Data Mining

Vera Goebel

Department of Informatics, University of Oslo

2009

Lecture Contents

- Knowledge Discovery in Databases (KDD)
  - Definition and Applications
- OLAP
- Architectures for OLAP and KDD
- KDD Life Cycle
- Data Mining
  - Mechanisms
  - Implications for the Database System

Definition - KDD

- Knowledge Discovery in Databases (KDD)
  - ”the non-trivial extraction of implicit, previously unknown and potentially useful knowledge from data”
- Why?
  - To find trends and correlations in existing databases, that help you change structures and processes in human organizations
    - to be more effective
    - to save time
    - to make more money
    - to improve product quality
    - to etc.

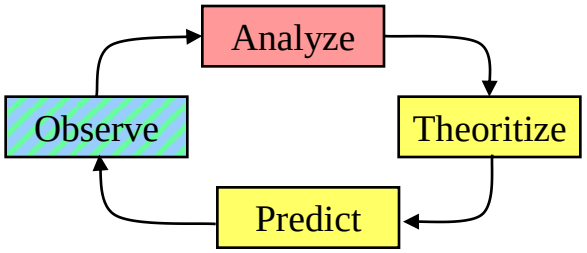
New knowledge
Beyond statistics

Applications - KDD

- Marketing
  - Find the most important segmentation for classifying my customers
  - Predict future sales for a specific product
- Product Maintenance
  - Define a service maintenance contract of interest to a majority of my customers
- Human Resource Management
  - Define an employee compensation package to increase employee retention to at least 5 years of service
  - For each university department, predict the number of new students that will major in that subject area
- Finance
  - Detect fraudulent use of credit cards

New Knowledge

Where SQL Stops Short



Data Mining Tools

Creates new ***knowledge*** *in the form of predictions, classifications, associations, time-based patterns*

OLAP Tools

Analyzes a multi-dimensional view of existing knowledge

DSS-Extended SQL Queries

Extends the DB schema to a limited, multi-dimensional view

Complex SQL Queries

DB schema describes the structure you already know

Database

- Successful KDD uses the entire tool hierarchy

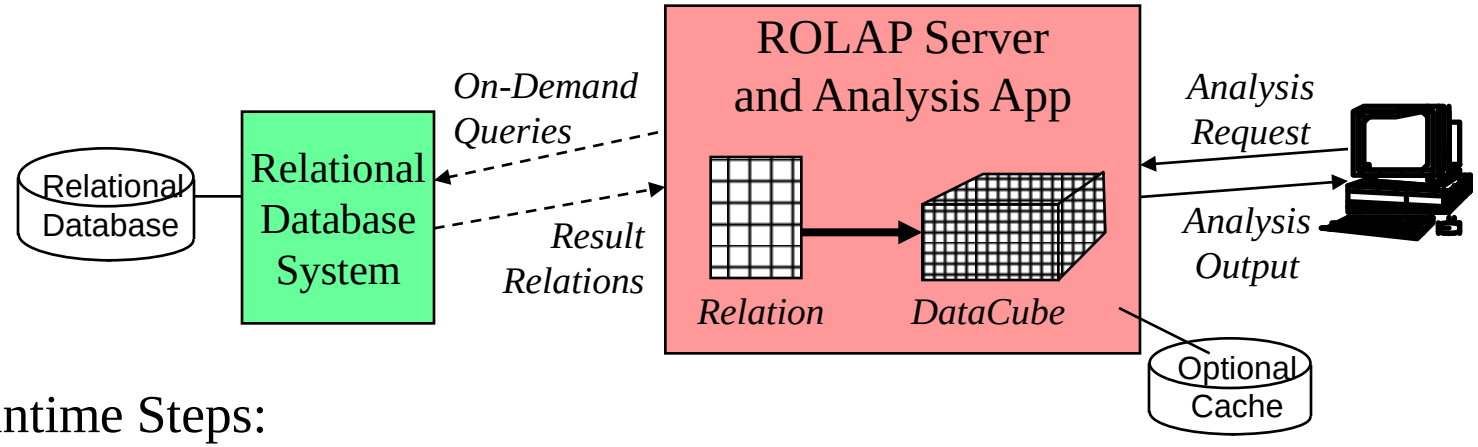
OnLine Analytic Processing (OLAP)

- OLAP
  - ”the dynamic synthesis, analysis, and *consolidation* of large volumes of multi-dimensional data”
  - Focuses on *multi-dimensional relationships* among existing data records
- Differs from extended SQL for data warehouses
  - DW operations: roll-up, drill-down, slice, dice, pivot
  - OLAP packages add application-specific analysis
    - Finance – depreciation, currency conversion, ...
    - Building regulations – usable space, electrical loading, ...
    - Computer Capacity Planning – disk storage requirements, failure rate estimation...

OnLine Analytic Processing (OLAP)

