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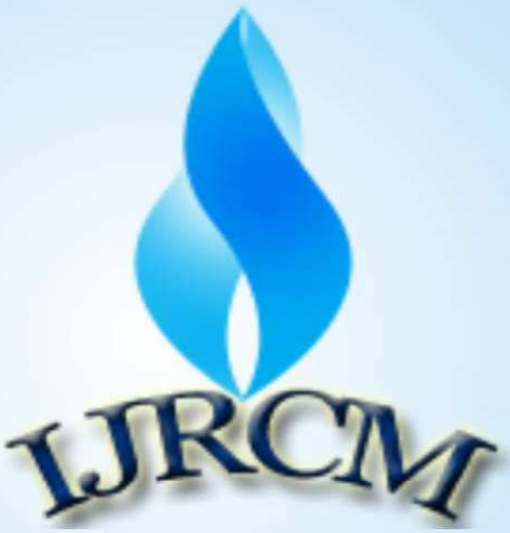

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A SURVEY OF THE DIMENSIONALITY REDUCTION TECHNIQUES IN DATA MINING: A REVIEW PAPER

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ABSTRACT

The objective of data mining is to identify valid novel, potentially useful, and understandable correlations and patterns in existing data [Chung and Gray 1999]. The volume of electronically accessible data in warehouses and on the Internet is growing faster than the speedup in processing times predicted by Moore's Law. Consequently, classical data mining algorithms that require one or more computationally intensive passes over the entire database are becoming prohibitively slow, and this problem will only become worse in the future. The scalability of mining algorithms has therefore become a major research topic. One approach to the scalability problem is to run mining algorithms on a small subset of data. That is Data Reduction is a very important issue. Data reduction techniques can be applied to obtain a reduced representation of the data set that is much smaller in volume, yet closely maintains the integrity of the original data. That is, mining on the reduced data set should be more efficient yet produce the same analytical results. In this paper mainly dimensionality reduction technique to reduce data is been discussed. Under it mainly two techniques i.e. SVD and PCA are been discussed.

KEYWORDS
Data Mining, eigen values, eigen vectors, PCA, SVD.

I. INTRODUCTION

The sheer volume of data today and its expected increase in the next few days are some of the key challenges in data mining and knowledge discovery applications[1]. Besides a huge number of data samples that are collected and processed, the high dimensional nature of data arising in many applications causes a need to develop effective and efficient techniques that are able to deal with massive amount of data[9]. As the dimensionality of data increases, many types of data analysis and classification problems become significantly harder.
Dimensionality reduction, feature selection, numerosity reduction, and data compression are some of the techniques to reduce the attribute space.

II. DATA REDUCTION TECHNIQUES

Dimensionality reduction is the process of reducing the number of random variables or attributes under consideration by producing the linear combination of the original data. Dimensionality reduction methods include transforms and principal components analysis which transform or project the original data onto a smaller space. The main advantage of this technique is that the size of attribute space is reduced without loosing a lot of information of the original attribute space. The disadvantage is the fact that the linear combinations of the original features are usually not interpretable and the information about how much an original attribute contributes is often lost.
Feature Selection works by removing redundant or irrelevant features from the data set as they can lead to a reduction of the classification accuracy or clustering quality and to unnecessary increase in the computational cost. The advantage of feature selection is that no information about the importance of single feature is lost. On the other hand, if a small set of features is required and the original features are diverse, information may be lost as some of the features must be omitted.
Numerosity reduction techniques replace the original data volume by alternative smaller forms of data representation.
Data compression, transformations are applied so as to obtain a reduced or "compressed" representation of original data.
In this paper we will mainly deal with dimensionality reduction technique of data reduction. Data reduction can be lossless or lossy. In dimensionality reduction, reduction of the dimensionality is done by using low rank approximation techniques to create new attributes that are combinations of the old, original variables. Dimensionality reduction is also referred to as feature transformation, feature extraction or feature construction. Some of the techniques covered under this are Principal Component Analysis(PCA), Singular Value Decomposition(SVD), Pseudoinverse(also called as Moore Penrose Pseudoinverse), etc.

