Congnitive Science Laboratory

Shuxue Ding
Professor

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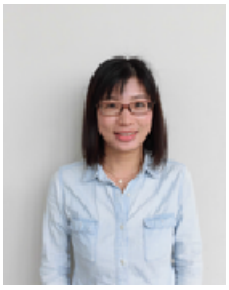

Li Zhenni
Visiting Researcher

Xiang Li
Visiting Researcher

The research and education activities in the laboratory focus on the cognitive science, computation and engineering, including broad applications of them. Our work covers Statistical signal processing, Neuro-Computing, Brain style signal processing and informatics, Multi-in and multi-out system (MIMO system), Information theory, Swarm intelligence, Machine learning, Optimization, Simulated acoustics, XML Transformation, Functional Logic Programming, Term Rewriting Systems, Program Transformation and related topics.

Areas of research interest include

- Sparse representation and sparse component analysis;
- Compressive sensing or sampling;
- Digital and statistical signal processing;
- Blind source separation and independent component analysis, and their applications in acoustic signals and vital signs;
- Neural computing and brain-style signal processing;
- Machine learning and optimization;
- Time-reversal wave propagation in ergodic environment and its applications in acoustics, ultrasonics and telecommunications;
- Application of logic, category theory, coinduction to computer science;
- Semantics, verification and implementation of functional reactive programming languages;

- Application of (functional) reactive programming in real-world problems such as robotics, embedded systems and network infrastructures;
- Program verification with interactive theorem provers;
- Theory and implementation of interactive theorem provers;
- Semantics and verification of hardware specification languages;
- Algorithms for efficient pattern matching based on finite automata;
- Semantics and verification of XML document transformation;
- Information theory and algorithmic complexity.
- Mechanical signal analysis with sparse representation approach
- Composites damage detection with signal processing method
- Structural health monitoring based on Lamb waves
- Non-destructive evaluation for thin-wall structures

Faculties of the Cognitive Science laboratory teach Algorithms and Data Structures, Digital Signal Processing, Introduction to Topology, Automata and Languages, Language Processing Systems, Computer Languages, Statistical Signal Processing (graduate course), Computation Theory (graduate course), Declarative Programming (graduate course), SCCPs and other selective courses. Students join faculty research and also develop their own research themes.

Refereed academic journal

[sding-106-005-01:2016] Guinan Wang, Hongjuan Zhang, Shiwei Yu, and Shuxue Ding. A family of the subgradient algorithm with several cosparsity inducing functions to the cosparse recovery problem. *Pattern Recognition Letters*, 80:64–69, Sept. 2016.

In the past decade, there has been a great interest in the sparse synthesis model for signal. The researchers have obtained a series of achievements about the sparse representation. The cosparse analysis model as the corresponding version of the sparse synthesis model has drawn much attention in recent years. Many approaches have been proposed to solve this model. In some conventional general, these methods usually relaxed l0-norm to l1-norm or l2-norm to represent the cospasity of signal, from which some reasonable algorithms have been developed. Furthermore, this work will present a new alternative way to replace the l0-norm based on the cosparsity inducing function, which is closer to l0-norm than l1-norm and l2-norm. Based on this function, we firstly construct the objective function and give a constrained optimal model of the cosparse recovery problem. Then we propose a subgradient algorithm-cosparsity inducing function (CIF) algorithm, which belongs to a two-layer optimization algorithm. Specifically, through converting the constrained optimal problem into the unconstrained case, we firstly obtain a temporary optimal variable, in which the cosparsity inducing function is approximated using its local linear approximation in order to avoid its nonconvex property. Secondly, a new cosupport is given by projecting the temporary optimal variable into the cosparse subspace and then keeping the l smallest elements. Besides, the desired signal is estimated using a conjugate gradient algorithm on the new cosupport. Moreover, we study the relative theoretical analysis about CIF algorithm. Simulations on the recovering of the unknown signal in the cosparse analysis model indicate its better performance at last.