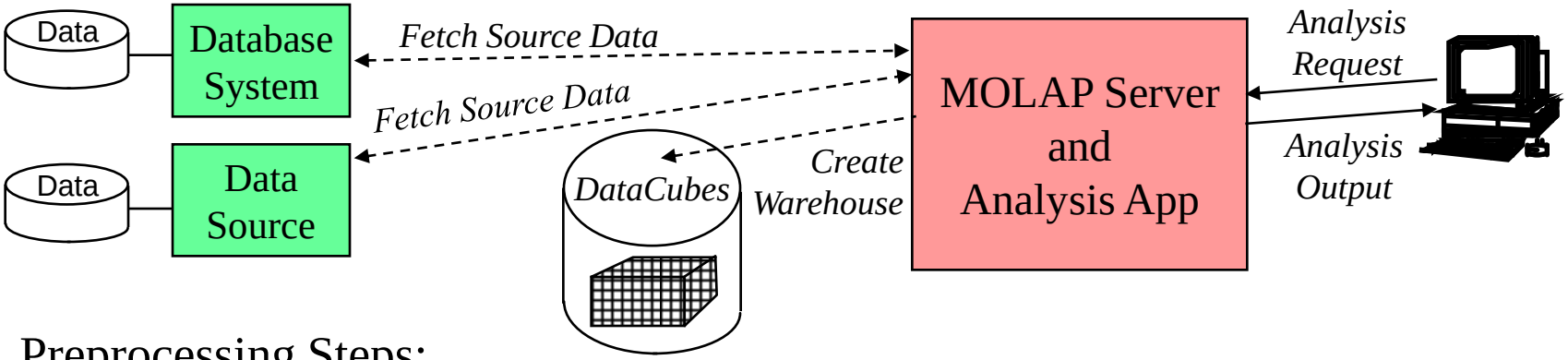
- OLAP differs from data mining
  - OLAP tools provide quantitative analysis of multi-dimensional data relationships
  - Data mining tools create and evaluate a set of possible problem solutions (and rank them)
    - Ex: Propose 3 marketing strategies and order them based on marketing cost and likely sales income
- Three system architectures are used for OLAP
  - Relational OLAP (ROLAP)
  - Multi-dimensional OLAP (MOLAP)
  - Managed Query Environment (MQE)

Relational OLAP



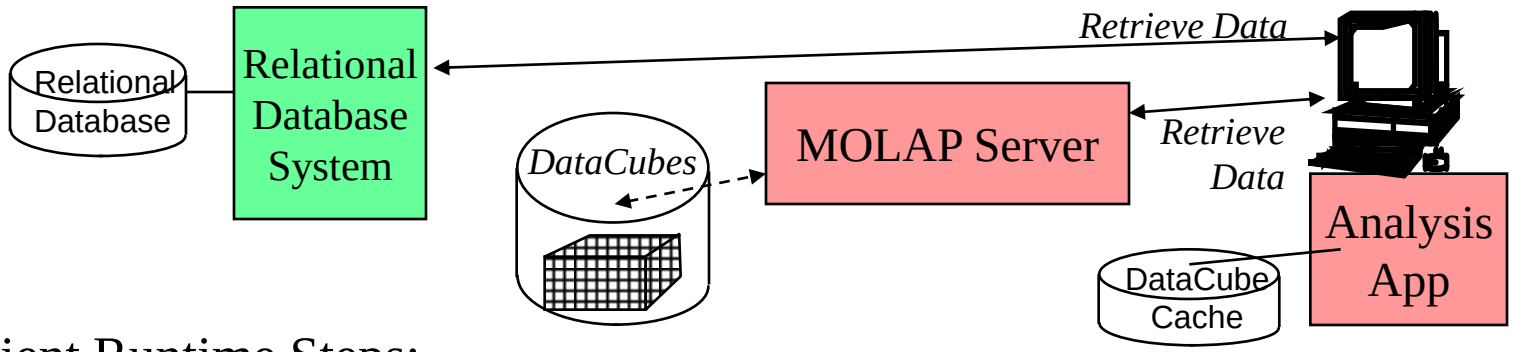
- Runtime Steps:
  - Translate client request into 1 or more SQL queries
  - Present SQL queries to a back-end RDBMS
  - Convert result relations into multi-dimensional datacubes
  - Execute the analysis application and return the results
- Advantages:
  - No special data storage structures, use standard relational storage structures
  - Uses most current data from the OLTP server
- Disadvantages:
  - Typically accesses only one RDBMS => no data integration over multiple DBSs
  - Conversion from flat relations to memory-based datacubes is slow and complex
  - Poor performance if large amounts of data are retrieved from the RDBMS