III. PRINCIPAL COMPONENT ANALYSIS

Principal component analysis (PCA)[2] is a standard tool in modern data analysis - in diverse fields from neuroscience to computer graphics - because it is a simple, non-parametric method for extracting relevant information from confusing data sets.
Often, the variables under study are highly correlated and as such they are effectively "saying the same thing". It may be useful to transform the original set of variables to a new set of uncorrelated variables called principal components. These new variables are linear combinations of original variables and are derived in decreasing order of importance so that the first principal component accounts for as much as possible of the variation in the original data. These new attributes (called principle components(PCs)) have to meet the following criteria: The PCs are (i) linear combinations of the original attributes, (ii) orthogonal to each other, and (iii) capture the maximum amount of variation in the data. Also, PCA is a linear dimensionality reduction technique, which identifies orthogonal directions of maximum variance in the original data, and projects the data into a lower-dimensionality space formed of a sub set of the highest variance components.
The goal of PCA is to reduce the dimensionality of the data while retaining as much as possible of the variation present in the original dataset.

A. Advantages and disadvantages of PCA

PCA is a relatively simple, non-parametric, generic method that is useful for finding new, more informative, uncorrelated features and it can be used to reduce dimensionality by rejecting low variance features. Since the principal components are orthogonal[7][8] to each other, every principal component is uncorrelated to every other principal component (i. e., they do not contain any redundant information). The principal components are designed to account for the highest percentage of the variation among the variables with as few PCs as possible. Thus, often the first few PCs account for some large percentage of the total variance, allowing for a compact representation of the data with only low dimensions.

However, PCA is limited to re-expressing the data as combinations of its basis vectors. A main drawback of PCA[5] is that each PC is a linear combination of all original variables, thus leading to a potentially difficult interpretation of the PCs. On the contrary, in a system with many variables PCA may be used to project the dimension down to a reasonable number of plots, and the principal components could be rotated towards a more meaningful representation. Moreover, PCA[6] is sensitive with respect to the units of measurement. If the units and the variances of attributes vary a lot, then variables with high variance tend to dominate the first few principal components. In this case, the data need to be normalized prior to the PCA transformation.

B. Computational complexity

From a computational point of view, the eigen value decomposition for solving the PCA transformation is rather expensive in terms of runtime, especially for a large number of attributes. There are several algorithms for solving symmetric eigen problems, but all of them are of order O(n3). So the complexity of solving PCA also revolves around the same.

IV. SINGULAR VALUE DECOMPOSITION

Singular Value Decomposition[3] can be viewed from three points of view:

1.It is a method for transforming correlated variables into a set of uncorrelated ones that better expose the various relationships among the original data items.

2.SVD is a method for identifying and ordering the dimensions along which data points exhibit the most variation.

3.Once we have identified where the most variation is, it is possible to find the best approximation of the original data points using fewer dimensions. Hence SVD can be seen as a method of data reduction.

SVD[4] is based on a theorem of linear algebra which says that a rectangular matrix can be broken down into a product of three matrices:

a) An orthogonal matrix U [i.e. $U^TU=I$] and the columns of U are orthonormal eigen vectors of $A.A^T$.

b) A diagonal matrix S, containing the square roots of eigen values from U or V in descending order.

c) Transpose of an orthogonal matrix V^T [i.e. $V^TV=I$] and the columns of V are orthonormal eigen vectors of $A^T.A$.

i.e. $A_{mn}=U_{mm}S_{mn}V^T_{nn}$

The truncated SVD (or reduced rank SVD) to A can be found by setting all but the first k largest singular values equal to zero and using only the first k columns of U and V . This is usually denoted like

$A_k=U_kS_kV^T_k$

or more explicitly,

$$A_k \approx (u_1,\ldots,u_k) \begin{pmatrix} \sigma_1 & & \\ & \ddots & \\ & & \sigma_k \end{pmatrix} \begin{pmatrix} V_1 \\ \vdots \\ V_k \end{pmatrix}$$

A. Computational complexity

In general, the computational complexity of the SVD algorithm for computing all three matrices U, S and V is $O(4m^2n+8mn^2+9n^3)$, for computing only the matrices S and V it is $O(4mn^2 + 8n^3)$, making the decomposition unfeasible for large datasets. The RSVD algorithm has a complexity of O(4m2n+22n3) for computing all three matrices, and a complexity of $O(2mn^2 + 11n^3)$ for computing only S and V.

Other than the data reduction the various other applications of SVD are:

1.*Numerical Rank:* The SVD can be used as a numerically reliable estimate of the effective rank of the matrix. The rank of a matrix is defined as the number of linearly independent coloumns in a matrix. The way to find these dependencies is to focus on the singular values that are of a larger magnitude than the measurement error. If there are *r* such singular values, the effective rank of the matrix is found to be *r:* The SVD is closely related to the idea of selecting the closest rank *r* approximation to a matrix, which is further considered in the data compression.

