CVPR 2009 Tutorial Proposal
Sparse Representation and Its Applications in High-Dimensional Pattern Recognition

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1 Program Description

In the past several years, there have been exciting breakthroughs in the study of sparse representation of high-dimensional signals. That is, a signal is represented as a linear combination of relatively few base elements in an over-complete dictionary. Much of the excitement centers around the discovery that a sufficiently sparse linear representation can be correctly and efficiently computed by convex optimization (i.e. the ℓ^0/ℓ^1 equivalence) or greedy algorithms, even though this problem is extremely difficult (NP-hard) in the general case. If this was not surprising enough, further studies have shown that such high-dimensional sparse signals can be accurately recovered from drastically smaller number of (even randomly selected) linear measurements, hence the catch phrase "compressive sensing" or sometimes, "compressed sensing."

These results have already caused a small revolution in the community of statistical signal processing as they provide entirely new perspectives to some of the fundamental principles and doctrines in signal processing such as the sampling bounds and the choice of bases for signal representation and reconstruction. The recent *Signal Processing Magazine special issue on Compressive Sampling* captures some of the most recent and exciting developments in this field. It is followed by another special issue of *IEEE Proceedings on Applications of Sparse Representation and Compressive Sensing* to be published in 2009, of which one of the presenters of the tutorial is the guest chief editor (see the website for more info: http://decision.csl.uiuc.edu/~yima/IEEE-Sparse.html).

We believe that these new results and the general mathematical principles behind them are of great interest to the computer vision and pattern recognition community. Through this tutorial, we intend to introduce the disruptive tools from sparse representation theory and their many successful applications to computer vision and image processing. Particularly, the goal of the lecture is threefold:

1. It provides the audience a comprehensive understanding about the mathematical theory of sparse representation and compressive sensing.

2. It introduces the basic results and algorithms from sparse representation and their applications to high-dimensional pattern recognition problems in computer vision that should be of great interest to the broad audience of CVPR.

3. It further highlights challenging open questions for solving real-world applications in the cross-disciplinary area between sparse representation and pattern recognition.

To achieve the above goal, the lecture will first provide a detailed treatment about the foundation of the sparse representation theory and enumerate several ℓ^1-minimization routines that effectively recover sparse representation from high-dimensional practical data sets. As one of the first applications to introduce sparse representation to the pattern recognition community, the problem of face recognition will be used as a cornerstone example to illustrate the striking effectiveness of these new tools (see the website for more info: http://perception.csl.uiuc.edu/recognition/Home.html). Finally, the lectures will touch basis to expand the scope of the discussion in several other areas such as motion segmentation, image processing, and distributed sensor networks.

Prerequisites and Supporting Material. The course is at the intermediate level which requires the audience to have some basic knowledge in graduate-level signal processing, pattern recognition, and linear algebra. The discussion about the applications of face recognition, motion segmentation, and sensor networks will be self-contained, and past research experience in these specific domains is not crucial for the audience.

The presenters of this tutorial have given similar lectures of the same topic at the University of Illinois and the University of California, respectively (see the website for an advanced graduate course given by the presenter in Fall 2008: http://decision.csl.uiuc.edu/~yima/ECE598-08.html). The lecture material (notes and slides) will be made available immediately during the tutorial. The course will be supplemented by hands-on programming demonstration using publicly available sparsity solvers in the MATLAB environment.

2 Tentative Schedule and Lecture Topics

A half-day tutorial is proposed consisting of two sessions of 1.5 hours each. The first session introduces the basic principles and results of sparse representation and their important applications in image processing processing and computer vision. The audience is expected to learn about basic theory and algorithms for sparse representation. After the audience obtains a broad understanding of the literature, the second session highlights several advanced topics about recent developments that uses results from sparse representation and compressive sensing to solve outstanding problems in high-dimensional pattern recognition and machine learning. Finally, the lecture will showcase some real-world applications and potential new directions of sparse representation for computer vision. A tentative schedule for the lecture is listed below.

I. Introduction and Overview of the Tutorial (10 minutes)

II. Robust Face Recognition via Sparse Representation – A Case Study (35 minutes)

   a. Face recognition literature: Feature selection, algorithms, databases.

   b. A sparse representation framework: Recognition, outlier rejection, occlusion robustness.

   c. Experimental validation and open problems.