Multi-dimensional OLAP



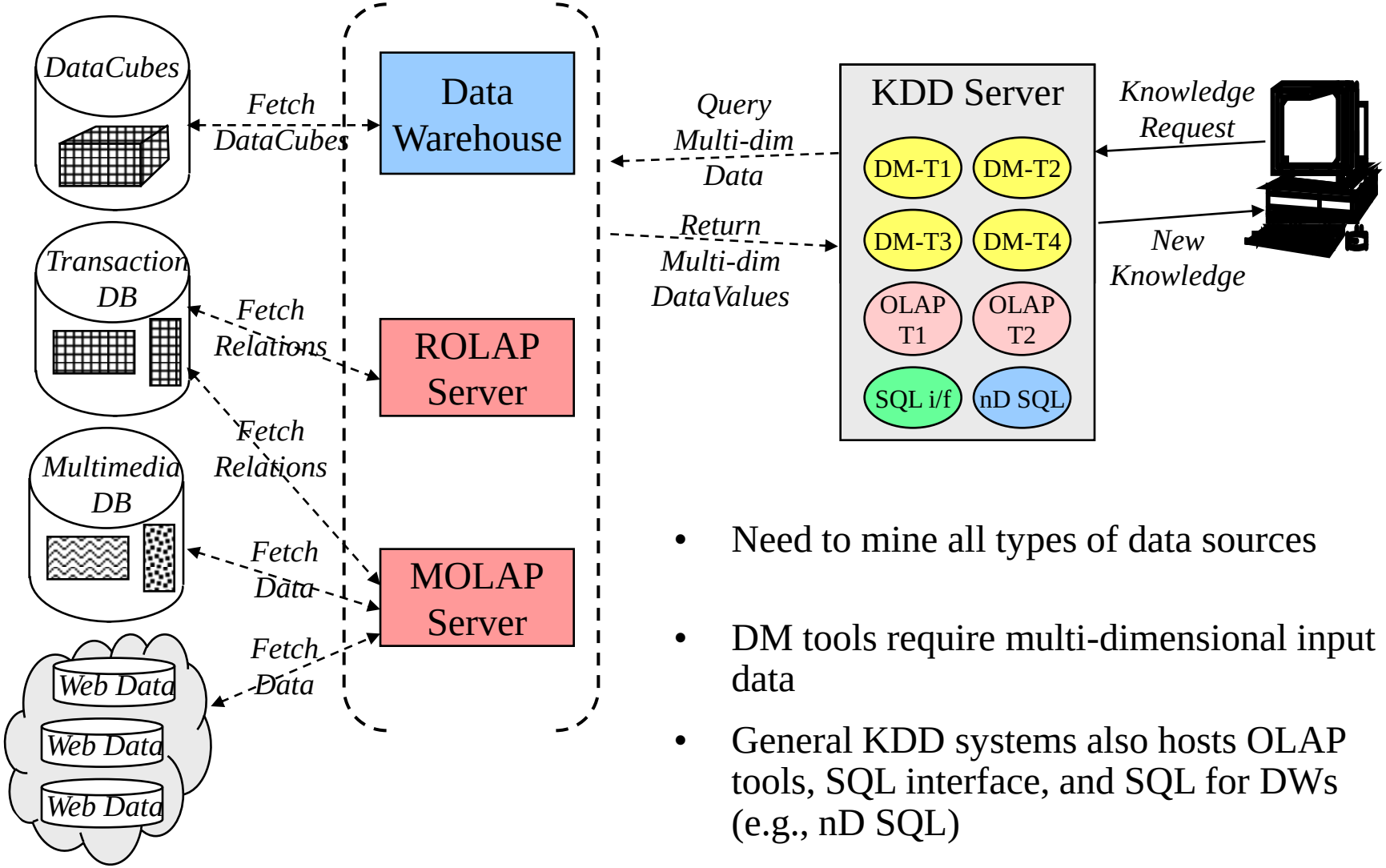
- Preprocessing Steps:
  - Extract data from multiple data sources
  - Store as a data warehouse, using custom storage structures
- Runtime Steps:
  - Access datacubes through special index structures
  - Execute the analysis application and returns the results
- Advantages:
  - Special, multi-dimensional storage structures give good retrieval performance
  - Warehouse integrates ”clean” data from multiple data sources
- Disadvantages:
  - Inflexible, multi-dimensional storage structures support only one application well
  - Requires people and software to maintain the data warehouse

Managed Query Environment (MQE)



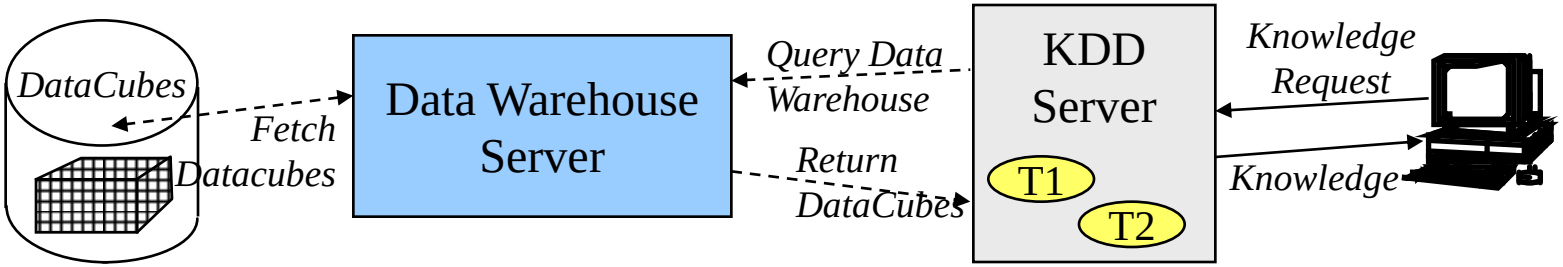
- Client Runtime Steps:
  - Fetch data from MOLAP Server, or RDBMS directly
  - Build memory-based data structures, as required
  - Execute the analysis application
- Advantages:
  - Distributes workload to the clients, offloading the servers
  - Simple to install, and maintain => reduced cost
- Disadvantages:
  - Provides limited analysis capability (i.e., client is less powerful than a server)
  - Lots of redundant data stored on the client systems
  - Client-defined and cached datacubes can cause inconsistent data
  - Uses lots of network bandwidth

