

System Intelligence Laboratory



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The main stream in our lab is related to computational intelligence. So far we have focused our study on three key words: recognition, learning and understanding. The goal of our research is to develop some learning models that are flexible enough to adapt changing environment, and also simple enough to be realized, interpreted and re-used. The ultimate goal is to design a system that can think, and decide what to do and how to grow-up based on its own thinking. For this purpose, many approaches have been studied - e.g., neuro-computation, memetic algorithms, reinforcement learning, awareness computing, and so on. Of course, results proposed in conventional symbol based artificial intelligence are also included.

So far, we have been trying to promote awareness science and technology through collaboration with different universities or organizations around the world. Our dream is to propose a new and better approach to realization of artificial intelligence.

So far we have used or proposed the following learning models:

- Neural network trees (NNTrees),
- Nearest neighbor classification trees (NNC-Trees),
- Support vector machines (SVMs),
- Neural network ensembles,
- Modular neural networks,
- Cellular automata, and
- Recurrent neural networks.

Division of Computer Science

Based on the above learning models, we have proposed many new algorithms. Examples include:

- IEA: individual evolutionary algorithm (also called the *R4*-rule),
- CoopCEA: cooperative co-evolutionary algorithms,
- EPNet: evolutionary programming neural net,
- Evolutionary design of neural network trees,
- Induction of NNC-Trees with the *R4*-rule,
- Fast neural network for face detection,
- Decision boundary making for inducing high performance neural networks, and
- 3-factor user authentication based on image morphing.

To verify and to improve the models and learning algorithms proposed so far, we have been studying on-line growing of neural network trees, evolution of neural network ensemble, evolutionary design of decision trees, and so on. Currently, we are very interested in applying our models and algorithms to solving practical problems related to producing a “safe, secure and healthy” society. Examples include: face detection, face/expression recognition, automatic image morphing, text mining, user authentication, steganography, and so on. We are also collaborating with local companies to solving practical problems using machine learning.

Refereed academic journal

[peiyan-105-036-01:2016] Yan Pei. Principal Component Selection Using Interactive Evolutionary Computation. *The Journal of Supercomputing*, First Online: 06 August 2016, 2016.

We propose a method to solve the selection problem of principal components in machine learning algorithms based on orthogonal transformation using interactive evolutionary computation. The orthogonal transformation presents a linear transformation method that preserves the inner product in the two coordinate systems, the one is before the transformation, and the other is after the transformation. One of the addressed subjects for machine learning algorithms based on orthogonal transformation is how to decide the number of principal components, and which of the principal components should be used to reconstruct the original data. In this work, we use the interactive differential evolution algorithm to study these subjects using real humans' subjective evaluation in optimization process. An image compression problem using principal component analysis is introduced to study the proposed method. We do not only solve the selection problem of principal components for machine learning algorithms based on orthogonal transformation using interactive evolutionary computation, but also can analyse the human aesthetical characteristics on visual perception and feature selection arising from the designed method and experimental evaluation. We also discuss and analyse potential research subjects and some open topics, which are invited to further investigate.

[yliu-105-036-01:2016] Y. Liu. Error awareness by lower and upper bounds in ensemble learning. *International Journal of Pattern Recognition and Artificial Intelligence*, 30(9):14 pages, 2016.

Two error bounds are introduced into negative correlation learning for preventing overfitting. One is the upper bound of error output (UBEO) which divides the training data into two groups based on the distances between the data and the formed decision boundary. The other is the lower bound of error rate (LBER) which is set as a learning switch. Before the performance measured by error rates is higher than LBER, negative correlation learning is applied on the whole training set. As soon as the performance is lower than LBER, negative correlation learning will only be applied to the group of data whose distances to the current decision boundary are within the range of UBEO. The other group of data outside of this range will not be learned anymore. Further learning on the data points in the later group would make the learned decision boundary too complex to classify

Summary of Achievement

the unseen data well. Experimental results would explore how LBER and UBEO would lead negative correlation learning towards a robust decision boundary.

