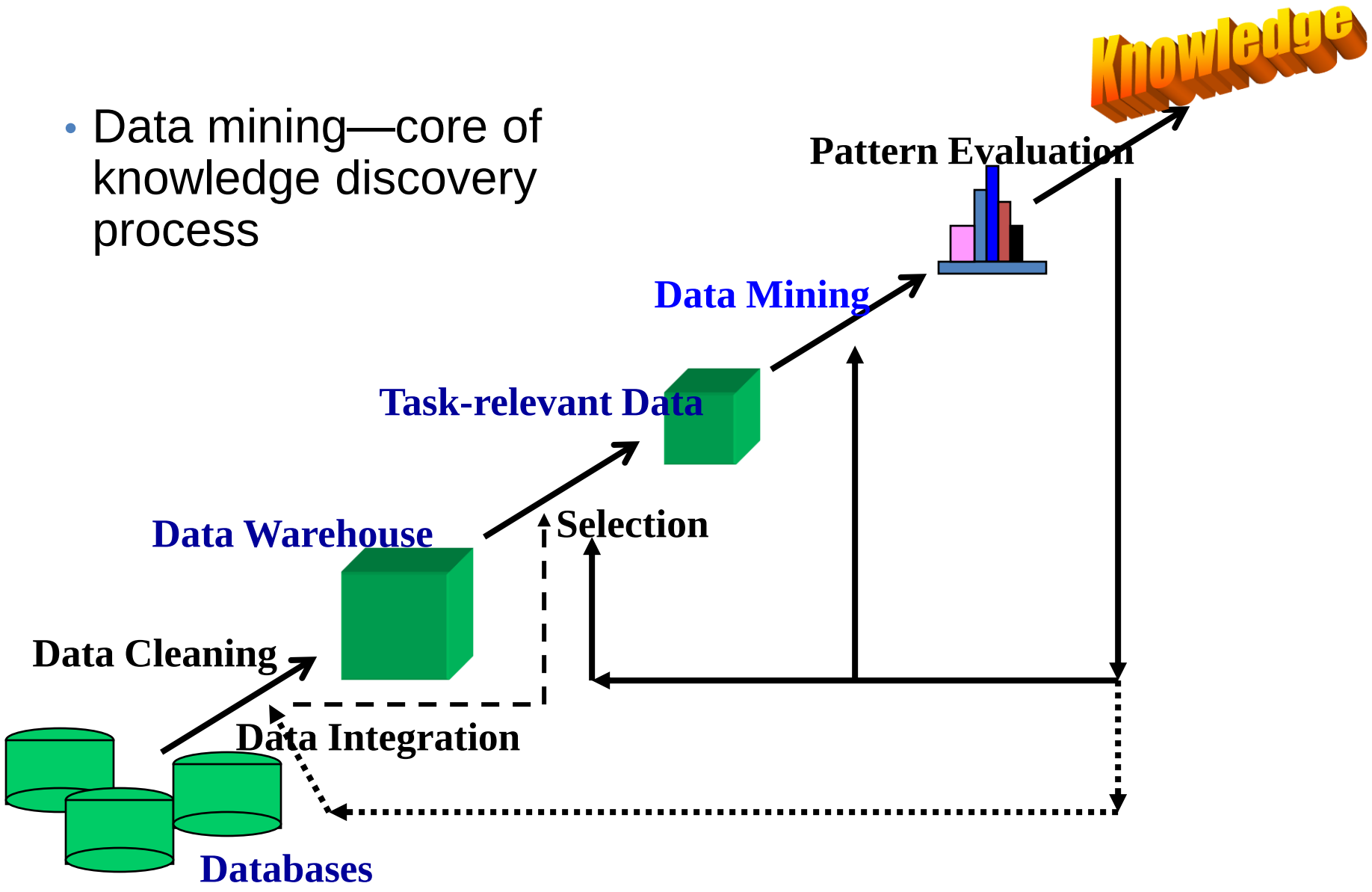
The Knowledge Discovery (KDD) process

- Problem fomulation
- Data collection
  - subset data: sampling might hurt if highly skewed data
  - feature selection: principal component analysis, heuristic search
- Pre-processing: cleaning
  - name/address cleaning, different meanings (annual, yearly), duplicate removal, supplying missing values
- Transformation:
  - map complex objects e.g. time series data to features e.g. frequency
- Choosing mining task and mining method:
- Result evaluation and Visualization:

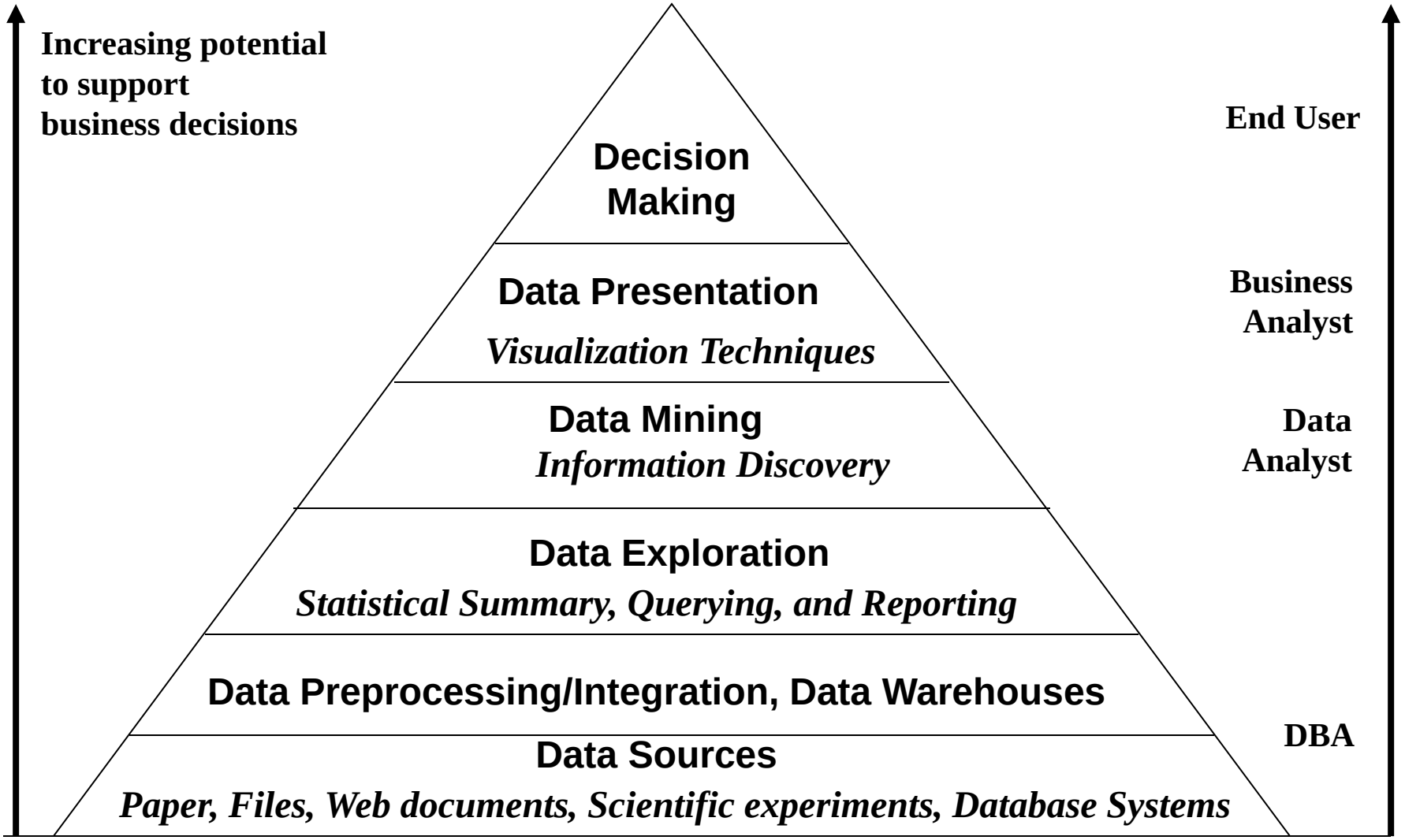
Knowledge discovery is an iterative process

Knowledge Discovery (KDD) Process

- Data mining—core of knowledge discovery process



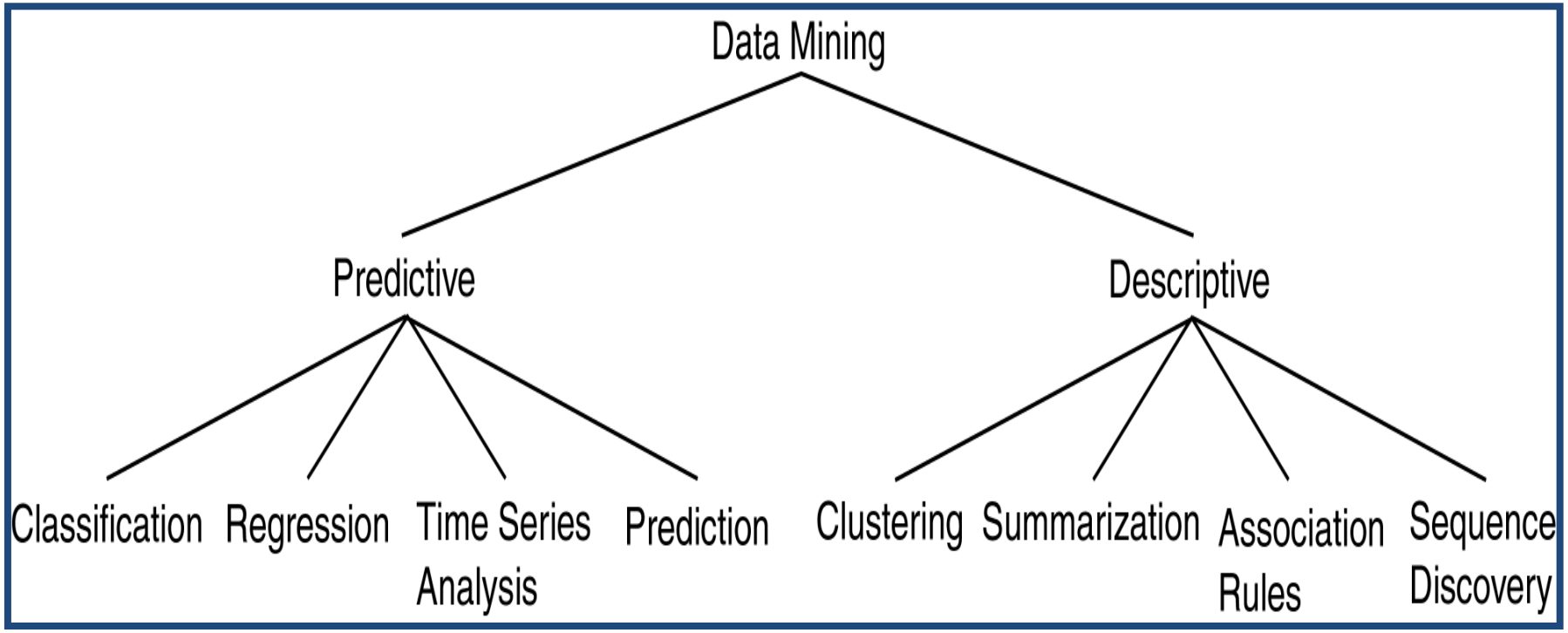
Data Mining and Business Intelligence



What can we do with data mining?

- Some examples:
  - Frequent itemsets and Association Rules extraction
  - Coverage
  - Clustering
  - Classification
  - Ranking
  - Exploratory analysis

Data Mining Models and Tasks



Frequent Itemsets and Association Rules

- Given a set of records each of which contain some number of items from a given collection;
  - Identify sets of items (itemsets) occurring frequently together
  - Produce dependency rules which will predict occurrence of an item based on occurrences of other items.