KDD System Architecture



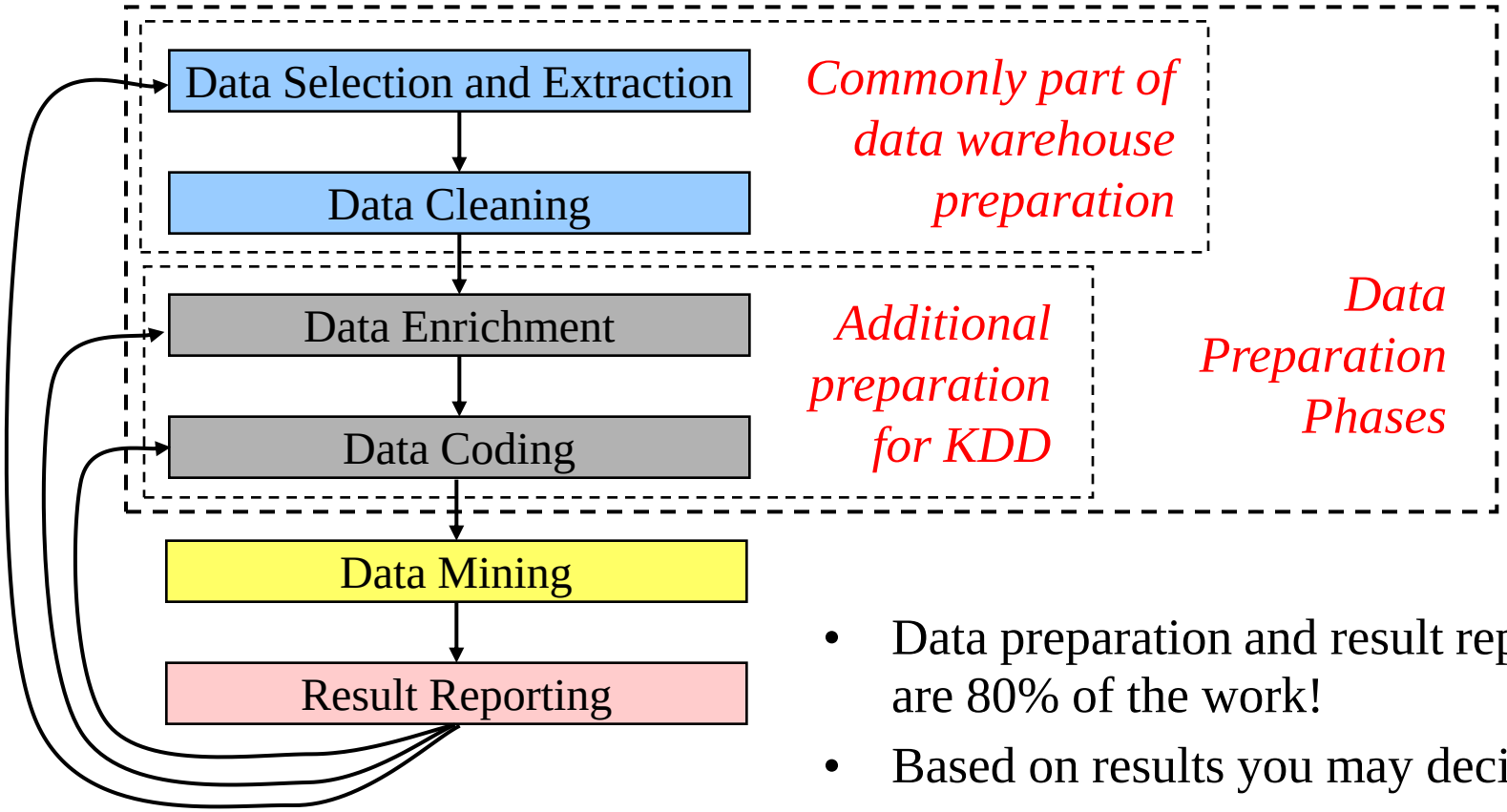
- Need to mine all types of data sources
- DM tools require multi-dimensional input data
- General KDD systems also hosts OLAP tools, SQL interface, and SQL for DWs (e.g., nD SQL)

Typical KDD Deployment Architecture



- Runtime Steps:
  - Submit knowledge request
  - Fetch datacubes from the warehouse
  - Execute knowledge acquisition tools
  - Return findings to the client for ”display”
- Advantages:
  - Data warehouse provides ”clean”, maintained, multi-dimensional data
  - Data retrieval is typically efficient
  - Data warehouse can be used by other applications
  - Easy to add new KDD tools
- Disadvantages:
  - KDD is limited to data selected for inclusion in the warehouse
  - If DW is not available, use MOLAP server or provide warehouse on KDD server

KDD Life Cycle



- Data preparation and result reporting are 80% of the work!
- Based on results you may decide to:
  - Get more data from internal data sources
  - Get additional data from external sources
  - Recode the data

Data Enrichment

- Integrating additional data from external sources
- Sources are public and private agencies
  - Government, Credit bureau, Research lab, …
- Typical data examples:
  - Average income by city, occupation, or age group
  - Percentage of homeowners and car owners by …
  - A person's credit rating, debt level, loan history, …
  - Geographical density maps (for population, occupations, …)
- New data extends each record from internal sources
- Database issues:
  - More heterogenous data formats to be integrated
  - Understand the semantics of the external source data

Data Coding

- Goal: to streamline the data for *effective* and *efficient* processing by the target KDD application
- Steps:

1) Delete records with many missing values
   - But …in fraud detection, missing values are indicators of the behavior you want to discover!

2) Delete extra attributes
   - Ex: delete customer names if looking at customer classes

3) Code detailed data values into categories or ranges based on the types of knowledge you want to discover
   - Ex: divide specific ages into age ranges, 0-10, 11-20, …
     map home addresses to regional codes
     convert homeownership to ”yes” or ”no”
     convert purchase date to a month number starting from Jan. 1990

The Data Mining Process

- Based on the questions being asked and the required ”form” of the output

1) Select the data mining mechanisms you will use
2) Make sure the data is properly coded for the selected mechnisms
   - Ex. A tool may accept numeric input only
3) Perform rough analysis using traditional tools
   - Create a naive prediction using statistics, e.g., averages
   - The data mining tools must do better than the naive prediction or you are not learning more than the obvious!
4) Run the tool and examine the results

Data Mining - Mechanisms

Purpose/Use	Knowledge Type	Mechanisms
To define classes and predict future behavior of existing instances.	Predictive Modeling	Decision Trees, Neural Networks, Regression Analysis Genetic Algorithms
To define classes and categorize new instances based on the classes.	Database Segmentation	K-nearest Neighbors, Neural Networks, Kohonen Maps
To identify a cause and predict the effect.	Link Analysis	Negative Association, Association Discovery, Sequential Pattern Discovery, Matching Time Sequence Discovery
To define classes and detect new and old instances that lie outside the classes.	Deviation Detection	Statistics, Visualization, Genetic Algorithms

Configuring the KDD Server

- Data mining mechanisms are <u>not</u> application-specific, they depend on the target knowledge type
- The application area impacts the type of knowledge you are seeking, so the application area guides the selection of data mining mechanisms that will be hosted on the KDD server.