Refereed proceedings of an academic conference

[peiyan-105-036-02:2016] Yan Pei. Data Compression with Linear Discriminant Analysis. In *Joint 8th International Conference on Soft Computing and Intelligent Systems and 17th International Symposium on Advanced Intelligent Systems (SCIS & ISIS2016)*, 2016.

The transform coding is one of data compression techniques that is established in the meaning of certain statistics of data. The conventional principal component analysis method yields the mean square error as the statistic, and it relates to the coding presentation without considering the inner relation of the data statistics. In this paper, we propose to use linear discriminant analysis for data compression to solve this problem. After solving the eigenvalue resolution by establishing between-class scatter matrix and within-class scatter matrix, we compress the data with the eigenvectors obtained by the statistical meaning of linear discriminant analysis, which considers the inner relation of the data. We use two methods for clustering the data into several groups in linear discriminant analysis. One separates them with equal data quantity by their physical storage, the other uses k-means clustering algorithm to decide the elements in each group. We apply our proposal in an image compression application to evaluate and investigate the performance of the proposal. The standard test image, Lenna, and several evaluation metrics, such as mean square error, peak signal-to-noise ratio, compression ratio, structural similarity, and information entropy are introduced in the evaluation. We found that the information entropy obtained with the same number of principal components by our proposal is less than that obtained by the principal component analysis method. It may be useful for machine learning algorithm or computer to recognize or restore the same information with less information uncertainty. We analyse the results arising from the evaluation, and some open topics, remaining works and future opportunities are discussed.

[peiyan-105-036-03:2016] Yan Pei. Principal component selection of machine learning algorithms based on orthogonal transformation by using interactive evolutionary computation. In *Systems, Man, and Cybernetics (SMC), 2016 IEEE International Conference on*, 2016.

We propose a method to solve the selection problem of principal components in machine learning algorithms based on orthogonal transformation by using interactive evolutionary computation. One of the addressed subjects for machine learning algorithms based on orthogonal transformation is how to decide the number of principal components, and which of the principal components should be used to reconstruct the original data. In this work, we use the interactive differential evolution algorithm to study these subjects by using real humans' subjective evaluation in an optimization process. An image compression problem using principal component analysis is introduced to study the proposed method. From the evaluation, we do not only solve the selection problem of principal components for machine learning algorithms based on orthogonal transformation, but also can analyse the human aesthetical characteristics on visual perception and feature selection from the designed method and experimental evaluation. We also discuss and analyse potential research subjects and some open topics, which are invited to further investigate.

[qf-zhao-105-036-01:2016] Masato Hashimoto; Yuya Kaneda; Qiangfu Zhao. An ELM-based privacy preserving protocol for cloud systems. In IEEE, editor, *Proceedings of IEEE Symposium Series on Computational Intelligence*, pages 1–6. IEEE, IEEE, 2016.

In this paper, we propose a privacy preserving protocol for cloud system utilization based on extreme learning machine (ELM). The purpose is to implement aware agents (Aagents) on portable/wearable computing devices (P/WCD). The proposed protocol is useful to reduce the calculation cost on the P/WCD. The basic idea of the protocol is to divide an ELM-based A-agent into two parts, one containing the weights of hidden layer(s) and the other containing the weights of the output layer. The former is implemented in the remote server and the latter is implemented in the P/WCD. In addition, the input data are first encrypted in the P/WCD using transposition cipher, and then sent to the server. Because the server can only see random weights and encrypted data, the user intention and privacy can be protected. In addition, since part of the computations is executed on the server, the cost for implementing A-agents in the P/WCD can be reduced. Experimental results on several public databases show that the proposed protocol is useful if the dimension of the input data is high.

[qf-zhao-105-036-02:2016] Yuya Kaneda; Qiangfu Zhao; Yong Liu. On-Line training with guide data: Shall we select the guide data randomly or based

Summary of Achievement

on cluster centers? In IEEE, editor, *Proceedings of IEEE Symposium Series on Computational Intelligence*, pages 1–7. IEEE, IEEE, 2016.

