Congnitive Science Laboratory

Shuxue Ding
Professor

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Senior Associate Professor

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.

Faculties of the Cognitive Science laboratory teach Algorithms and Data Structures, Digital Signal Processing, Introduction to Topology, Automata and Languages, Literacy II, 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 Journal Papers

[sding-13:2014] Z. Li, S. Ding, and Y. Li. A Fast Algorithm for Learning Overcomplete Dictionary for Sparse Representation Based on Proximal Operators. *Neural computation, has been accepted for a publication*, page In press, 2015.

We present a fast, efficient algorithm for learning an overcomplete dictionary for sparse representation of signals. The whole problem is considered as a minimization of the approximation error function with a coherence penalty for the dictionary atoms and with the sparsity regularization of the coefficient matrix. Because the problem is nonconvex and nonsmooth, this minimization problem cannot be solved efficiently by an ordinary optimization method. We propose a decomposition scheme and an alternating optimization that can turn the problem into a set of minimizations of piecewise quadratic and univariate subproblems, each of which is a single variable vector problem, either of one dictionary atom or one coefficient vector. Although the subproblems are still nonsmooth, remarkably, they become much simpler so that we can find a closed-form solution by introducing a proximal operator. This leads an efficient algorithm for sparse representation. To our knowledge, applying the proximal operator to the problem with an incoherence term and obtaining the optimal dictionary atoms in closed form with a proximal operator technique have not previously been studied. The main advantages of the proposed algorithm are that, as suggested by our analysis and simulation study, it has lower computational complexity and a higher convergence rate than state-of-the-art algorithms. In addition, for real applications, it shows good performance and significant reductions in computational time.

Refereed Proceeding Papers

[sding-14:2014] Y. Li, S. Ding, and Z. Li. Analysis Dictionary Learning Based on Summation of Blocked Determinants Measure of Sparseness. In *Proc. 2015 IEEE International Conference on Digital Signal Processing*, page Has been accepted for a publication, Singapore, July 2015. DSP 2015, IEEE.

This paper addresses the dictionary learning and sparse representation with the analysis model. Though it has been studied in the literature, there is still not an investigation in the context of dictionary learning for nonnegative signal representation. For measuring the sparseness, in this paper, we propose a measure that is so called the summation of blocked determinants. Based on this measure, a new analysis sparse model is derived, and an iterative sparseness maximization approach is proposed to solve this model. In the approach, the nonnegative sparse representation problem can be casted into row-to-row optimizations with respect to the dictionary, and then the quadratic programming(QP) technique is used to optimize each row. Numerical experiments on recovery of analysis dictionary show the effectiveness of the proposed algorithm.

[sding-15:2014] Z. Li, S. Ding, and Y. Li. Dictionary Learning with Log-regularizer for Sparse Representation. In *Proc. 2015 IEEE International Conference on Digital Signal Processing*, page Has been accepted for a publication, Singapore, July 2015. DSP 2015, IEEE.

We propose a fast and efficient algorithm for learning overcomplete dictionary for sparse representation of signals using the nonconvex log-regularizer for sparsity. The special importance of log-regularizer has been recognized in recent studies on sparse modeling. The log-regularizer, however, leads to a nonconvex and nonsmooth optimization problem that is difficult to solve efficiently. In this paper, We propose a method based on a decomposition scheme and alternating optimization that can turn the whole problem into a set of subminimizations of univariate functions, each of which is dependent on only one dictionaryatom or the coefficient vector. Although the subproblem with respects to the coefficient vector is still nonsmooth and nonconvex, remarkably, it becomes much simpler and it has a closed-form solution by introducing a novel technique that is log-thresholding operator. The main advantages of the proposed algorithm is that, as suggested by our analysis and simulation study, it is more efficient than state-of-the-art algorithms with different sparsity constraints.

[sding-16:2014] Y. Li, S. Ding, Z. Li, and W. Chen. Nonnegative Dictionary-Learning Algorithm for the analysis model based on L1 norm. In *Proc. 4th International Congress on Advanced Applied Informatics*, page Has been accepted for a publication, Okayama, Japan, July 2015. IIAI-AAI-ICSCAI-2015, Conference Publishing Services.

Sparse representation of signals has been successfully applied in signal processing. Most of existing methods for sparse representation are based on the synthesis model, in which the dictionary is overcomplete. This paper addresses the dictionary learning and sparse representation with the so-called analysis model. Based on this model, the analysis dictionary multiplying the signals can lead to a sparse outcome. Though this model has been studied in some literatures, there are still less investigations in the context of nonnegative dictionary learning for signal representation. So we focus on nonnegative dictionary learning for signal representation. In this paper, we propose to learn an analysis dictionary from signals using l1-norm as the sparsity measure. In the formulation, we adopt the Euclidean distance as the error measure. Based on these, we present a new algorithm for the nonnegative dictionary learning and sparse representation for signals. Numerical experiments on recovery of analysis dictionary in the noiseless and noisy situation show the effectiveness of the proposed method.

Unrefereed Papers

[taro-01:2014] H. Ito and T. Suzuki. Implementation of a music composition algorithm by Haskell. In *2014 Tohoku-Section Joint Convention of Institutes of Electrical and Information Engineers*, page 252, August 2014.

[taro-02:2014] S. Watanabe and T. Suzuki. Implementation of the Arrow type class in the Coq theorem prover. In *2014 IPSJ Tohoku-Section Workshop at The University of Aizu*, pages A1–5, 1–5, January 2015.

Grants

[sding-17:2014] Shuxue Ding. Research on the source signal recovery and shape image reconstruction from data with incomplete information based on sparse representation, 2011-2014.

This is supported as the project of Scientific Research C, No. 24500280, 2011 Grants-In-Aid for Scientific Research, Ministry of Education, Culture, Sports, Science and Technology, Japan.

Academic Activities

[sding-18:2014] S. Ding, 2014.

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

[sding-19:2014] S. Ding, 2014.

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

[sding-20:2014] S. Ding, 2014.

IEEE Signal Processing Society, Membership.

[sding-21:2014] S. Ding, 2014.

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

[sding-22:2014] S. Ding, 2014.

The Association for Computing Machinery (ACM), Membership.

[taro-03:2014] Taro Suzuki, 2014.

Chair of the Algorithm session

[taro-04:2014] Taro Suzuki, 2014.

member

[taro-05:2014] Taro Suzuki, 2014.

member

[taro-06:2014] Taro Suzuki, 2014.

member

Ph.D and Others Theses

[sding-23:2014] Kengo Sato. Graduation Thesis: Independent Component Analysis for Sub-Gaussian Distributed Signals, University of Aizu, 2014.

Thesis Advisor: Shuxue Ding

[sding-24:2014] Shiori Watanabe. Graduation Thesis: Effcient Nonnegative Matrix Factorization for Sparse Coding Based on the Auxiliary Function Method, University of Aizu, 2014.

Thesis Advisor: Shuxue Ding

[sding-25:2014] Yoshitaka Ozaki. Master Thesis: Online Independent Component Analysis for Separation of Signals including Super-Gaussian and Sub-Gaussian Components, University of Aizu, 2014.

Thesis Advisor: Shuxue Ding

[taro-07:2014] Yoshitaka Hashimoto. Graduation Thesis: Implementation of hedge partial derivatives for XML transformation, University of Aizu, 2015.

Thesis Advisor: T. Suzuki

[taro-08:2014] Naohiro Hara. Graduate Thesis: Design and implementation of a Yampa game engine, University of Aizu, 2015.

Thesis Advisor: T. Suzuki