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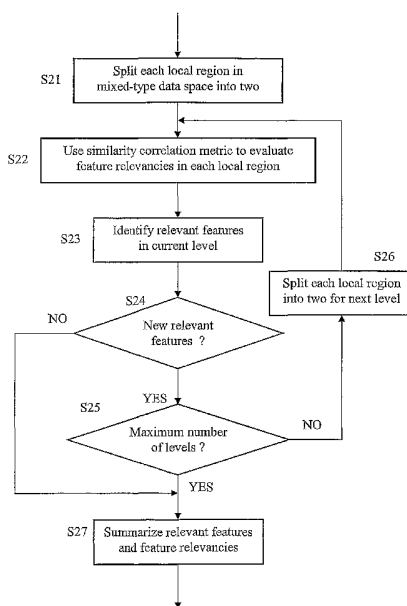
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Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) Title: HIERARCHICAL DETERMINATION OF FEATURE RELEVANCY FOR MIXED DATA TYPES



(57) Abstract: A method for feature selection based on hierarchical local-region analysis of feature characteristics in a data set of mixed data type is provided. A data space associated with a mixed-type data set is partitioned into a hierarchy of plural local regions. A relationship metric (for example, a similarity correlation metric) is used to evaluate for each local region a relationship measure between input features and a target. One or more relevant features is identified, by using the relationship measure for each local region.



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HIERARCHICAL DETERMINATION OF FEATURE RELEVANCY FOR MIXED DATA TYPES

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application is a continuation-in-part of U.S. application Serial No. 10/615,885, filed July 8, 2003 and entitled "HIERARCHICAL DETERMINATION OF FEATURE RELEVANCY".

TECHNICAL FIELD

10 This application relates to pattern recognition and data mining. In particular, the application relates to determining feature relevancy in multivariate data analysis of a mixed-type data set.

15 DESCRIPTION OF RELATED ART

 Feature selection is of theoretical interest and practical importance in the practice of pattern recognition and data mining. Objects or data entities may be described in terms of many features. However, some features may be
20 redundant or irrelevant for specific tasks, serving primarily as a source of confusion. In addition, for any one specific task, different subsets of features might be relevant in different regions of input data space. Accordingly feature selection is a matter of considerable
25 interest and importance in multivariate data analysis.

 For example, in modeling a specific behavior of a given system, it is desirable to include only the parameters that contribute to that specific system behavior

and not the ones that contribute to other behaviors of the system but are not much relevant to that specific behavior.

Most of feature selection algorithms are either filter methods or wrapper methods. Filter methods use the feature selection as a preprocessing step and filter out irrelevant features before learning a model. Thus, the filter methods are independent of the learning algorithm. Wrapper methods embed the learning algorithm within the feature selection process and use the learning algorithm to evaluate the performance of the feature selection. Each approach has both advantages and disadvantages. A filter approach is usually more efficient and can be combined with any learning algorithm, while a wrapper approach can usually provide a better performance for the learning algorithm.

In any event, conventional feature selection algorithms are typically adapted for processing of numerical features, but are not proficient for handling a data set of mixed data types. Improved methodologies for determining feature relevancy for mixed data types are needed.

SUMMARY

Methods for feature selection based on hierarchical local-region analysis of feature characteristics in a data set of mixed data type are described herein. A method for feature selection based on hierarchical local-region

analysis of feature characteristics in a data set of mixed data type, according to one exemplary embodiment, comprises partitioning a data space associated with a mixed-type data set into a hierarchy of pluralities of local regions, using
5 a relationship metric to evaluate for each local region a relationship measure between input features and a target, and identifying one or more relevant features, by using the relationship measure for each local region. The relationship metric preferably is or includes a similarity
10 correlation metric (discussed below).

A similarity correlation metric can be used in methods for analyzing feature characteristics in a data set of mixed data type. According to an exemplary embodiment, a method for analyzing feature characteristics in a data set
15 of mixed data type comprises mapping a data space associated with a mixed-type data set to a distance space, and determining a relationship measure between each input feature and the target by using a distance-based relationship measure. When a similarity correlation metric
20 is used, the relationship measure is determined by using distance correlation.