To configure a KDD server →

Select an application area
Select (or build) a data source
Select N knowledge types (types of questions you will ask)
For each knowledge type Do
    Select 1 or more mining tools for that knowledge type

<u>Example:</u>
Application area: marketing
Data Source: data warehouse of current customer info
Knowledge types: classify current customers, predict future sales, predict new customers
Data Mining Tools: decision trees, and neural networks

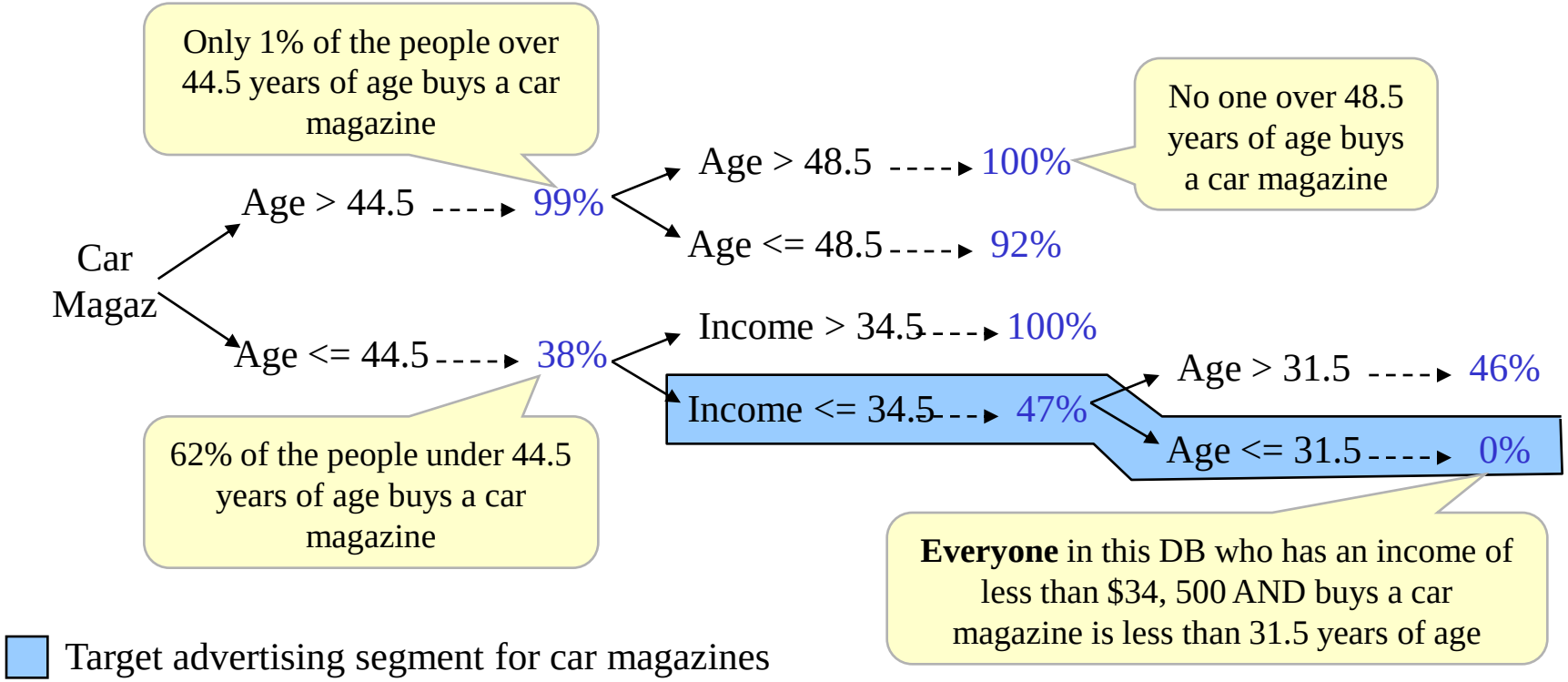
Data Mining Example - Database Segmentation

- Given: a coded database with 1 million records on subscriptions to five types of magazines
- Goal: to define a classification of the customers that can predict what types of new customers will subscribe to which types of magazines

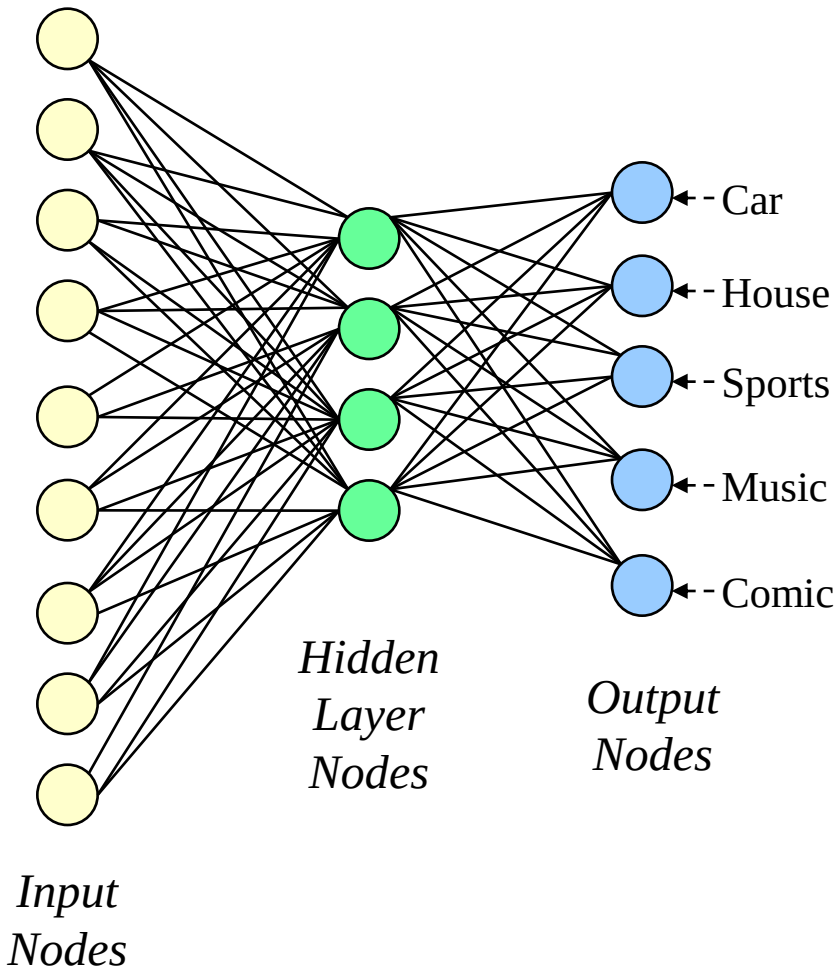
Client#	Age	Income	Credit	Car Owner	House Owner	Home Area	Car Magaz	House Magaz	Sports Magaz	Music Magaz	Comic Magaz
2303	20	18.5	17.8	0	0	1	1	1	0	1	1
2309	25	36.0	26.6	1	0	1	0	0	0	0	1
2313	42	24.0	20.8	0	0	1	0	0	1	0	0
2327	31	48.2	24.5	1	1	1	0	1	1	1	0
2328	56	94.0	40.0	1	1	1	1	0	1	0	1
2330	43	18.0	7.0	1	0	1	0	0	1	0	0
2333	22	36.3	15.8	1	0	1	1	0	1	0	1
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.

Decision Trees for DB Segmentation

- Which attribute(s) best predicts which magazine(s) a customer subscribes to *(sensitivity analysis)*
  - Attributes: age, income, credit, car-owner, house-owner, area
- Classify people who subscribe to a car magazine

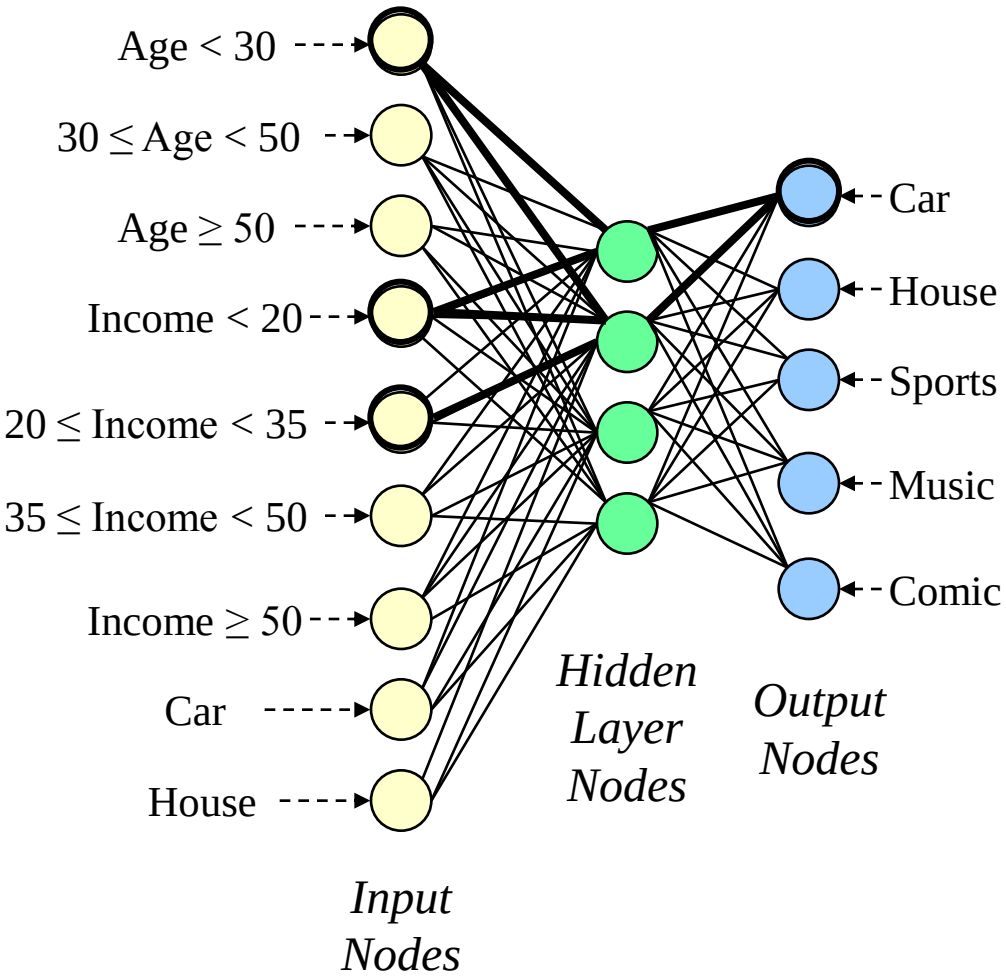


Neural Networks



- Input nodes are connected to output nodes by a set of hidden nodes and edges
- Inputs describe DB instances
- Outputs are the categories we want to recognize
- Hidden nodes assign weights to each edge so they represent the weight of relationships between the input and the output of a large set of training data

Training and Mining



- Training Phase (*learning*)
  - –Code all DB data as 1's and 0's
  - –Set all edge weights to prob = 0
  - –Input each coded database record
  - –Check that the output "is correct"
  - –The system adjusts the edge weights to get the correct answer
- Mining Phase (*recognition*)
  - –Input a new instance coded as 1's and 0's
  - –Output is the classification of the new instance
- Issues:
  - Training sample must be large to get good results
  - Network is a "black box", it does not tell "why" an instance gives a particular output (*no theory*)