To retrain an existing multilayer perceptron (MLP) on-line using newly observed data, it is necessary to incorporate the new information while preserving the performance of the network. This is known as the plasticitystability problem. For this purpose, we proposed an algorithm for on-line training with guide data (OLTA-GD). OLTA-GD is good for implementation in portable/wearable computing devices (P/WCDs) because of its low computational cost, and can make us more independent of the internet. Results obtained so far show that, in most cases, OLTA-GD can improve an MLP steadily. One question in using OLTA-GD is how we can select the guide data more efficiently. In this paper, we investigate two methods for guide data selection. The first one is to select the guide data randomly from a candidate data set G , and the other is to cluster G first, and select the guide data from G based on the cluster centers. Results show that the two methods do not have significant difference in the sense that both of them can preserve the performance of the MLP well. However, if we consider the risk of instantaneous performance degradation, random selection is not recommended. In other words, cluster center-based selection can provide more reliable results for the user during on-line training.

[qf-zhao-105-036-03:2016] Ryota Hanyu; Qiangfu Zhao; Yuya Kaneda. A new protocol for on-line user identification based on hand-writing characters. In IEEE, editor, *Proceedings of IEEE Symposium Series on Computational Intelligence*, pages 1–7. IEEE, IEEE, 2016.

Biometric authentication (BA) is becoming more and more popular. Usually, we expect that BA can make various service systems more secure, but in fact it can be more dangerous. For example, fingerprint is one of the popular biometrics for authentication. We say it is dangerous because we cannot change our fingerprints even if they are collected and duplicated by some malicious third parties. This kind of lifelong biometrics, once they are stolen, can never be used as an authentication factor in the future. To solve the problem, we may use changeable biometrics. Examples include face, voice, and hand-writing characters. In this study, we use hand-writing characters. Hand-writing characters can change naturally in the aging process, they can also be changed intentionally through training. This paper investigates the feasibility of on-line user identification using hand-writing non-alphanumeric characters. Our main purpose is to develop some core technologies that can improve the security of service systems in some Asia countries that use Chinese characters.

[qf-zhao-105-036-04:2016] Masato Hashimoto; Yuya Kaneda; Qiangfu Zhao; Yong Liu. DBM vs ELM: A study on effective training of compact MLP. In IEEE, editor, *Proceedings of IEEE International Conference on Systems, Man, and Cybernetics*, pages 1291–1296. IEEE, IEEE, 2016.

We compare the performance of multilayer perceptrons (MLPs) obtained using back propagation (BP), decision boundary making (DBM) algorithm and extreme learning machine (ELM), and investigate better method for developing aware agents (A-agent) that are suitable for implementation in portable/wearable computing devices (P/WCD). The DBM has been proposed by us for inducing compact and high performance learning models that are suitable for implementation in P/WCD. The basic idea of the DBM is to generate data to fit the decision boundary (DB) of a high performance model, and then induce a compact model based on the generated data. In our study, support vector machine (SVM) is used as the high performance model, and a single hidden layer MLP is used as the compact model for the DBM algorithm. ELM is paid attention as new learning method for neural networks in recent years. It is known that hidden layer is not to be tuned and available fast training compared to traditional gradient-based learning methods. Experimental results show that the performance of DBM is the highest in three training methods when the number of hidden neurons is small for all databases used in the experiment. This means that the accuracy of DBM converged to high score, when the number of hidden neuron is small. Therefore, we found that DBM is the best algorithm for developing compact and high performance A-agents.

[qf-zhao-105-036-05:2016] Yuya Kaneda; Qiangfu Zhao; Yong Liu. Guide data generation for on-line learning of DBM-initialized MLP. In IEEE, editor, *Proceedings of IEEE International Conference on Systems, Man, and Cybernetics*, pages 1340–1345. IEEE, IEEE, 2016.

In this paper, we propose a method for generating guide data, and investigate its efficiency and efficacy for online learning with guide data. On-line learning in this research updates a learning model initialized by the decision boundary making algorithm proposed by us in our earlier study. The problem is that, if the guide data are not properly generated, on-line learning may require high computational cost in terms of time, and the learning process may not converge to good result. To solve this problem, we propose to use k-means to cluster all candidates of guide data, and use one datum from each cluster as the guide datum. We conducted experiments on several public databases, using different settings, and confirmed the performance of the proposed method. Specifically,

Summary of Achievement

if $k=5$, we can obtain good models with low computational cost through on-line learning.

[qf-zhao-105-036-06:2016] Yuta Kobiyama; Qiangfu Zhao; Kazuki Omomo. Privacy preserving infrared sensor array based indoor location awareness. In IEEE, editor, *Proceedings of IEEE International Conference on Systems, Man, and Cybernetics*, pages 1353–1358. IEEE, IEEE, 2016.

In recent years, researches on smart environments (SEs) especially smart homes for senior care have attracted great attention. One important issue in constructing such kind of SEs is privacy, because the target environment (e.g. a home or a room) is not public space, and devices like video cameras cannot be used. For individual or personal spaces, the SE should not be too smart to invade the resident privacy. The objective of this study is to establish a technology for constructing privacy preserving SEs. This technology will be a core for supporting our daily lives. Our solution is to use an array of some homogeneous sensors (e.g. infrared sensor) to detect various daily activities with an accuracy just good for supporting the residents. In this paper, we investigate the possibility of location awareness using an array containing 10 infrared sensors. Experimental results show that the array can provide enough information for recognizing the locations, and various classifiers can be used to recognize the locations with a relatively high accuracy.

[qf-zhao-105-036-07:2016] Qiangfu Zhao. Making aware systems interpretable. In IEEE, editor, *Proceedings of International Conference on Machine Learning and Cybernetics*, pages 881–887. IEEE, IEEE, 2016.

We human beings are often careless, forgetful and ignorant. We often miss good timing for capturing chances or avoiding risks. Computational awareness (CA) can help us to be more aware. An aware system can distinguish novel events from normal ones, inform us when the novel events are detected, and tell us the correct reaction. In many cases, we are interested in knowing reasons why certain situations are novel, and why certain reactions are necessary under these situations. The ability of providing understandable reasons can make the system more trustable. Designing interpretable aware systems should be an important goal of CA researches. In this article, we provide a method for translating an aware system into an expert system that in turn can be used to provide reasons for making decision. As a case study, we show the process for interpreting a learned 3-valued logic multilayer perceptron. The proposed method should be useful for achieving the goal of CA.

- [qf-zhao-105-036-08:2016] Qiangfu Zhao Yuta Kobiyama and Kazuki Omomo. Location awareness based on infrared sensor array. In IEEE, editor, *Proceedings of International Conference on Machine Learning and Cybernetics*, pages 899–904. IEEE, IEEE, 2016.

Smart environment is a situation aware system for improving the quality of life. This kind of systems are extremely useful for solving or avoiding several issues. The issue we consider in this research is the care of elderly peoples living in their own homes. Usually, information needed for situation awareness is obtained from various devices such as video cameras and voice recorders. However, these devices often collect unnecessary information. For example, video images may include face images and conversations of the residents. This may make the residents discomfort. To avoid the problem, we can use only simple sensors (e.g., infrared sensor, temperature sensor and light sensor). To investigate the ability of the simple sensors, we set an experiment environment in a special corner of our laboratory. As the first step, we try to detect some frequently appeared locations of a resident with a sensor array containing seven infrared sensors. Experimental results show that the sensor array is quite effective, and is able to recognize the resident locations with a relatively high accuracy.

- [qf-zhao-105-036-09:2016] Qiangfu Zhao. A Study on Realizing Awareness Using 3VL-MLP. In IEEE, editor, *IEEE 46th International Symposium on Multiple-Valued Logic*, pages 258–263. IEEE, IEEE, 2016.