TID	Items
1	Bread, Coke, Milk
2	Beer, Bread
3	Beer, Coke, Diaper, Milk
4	Beer, Bread, Diaper, Milk
5	Coke, Diaper, Milk

Itemsets Discovered:
{Milk,Coke}
{Diaper, Milk}

Rules Discovered:
{Milk} --> {Coke}
{Diaper, Milk} --> {Beer}

Tan, M. Steinbach and V. Kumar, Introduction to Data Mining

Frequent Itemsets: Applications

- Text mining: finding associated phrases in text
  - There are lots of documents that contain the phrases "association rules", "data mining" and "efficient algorithm"

- Recommendations:
  - Users who buy this item often buy this item as well
  - Users who watched James Bond movies, also watched Jason Bourne movies.

  - Recommendations make use of item and user similarity

Association Rule Discovery: Application

- Supermarket shelf management.
  - Goal: To identify items that are bought together by sufficiently many customers.
  - Approach: Process the point-of-sale data collected with barcode scanners to find dependencies among items.
  - A classic rule --
    - If a customer buys diaper and milk, then he is very likely to buy beer.
    - So, don’t be surprised if you find six-packs stacked next to diapers!

Clustering Definition

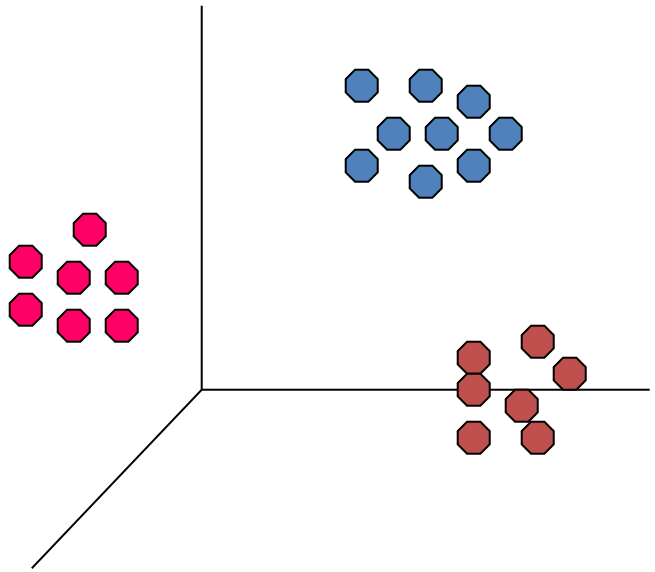
- Given a set of data points, each having a set of attributes, and a similarity measure among them, find clusters such that
  - Data points in one cluster are more similar to one another.
  - Data points in separate clusters are less similar to one another.
- Similarity Measures?
  - Euclidean Distance if attributes are continuous.
  - Other Problem-specific Measures.

Illustrating Clustering

Euclidean Distance Based Clustering in 3-D space.

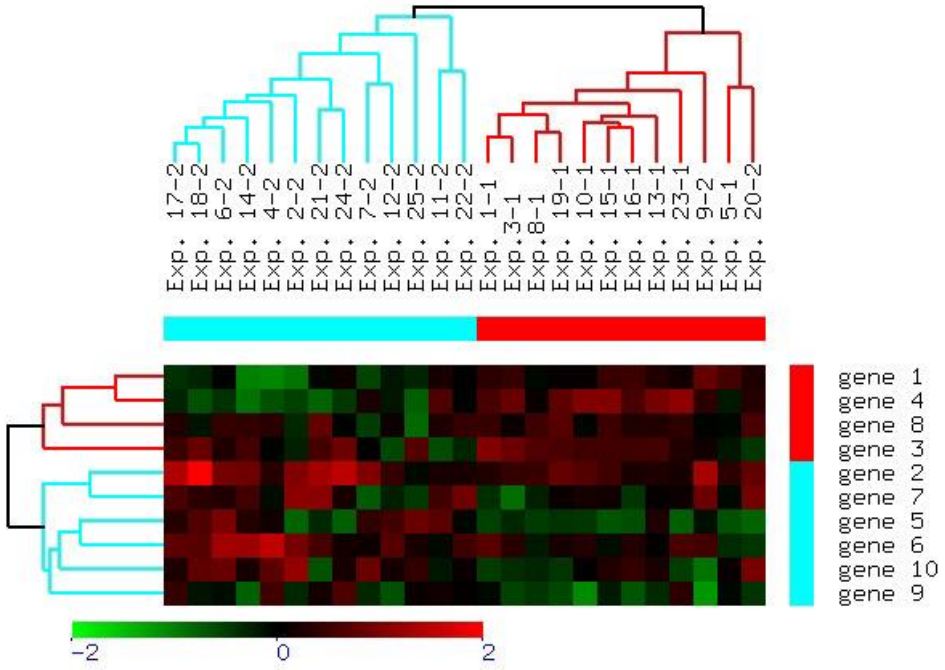
Intracluster distances are minimized

Intercluster distances are maximized



Clustering: Application 1

- Bioinformatics applications:
  - Goal: Group genes and tissues together such that genes are coexpressed on the same tissues



Clustering: Application 2

- Document Clustering:
  - Goal: To find groups of documents that are similar to each other based on the important terms appearing in them.
  - Approach: To identify frequently occurring terms in each document. Form a similarity measure based on the frequencies of different terms. Use it to cluster.
  - Gain: Information Retrieval can utilize the clusters to relate a new document or search term to clustered documents.

Clustering of S&P 500 Stock Data

- Observe Stock Movements every day.
- Cluster stocks if they change similarly over time.

	Discovered Clusters	*Industry Group*
1	Applied-Matl-DOWN,Bay-Network-Down,3-COM-DOWN, Cabletron-Sys-DOWN,CISCO-DOWN,HP-DOWN, DSC-Comm-DOWN,INTEL-DOWN,LSI-Logic-DOWN, Micron-Tech-DOWN,Texas-Inst-Down,Tellabs-Inc-Down, Natl-Semiconduct-DOWN,Oracl-DOWN,SGI-DOWN, Sun-DOWN	Technology1-DOWN
2	Apple-Comp-DOWN,Autodesk-DOWN,DEC-DOWN, ADV-Micro-Device-DOWN,Andrew-Corp-DOWN, Computer-Assoc-DOWN,Circuit-City-DOWN, Compaq-DOWN, EMC-Corp-DOWN, Gen-Inst-DOWN, Motorola-DOWN,Microsoft-DOWN,Scientific-Atl-DOWN	Technology2-DOWN
3	Fannie-Mae-DOWN,Fed-Home-Loan-DOWN, MBNA-Corp-DOWN,Morgan-Stanley-DOWN	Financial-DOWN
4	Baker-Hughes-UP,Dresser-Inds-UP,Halliburton-HLD-UP, Louisiana-Land-UP,Phillips-Petro-UP,Unocal-UP, Schlumberger-UP	Oil-UP

Coverage

- Given a set of customers and items and the transaction relationship between the two, select a small set of items that “covers” all users.
  - For each user there is at least one item in the set that the user has bought.

- Application:
  - Create a catalog to send out that has at least one item of interest for every customer.

Classification: Definition

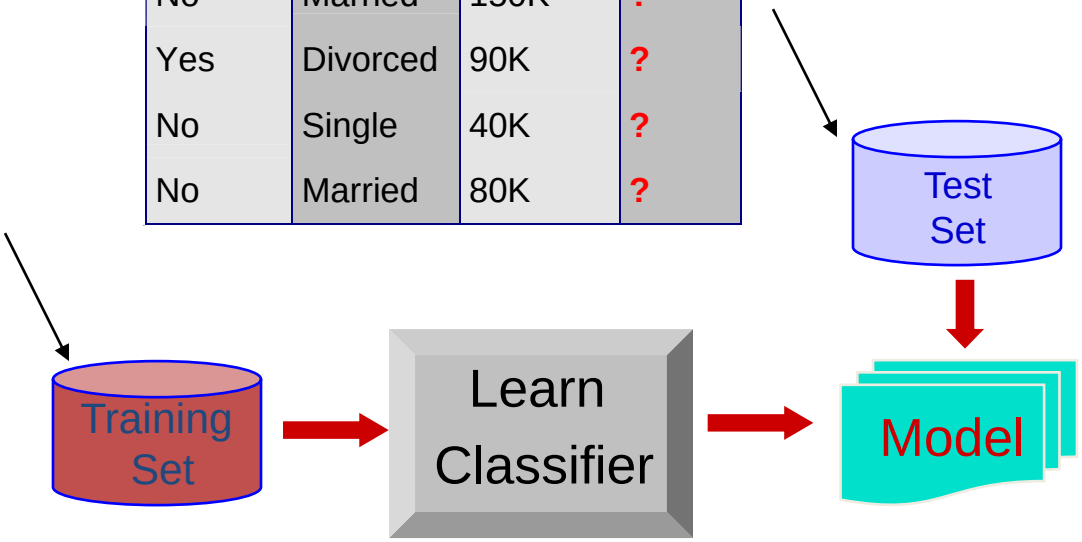
- Given a collection of records (*training set*)
  - Each record contains a set of *attributes*, one of the attributes is the *class*.
- Find a *model* for class attribute as a function of the values of other attributes.

- Goal: previously unseen records should be assigned a class as accurately as possible.
  - A *test set* is used to determine the accuracy of the model. Usually, the given data set is divided into training and test sets, with training set used to build the model and test set used to validate it.

Classification Example

Tid	Refund (categorical)	Marital Status (categorical)	Taxable Income (continuous)	Cheat (class)
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	95K	Yes
6	No	Married	60K	No
7	Yes	Divorced	220K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes

Refund	Marital Status	Taxable Income	Cheat
No	Single	75K	?
Yes	Married	50K	?
No	Married	150K	?
Yes	Divorced	90K	?
No	Single	40K	?
No	Married	80K	?



Classification: Application 1

- Ad Click Prediction
  - Goal: Predict if a user that visits a web page will click on a displayed ad. Use it to target users with high click probability.
  - Approach:
    - Collect data for users over a period of time and record who clicks and who does not. The {click, no click} information forms the class attribute.
    - Use the history of the user (web pages browsed, queries issued) as the features.
    - Learn a classifier model and test on new users.

Classification: Application 2

- Fraud Detection
  - Goal: Predict fraudulent cases in credit card transactions.
  - Approach:
    - Use credit card transactions and the information on its account-holder as attributes.
    - When does a customer buy, what does he buy, how often he pays on time, etc
    - Label past transactions as fraud or fair transactions. This forms the class attribute.
    - Learn a model for the class of the transactions.
    - Use this model to detect fraud by observing credit card transactions on an account.

Link Analysis Ranking

- Given a collection of web pages that are linked to each other, rank the pages according to importance (authoritativeness) in the graph
  - Intuition: A page gains authority if it is linked to by another page.

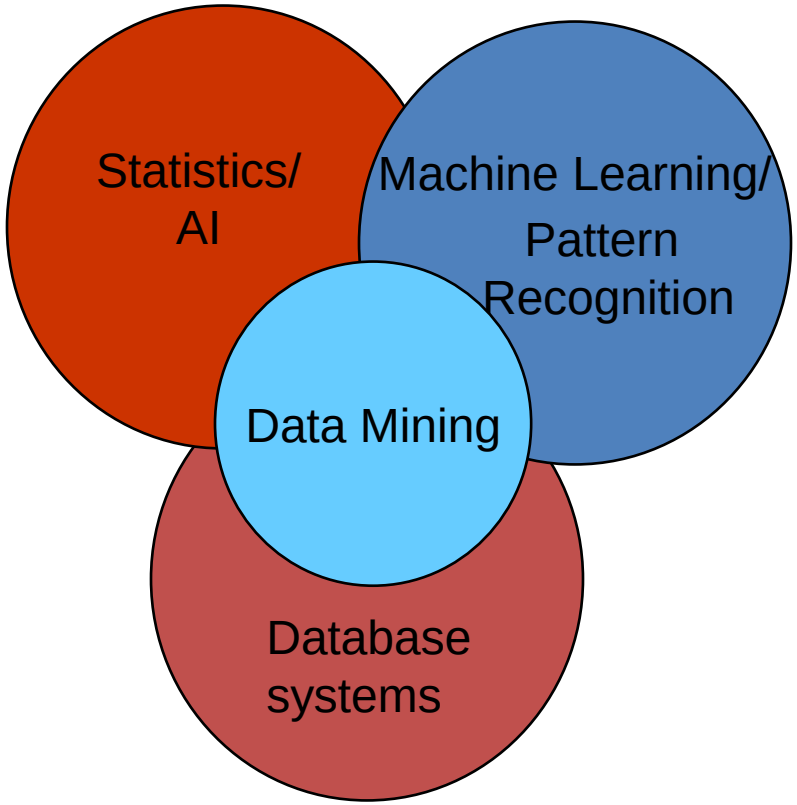
- Application: When retrieving pages, the authoritativeness is factored in the ranking.

Exploratory Analysis

- Trying to understand the data as a physical phenomenon, and describe them with simple metrics
  - What does the web graph look like?
  - How often do people repeat the same query?
  - Are friends in facebook also friends in twitter?
- The important thing is to find the right metrics and ask the right questions
- It helps our understanding of the world, and can lead to models of the phenomena we observe.

Connections of Data Mining with other areas

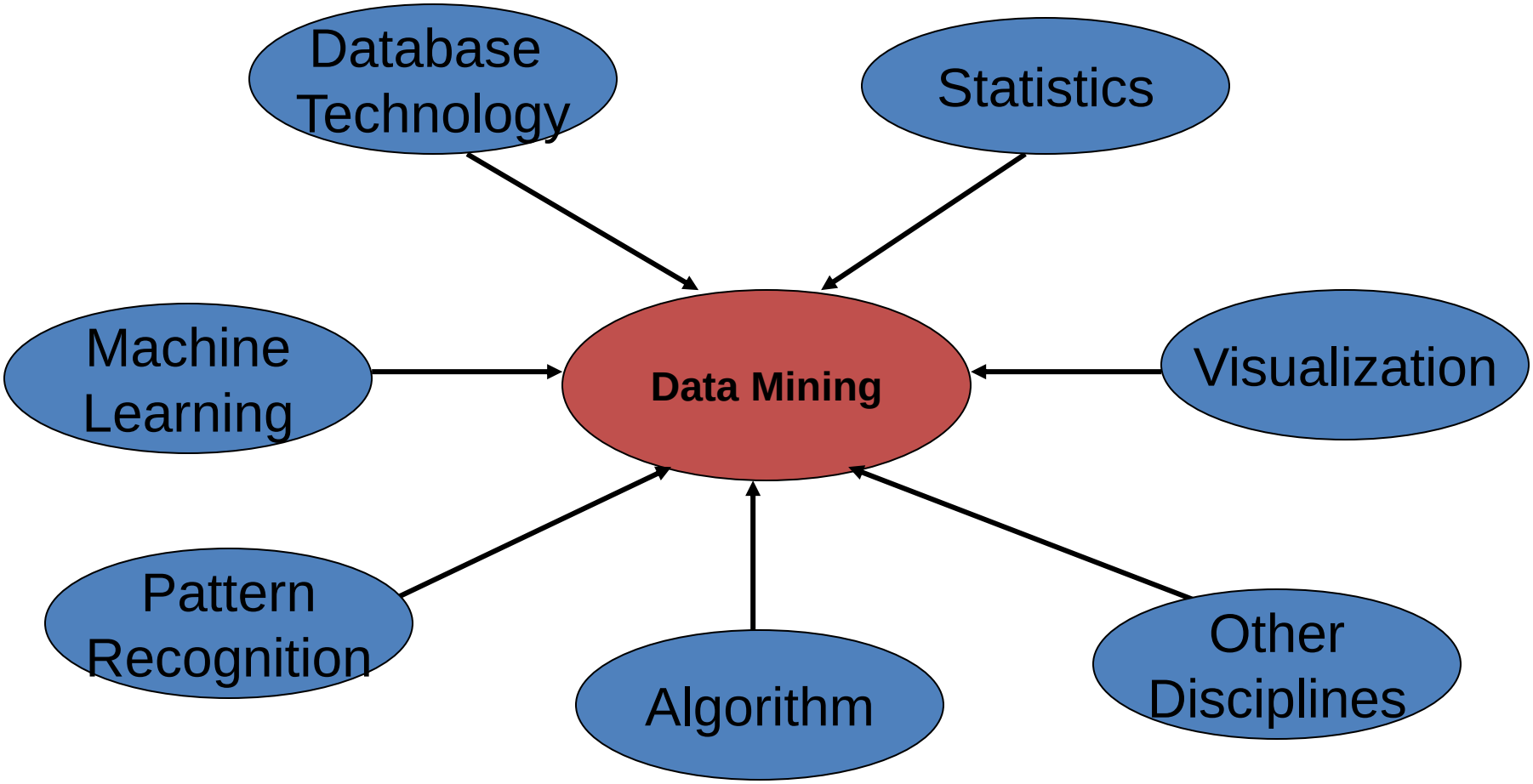
- Draws ideas from machine learning/AI, pattern recognition, statistics, and database systems
- Traditional Techniques may be unsuitable due to
  - Enormity of data
  - High dimensionality of data
  - Heterogeneous, distributed nature of data
  - Emphasis on the use of data



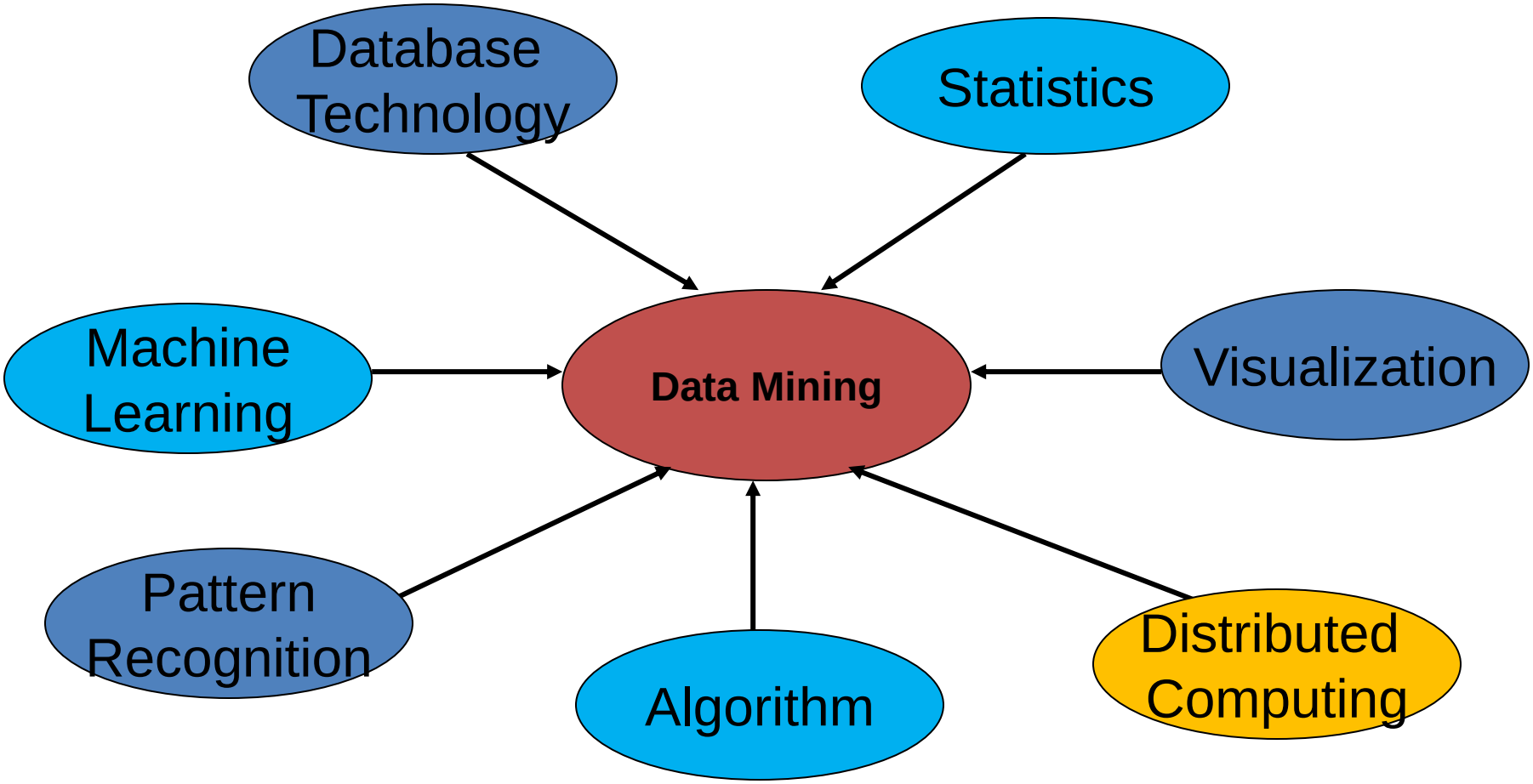
Cultures

- Databases: concentrate on large-scale (non-main-memory) data.
- AI (machine-learning): concentrate on complex methods, small data.
  - In today's world data is more important than algorithms
- Statistics: concentrate on models.

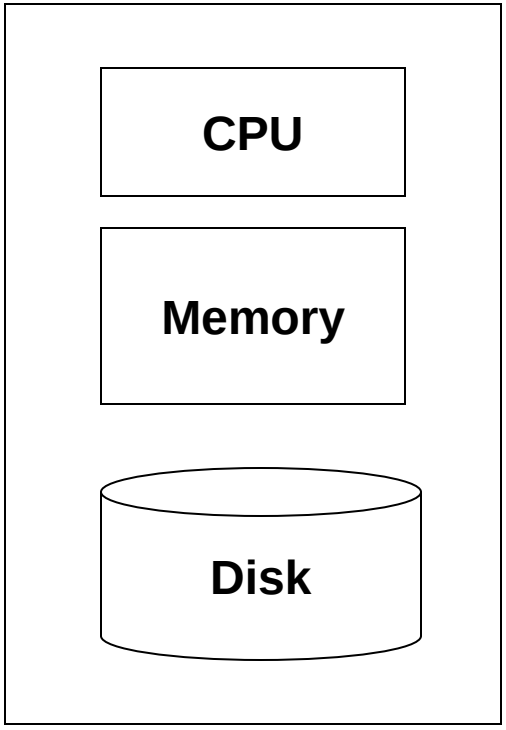
Data Mining: Confluence of Multiple Disciplines



