CS6220: DATA MINING TECHNIQUES

Chapter 2: Getting to Know Your Data

Instructor: Yizhou Sun

yzsun@ccs.neu.edu

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Chapter 2: Getting to Know Your Data

Data Objects and Attribute Types



- Basic Statistical Descriptions of Data
- Data Visualization
- Measuring Data Similarity and Dissimilarity
- Summary

Types of Data Sets

- Record
 - Relational records
 - Data matrix, e.g., numerical matrix, crosstabs
 - Document data: text documents: termfrequency vector
 - Transaction data
- Graph and network
 - World Wide Web
 - Social or information networks
 - Molecular Structures
- Ordered
 - Video data: sequence of images
 - Temporal data: time-series
 - Sequential Data: transaction sequences
 - Genetic sequence data
- Spatial, image and multimedia:
 - Spatial data: maps
 - Image data:
 - Video data:

-	team	coach	pla y	ball	score	game	n Wi	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

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

Data Objects

- Data sets are made up of data objects.
- A data object represents an entity.
- Examples:
 - sales database: customers, store items, sales
 - medical database: patients, treatments
 - university database: students, professors, courses
- Also called samples, examples, instances, data points, objects, tuples.
- Data objects are described by **attributes**.
- Database rows -> data objects; columns ->attributes.

Attributes

- Attribute (or dimensions, features, variables): a data field, representing a characteristic or feature of a data object.
 - E.g., customer_ID, name, address
- Types:
 - Nominal
 - Binary
 - Ordinal
 - Numeric: quantitative
 - Interval-scaled
 - Ratio-scaled

Attribute Types

- Nominal: categories, states, or "names of things"
 - Hair_color = {auburn, black, blond, brown, grey, red, white}
 - marital status, occupation, ID numbers, zip codes
- Binary
 - Nominal attribute with only 2 states (0 and 1)
 - <u>Symmetric binary</u>: both outcomes equally important
 - e.g., gender
 - <u>Asymmetric binary</u>: outcomes not equally important.
 - e.g., medical test (positive vs. negative)
 - Convention: assign 1 to most important outcome (e.g., HIV positive)
- Ordinal
 - Values have a meaningful order (ranking) but magnitude between successive values is not known.
 - *Size = {small, medium, large},* grades, army rankings

Numeric Attribute Types

- Quantity (integer or real-valued)
- Interval
 - Measured on a scale of equal-sized units
 - Values have order
 - E.g., temperature in C°or F°, calendar dates
 - No true zero-point
 - We can evaluate the difference of two values, but one value cannot be a multiple of another
- Ratio
 - Inherent zero-point
 - We can speak of values as being an order of magnitude larger than the unit of measurement (10 K° is twice as high as 5 K°).
 - e.g., temperature in Kelvin, length, counts, monetary quantities

Discrete vs. Continuous Attributes

Discrete Attribute

- Has only a finite or countably infinite set of values
 - E.g., zip codes, profession, or the set of words in a collection of documents
- Sometimes, represented as integer variables
- Note: Binary attributes are a special case of discrete attributes

Continuous Attribute

- Has real numbers as attribute values
 - E.g., temperature, height, or weight
- Practically, real values can only be measured and represented using a finite number of digits
- Continuous attributes are typically represented as floating-point variables

Chapter 2: Getting to Know Your Data

- Data Objects and Attribute Types
- Basic Statistical Descriptions of Data



- Data Visualization
- Measuring Data Similarity and Dissimilarity
- Summary

Basic Statistical Descriptions of Data

- <u>Central Tendency</u>
- Dispersion of the Data
- Graphic Displays

Measuring the Central Tendency

- Mean (algebraic measure) (sample vs. population):
 Note: n is sample size and N is population size.
 - Weighted arithmetic mean:
 - Trimmed mean: chopping extreme values
- Median:
 - Middle value if odd number of values, or average of the middle two values otherwise
 - Estimated by interpolation (for *grouped data*):

$$median = L_1 + \left(\frac{n/2 - (\sum freq)l}{freq_{median}}\right) width$$

- Mode
 - Value that occurs most frequently in the data
 - Unimodal, bimodal, trimodal
 - Empirical formula: $mean mode = 3 \times (mean median)$

$$\overline{x} = \frac{1}{n} \sum_{i=1}^{n} x_{i} \qquad \mu = \frac{\sum_{i=1}^{n} x_{i}}{N}$$
$$\overline{x} = \frac{\sum_{i=1}^{n} w_{i} x_{i}}{\sum_{i=1}^{n} w_{i}}$$

age	frequency
1-5	200
6 - 15	450
16 - 20	300
21 - 50	1500
51 - 80	700
81 - 110	44

