ECE 598YM: Sparse Representation and High-Dimensional Geometry for Pattern Recognition

Fall 2008 Course Proposal by Professor Yi Ma
Department of Electrical & Computer Engineering

Course Description: This course covers recent developments of the new mathematical theory of sparse representation and compressed sensing in statistical signal processing, especially the concepts and results that can be readily applied to pattern recognition, computer vision, and image processing.

Prerequisite: Mathematically, the theory of sparse representation and compressed sensing builds on numerical linear algebra (Math 415/426) and optimization, especially linear programming and convex optimization (ECE490/Math482). It also involves properties of random matrices and measure concentration results that requires knowledge in probability and statistics (ECE413/Stat510). In this course, we will see the application of this powerful new theory in image processing (ECE547), computer vision (ECE549), signal processing (ECE551), and pattern recognition & machine learning. Knowledge in some of these application domains will increase your appreciation of this course, but not entirely necessary.

Target Audience: The course targets at the following students:

1. Graduate students in ECE and CS in the areas of signal/image processing, computer vision, pattern recognition, and machine learning.
2. Graduate students in Mathematics interested in the connections between convex optimization, discrete & polytope geometry, and statistical signal processing.

General Information:

- **Recommended books:**
  1. *Lectures on Discrete Geometry*, Jiří Matoušek, Springer, 2002.
  2. *Convex Polytope*, Branko Grünbaum, Springer, 2002.
- **Web resource:** Course notes and papers to present will be selected from the *Compressive Sensing Resources*: `http://www.dsp.ece.rice.edu/cs/`.
- **Grading policy:** Homework & Paper Reading (60%), and Final Project (40%). The final project can be done in a group of 2 or 3 students. The project can be theoretical, experimental or a mixture of both. It consists of a midterm proposal, a final presentation (in class) and a web-based report.

Tentative Course Syllabus and Schedule:

1. **Introduction (1.5 hours)**: High-Dimensional Geometry, Sparsity, Dimension Reduction, Data Processing and Classification. Applications in Face Recognition, Image Processing, etc.
2. **Mathematical Theory:**
   (a) **Sparse Solution via Linear Programming (3 hours)**: Under-determined Systems of Linear Equations. ℓ^0, ℓ^1, and ℓ^2 Solutions.

(b) **Approximate Sparse Solution and Lasso (1.5 hours)**: Numerical Stability, Statistical Consistency.

(c) **Error Correction via Linear Programming (1.5 hours)**: Robustness to Gross Error, Incomplete Data.

(d) **Signal Recovery from Random Projections (3 hours)**: Johnson-Lindenstrauss Lemma.

(e) **High-Dimensional Polytope Geometry (4.5 hours)**: Neighborliness, Almost Spherical Sections, Projections of High-Dimensional Polytopes.

(f) **Generalizations of Compressed Sensing (3 hours)**: Rank Minimization, Learning of Manifolds.

3. **Midterm Project Proposal (1.5 hours)**.

4. **Algorithms:**

   (a) **Convex Optimization and Linear Programming (3 hours)**: Review, Numerical Implementations.

   (b) **Compressive Sensing Recovery Algorithms (4.5 hours)**: Matching Pursuit, ℓ^1 Magic, Fast Algorithms for Sparse Solutions.

5. **Applications:**

   (a) **Image Processing (3 hours)**: Image Compression, Denoising, and Super-resolution.

   (b) **Classification and Object Recognition (4.5 hours)**: Face Recognition, Feature Selection, Robustness to Occlusion.

   (c) **Multiple Motion Segmentation in Videos (3 hours)**: Sparsity-Based Clustering, Missing, Incomplete, Corrupted Features.

   (d) **Other Applications (3 hours)**: Speech Recognition, Bioinformatics.

6. **Final Project Presentation (3 hours)**.