Data Mining: Confluence of Multiple Disciplines



Single-node architecture



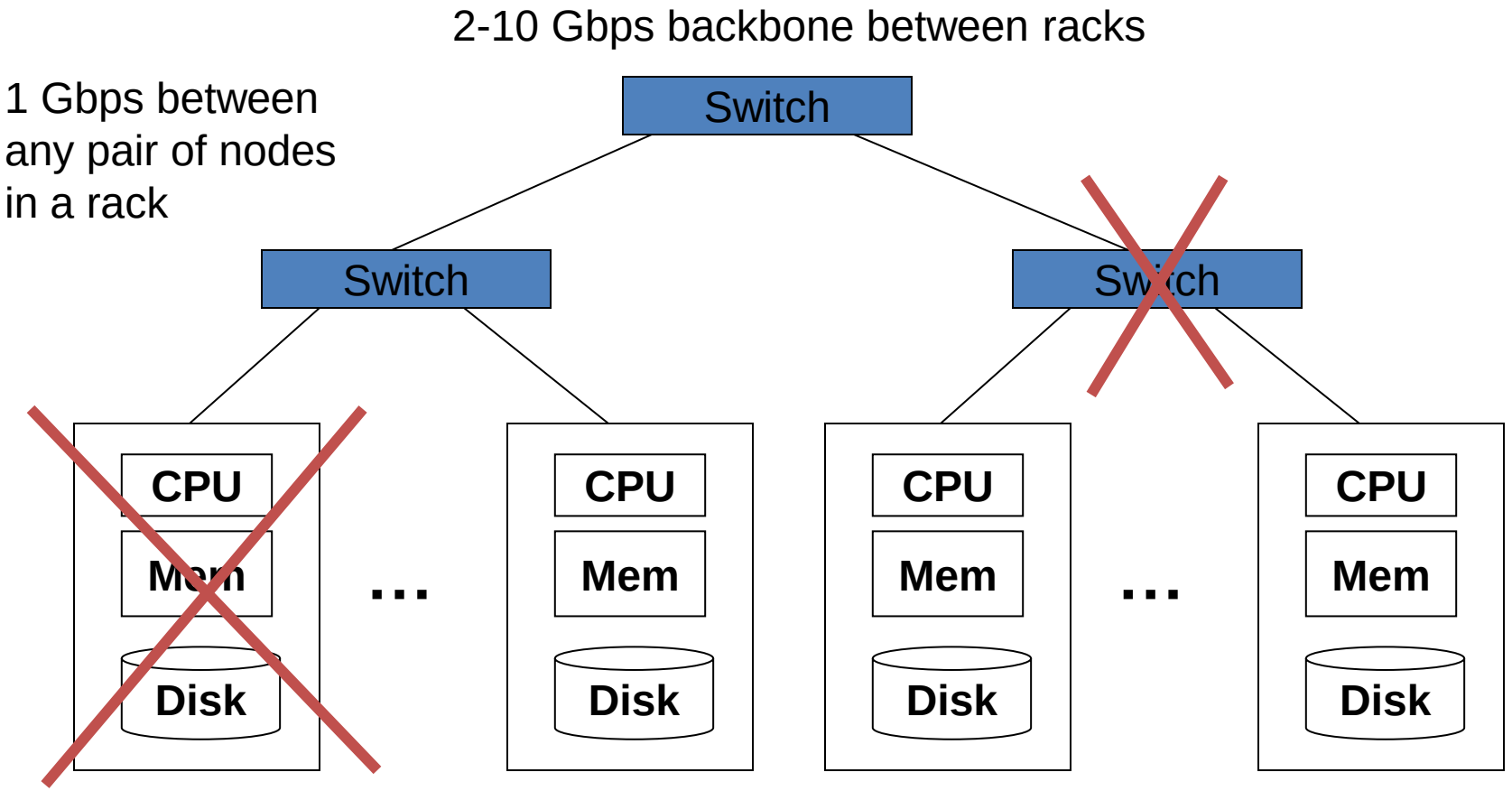
Machine Learning, Statistics

"Classical" Data Mining

Commodity Clusters

- Web data sets can be very large
  - Tens to hundreds of terabytes
  - Cannot mine on a single server
- Standard architecture emerging:
  - Cluster of commodity Linux nodes, Gigabit ethernet interconnect
  - Google GFS; Hadoop HDFS; Kosmix KFS
- Typical usage pattern
  - Huge files (100s of GB to TB)
  - Data is rarely updated in place
  - Reads and appends are common
- How to organize computations on this architecture?
  - Map-Reduce paradigm

Cluster Architecture



The data analysis pipeline

- Mining is not the only step in the analysis process

- Preprocessing: real data is noisy, incomplete and inconsistent. Data cleaning is required to make sense of the data
  - Techniques: Sampling, Dimensionality Reduction, Feature selection.
  - A dirty work, but it is often the most important step for the analysis.
- Post-Processing: Make the data actionable and useful to the user
  - Statistical analysis of importance
  - Visualization.
- Pre- and Post-processing are often data mining tasks as well

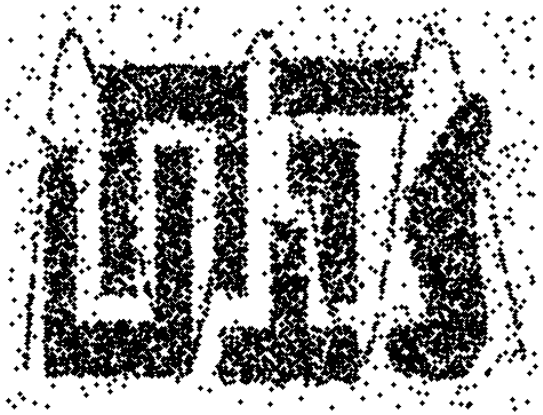
Data Quality

- Examples of data quality problems:
  - Noise and outliers
  - missing values
  - duplicate data

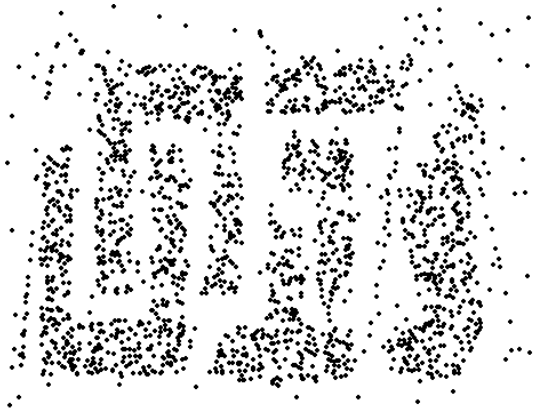
Sampling

- Sampling is the main technique employed for data selection.
  - It is often used for both the preliminary investigation of the data and the final data analysis.
- Statisticians sample because obtaining the entire set of data of interest is too expensive or time consuming.
- Sampling is used in data mining because processing the entire set of data of interest is too expensive or time consuming.