An Explosion of Mining Results

- Data Mining tools can output thousands of rules and associations (collectively called *patterns*)

When is a pattern *interesting*?	Metrics of *interestingness*
1) If it can be understood by humans	Simplicity: *Rule Length* for ($A \Rightarrow B$) is the number of conjunctive conditions or the number of attributes in the rule
2) The pattern is strong (i.e., valid for many new data records)	Confidence: *Rule Strength* for ($A \Rightarrow B$) is the conditional probability that A implies B *(#recs with A & B)/(#recs with A)*
3) It is potentially useful for your business needs	Support: *Support* for ($A \Rightarrow B$) is the number or percentage of DB records that include A and B
4) It is novel (i.e., previously unknown)	Novelty: *Rule Uniqueness* for ($A \Rightarrow B$) means no other rule includes or implies this rule

Genetic Algorithms

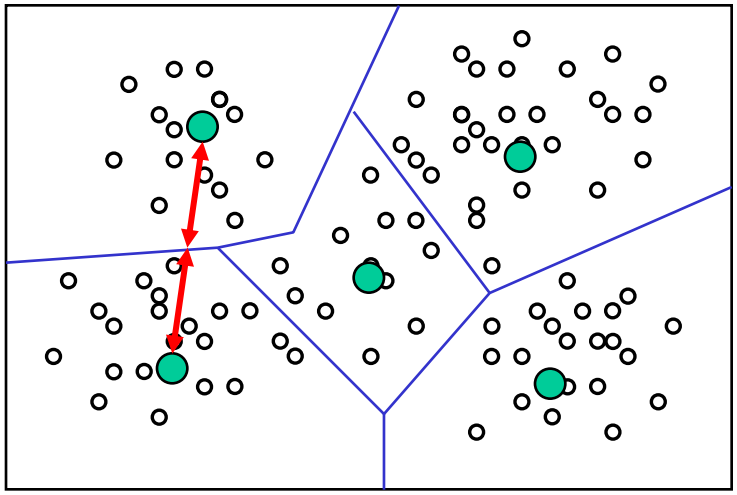
- Based on Darwin's theory of "survival of the fittest"
  - Living organisms reproduce,
    individuals evolve/mutate,
    individuals survive or die based on fitness
- The output of a genetic algorithm is the set of "fittest solutions" that will survive in a particular environment
- The input is an initial set of possible solutions
- The process
  - Produce the next generation (by a cross-over function)
  - Evolve solutions (by a mutation function)
  - Discard weak solutions (based on a fitness function)

Classification Using Genetic Algorithms

- Suppose we have money for 5 marketing campaigns, so we wish to cluster our magazine customers into 5 target marketing groups
- Customers with similar attribute values form a cluster (assumes similar attributes => similar behavior)
- Preparation:
  - Define an encoding to represent solutions (i.e., use a character sequence to represent a cluster of customers)
  - Create 5 possible initial solutions (and encode them as strings)
  - Define the 3 genetic functions to operate on a cluster encoding
    - Cross-over( ), Mutate( ), Fitness_Test( )

Genetic Algorithms - Initialization

- Define 5 initial solutions
  - Use a subset of the database to create a 2-dim scatter plot
    - Map customer attributes to 2 dimensions
  - Divide the plot into 5 regions
  - Calculate an initial solution point (*guide point*) in each region
    - Equidistant from region lines



Voronoi Diagram

- Define an encoding for the solutions
  - Strings for the customer attribute values
  - Encode each guide point