III. Basic Theory of Sparse Representation and Compressive Sensing (45 minutes)

   a. Literature review: The past and present.

   b. ℓ^0/ℓ^1 equivalence: Uniqueness, coherence, restricted isometry property, convex polytope theory.

   c. Algorithms for sparse representation: matching pursuit, iterative thresholding and interior point solvers, homotopy methods (LARS/LASSO)

IV. Advanced Topics: Sparse Representation Meets High-Dimensional Pattern Recognition (45 minutes)

   a. Theoretical problems arising from vision: cross-and-bouquet model.

   b. Extension to low-rank matrix recovery: matrix completion and robust PCA.

V. Applications to Computer Vision and Distributed Sensor Networks (45 minutes)

a. A robust and scalable face recognition system.

b. Motion segmentation with outliers and corruption.

c. Image superresolution.

d. Distributed sensor perception.

3 Brief Biographies of Presenters

Yi Ma (Associate Professor, ECE, CSL, Beckman, University of Illinois at Urbana-Champaign) received his two Bachelors degree in Automation and Applied Mathematics from Tsinghua University, China, in 1995. He then received the Master of Science degree in Electrical Engineering and Computer Sciences in 1997, the Master of Arts degree in Mathematics in 2000 and the PhD degree in Electrical Engineering and Computer Sciences in 2000, all from the University of California at Berkeley. In August 2000, he joined the faculty of the Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign as an assistant professor. Since 2006, he has been an associate professor, and also served as research professor at the Coordinated Science Lab and the Beckman Institute. From January 2009, he is on leave as a Senior Researcher at Microsoft Research Asia and serves as the Manager of the Visual Computing Group. His research interests are in computer vision and systems theory.

Yi Ma received the first prize for Excellent Student Scholarship from Tsinghua University in 1994, and the Regents Fellowship from U.C. Berkeley from 1995 to 1996. His work has won the David Marr Best Paper Prize at the 7th International Conference on Computer Vision (awarded by the IEEE Computer Society) in 1999, and honorable mention for the Longuet-Higgins Best Paper Prize at the European Conference on Computer Vision in 2004. He received the Faculty Early Career Development (CAREER) Award from National Science Foundation (NSF) in 2003, and the Young Investigator Program (YIP) Award from the Office of Naval Research (ONR) in 2005. Yi Ma is an Associate Editor of the IEEE Transactions on Pattern Analysis and Machine Intelligence. He is the Guest Chief Editor of Proceedings of the IEEE Special Issue on Applications of Sparse Representation and Compressive Sensing.

John Wright (PhD Candidate, ECE, University of Illinois at Urbana-Champaign) received his BS in Computer Engineering and MS in Electrical Engineering from the University of Illinois at Urbana-Champaign. He is currently a PhD candidate in the Decision and Control Group at the University of Illinois. His research interests included automatic face and object recognition, sparse signal representation, and minimum description length techniques in supervised and unsupervised learning,

and has published a number of papers on these subjects. He has been the recipient of several awards and fellowships, including the UIUC ECE Distinguished Fellowship and a Carver Fellowship. Most recently, in 2008 he received a Microsoft Research Fellowship, sponsored by Microsoft Live Labs.

Allen Y. Yang (Research Scientist, EECS, University of California, Berkeley) received his BEng in Computer Science from the University of Science and Technology of China (USTC) in 2001. He received an MS in Electrical Engineering in 2003, an MS in Mathematics in 2005, and a PhD in Electrical and Computer Engineering in 2006, all from the University of Illinois at Urbana-Champaign (UIUC). He currently holds a research position at the University of California, Berkeley. His primary research is in pattern analysis of geometric and statistical models in very high-dimensional data spaces, and applications in motion segmentation, image segmentation, face recognition, and signal processing in heterogeneous sensor networks.

Allen Yang has published six journal papers and more than 10 conference papers. He is the inventor of three US patent applications. Among the awards he received are a Best Bachelor's Thesis Award from USTC and a Henry Ford II Scholar Award from UIUC.