[sding-106-005-02:2016] Zhenni Li, Shuxue Ding, Takafumi Hayashi, and Yujie Li. Incoherent Dictionary Learning with Log-regularizer Based on Proximal Operators. *Digital Signal Processing (Elsevier)*, 63(4):86–99, Jan. 2017.

In this study, we propose a novel dictionary learning algorithm with the log-regularizer and simultaneously with the coherence penalty based on proximal operators. Our proposed algorithm simply employs a decomposition scheme and alternating optimization, which transforms the overall problem into a

set of single-vector variable subproblems, with either one dictionary atom or one coefficient vector. Although the subproblems are still nonsmooth and even nonconvex, remarkably they can be solved by proximal operators, and the closed-form solutions of the dictionary atoms and the coefficient vectors are obtained directly and explicitly. To the best of our knowledge, no previous studies of dictionary learning have applied proximal operators to sparse coding with the log-regularizer and simultaneously to dictionary updating with the coherence penalty. According to our analysis and simulation study, the main advantages of the proposed algorithm are its greater ability of recovering the dictionary and its faster convergence for reaching the values of the dictionary recovery ratios than state-of-the-art algorithms. In addition, for real-world applications, our proposed algorithm can obtain good performances on audio data and image classification.

[sding-106-005-03:2016] Zhenni Li, Takafumi Hayashi, Shuxue Ding, and Yujie Li. Dictionary learning with the L1/2-regularizer and the coherence penalty and its convergence analysis. *International Journal of Machine Learning and Cybernetics*, 2017:1–14, Mar. 2017.

The L1/2-regularizer has been studied widely in compressed sensing, but there have been few studies about dictionary learning problems. The dictionary learning method with the L1/2-regularizer aims to learn a dictionary, which requires solving a very challenging nonconvex and nonsmooth optimization problem. In addition, the low mutual coherence of a dictionary is an important property that ensures the optimality of the sparse representation in the dictionary. In this paper, we address a dictionary learning problem involving the L1/2-regularizer and the coherence penalty, which is difficult to solve quickly and efficiently. We employ a decomposition scheme and an alternating optimization, which transforms the overall problem into a set of minimizations of single-vector-variable subproblems. Although the subproblems are nonsmooth and even nonconvex, we propose the use of proximal operator technology to conquer them, which leads to a rapid and efficient dictionary learning algorithm. In a theoretical analysis, we establish the algorithm's global convergence. Experiments were performed for dictionary learning using both synthetic data and real-world data. For the synthetic data, we demonstrated that our algorithm performed better than state-of-the-art algorithms. Using real-world data, the learned dictionaries were shown to be more efficient than algorithms using L1-norm for sparsity.

[taro-106-005-01:2016] S. Okui, T. Matsuda, and T. Suzuki. A DFA-based Ap-

proach to Greedy Partial Regular Expression Matching with Subterm Addressing. *Journal of Information Processing Society of Japan*, 57(12):2769–2783, 2016.

We present a DFA-based approach which enables greedy partial regular expression matching and subterm addressing without relying on any backtrack search. Each state of our DFA consists, compared to the standard construction regarding subsets of NFA-states as DFA-states, of an non-duplicating sequence of NFA-states and a flag indicating whether the final state has been found or not. The worst case computational cost for matching is O(nm) in the case of on-the-fly construction of DFA, and O(m) if DFA has been constructed in advance where n is the number of subexpressions in the regular expression and m the length of the input string, while the cost for subterm addressing requires O(mk) where k is the number of subexpression to be addressed. We prove the correctness of our algorithm with respect to a formalization of matching semantics. Our experimental implementation shows certain improvement to Google RE2 library for the test case they have given. We also mention a relation with a classical string matching algorithm given by Knuth, Morris and Pratt, or Aho-Corasick automata.

Refereed proceedings of an academic conference

[sding-106-005-04:2016] Zhenni Li, Takafumi Hayashi, Shuxue Ding, and Xiang Li. Constrained Analysis Dictionary Learning with the l1/2-norm Regularizer. In *Proc. IEEE International Conference on Signal Processing (ICSP 2016, Chengdu, China, November 7 - 9, 2016)*, pages 890–894, Nov. 2016.