The similarity correlation metric is provided to handle features of different data types, and facilitates analysis of feature relevancy by computing the correlations
25 between input features and a target.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present application can be more readily understood from the following detailed description with reference to the accompanying drawings wherein:

5 FIG. 1A shows a flow chart of a method for feature selection based on hierarchical local-region analysis of feature characteristics in a data set of mixed data type, according to an exemplary embodiment of the present application;

10 FIG. 1B shows a flow chart of a method for analyzing feature characteristics in a data set of mixed data type, according to an exemplary embodiment of the present application;

 FIG. 2 shows a flow chart of another exemplary
15 embodiment of a method for feature selection based on hierarchical local-region analysis of feature characteristics in a data set of mixed data type;

 FIG. 3 shows a three-dimensional plot of an extended parity-2 problem;

20 FIG. 4 shows a table of feature relevancy values for an extended parity-2 problem, obtained by applying an exemplary embodiment of this application; and

 FIG. 5 shows a table of feature relevancy values for the Monk's problem, obtained by applying an exemplary
25 embodiment of this application.

DETAILED DESCRIPTION

This application provides tools for determining feature relevancy of mixed data types in multivariate data analysis. The tools of this disclosure may be a computer
5 program stored on a computer readable medium and/or transmitted via a computer network or other transmission medium.

A similarity correlation metric is discussed exemplarily below, as a new relevancy evaluation metric for
10 an enhancement of the Hierarchical Determination of Feature Relevancy (HDFR) methodology which is discussed in U.S. application Serial No. 10/615,885, filed July 8, 2003 and entitled "HIERARCHICAL DETERMINATION OF FEATURE RELEVANCY", the entire contents of which are incorporated herein by
15 reference. The enhanced HDFR methodology can be used to process features with mixed data types.

The Hierarchical Determination of Feature Relevancy (HDFR) methodology can be employed for feature selection based on hierarchical local-region analysis of feature
20 characteristics. Hierarchical k-means clustering can be applied to partition the entire data space into local regions, which may or may not be overlapping, and then for each local region evaluates each feature individually based on its correlation with the target. In each local region
25 there might be a particular, corresponding subset of features that is relevant according to the target for the

local region. The subsets do not need to be the same for different regions of input data space. In other words, a feature or subset of features might not show strong relevancy to a particular task over the entire range of data but might show strong relevancy over different delineated regions. Such a feature is still considered relevant and can be identified for use in the appropriate regions.

A typical implementation of the HDFR methodology utilizes a linear correlation metric to evaluate the relevancy of a feature. The linear correlation metric computes the R-squared correlation between the feature and the target. However, the R-squared correlation computation is applied to numerical values. In order to use the linear correlation metric, non-numerical features (such as symbolic ones) are converted to numerical form by using conversion techniques such as, for example, cross tabulation. Cross tabulation converts a symbolic feature into many numerical features corresponding to the distinctive symbolic values. Such conversion often results in very large number of cross tabulated features with mostly 0 entries, which increases not only the computational cost but also the risks of discovering accidental relationships.

On the other hand, some advances have been made in handling non-numerical features in machine learning

techniques. For example, as disclosed in U.S. application Serial No. 10/418,659, filed April 18, 2003 and entitled "PROCESSING MIXED NUMERIC AND NON-NUMERIC DATA", the entire contents of which are incorporated herein by reference, some similarity metrics such as set distance metric are designed to compute the distance of non-numerical values. Such similarity metrics can be used in learning methodologies such as hierarchical k-means clustering which can be utilized in the HDFR methodology. Therefore, the HDFR methodology can be adapted to have the capability of partitioning data space with non-numerical features. However, in order to evaluate relevancy of non-numerical features, a new relevancy evaluation metric other than the typical linear metric is desirable. A similarity correlation metric is discussed below as a new relevancy evaluation metric which adapts existing similarity metrics to compute the similarities of features and a target, and then computes the correlations between the similarities of input features and the similarities of the target.

A method for feature selection based on hierarchical local-region analysis of feature characteristics in a data set of mixed data type is described below with reference to Fig. 1A. A data space associated with a mixed-type data set is partitioned into a hierarchy of plural local regions (step S11). A relationship metric (for example, a similarity correlation metric) is used to evaluate for each

local region a relationship measure between input features and a target (step S13). One or more relevant features is identified, by using the relationship measure for each local region (step S15). The relationship metric
5 preferably includes a similarity correlation metric.

According to another embodiment, a method for analyzing feature characteristics in a data set of mixed data type (Fig. 1B) can be adapted to use the similarity correlation metric. A data space associated with a mixed-
10 type data set is mapped to a distance space (step S17). A relationship measure between each input feature and the target is determined by using a distance-based relationship measure (step S19). When a similarity correlation metric is used, the relationship measure is determined by using
15 distance correlation.