Symmetric vs. Skewed Data

 Median, mean and mode of symmetric, positively and negatively skewed data





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Measuring the Dispersion of Data

- Quartiles, outliers and boxplots
 - **Quartiles**: Q₁ (25th percentile), Q₃ (75th percentile)
 - Inter-quartile range: IQR = Q₃ Q₁
 - Five number summary: min, Q₁, median, Q₃, max
 - Boxplot: ends of the box are the quartiles; median is marked; add whiskers, and plot outliers individually
 - Outlier: usually, a value higher/lower than 1.5 x IQR
- Variance and standard deviation (sample: s, population: σ)
 - Variance: (algebraic, scalable computation)

$$s^{2} = \frac{1}{n-1} \sum_{i=1}^{n} (x_{i} - \overline{x})^{2} = \frac{1}{n-1} \left[\sum_{i=1}^{n} x_{i}^{2} - \frac{1}{n} (\sum_{i=1}^{n} x_{i})^{2} \right] \qquad \sigma^{2} = \frac{1}{N} \sum_{i=1}^{n} (x_{i} - \mu)^{2} = \frac{1}{N} \sum_{i=1}^{n} x_{i}^{2} - \mu^{2}$$

• Standard deviation s (or σ) is the square root of variance s^2 (or σ^2)

Boxplot Analysis

- Five-number summary of a distribution
 - Minimum, Q1, Median, Q3, Maximum
- Boxplot
 - Data is represented with a box
 - The ends of the box are at the first and third quartiles, i.e., the height of the box is IQR
 - The median is marked by a line within the box
 - Whiskers: two lines outside the box extended to Minimum and Maximum
 - Outliers: points beyond a specified outlier threshold, plotted individually





Visualization of Data Dispersion: 3-D Boxplots



Properties of Normal Distribution Curve

- The normal (distribution) curve
 - From μ–σ to μ+σ: contains about 68% of the measurements (μ: mean, σ: standard deviation)
 - From μ -2 σ to μ +2 σ : contains about 95% of it
 - From μ -3 σ to μ +3 σ : contains about 99.7% of it



Graphic Displays of Basic Statistical Descriptions

- **Boxplot**: graphic display of five-number summary
- Histogram: x-axis are values, y-axis repres. frequencies
- Quantile plot: each value x_i is paired with f_i indicating that approximately 100 f_i % of data are $\leq x_i$
- Quantile-quantile (q-q) plot: graphs the quantiles of one univariant distribution against the corresponding quantiles of another
- Scatter plot: each pair of values is a pair of coordinates and plotted as points in the plane

Histogram Analysis

- Histogram: Graph display of tabulated frequencies, shown as bars
- It shows what proportion of cases fall into each of several categories
- Differs from a bar chart in that it is the area of the bar that denotes the value, not the height as in bar charts, a crucial distinction when the categories are not of uniform width
- The categories are usually specified as non-overlapping intervals of some variable. The categories (bars) must be adjacent



Histograms Often Tell More than Boxplots



- The two histograms shown in the left may have the same boxplot representation
 - The same values for: min, Q1, median, Q3, max
- But they have rather different data distributions

Quantile Plot

- Displays all of the data (allowing the user to assess both the overall behavior and unusual occurrences)
- Plots quantile information
 - For a data x_i data sorted in increasing order, f_i indicates that approximately 100 f_i^{∞} of the data are below or equal to the value x_i



Quantile-Quantile (Q-Q) Plot

- Graphs the quantiles of one univariate distribution against the corresponding quantiles of another
- View: Is there is a shift in going from one distribution to another?
- Example shows unit price of items sold at Branch 1 vs. Branch 2 for each quantile. Unit prices of items sold at Branch 1 tend to be lower than those at Branch 2.