Sparse representation has been proven to be a powerful tool for analysis and processing of signals and images.Whereas the most existing sparse representation methods are based on the synthesis model, this paper addresses sparse representation with the so-called analysis model. The l1/2-norm regularizer theory in compressive sensing (CS) shows that the l1/2-norm regularizer can yield stronger sparsity-promoting solutions than the l1-norm regularizer. In this paper, we propose a novel and efficient algorithm for analysis dictionary learning problem with l1/2-norm regularizer as sparsity constraint, which includes two stages: the analysis sparse coding stage and the analysis dictionary update stage. In the analysis sparse coding stage, adaptive half-thresholding is employed to solve the l1/2-norm regularizer problem. In the analysis dictio-

nary update stage, the solution can be straightforwardly obtained by solving the relatedleast square problem followed by a projection. According to our simulation study, the main advantage of the proposed algorithms is its greater learning efficiency in different cosparsities.

[sding-106-005-05:2016] Yujie Li, Shuxue Ding, Benying Tan, Zhenni Li, and Haoli Zhao. Nonnegative Sparse Representation Based On the Determinant Measure. In *Proc. IEEE International Conference on Digital Signal Processing (DSP 2016, Beijing, China, October 16-18, 2016)*, pages 599–603, Oct. 2016.

Recently, sparse representations via an overcomplete dictionary has become a major field of researches in signal processing. This paper focuses on sparse representation of nonnegative signals since signals and corresponding dictionary have nonnegativity limitations in some applications, e.g., multispectral data analysis. We present a novel sparsity measure based on a kind of determinant of matrix. Unlike the conventional sparsity measures, the proposed measure is differentiable and easy to optimize. Based on this measure, a new sparse model is derived, and an iterative sparseness minimization approach is proposed to solve this model. In the approach, the nonnegative sparse representation problem can be cast into row-to-row optimizations with respect to the sparse coefficient matrix, and then the quadratic programming (QP) is used to optimize each row. Numerical experiments on recovery of the sparse coefficient and synthesis dictionary show the effectiveness of the proposed algorithm.

[sding-106-005-06:2016] Haoli Zhao, Shuxue Ding, Yujie Li, Zhenni Li, Xiang Li, and Benying Tan. Dictionary Learning for sparse representation using weighted l1-norm. In *Proc. 2016 IEEE Global Conference on Signal and Information Processing (GSIP 2016, Greater Washington,D.C., USA, December 7-9, 2016)*, pages 292–296, Dec. 2016.

An efficient algorithm for overcomplete dictionary learning with lp-norm as sparsity constraint to achieve sparse representation from a set of known signals is presented in this paper. The special importance of the lp-norm (0 ¡ p ¡ 1) has been recognized in recent studies on sparse modeling, which can lead a stronger sparsity-promoting solutions than the l1-norm. The lp-norm, however, leads to a nonconvex optimization problem that is difficult to solve efficiently. In this paper, the hierarchically alternating update strategy and the weighted l1-norm method are introduced to the learning procedure which

find local optimal at each iteration. This algorithm is validated to be effective in numerical experiments and present the advantages in recovery ratios of dictionary and robustness of noise compared to MOD, K-SVD and FOCUSS-CNDL.

[xiangli-106-005-01:2016] Zhenni Li Haoli Zhao Benying Tan Xiang Li, Shuxue Ding. Defect Detection on Thin-Wall Structure via Dictionary Learning. In *2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, Turin, Italy, 2017 (Received in 2016).

IEEE Instrumentation and Measurement Society

[xiangli-106-005-02:2016] Yujie Li Zhenni Li Xiang Li Benying Tan Haoli Zhao, Shuxue Ding. Dictionary learning for sparse representation using weighted L1-norm. In *2016 IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, 2016.

