Course Proposal for Spring 2006

Course Description: In many scientific and engineering problems, the data of interest can be viewed as drawn from a mixture of models instead of a single one. Such data are often referred to in different contexts as “mixed,” or “heterogenous,” or “multi-modal,” or “hybrid.” For instance, a natural image normally consists of different textural regions, a traffic surveillance video consists of multiple independently moving cars, and an ultrasonic video of a beating heart consists of multiple phases.

A common problem in processing or modeling such hybrid data is how to simultaneously segment the data into homogeneous subsets and model each subset with a different parametric model. In other words, one needs to infer from the data a number of models and their individual parameters that best fit subsets of the data. In the past few years, many different methods and algorithms for solving this problem have been developed in different application domains, including but not limited to sparse image representation and compression in image processing; image and video segmentation in computer vision; hybrid system identification in systems theory; and data modeling and analysis in biomedicine. These methods have shown great potential of exceeding many conventional techniques.

In this course, we aim to provide a comprehensive and balanced coverage of the theory for the estimation of hybrid models. We will cover both algebraic and statistical approaches to this problem, study and compare algebraic and statistical algorithms for the estimation of hybrid models from (possibly noisy and corrupted) data, and apply the theory and algorithms to a wide spectrum of engineering problems in image processing, computer vision, system identification and bioengineering.

Prerequisite: This is an advanced course, and it can be considered as a follow-up course to either the computer vision course ECE549, or the image processing course ECE547, or the “Pattern Recognition” course offered by Narendra Ahuja as ECE598, or the linear system course ECE515, or the random processes course ECE534, or the estimation theory course ECE561. You may get the permission from the instructor if you have background in linear algebra (Math415/426) and probability theory (ECE413). Some familiarity with abstract algebra (Math417) and advanced mathematical statistics (STAT510) would increase your appreciation but not crucial. Given that, this course is self-contained: The more advanced concepts in mathematical statistics and abstract algebra will be covered during the course. In addition, background in image/video processing, computer vision, machine learning, and systems theory may help the student identify applications of his or her own interest. Plenty of codes will be provided to students to get hands-on experience with these applications.

Target Audience: The course targets at the following students:

1. Graduate students in ECE/CS in the areas of computer vision, image processing, and pattern recognition interested in data modeling, clustering, and segmentation.

2. Graduate students in ECE or ME in the areas of control interested in estimation theory and (hybrid) system identification.

3. Graduate students in Mathematics interested in applications of commutative algebra or students in statistics interested in estimation of mixtures of models.
General Information:

- **Required textbook:** *Generalized Principal Component Analysis: Estimation and Segmentation of Hybrid Models*, Rene Vidal, Yi Ma, and S. Sastry, book draft will be made available as lecture notes. Additional references will be provided to the students throughout the semester.

- **Grading policy:** Weekly homework (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):** data modeling, hybrid models, and model estimation.

2. **Review of Data Modeling with a Single Subspace (3 hours):** Principal Component Analysis (PCA) and its extensions.


4. **Algebraic Methods for Multiple-Subspace Segmentation (7.5 hours):** Special cases, Generalized Principal Component Analysis (GPCA), recursive GPCA, algebraic properties of subspace arrangements, Hilbert function and series for subspace arrangements.

5. **Statistical Analysis and Robustness Issues (3 hours):** Discriminative analysis, model selection criteria, and outliers in the context of subspace methods.

6. **Extension to Arrangements of Nonlinear Surfaces (1.5 hours):** Arrangements of quadratic surfaces, other nonlinear manifolds.

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

8. **Image Representation, Segmentation & Classification (3 hours)**

9. **Motion Segmentation in Computer Vision (6 hours):** 2D motion segmentation from image partial derivatives, 3D motion segmentation from feature correspondence.

10. **Dynamical Texture and Video Segmentation (3 hours)**

11. **Hybrid System Identification (3 hours):** Switched linear systems, input-output models and state-space models.

12. **Applications in System Biology and Bioengineering (3 hours)**

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