Scatter plot

- Provides a first look at bivariate data to see clusters of points, outliers, etc
- Each pair of values is treated as a pair of coordinates and plotted as points in the plane



Positively and Negatively Correlated Data





- The left half fragment is positively correlated
- The right half is negative correlated

Uncorrelated Data







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- Measuring Data Similarity and Dissimilarity
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Data Visualization

- Why data 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

Direct Data Visualization



3D Scatter Plot



Scatterplot Matrices



Matrix of scatterplots (x-y-diagrams) of the k-dim. data [total of (k2/2-k) scatterplots]

Landscapes



news articles visualized as a landscape

- Visualization of the data as perspective landscape
- The data needs to be transformed into a (possibly artificial) 2D spatial representation which preserves the characteristics of the data

Parallel Coordinates

- n equidistant axes which are parallel to one of the screen axes and correspond to the attributes
- The axes are scaled to the [minimum, maximum]: range of the corresponding attribute
- Every data item corresponds to a polygonal line which intersects each of the axes at the point which corresponds to the value for the attribute



Parallel Coordinates of a Data Set



Visualizing Text Data

• Tag cloud: visualizing user-generated tags

 The importance of tag is represented by font size/color

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Newsmap: Google News Stories in 2005

Visualizing Social/Information Networks



Computer Science Conference Network

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Summary

Similarity and Dissimilarity

Similarity

- Numerical measure of how alike two data objects are
- Value is higher when objects are more alike
- Often falls in the range [0,1]
- Dissimilarity (e.g., distance)
 - Numerical measure of how different two data objects are
 - Lower when objects are more alike
 - Minimum dissimilarity is often 0
 - Upper limit varies
- Proximity refers to a similarity or dissimilarity

Data Matrix and Dissimilarity Matrix

- Data matrix
 - n data points with p dimensions
 - Two modes

- Dissimilarity matrix
 - n data points, but registers only the distance
 - A triangular matrix
 - Single mode

$$\begin{bmatrix} x_{11} & \cdots & x_{1f} & \cdots & x_{1p} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{i1} & \cdots & x_{if} & \cdots & x_{ip} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{n1} & \cdots & x_{nf} & \cdots & x_{np} \end{bmatrix}$$

$$\begin{bmatrix} 0 & & & \\ d(2,1) & 0 & & \\ d(3,1) & d(3,2) & 0 & \\ \vdots & \vdots & \vdots & \\ d(n,1) & d(n,2) & \dots & \dots & 0 \end{bmatrix}$$

Proximity Measure for Nominal Attributes

- Can take 2 or more states, e.g., red, yellow, blue, green (generalization of a binary attribute)
- <u>Method 1</u>: Simple matching
 - *m*: # of matches, *p*: total # of variables

$$d(i,j) = \frac{p-m}{p}$$

- <u>Method 2</u>: Use a large number of binary attributes
 - creating a new binary attribute for each of the *M* nominal states

Proximity Measure for Binary Attributes

- Object *j* sum A contingency table for binary data q+rObject *i* s+tq+s r+tsum p Distance measure for symmetric binary $d(i, j) = \frac{r+s}{q+r+s+t}$ variables: Distance measure for asymmetric binary $d(i,j) = \frac{r+s}{a+r+s}$ variables: Jaccard coefficient (*similarity* measure $sim_{Jaccard}(i, j) = \frac{q}{q+r+s}$ for *asymmetric* binary variables):
- Note: Jaccard coefficient is the same as "coherence":

$$coherence(i, j) = \frac{sup(i, j)}{sup(i) + sup(j) - sup(i, j)} = \frac{q}{(q+r) + (q+s) - q}$$

Dissimilarity between Binary Variables

• Example

Name	Gender	Fever	Cough	Test-1	Test-2	Test-3	Test-4
Jack	Μ	Y	Ν	Р	Ν	Ν	Ν
Mary	F	Y	Ν	Р	Ν	Р	Ν
Jim	Μ	Y	Р	N	Ν	Ν	Ν

- Gender is a symmetric attribute
- The remaining attributes are asymmetric binary
- Let the values Y and P be 1, and the value N 0

$$d(jack, mary) = \frac{0+1}{2+0+1} = 0.33$$
$$d(jack, jim) = \frac{1+1}{1+1+1} = 0.67$$
$$d(jim, mary) = \frac{1+2}{1+1+2} = 0.75$$

Standardizing Numeric Data

• Z-score:

$$z = \frac{x - \mu}{\sigma}$$

- X: raw score to be standardized, μ : mean of the population, σ : standard deviation
- the distance between the raw score and the population mean in units of the standard deviation
- negative when the raw score is below the mean, "+" when above
- An alternative way: Calculate the mean absolute deviation

$$s_{f} = \frac{1}{n}(|x_{1f} - m_{f}| + |x_{2f} - m_{f}| + ... + |x_{nf} - m_{f}|)$$
where
$$m_{f} = \frac{1}{n}(x_{1f} + x_{2f} + ... + x_{nf})$$

$$z_{if} = \frac{x_{if} - m_{f}}{s_{f}}$$
• standardized measure (*z*-score):

• Using mean absolute deviation is more robust than using standard deviation

Example: Data Matrix and Dissimilarity Matrix

Data Matrix

point	attribute1	attribute2
x1	1	2
<i>x2</i>	3	5
<i>x3</i>	2	0
<i>x4</i>	4	5

Dissimilarity Matrix

(with Euclidean Distance)

	<i>x1</i>	<i>x2</i>	<i>x3</i>	<i>x4</i>
<i>x1</i>	0			
<i>x2</i>	3.61	0		
<i>x3</i>	2.24	5.1	0	
<i>x</i> 4	4.24	1	5.39	0

Distance on Numeric Data: Minkowski Distance

• *Minkowski distance*: A popular distance measure

$$d(i, j) = \sqrt[h]{|x_{i1} - x_{j1}|^h + |x_{i2} - x_{j2}|^h + \dots + |x_{ip} - x_{jp}|^h}$$

where $i = (x_{i1}, x_{i2}, ..., x_{ip})$ and $j = (x_{j1}, x_{j2}, ..., x_{jp})$ are two *p*-dimensional data objects, and *h* is the order (the distance so defined is also called L-*h* norm)

- Properties
 - d(i, j) > 0 if $i \neq j$, and d(i, i) = 0 (Positive definiteness)
 - d(i, j) = d(j, i) (Symmetry)
 - $d(i, j) \le d(i, k) + d(k, j)$ (Triangle Inequality)
- A distance that satisfies these properties is a metric

Special Cases of Minkowski Distance

- h = 1: Manhattan (city block, L₁ norm) distance
 - E.g., the Hamming distance: the number of bits that are different between two binary vectors

$$d(i,j) = |x_{i_1} - x_{j_1}| + |x_{i_2} - x_{j_2}| + \dots + |x_{i_p} - x_{j_p}|$$

• h = 2: (L₂ norm) Euclidean distance

$$d(i,j) = \sqrt{(|x_{i_1} - x_{j_1}|^2 + |x_{i_2} - x_{j_2}|^2 + \dots + |x_{i_p} - x_{j_p}|^2)}$$

- $h \rightarrow \infty$. "supremum" (L_{max} norm, L_{∞} norm) distance.
 - This is the maximum difference between any component (attribute) of the vectors

$$d(i, j) = \lim_{h \to \infty} \left(\sum_{f=1}^{p} |x_{if} - x_{jf}|^h \right)^{\frac{1}{h}} = \max_{f}^{p} |x_{if} - x_{jf}|$$

Example: Minkowski Distance

point	attribute 1	attribute 2
x1	1	2
x2	3	5
x3	2	0
x4	4	5

Dissimilarity Matrices Manhattan (L₁)

L	x1	x2	x3	x4
x1	0			
x2	5	0		
x3	3	6	0	
x4	6	1	7	0

Euclidean (L₂)