In typical implementations of HDFR (heretofore), the linear correlation metric was used to evaluate the feature relevancy. The linear correlation metric computes the R-squared correlation between a feature and the target.
20 Assume a numerical input feature is x and the numerical target is y . The R-squared value between x and y represents the proportion of the variance in y attributable to the variance in x . Given observed pairs, (x_i, y_i) , $i = 1 \sim n$, the mathematical formulation of R-square value is:

25

$$RSQ = \frac{\left(\sum_i (x_i - \bar{x})(y_i - \bar{y}) \right)^2}{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2} \quad (1)$$

where $\bar{x}$ and $\bar{y}$ are the mean of x_i s and y_i s

There is a limitation on the R-squared correlation
 5 computation that it can only apply to numerical values.
 This disclosure describes a new relevancy evaluation
 metric, the similarity correlation metric, to be used to
 evaluate relevancies of non-numerical features.

In Serial No. 10/418,659, some similarity metrics are
 10 discussed to handle non-numerical data types. One example
 is the set distance metric. The set distance metric can
 compute the distance between two non-numerical values. It's
 also proposed some methods to compute the center of a set
 of non-numerical values. The similarity correlation metric
 15 takes advantages of these mixed data handling techniques.
 Assume both the input feature x and the target y have non-
 numerical values. The similarity correlation metric first
 uses the similarity metric to compute the center of the
 observed values. Next, the distances of individual
 20 observations to the center are computed by the similarity
 metric, to obtain distance pairs, $(dist.x_i, dist.y_i)$, $i = 1$
 $\sim n$, from the raw data pairs (x_i, y_i) . The similarity

correlation metric measures the correlation between x and y using the distance correlation as in equation 2:

$$SCR = \frac{\left(\sum_i \left(dist.x_i - \overline{dist.x} \right) \left(dist.y_i - \overline{dist.y} \right) \right)^2}{\sum_i \left(dist.x_i - \overline{dist.x} \right)^2 \left(dist.y_i - \overline{dist.y} \right)^2} \quad (2)$$

where $\overline{dist.x}$ and $\overline{dist.y}$ are the mean of $dist.x_i$ s and $dist.y_i$ s

5

Comparing equation 1 and 2, one can see that they are very similar. The similarity correlation metric is different from the linear correlation metric in that it actually computes the linear correlation in a mapped space, the distance space, rather than in the original raw data space.

Mapping from the raw data space to the distance space allows the methodology to evaluate numerically the relevancies of non-numerical features. This is an advantage of the similarity correlation metric over the linear correlation metric. The similarity correlation metric also has an advantage over the linear correlation metric in discovering a nonlinear relationship in the numerical data space, which is demonstrated by the following simple example.

20

Consider the simple nonlinear case $y = x^2$, where x is from $-\infty$ to $+\infty$. A R-squared correlation score of 0 is obtained by using the linear correlation metric which

results from the cancellation of negative correlation of x and y when x is negative, and the positive correlation of x and y when x is positive. The similarity correlation metric uses two steps to evaluate correlation between x and y .
5 First it maps the original space to the distance space. Assume the mean of x is 0. The mapping results in function $dist.y = (dist.x)^2$. The similarity correlation metric then computes the linear correlation between $dist.x$ and $dist.y$. But due to the space mapping there is no more negative
10 correlation between $dist.x$ and $dist.y$. Therefore, a high similarity correlation score of 0.969 is obtained.

The effect of space mapping is similar to space partitioning under the HDFR methodology. The HDFR methodology can partition (x, y) space along axis $x = 0$ and
15 then compute the correlation between x and y in two partitioned spaces. The space mapping is to fold the original space along axis $x = 0$ and $y = 0$ and compute the correlation in the folded space. Both techniques can be targeted to identify the nonlinear relations.

20 This disclosure describes an enhancement to the HDFR methodology, utilizing the similarity correlation metric, to handle features with mixed data types. The enhanced HDFR methodology is designed to discover the feature relevancies of mixed data types. According to an exemplary embodiment
25 of the enhanced HDFR methodology, a hierarchical k-means

clustering is used to partition and transform data into groups of points in hyper-spherical local regions. The similarity correlation metric is used to evaluate the relevancies of input features of mixed data types.

