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論 文 要 旨

THESIS SUMMARY

専攻： Department of	Computer Science 専攻	申請学位（専攻分野）： Academic Degree Requested	博士 (Engineering) Doctor of
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this thesis we investigate learning with tensor data and tensor structured models using low rank tensor regularizations. We propose a new low rank inducing norm called the scaled latent trace norm and apply it to supervised learning with tensor data and tensor based multitask learning. The thesis is structured as five chapters and they are structured as follows.

In the first chapter we first give an overview on machine learning and different methods of learning. We next describe supervised learning models and explains the process of learning with labeled data. We review how supervised learning can be modeled for different data formats such as vectors, matrices and tensors explaining their usages. Next we focus on multitask learning and first explain how matrix based multitask learning with low rank matrix regularization can be modeled. We next explain the multilinear multitask learning which deals with learning from multiple learning tasks that can be arranged as a tensor with low rank tensor regularizations to improve the performance among tasks by sharing information. We also review existing tensor norms used for regularization and discuss their limitations.

In Chapter 2, our main purpose is to propose a new tensor norm called the scaled latent trace norm. First we review basic concepts of tensors and describe existing tensor norms such as the overlapped trace norm and the latent trace norm and explain their limitations. We identify that both these tensor norms do not consider the relative ranks with respect to the mode dimensions which make them perform poorly with tensors having high variations in multilinear ranks and mode dimensions. Next we define the scaled latent trace norm as an extension of the latent trace norm which can consider the relative ranks with respect to the mode dimensions when regularized. We provide theoretical properties of the scaled latent trace norm such as its duality and its relationship to the Frobenius norm.

In Chapter 3, we focus on supervised learning with tensor data using tensor norm regularizations. First we propose regression and classification of tensor data for the overlapped trace norm, the latent trace norm and the newly defined scaled latent trace norm. Next we provide optimisation methods to solve tensor based regression and classification for each of the tensor norms using the alternating direction method of multipliers (ADMM). We derive excess risk bounds for all the tensor norm regularized learning models which are missing in existing research literature. Our theoretical bounds derived using Rademacher complexity analysis are able to show the relationship of multilinear ranks and tensor dimensions with the excess risk bounds for each tensor norm. We show that for the overlapped trace norm regularization, the excess risk is bounded with the sum of the square root of multilinear ranks of the tensor, for the latent trace norm regularization the excess risk is bounded with the minimum of the multilinear ranks and for the scaled latent trace norm the excess risk is bounded with the ratio of the minimum rank to mode dimension. We show that the scaled latent trace norm is superior compared to other norms with tensors having high variations in multilinear ranks and mode dimensions since it considers the relative rank with respect to the mode dimension. In the experiments section we first provide simulation experiments with tensor based regression to understand how different tensor norms perform under different multilinear ranks and tensor mode dimensions. Next we demonstrate real data experiments with hand gesture recognition data and BCI data. Using both simulation and real world experiments we show that learning from tensor data without converting to vectors and applying low rank regularization leads to better performances compared to vector and matrix based learning.

In Chapter 4, we describe our proposed extensions of the multilinear multitask learning with the latent

trace norm and the scaled latent trace norm. First we describe the proposed models and provide the details of optimization procedures based on ADMM. Similarly to the supervised learning we derive excess risk bounds for multilinear multitask learning problems with all the tensor norms using the Rademacher complexity analysis. Based on the bounds we derive we show that for the overlapped trace norm regularization, the excess risk is bounded with average of the square root of multilinear ranks of the tensor, for the latent trace norm regularization the excess risk is bounded with the minimum of multilinear ranks and for the scaled latent trace norm the excess risk is bounded with the ratio of the minimum rank to mode dimension. Our experiments with real world data show that our proposed scaled latent trace norm performs the best compared to other tensor norms.

The final chapter gives the conclusions and future works based on the research in this thesis.