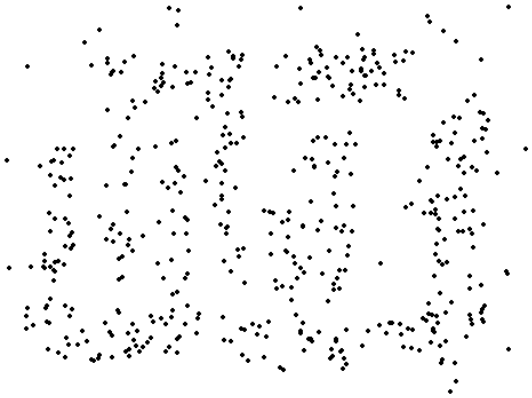
Sample Size



8000 points



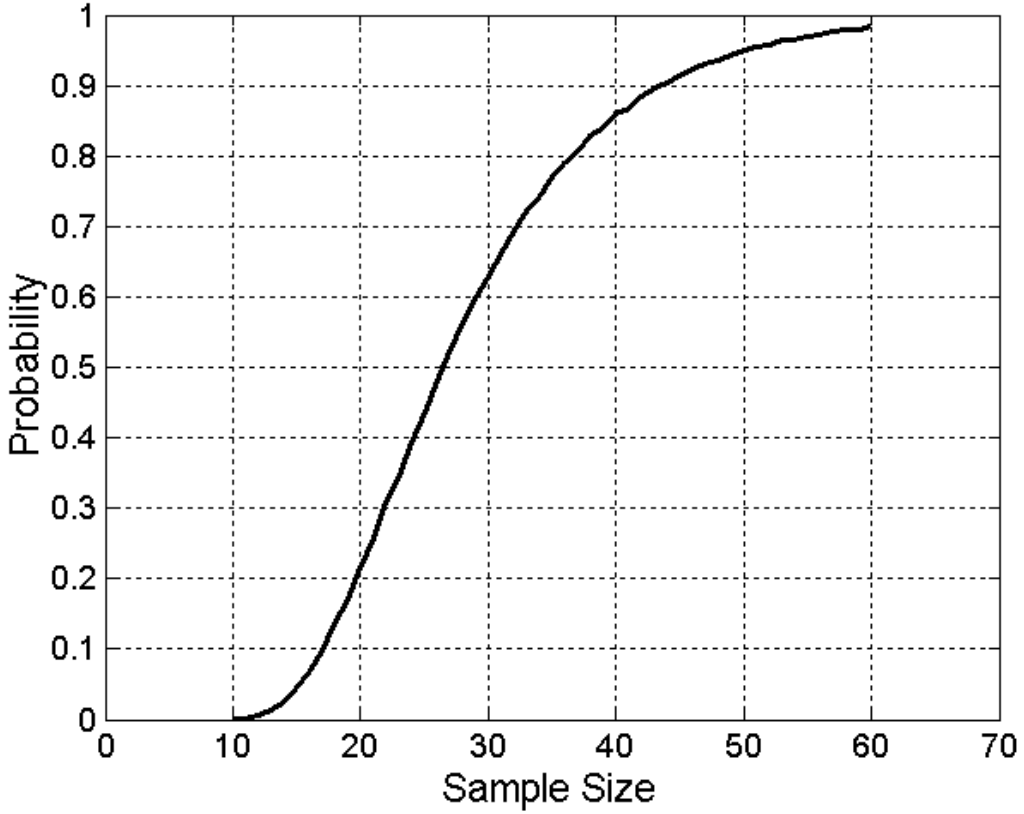
2000 Points



500 Points

Sample Size

- **What sample size is necessary to get at least one object from each of 10 groups.**



Why Not Traditional Data Analysis?

- 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

Multi-Dimensional View of Data Mining

- **Data to be mined**
  - Relational, data warehouse, transactional, stream, object-oriented/relational, active, spatial, time-series, text, multi-media, heterogeneous, legacy, WWW
- **Knowledge to be mined**
  - Characterization, discrimination, association, classification, clustering, trend/deviation, outlier analysis, etc.
  - Multiple/integrated functions and mining at multiple levels
- **Techniques utilized**
  - Database-oriented, data warehouse (OLAP), machine learning, statistics, visualization, etc.
- **Applications adapted**
  - Retail, telecommunication, banking, fraud analysis, bio-data mining, stock market analysis, text mining, Web mining, etc.

Data Mining vs. DBMS

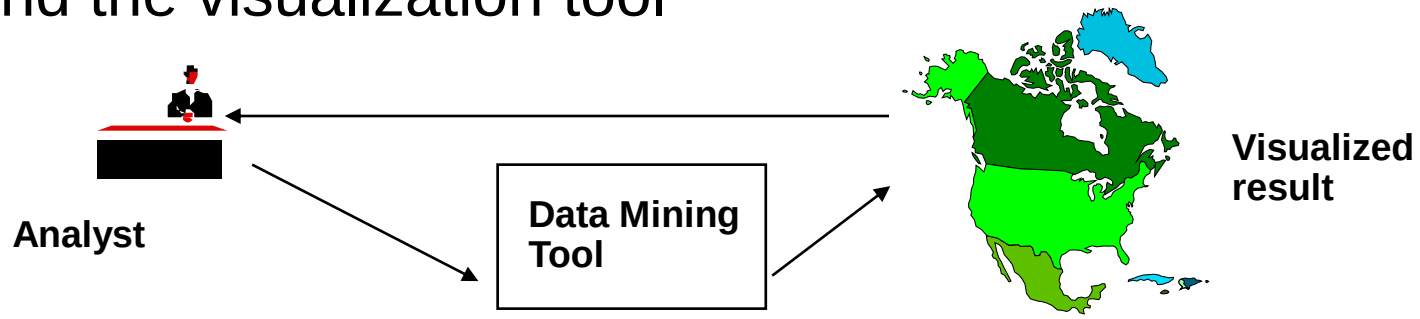
- Example DBMS Reports [Answers WHAT]
  - Last months sales for each service type
  - Sales per service grouped by customer sex or age bracket
  - List of customers who lapsed their policy
- Questions answered using Data Mining [Answers HOW]
  - What characteristics do customers that lapse their policy have in common and how do they differ from customers who renew their policy?
  - Which motor insurance policy holders would be potential customers for my House Content Insurance policy?

Related Techniques: Visualization

- Visualization uses human perception to recognize patterns in large data sets
- Advantages relative to data mining
  - Perceive “unconsidered” patterns
  - Recognize non-linear relationships
- Disadvantages relative to data mining
  - Data set size limited by resolution constraints
  - Hard to recognize “small” patterns
  - Difficult to quantify results

Data Mining and Visualization

- Approaches
  - Visualization to display results of data mining
    - Help analyst to better understand the results of the data mining tool
  - Visualization to aid the data mining process
    - Interactive control over the data exploration process
    - Interactive steering of analytic approaches (“grand tour”)
- Interactive data mining issues
  - Relationships between the analyst, the data mining tool and the visualization tool



Some IDD visualizations