Inverse Problems:
PE 7813, Spring 2008

Instructor, Al Reynolds

Office Hours: MW: 2:30-4:00. TTH: 9:30-11.
Location: Keplinger Hall, L115.
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The course will provide the broad overview of inverse theory necessary to apply it to solve problems in science and engineering. In particular, the course provides much of the background necessary to address problems related to data integration and automatic history matching for the purpose of petroleum reservoir characterization within the framework of Bayesian statistics, but the course is definitely not taught as a petroleum engineering course and no background in engineering is required. