CVPR'09 Tutorial
Sparse Representation and Its Applications – Compressive Sensing Meets Machine Learning

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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.

We believe that these new results and the general mathematical principles behind them are of great interest to the computer vision and pattern recognition com-

munity. Through this tutorial

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 of applications in face recognition, motion segmentation, and sensor networks will be self-contained, and the 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. 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 Preliminary Schedule

A half-day tutorial is proposed consisting of two sessions of 1.5 hours each. The first session opens up the discipline of compressive sensing and its important applications in signal processing and computer vision. The audience is expected to learn about basic compressive sensing theory and algorithms to recover sparse representation. After the audience obtains a broad understanding of the literature, the second session highlights several advanced topics in the recent development of applying compressive sensing theory to machine learning. Finally, the lecture will showcase some real-world applications and potential new directions of compressive sensing. 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 compensation.

   c. Experimental validation and open problems.

III. Basic Compressive Sensing Theory (45 minutes)

   a. Literature review: The past and today of compressive sensing.

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

c. ℓ^1-minimization solvers: matching pursuit, basis pursuit, LASSO, polytope face pursuit.

IV. Advanced Topics: Compressive Sensing Meets Machine Learning (45 minutes)

(a) Numerical validation for ℓ^0/ℓ^1 equivalence.

(b) Cross-and-bouquet model.

(c) Towards a comprehensive face recognition system.

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

a. Motion segmentation.

b. Sparse support recover.

c. Distributed compressive sensing.

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 is associate professor, and also serves as a research assistant professor both in the Decision & Control Group of the Coordinated Science Laboratory and in the Image Formation & Processing Group of the Beckman Institute on the same campus. His research interests are in systems theory and computer vision. His research topics include geometric and algebraic theory of computer vision, vision based control & navigation, and control of nonlinear systems.

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)

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.