30	10
40	20
55	28
30	50
80	16

Guide Point #1
10 Attribute Values

Genetic Algorithms – Evolution

1st Gen

30	10
40	20
55	28
30	50
80	16

Solution 1

35	18
42	20
55	15
40	48
75	16

Solution 2
Fitness 14.5

15	30
37	15
50	28
30	50
75	16

Solution 3
Fitness 17

10	90
33	10
48	28
26	50
57	80

Solution 4
Fitness 30

10	90
33	10
37	28
26	37
57	46

Solution 5
Fitness 33

30	10
24	20
55	28
30	45
80	16

Mutation
Fitness 16

Fitness 13

35	18
42	20
50	28
30	50
75	16

Fitness 25

15	30
37	15
50	28
40	48
75	16

Cross-over
creating 2 children

2nd Gen

30	10
24	20
55	28
30	45
80	16

35	18
42	20
50	28
30	50
75	16

15	30
37	15
50	28
40	48
75	16

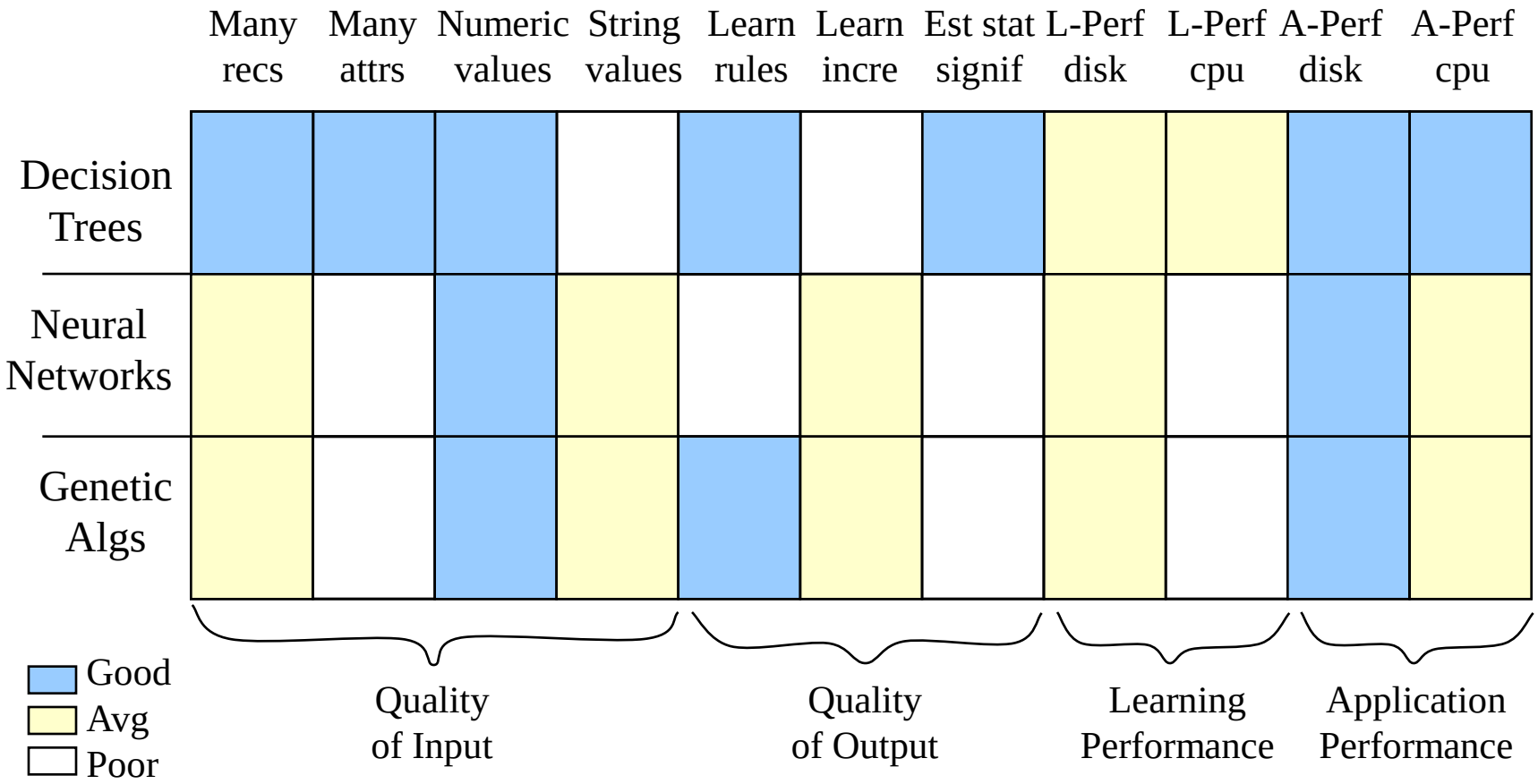
35	18
42	20
55	15
40	48
75	16

15	30
37	15
50	28
30	50
75	16

- Cross-over function
  Create 2 children
  Take 6 attribute values from one parent and 4 from the other
- Mutate function
  Randomly switch several attribute values from values in the sample subspace
- Fitness function:
  Average distance between the solution point and all the points in the sample subspace
- Stop when the solutions change very little

Selecting a Data Mining Mechanism

- Multiple mechanisms can be used to answer a question – select the mechanism based on your requirements



So ...

Artificial Intelligence is fun, ...
but what does this have to do with database?

- Data mining is just another database application
- Data mining applications have requirements
- The database system can help mining applications meet their requirements

So, what are the challenges for data mining systems and how can the database system help?

Database Support for DM Challenges

Data Mining Challenge	Database Support
• Support many data mining mechanisms in a KDD system	• Support multiple DB interfaces (for different DM mechanisms)
• Support interactive mining and incremental mining	• Intelligent caching and support for changing views over query results
• Guide the mining process by integrity constraints	• Make integrity constraints query-able (meta-data)
• Determine usefulness of a data mining result	• Gather and output runtime statistics on DB ”support”, ”confidence”, and other metrics
• Help humans to better understand mining results (e.g., visualization)	• Prepare output data for selectable presentation formats

Database Support for DM Challenges

Data Mining Challenge	Database Support
• Accurate, efficient, and flexible methods for data cleaning and data encoding	• ”Programmable” data warehouse tools for data cleaning and encoding; Fast, runtime re-encoding
• Improved performance for data mining mechanisms	• Parallel data retrieval and support for incremental query processing
• Ability to mine a wide variety of data types	• New indexing and access methods for non-traditional data types
• Support web mining	• Extend XML and WWW database technology to support large, long running queries
• Define a data mining query language	• Extend SQL, OQL and other interfaces to support data mining

Commercial Data Mining Products and Tools

- Some DB companies with Data Mining products:
  - Oracle – Oracle 9i, with BI-Beans (an OLAP toolset)
  - IBM – ”Data Miner for Data” and ”Data Miner for Text”
  - NCR – TeraMiner™ for the TeraData™ warehouse
- Companies with Data Mining tools
  - COGNOS – “Scenario”, a set of DM and OLAP tools
  - Elseware – ”Classpad”(classification) and ”Previa” (prediction)
  - Logic Programming Associates, Ltd. – ”Datamite” (clustering)
  - Prudential System Software GmbH – credit card fraud
  - RedShed Software – ”Dowser” (association discovery)

http://www.kdnuggets.com/companies/products.html

Conclusions

- To support data mining, we should
  - Enhance database technologies developed for
    - Data warehouses
    - Very large database systems
    - Object-oriented (navigational) database systems
    - View Management mechanisms
    - Heterogeneous databases
  - Create new access methods based on mining access
  - Develop query languages or other interfaces to better support data mining mechanisms
  - Select and integrate the needed DB technologies