ECE 174

Intro to Linear & Nonlinear Optimization

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ECE Department  UCSD
Contact Information – Fall 2015

► Course Website
  • Accessible from http://dsp.ucsd.edu/~kreutz

► Course Lecture Time & Location
  • TuTh – 3:30-4:50pm, Pepper Canyon Hall, Room 106

► Instructor
  • Prof. Ken Kreutz-Delgado, kreutz@ece.ucsd.edu
    Office Hour: Wednesday, Noon-1pm, EBU-I 5605

► Teaching Assistants
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    (858) 822-4697, Jacobs Hall, Room 2608
Textbook

- *Matrix Analysis & Applied Linear Algebra*
  Carl D. Meyer, SIAM, 2000
  3\textsuperscript{rd} printing is latest

- Suggested Supplemental Texts
  - *Linear Algebra*, 4\textsuperscript{th} Edition
    S. Lipschutz & M Lipson
    Schaum’s Outlines, McGraw-Hill, 2009
  - *Linear Algebra and its Applications*, 4\textsuperscript{th} Edition
    G. Strang, Brooks Cole, 2005
Course Objectives

- **How to think geometrically** in vector-valued signal and data spaces.

- **How to solve linear and nonlinear inverse problems** using basic quadratic optimization techniques.
  - How to use abstract geometric thinking when solving linear and nonlinear inverse problems in signal and data spaces.

- **Become comfortable with the process of moving back-and-forth** between abstract mathematical solution techniques and practical engineering problems.
  - At the end of the quarter students will be able to apply abstract mathematical concepts to practical engineering problems.
Assumed Course Background

- It is assumed that students know the material from linear algebra **well**. As well as basic **complex variables** and (some) **probability**.

- The goal of this course **is not** to teach **fundamental concepts** of linear algebra (which **you are assumed to already know** from Math 20F, or the equivalent).

- The goal **is** to ensure that students are comfortable with the underlying **geometric concepts** associated with linear mappings between inner-product vector spaces and linear inverse problems encountered in many different **application domains** in engineering and science.

- Because the **students are assumed to already know linear algebra**, the course reading and homework will **not** be assigned in the order of presentation given in the textbook.
Assumed Programming Skills

- It is assumed that students know **Matlab**, or an equivalent high-level scripting language (such as python), well.

- Proficiency in Matlab or the equivalent is needed to perform the mandatory computer assignments which comprise 20% of your total, overall grade.
Course Performance Evaluation

10% Homework. 20% Computer Projects. 30% Midterm Exam. 40% Final Exam. *This breakdown is firm and non-negotiable.*

- Homework (10%) is graded “A for *Actual* Effort”. You get full credit merely for turning it in and if it is evident that you worked on *all* of the problems. You get partial (or even zero) credit if you are missing problems or it is clear that no real good faith effort was expended in attempting to solve the homework problems. You get no credit if you don’t turn in the homework. Note that *the individual problems are not* corrected or graded.

- Computer assignments (20%) are rigorously graded for correctness of content and results, and for quality of the reports.

- Midterm (30%) and Final (40%) are rigorously graded for correctness of derivations and results.

- The Final Exam is scheduled for Monday, December 7, 2015, 3-6pm. *This date and time is firm and non-negotiable.*
Student Collaboration & Cheating

Students are encouraged to discuss homework problems among themselves.

- **Individual write-ups must be turned in.**
- Not understanding homework solutions will hurt you on the midterm and final exams which together comprise 70% of the overall course grade.

Computer project **reports and coding** must be done individually. You are allowed to discuss the projects.

- **Individually written** code and reports must be turned in.
- Identical, or unreasonably similar, overlap of code between two students will be perceived as cheating.

Exams are **closed notes and closed book**.

**Aggressive administrative action will be taken against students caught cheating.**
Course Topics - I

- Overview of (constrained and unconstrained) linear least squares and nonlinear optimization.
  - Brief discussion of real-world linear and non-linear inverse problems encountered in engineering drawn from circuit analysis, robotics, GPS, and signal processing.

- Signal spaces as abstract vector spaces and matrices as representing linear mappings between signal spaces.

- Under- and over-constrained linear systems of equations and linear inverse problems.
  - Well-posed and ill-posed linear inverse problems.

- Constrained and unconstrained quadratic optimization of linear systems (the "linear least squares" problem).
Course Topics - II

- Solutions to the linear least squares problem.
  - Relationship to the four fundamental subspaces of linear algebra.
  - The projection theorem, adjoint operators, the normal equation, generalized inverses, & the Moore-Penrose pseudoinverse.

- The Singular Value Decomposition (SVD).
  - SVD and the four fundamental subspaces of linear algebra.
  - Use of the SVD to solve linear inverse problems and to obtain the Moore-Penrose pseudoinverse.

- Quadratic forms and weighted least-squares
  - Use in modeling energy, power, and uncertainty quantities encountered in engineering applications.
  - The weighted least squares problem and its relationship to the problem of maximum likelihood (MLE) estimation in statistics.
Course Topics - III

- Nonlinear least squares theory.
  - Vector differentiation and Hessians.
  - Necessary & sufficient conditions for an optimum to exist.

- Linearization-based nonlinear optimization techniques.
  - Iterative optimization techniques, including steepest descent, Gauss's method, and Newton's method.
  - Constrained nonlinear optimization and the method of Lagrange multipliers (time permitting).
Computer Programming Assignments
(Two projects)

For each assignment students will turn in an "Engineering Technical Report"

- You should write these up assuming that you will show them to prospective employers during job interviews.
- Students have had positive responses in job interviews.

1) Linear least-squares project.
   - Speech compression via differential coding.

2) Nonlinear least-squares project.
   - GPS positioning.