Awareness is a way from sensory data to cognition. The main purpose of computational awareness (CA) is to understand the awareness mechanism and realize it in computers. Various awareness are used in our daily lives for making decisions, but most of them are tacit. For the purpose of CA, we need to interpret and understand tacit awareness as far as possible. In our earlier study, we introduced a general graph model of aware systems. In this paper, we focus on the multilayer perceptron (MLP) model, and study the feasibility of interpreting MLPs using 3-valued logic (3VL). The main purpose is to show via experiments on several public data 1) 3VL is more accurate than binary logic for interpreting a trained MLP; 2) the MLP can be more interpretable if we use structural learning with forgetting, and 3) the performance of the discretized MLPs can be improved through retraining. Based on the results obtained here, we will point out some important topics for further study.

- [qf-zhao-105-036-10:2016] Tomoya Furukawa Satoshi Watanabe, Kazuki Murakami and Qiangfu Zhao. Steganalysis of JPEG image-based steganography with support vector machine. In IEEE, editor, *17th IEEE/ACIS*

Summary of Achievement

International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing, pages 631–636. IEEE, IEEE, 2016.

Recently, concern for information security is increasing. Image-based steganography is an information hiding technique for increasing information security. Its purpose is to prevent others being aware of the existence of secret data. Recently, a stego-image detection scheme was proposed in the literature, which uses the so called extreme learning machine and features generated by markov chain. Verification results show that some steganography techniques are in fact not very secure. In this study, we investigate detection rates under different conditions and analyze the efficacy of the features using support vector machines. Results show that although the accuracy is not as high as the one given in the literature, the possibility of detecting the stego-images is very high.

[yliu-105-036-02:2016] Y. Liu. How to confine errors in negative correlation learning. In *Proceedings of 2016 International Joint Conference on Neural Networks*, pages 4070–4075. IEEE, 2016.

This paper proposes a confined error function in negative correlation learning to balance these two pressures by scaling down or up the error signals. Experimental results would explore how the confined error functions could favor the difference learning and maintain the performance.

[yliu-105-036-03:2016] Y. Liu. Learning self-awareness in committee machines. In *Proceedings of the 2016 International Conference of Machine Learning and Cybernetics*, page 6 pages. IEEE, 2016.

This paper proposes negative correlation learning with self-awareness in order for each artificial neural network (ANN) in a committee machine to be self-aware in learning so that it could decide by itself to learn more or less. It is expected that such ANNs being aware of their own behavior and performance can manage trade-offs between goals at run-time. Such self-awareness enables a committee machine to better meet their requirements for predictions on the unknown data. Measurement results have been presented to how self-awareness could support the different behaviors and maintain the performance.

[yliu-105-036-04:2016] Y. Liu. Enforcing negativity in negative correlation learning. In *Proceedings of the 2016 IEEE International Conference on Information and Automation*, pages 1122–1125. IEEE, 2016.

Two different implementations of negative correlation learning are discussed in this paper. In the first implementation, every learner is forced to learn to

be different to the ensemble on every data point no matter what have been learned by the ensemble and itself. In the second implementation, every learner is selectively to learn to be different to the ensemble on every data point. It is to hope that such selective learning could balance well between the learning accuracy and the low correlations among the ensemble. Experimental results were carried out to show how the correlation penalty should be enforced in order to achieve the better generalization.

[yliu-105-036-05:2016] Y. Liu. Control of the error signals in negative correlation learning. In *Proceedings of the 2016 IEEE International Conference on Signal Processing, Communications and Computing*, pages 176–179. IEEE, 2016.

A new version of negative correlation learning based on the error signal adjustment have been implemented in this paper. Experimental results were carried out to show how the error signal adjustment would help to achieve the better generalization.

[yliu-105-036-06:2016] Y. Liu. Negative selection in negative correlation learning. In *Proceedings of 2016 12th International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery*, pages 1608–1612. IEEE, 2016.