5 Relevancies of features over the local regions are summarized as the relevancies of input features.

A flow chart of the enhanced HDFR methodology using a similarity correlation metric, according to an exemplary embodiment, is shown in Fig. 2. The mixed-type data space

10 is partitioned initially into two regions (step S21). For each of the regions in the present level of the hierarchy, a similarity correlation metric is utilized to evaluate feature relevancies based on samples in the region (step S22). The feature relevancies in the level are used to

15 identify relevant features which have significantly larger relevancies than the others (step S23). If no new relevant features can be identified for a certain number of levels (step S24, "NO") or a specified maximum number of levels is reached (step S25, "YES"), the feature relevancies can be

20 summarized at all of the levels and a list of relevant features and their relevancies provided (step S27). The local regions in the current level are split further for the next level (step S26), until no new relevant features can be identified for a specified or predetermined number

25 of iterations or a specified maximum number of levels is reached.

The performance of the enhanced HDFR methodology is discussed exemplarily through two examples below. One example is the extended parity-2 problem and the other is the three Monk's problems. The extended parity-2 problem is from the well-known parity-2 problem, but extended to use inputs and output of continuous values. Some random noise inputs are also added to see if the enhanced HDFR methodology can still work on numerical features. The three Monk's problems have been used as a standard for comparing many different learning methodologies. The problems have discrete input features and the first and the third problems can be used as feature selection tasks.

The parity-2 problem is a well-known problem. In this problem, the output is the mod-2 sum of two binary input features. It is extended by using continuous inputs and output. A nonlinear equation is used to simulate the problem:

$$y = x_1 + x_2 - 2 * x_1 * x_2$$

where x_1 , x_2 and $y \in [0, 1]$.

A 3-D plot of the above equation is shown in Fig. 3.

For testing purpose, 8 random input features, x_3 to x_{10} , are added as noise and 500 samples are randomly generated. The task is to identify the relevant features, x_1 and x_2 , from the noise features, x_3 to x_{10} .

Estimated feature relevancies obtained by applying the

enhanced HDFR methodology to the data of the extended parity-2 problem are shown tabularly in Fig. 4. The results show that the relevant features, x_1 and x_2 , have significantly larger relevancy values than other noise features. This demonstrates that the enhanced HDFR methodology using a similarity correlation metric can still identify the relevant numerical features.

The Monk's problems have been used as a standard for comparing many different learning methodologies. There are six input features, $x_1, x_2, \dots, x_6$, and one binary target y . Among the six input features, both feature x_3 and x_6 have only two discrete values and they are treated as binary numerical features. All of the other features have multiple discrete values and are treated as non-numerical features. The target y is binary and treated as numerical. The following is the definition of Monk's problems:

Monk-1: $y = 1$ if $(x_1 = x_2)$ or $(x_5 = 1)$, otherwise $y = 0$.

Monk-2: $y = 1$ if exactly two of $\{x_1 = 1, x_2 = 1, x_3 = 1, x_4 = 1, x_5 = 1, x_6 = 1\}$, otherwise $y = 0$.

Monk-3: $y = 1$ if $(x_5 = 3 \text{ and } x_4 = 1)$ or $(x_5 \neq 4 \text{ and } x_2 \neq 3)$, otherwise $y = 0$ (5% class noise added to the training set).

From the definition one can check what features are

relevant to the problems. For the first problem, one can see that only three features, x_1 , x_2 and x_5 , are relevant to the problem. For the second problem, all six features are relevant to the problem. For the third problem, three
5 features, x_2 , x_4 and x_5 , are relevant to the problem. Therefore, the first and the third problem can be used as feature selection tasks. Exemplary feature relevancy values obtained by applying the enhanced HDFR methodology to the three Monk's problems is set forth in Fig. 5.

10 As can be seen from the estimated feature relevancies shown tabularly in Fig. 5, the ranks of feature x_1 , x_2 and x_5 in the first problem are 2, 4 and 1 respectively. The ranks of feature x_2 , x_4 and x_5 in the third problem are 1, 5 and 2 respectively. Feature x_4 in the third problem does not
15 rank higher as might expect it to be. However, this is not surprising because the relevancy of feature x_4 is actually very small from the problem definition. Without feature x_4 , only 12 out of 228 positive examples cannot be defined. Furthermore, the 5% class noise added to the dataset also
20 diminishes the chance of methodologies to identify feature x_4 as a relevant feature.

This disclosure describes a new feature relevancy evaluation metric, the similarity correlation metric, which enhances the HDFR methodology, for handling features with
25 mixed data types. Experiment results show that the enhanced HDFR methodology works well for features of both numerical

and non-numerical data types.

The enhanced HDFR methodology can be adapted for any of various applications. For example, it can be integrated in a context-sensitive search engine. As another example,
5 it can be adapted to be applied in intelligent software for monitoring electronic communications (such as e-mails, instant messages, other Internet communications, etc.). In addition, the enhanced HDFR methodology can be integrated in a system for cataloging textual information (such as
10 news stories, books, scientific papers, etc.). It can be used by on-line book vendors to automatically suggest alternative titles when a book sought by a customer is not available (or even if it is available). Numerous other applications of the enhanced HDFR methodology are possible.

15 The above specific embodiments are illustrative, and many variations can be introduced on these embodiments without departing from the spirit of the disclosure or from the scope of the appended claims. For example, elements and/or features of different illustrative embodiments may
20 be combined with each other and/or substituted for each other within the scope of this disclosure and appended claims.

Additional variations may be apparent to one of ordinary skill in the art from reading the following
25 applications, the entire contents of which are incorporated herein by reference.

U.S. application Serial No. 10/615,885, filed July 8, 2003 and entitled "HIERARCHICAL DETERMINATION OF FEATURE RELEVANCY"; and

5 U.S. application Serial No. 10/418,659, filed April 18, 2003 and entitled "PROCESSING MIXED NUMERIC AND NON-NUMERIC DATA".

What is claimed is:

1. A method for feature selection based on hierarchical local-region analysis of feature characteristics in a data set of mixed data type,
5 comprising:

partitioning a data space associated with a mixed-type data set into a hierarchy of pluralities of local regions;

using a relationship metric to evaluate for each local region a relationship measure between input features and a
10 target; and

identifying one or more relevant features, by using the relationship measure for each local region.

2. The method of claim 1, wherein the relationship
15 metric includes determining for each local region a center of data from said data set in the local region.

3. The method of claim 2, wherein the relationship metric includes determining for each local region distances
20 between respective data points in the local region and the center of the local region.

4. The method of claim 3, wherein the relationship metric maps the data space associated with the mixed-type
25 data set to a distance space, and determines a correlation between each input feature and the target by using a

distance correlation.

5. The method of claim 1, wherein the relationship metric includes a similarity correlation metric.

5

6. A computer system, comprising:

a processor; and

a program storage device readable by the computer system, tangibly embodying a program of instructions
10 executable by the processor to perform the method claimed in claim 1.

7. A program storage device readable by a machine, tangibly embodying a program of instructions executable by
15 the machine to perform the method claimed in claim 1.

8. A computer data signal transmitted in one or more segments in a transmission medium which embodies instructions executable by a computer to perform the method
20 claimed in claim 1.

9. An apparatus for feature selection based on hierarchical local-region analysis of feature characteristics in a data set of mixed data type,
25 comprising:

partition means for partitioning a data space

associated with a mixed-type data set into a hierarchy of pluralities of local regions;

evaluation means for using a relationship metric to evaluate for each local region a relationship measure
5 between input features and a target; and

relevant feature identification means for identifying one or more relevant features, by using the relationship measure for each local region.

10 10. The apparatus of claim 9, wherein the relationship metric includes a similarity correlation metric.

 11. A method for analyzing feature characteristics in
15 a data set of mixed data type, comprising:

 mapping a data space associated with a mixed-type data set to a distance space; and

 determining a relationship measure between each input feature and the target by using a distance-based
20 relationship measure.

 12. The method of claim 11, wherein the distance-based relationship measure is a distance correlation.

25 13. A computer system, comprising:
 a processor; and

a program storage device readable by the computer system, tangibly embodying a program of instructions executable by the processor to perform the method claimed in claim 11.

5

14. A program storage device readable by a machine, tangibly embodying a program of instructions executable by the machine to perform the method claimed in claim 11.

10 15. A computer data signal transmitted in one or more segments in a transmission medium which embodies instructions executable by a computer to perform the method claimed in claim 11.

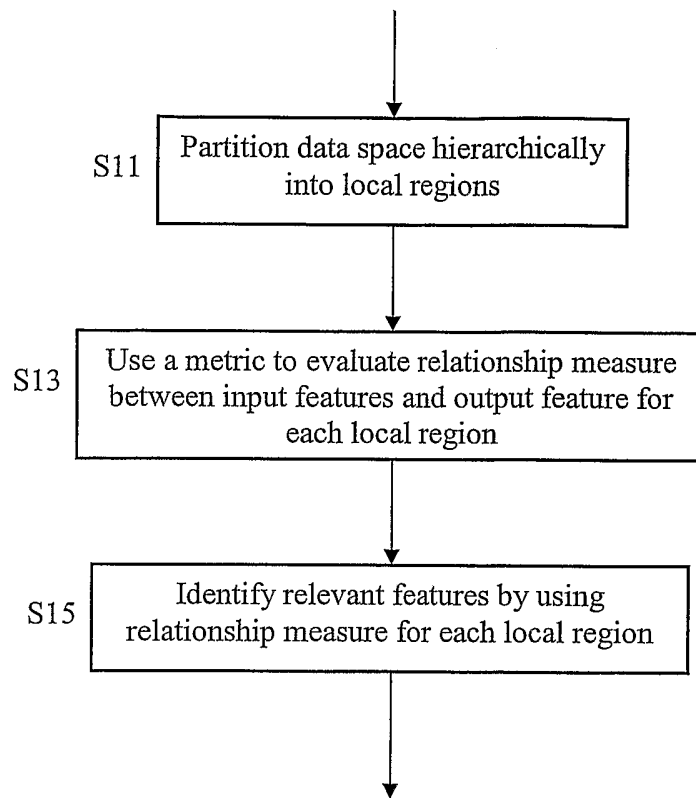
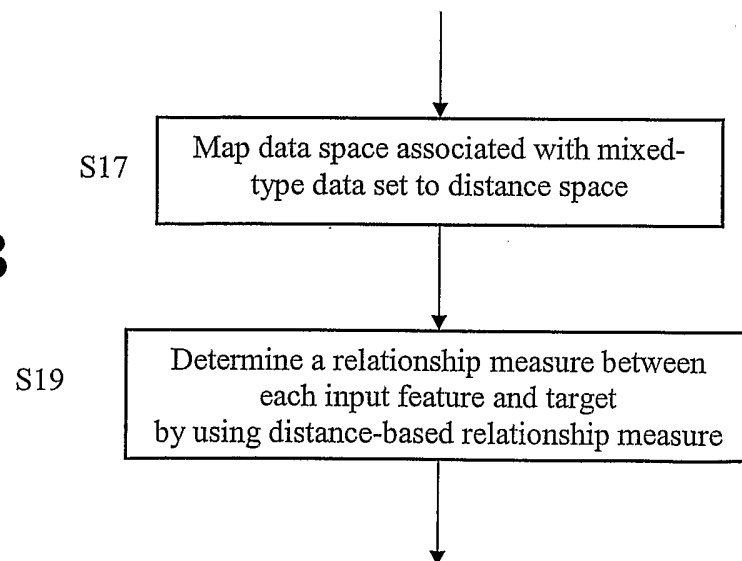
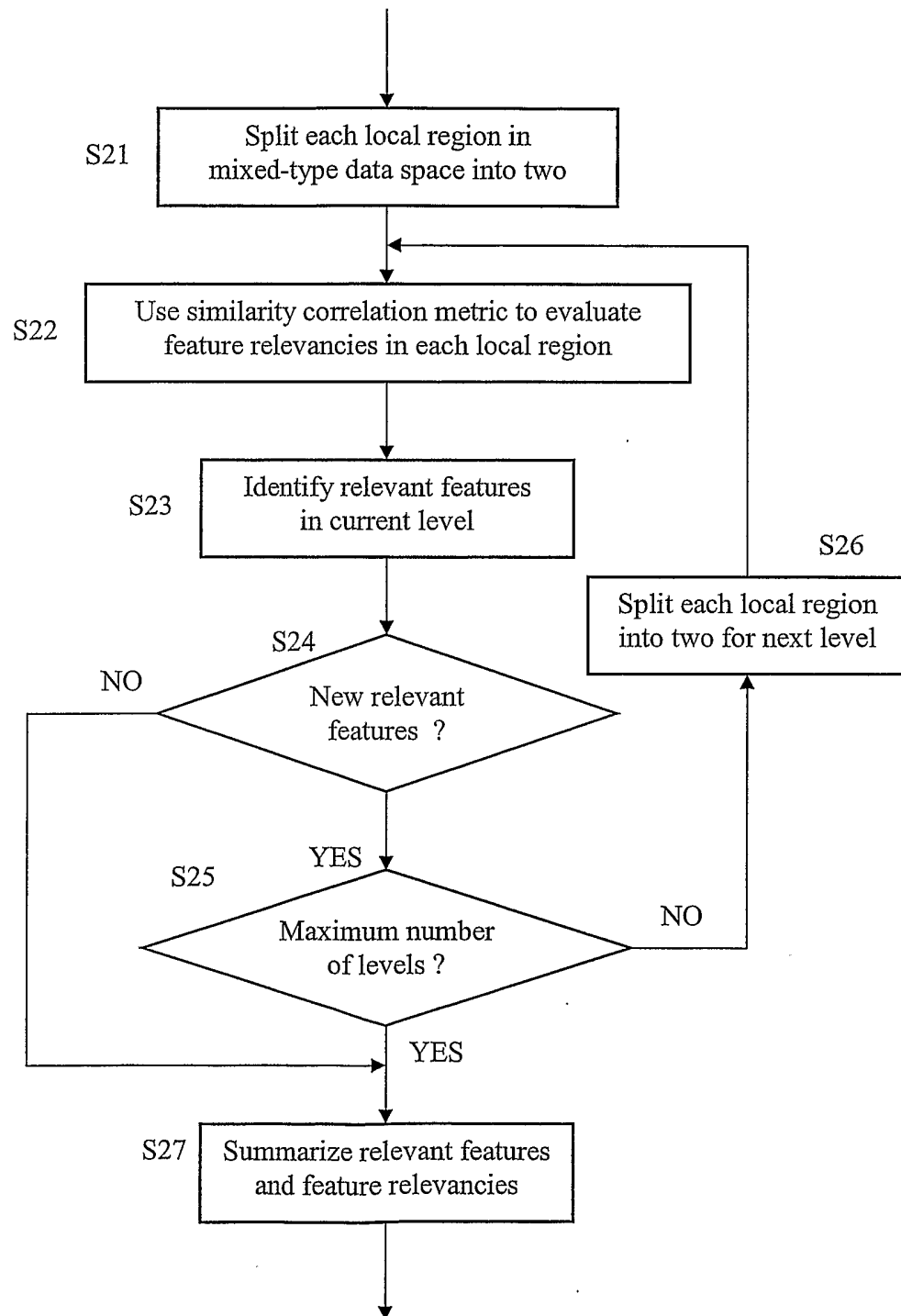
**FIG. 1A****FIG. 1B**

FIG. 2

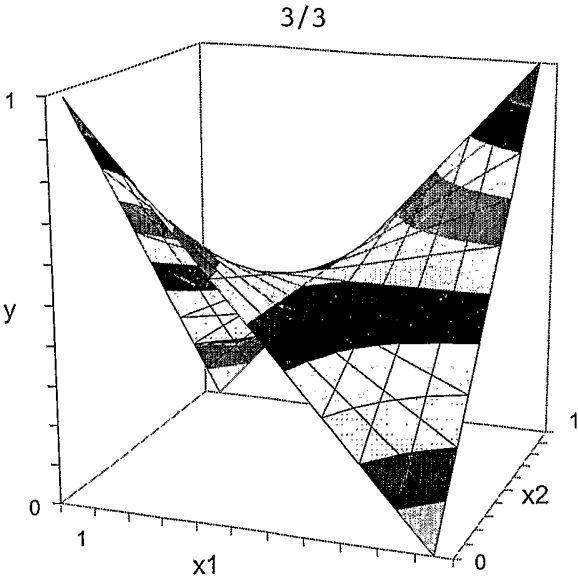


FIG. 3

FIG. 4

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
y	47.16	36.69	2.48	2.67	2.55	1.90	1.76	1.62	1.93	1.23

FIG. 5

	x_1	x_2	x_3	x_4	x_5	x_6
Monk-1	14.15	11.91	9.67	13.04	51.23	0.00
Monk-3	5.31	36.60	7.84	7.35	33.32	9.58

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K9/62

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	M. HALL ET AL.: "Benchmarking attribute selection techniques for discrete class data mining" IEEE TRANS. KNOWLEDGE AND DATA ENGINEERING, vol. 15, no. 6, November 2003 (2003-11), pages 1437-1447, XP002387331 Section 2. "Attribute selection techniques", in particular subsection 2.4. "Correlation based Feature Selection" ----- -/--	1-15

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2006/007158

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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