IEEE Signal Processing Society

[xiangli-106-005-03:2016] Shuxue Ding Yujie Li Xiang Li Zhenni Li, Takafumi Hayashi. Constrained analysis dictionary learning with the L1/2-norm regularizer. In *2016 IEEE 13th International Conference on Signal Processing (ICSP)*. IEEE, 2016.

IEEE Signal Processing Society

[xiangli-106-005-04:2016] Xiang Li Zhenni Li Takafumi Hayashi, Shuxue Ding. An efficient algorithm for incoherent analysis dictionary learning based on proximal operator. In *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*. IEEE, 2016.

IEEE Signal Processing Society

Research grants from scientific research funds and public organizations

[sding-106-005-07:2016] Shuxue Ding. Research on real-time processing of compressive sensing and sparse representation, 2016-2019.

Academic society activities

[sding-106-005-08:2016] Shuxue Ding, 2016.

Committee member of Technical Committee on Awareness Computing, Systems, Man & Cybernetics Society, IEEE.

[sding-106-005-09:2016] Shuxue Ding, 2016.

Institute of Electrical and Electronics Engineers (IEEE), Membership.

[sding-106-005-10:2016] Shuxue Ding, 2016.

IEEE Signal Processing Society, Membership.

[sding-106-005-11:2016] Shuxue Ding, 2016.

The Institute of Electronics, Information and Communication Engineers (IEICE), Membership.

[sding-106-005-12:2016] Shuxue Ding, 2016.

The Association for Computing Machinery (ACM), Membership.

[taro-106-005-02:2016] T. Suzuki, 2016.

A reviewer of a paper submitted to TOPLAS.

[taro-106-005-03:2016] T.Suzuki, 2016.

A reviewer of Grants-in-Aid for Scientific Research

Advisor for undergraduate research and graduate research

[sding-106-005-13:2016] Norihiro Kiyota. Graduation Thesis: Sparse Coding Using Negentropy and L1 Norm Regularization, School of Computer Science and Engineering, University of Aizu, 2016.

[sding-106-005-14:2016] Yuya Arakawa. Graduation Thesis: Deep Learning Using Convolutional Neural Network with New Activation Function, School of Computer Science and Engineering, University of Aizu, 2016.

[sding-106-005-15:2016] Shiori Watanabe. Master Thesis: Nonnegative Sparse Representation with lp-norm Constraint Based on Majorize-Minimization, Graduate School, University of Aizu, 2016.

[sding-106-005-16:2016] Yujie Li. PhD Thesis: Dictionary learning algorithms for sparse representation of signal with the analysis model, Graduate School, University of Aizu, 2016.

[taro-106-005-04:2016] Hirokazu Arai. Graduation Thesis: Proof-Driven-Development of Counting Shortest Path Program with Ssreflect, University of Aizu, March 2017.

Thesis Advisor: T. Suzuki

[taro-106-005-05:2016] Masayuki Hirasawa. Graduation Thesis: Implementation of visual programming environment plugin for yampa programs, University of Aizu, March 2017.

Thesis Advisor: T. Suzuki

Contributions related to syllabus preparation

[sding-106-005-17:2016] Following course planning, I made a syllabus for the Master course: Statistical Signal Processing.

[sding-106-005-18:2016] Following course planning, I made a syllabus for the undergraduate course: Introduction to Topology.

Contribution related to educational planning management

[sding-106-005-19:2016] Graduate School Academic Affairs Committee Member, School of Computer Science and Engineering.

[sding-106-005-20:2016] Evaluation committee member for the projects Competitive Research Funding, projects for FY-2016, University of Aizu

[sding-106-005-21:2016] Committee member of Graduate School Entrance Examination Committee

Other significant contribution toward university planning, management, or administration

[sding-106-005-22:2016] Chair of Graduate Department of Computer and Information Systems.

[sding-106-005-23:2016] Committee member of The Education and Research Council, University of Aizu

[sding-106-005-24:2016] Committee member of The Deans and Directors Council, University of Aizu