Two different negative selections have been introduced in negative correlation learning for letting individual learners be able to adapte the learning error functions in the whole learning process. The first negative selection is based on the opposition learning which some learners in a committee could turn to learn the opposite targets rather than the correct targets. The second negative selection is through difference learning in which each learner could decide to weaken or strengthen its learning signal on each data based on how different it is to the rest of learners in the committee machine.

[yliu-105-036-07:2016] Y. Liu. Control of the error signals by self-awareness in committee machines. In *Proceedings of 2016 9th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics*, page 4 pages. IEEE, 2016.

In this paper, negative correlation learning with the scaled error signals were tested on the two medical data sets to show how important it is to adjust the error signals by the individual learners themselves in the committee machines.

Summary of Achievement

[yliu-105-036-08:2016] Y. Liu. Negative selections in ensemble learning. In *Proceedings of 2016 IEEE Symposium Series on Computational Intelligence*, page 5 pages. IEEE, December 2016.

Two different modifications are developed in adjusting minimization of these two terms in negative correlation learning. One is to increase the weight of the estimated correlation, while the other is to increase the squared difference on some selected data. The first modification was implemented in negative correlation learning by fixing the weight of the minimization of the squared difference and increasing the weight of the minimization of the estimated correlation. The second modification was to shift the target output so that the learned output could be in a wider range. It would lead the individual learners to be more different.

Unrefereed proceedings of an academic conference

[peiyan-105-036-04:2016] Yan Pei. Autoencoder Using Kernel Method. In *The society of instrument and control engineers, Tohoku chapter 305th meeting*, 2016.

Writing a part of textbook or technical book

[qf-zhao-105-036-11:2016] Q. F. Zhao and Yong Liu. *Memetic Algorithms*, volume 2, chapter 17, pages 607–632. World Scientific, May 2016.

Roughly speaking, genes carry information for constructing a body, in which they usually work in groups to construct a meaningful body. Similarly, memes carry information for constructing a culture, in which many memes usually work together to construct a meaningful culture. Although in real world genes and memes are realized in different forms (e.g. DNA for genes and language for memes), in evolutionary computation (EC), both of them can be represented using strings defined on some alphabetic set. Thus, in EC we can study genetic evolution and memetic evolution in the same way. We can also combine them together to improve the efficiency and efficacy of the evolutionary search process. Memetic algorithms (MAs) are search algorithms obtained by combining genetic evolution and memetic evolution. In MAs, genetic evolution is often used for global search and memetic evolution is used to find the best local search strategy. So far, a great number of MAs have been proposed in the literature. In this chapter we first define some

fundamental concepts related to memetic evolution, and then introduce several templates that may cover most existing MAs. For each template, we provide a pseudo code, so that readers can understand the algorithms easily, and can develop programs to solve their own problems

Research grants from scientific research funds and public organizations

[qf-zhao-105-036-12:2016] Qiangfu ZHAO. Activity pattern recognition based on a small scale sensor network, 2016.

[yliu-105-036-09:2016] Y. Liu. The Grant-In-Aid for Scientific Research Fund (Kakenhi), 2015-2017.

Advisor for undergraduate research and graduate research

[qf-zhao-105-036-13:2016] Tatsuya Hanyu. Graduation thesis, Undergraduate school, 3 2017.

Currently, the image recognition technology has surprisingly improved. But constructed some discriminator often make mistake. So in this thesis, we tried to construct the strong discriminator in a particular place.

[qf-zhao-105-036-14:2016] Yuta Kobiyama. Master thesis, Graduate School, 3 2017.

Smart environments especially smart homes for senior care have attracted great attention. For the purpose, one important issue in constructing smart home is privacy, because the target environment (e.g. a home or a room) is not public space, and devices like video cameras cannot be used. For individual or personal spaces, the SE should not be too smart to invade the resident privacy. The objective of this study is to establish a technology for constructing privacy preserving SEs. This technology will be a core for supporting our daily lives. Our solution is to use an array of some homogeneous sensors (e.g. infrared sensor) to detect various daily activities with an accuracy just good for supporting the residents. In this paper, we investigate the possibility of location awareness and activity awareness using an array containing 10 infrared sensors. Experimental results show that the array can provide enough information for recognizing the locations and activities, and various classifiers can be used to recognize the locations and activities with a relatively high accuracy. viii

Summary of Achievement

[qf-zhao-105-036-15:2016] Ryota Hanyu. Master thesis, Graduate School, 3 2017.