L2	x1	x2	x3	x4
x1	0			
x2	3.61	0		
x3	2.24	5.1	0	
x4	4.24	1	5.39	0

Supremum

L_{∞}	x1	x2	x3	x4
x1	0			
x2	3	0		
x3	2	5	0	
x4	3	1	5	0

Ordinal Variables

- An ordinal variable can be discrete or continuous
- Order is important, e.g., rank
- Can be treated like interval-scaled
 - replace *x_{if}* by their rank

$$r_{if} \in \{1, \dots, M_f\}$$

• map the range of each variable onto [0, 1] by replacing *i*-th object in the *f*-th variable by

$$z_{if} = \frac{r_{if} - 1}{M_f - 1}$$

• compute the dissimilarity using methods for interval-scaled variables

Attributes of Mixed Type

- A database may contain all attribute types
 - Nominal, symmetric binary, asymmetric binary, numeric, ordinal
- One may use a weighted formula to combine their effects

$$d(i,j) = \frac{\sum_{f=1}^{p} \delta_{ij}^{(f)} d_{ij}^{(f)}}{\sum_{f=1}^{p} \delta_{ij}^{(f)}}$$

• *f* is binary or nominal:

 $d_{ij}^{(f)} = 0$ if $x_{if} = x_{jf}$, or $d_{ij}^{(f)} = 1$ otherwise

- f is numeric: use the normalized distance
- f is ordinal
 - Compute ranks r_{if} and
 - Treat z_{if} as interval-scaled

$$Z_{if} = \frac{r_{if} - 1}{M_f - 1}$$

Cosine Similarity

• A **document** can be represented by thousands of attributes, each recording the *frequency* of a particular word (such as keywords) or phrase in the document.

Document	team	coach	hockey	base ball	soccer	penalty	score	win	loss	season
Document1	5	0	3	0	2	0	0	2	0	0
Document2	3	0	2	0	1	1	0	1	0	1
Document3	0	7	0	2	1	0	0	3	0	0
Document4	0	1	0	0	1	2	2	0	3	0

- Other vector objects: gene features in micro-arrays, ...
- Applications: information retrieval, biologic taxonomy, gene feature mapping, ...
- Cosine measure: If d₁ and d₂ are two vectors (e.g., term-frequency vectors), then cos(d₁, d₂) = (d₁ d₂) / ||d₁|| ||d₂||, where indicates vector dot product, ||d||: the length of vector d

Example: Cosine Similarity

- $\cos(d_1, d_2) = (d_1 \bullet d_2) / ||d_1|| ||d_2||$, where • indicates vector dot product, ||d|: the length of vector d
- Ex: Find the **similarity** between documents 1 and 2.

 $d_1 = (5, 0, 3, 0, 2, 0, 0, 2, 0, 0)$ $d_2 = (3, 0, 2, 0, 1, 1, 0, 1, 0, 1)$

 $\begin{aligned} &d_1 \bullet d_2 = 5^* 3 + 0^* 0 + 3^* 2 + 0^* 0 + 2^* 1 + 0^* 1 + 0^* 1 + 2^* 1 + 0^* 0 + 0^* 1 = 25 \\ &| |d_1| |= (5^* 5 + 0^* 0 + 3^* 3 + 0^* 0 + 2^* 2 + 0^* 0 + 0^* 0 + 2^* 2 + 0^* 0 + 0^* 0)^{0.5} = (42)^{0.5} = 6.481 \\ &| |d_2| |= (3^* 3 + 0^* 0 + 2^* 2 + 0^* 0 + 1^* 1 + 1^* 1 + 0^* 0 + 1^* 1 + 0^* 0 + 1^* 1)^{0.5} = (17)^{0.5} = 4.12 \\ &\cos(d_1, d_2) = 0.94 \end{aligned}$

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Summary

- Data attribute types: nominal, binary, ordinal, interval-scaled, ratio-scaled
- Many types of data sets, e.g., numerical, text, graph, Web, image.
- Gain insight into the data by:
 - Basic statistical data description: central tendency, dispersion, graphical displays
 - Data visualization: map data onto graphical primitives
 - Measure data similarity
- Above steps are the beginning of data preprocessing.
- Many methods have been developed but still an active area of research.

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