2.*Pseudoinverse:* Another application of the SVD is to the computation of what is called the generalized inverse of a matrix. This is very closely related to the linear least squares problem. If A is square and full-rank it has an inverse. But for the tall and fat matrices i.e. when m>n and m<n respectively the inverse cannot be taken out directly. In such cases the pseudoinverse is been taken out. Various methods for calculating the pseudoinverse have been found. The pseudoinverse of a sparse matrix is been found in [12]. Similarly the pseudoinverse can also be taken out by Linear Solver[11] which takes out the inverse by deviding the matrix into two parts.

3.*Rank Deficient Least Squares:* As with most of our other linear algebra tools, SVD provides yet another way to solve linear systems. This is stable when the we deal with square matrices One of the strengths of the SVD is that it works when the matrix is singular. It also deals with the overdetermined and underdetermined cases when the number of equations is not equal to the number of unknowns.

B. Relation to PCA

Calculating the SVD is equivalent of finding the eigen values and eigen vectors of AA^T and A^TA. The eigenvectors of AA^T make up the columns of U, the eigenvectors of A^TA make up the columns of V. Moreover, the singular values in S are the square roots of eigen values from AA^T and A^TA. The SVD-PCA connection stems from the straightforward linear algebra calculations

$AA^T=(USV^T)(VS^TU^T)=US^2U^T$, *and*

$A^TA=(VS^TU^T)(USV^T)=VS^2V^T$

An often mentioned difference between these two approaches is that PCA removes

the mean of each variable whereas SVD uses the original data (however, the mean could also be removed before computing the SVD). Especially for sparse data it is not always preferable to remove the mean of the data.

V. METHODS

There are various methods to solve matrix equations that are specialised to particular problems. We can select between these based on the type of data. Various methods used for the same are as follows:

1.LAPACK: It is the default method for solving dense numerical matrices. When the matrix is square and non-singular the routines dgesv, dlange, and dgecon are used for real matrices and zgesv, zlange, and zgecon for complex matrices. When the matrix is non-square or singular dgelss is used for real matrices and zgelss for complex matrices. If the input matrix uses arbitrary-precision numbers, then LAPACK algorithms extended for arbitrary-precision computation are used.

2.Multifrontal: The Multifrontal method is a direct solver used by default if the input matrix is sparse. If the input matrix to the Multifrontal method is dense, it is converted to a sparse matrix. The implementation of the Multifronal method uses the UMFPACK library.

3.Krylov: The Krylov method is an iterative solver that is suitable for large sparse linear systems, such as those arising from numerical solving of PDEs. Basically two Krylov methods are implemented: Conjugate Gradient (for symmetric positive definite matrices) and BiCGSTAB (for non-symmetric systems). The default method for Krylov, BiCGSTAB, is more expensive but more generally applicable. The ConjugateGradient method is suitable for symmetric positive definite systems, always converging to a solution (though the convergence may be slow). If the matrix is not symmetric positive definite the ConjugateGradient may not converge to a solution.

4.Cholesky: The Cholesky method is suitable for solving symmetric positive definite systems. This method is far more fast and stable. For dense matrices the Cholesky method uses LAPACK functions such as dpotrf and dpotrs for real matrices and zpotrf and zpotrs for complex matrices. For sparse matrices the Cholesky method uses the TAUCS library.

5.Symbolic Methods: There are a number of methods that are specific to symbolic and exact computation: CofactorExpansion, DivisionFreeRowReduction and OneStepRowReduction.

VI. CONCLUSIONS AND FUTURE WORK

In this paper we have discussed about data reduction techniques and from them we conclude various advantages of data reduction. It leads to better understanding of underlying model. It is simply the usage of various visualization techniques(eg looking at peers or triplets of attributes, self organizing maps, etc.). Data reduction significantly reduces the computational cost and memory requirements of the classification algorithm applied to data. Here mainly the dimensionality reduction aspect of data reduction is considered. SVD and PCA can be mainly used for dimensionality reduction. While PCA mainly works with principal components SVD deals with whole data and mainly with sparse matrix. From a theoretical point of view, PCA and SVD have the best theoretically provable properties, and give the best approximation in terms of approximation error. Moreover, both techniques are purely deterministic and always produce reproducible results (for identical input).

The availability of fast and efficient algorithms is also an important aspect of dimensionality reduction methods. The software libraries as described in the method part provide several algorithmic variants for efficiently computing singular value decomposition and eigen value decomposition(to be used in PCA).

The future work for these techniques can be that various applications of these techniques can be explored and the accuracy of data reduction can be increased.

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