Biometric authentication (BA) is becoming more and more popular. Usually, we expect that BA can make various service systems more secure, but in fact it can be more dangerous. For example, fingerprint is one of the popular biometrics for authentication. We say it is dangerous because we cannot change our fingerprints even if they are collected and duplicated by some malicious third parties. This kind of life-long biometrics, once they are stolen, can never be used as a truly trustable authentication factor in the future. To solve the problem, we may use changeable biometrics. Examples include face, voice, and hand-writing characters. In this study, we use hand-writing characters. Hand-writing characters can change naturally in the aging process, they can also be changed intentionally through training. This paper investigates the feasibility of on-line user authentication using hand-writing non-alphanumeric characters. Our main purpose is to develop some core technologies that can improve the security of service systems in some Asia countries that use Chinese characters.

[qf-zhao-105-036-16:2016] Yuya Kaneda. Doctor thesis, Graduate school, 3 2017.

Decision boundary making (DBM) algorithm was proposed to induce compact and high performance machine learning models for implementing aware agents (A-agents) on portable/wearable computing devices (P/WCDs). The DBM algorithm reconstructs the decision boundary (DB) of a support vector machine (SVM) using a less expensive single hidden layer multilayer perceptron (MLP). The DBM can obtain compact MLPs that preserve the performance of the SVMs, and this has been proved via experiments on many databases. In this thesis, I propose two efficient and effective learning algorithms for the DBM algorithm to use machine learning models in real applications. The one is to improve the DBM performance by removing outlier data. In previous experiments, sometimes the DBM performance is not good enough compared with SVM. To improve the performance, I propose an SVM-based outlier detection method using a threshold parameter. Experimental results show that the DBM algorithm with the SVM-based outlier detection improve the performance, and the performance becomes higher or equivalent to the SVM performance in almost all cases. In addition, this thesis also investigates the classification time performance of the DBM using some different P/WCDs. The DBM algorithm can reduce the classification time greatly, and the effectiveness of the DBM is proportional to the number of training data. Another contribution is to upgrade the model performance efficiently in real time on P/WCDs. I propose an on-line training algorithm with guide data (OLTAGD) to update the model using the guide data and each da-

tum observed in real time. By updating the model efficiently in real time, the model performance can be kept in high level, and this also can resolve problems, such as some new projects have to collect many data at the beginning and so on. To generate the guide data set, I also investigate three methods for guide data selection, namely random selection, and two cluster center based selection methods. The cluster centers are found either by the k-means algorithm or by the decision surface mapping (DSM) algorithm. Experimental results for OLTA-GD reveal that OLTA-GD with the cluster center based selection using k-means outperforms others on stability and efficient performance for model updating. By the two learning algorithms, the DBM algorithm becomes more efficient and effective algorithm for real applications.

[yliu-105-036-10:2016] Kohei Aikawa. Graduation Thesis: Stock Portfolio Constructions and Modeling by Neural Networks, University of Aizu, 2017.

Thesis Advisor: Y. Liu

[yliu-105-036-11:2016] Fumiya Watanabe. Graduation Thesis: Develop Learning Models for Predicting and Analyzing Stock Prices, University of Aizu, 2017.

Thesis Advisor: Y. Liu

[yliu-105-036-12:2016] Masato Adachi. Master Thesis: Evolving Cooperation in Prisoner's Dilemma, University of Aizu, 2017.

Thesis Advisor: Y. Liu

[yliu-105-036-13:2016] Masayuki Takei. Master Thesis: Improve the Generalization of the Evolved Strategies in the Iterated Rock-Paper-Scissors, University of Aizu, 2017.

Thesis Advisor: Y. Liu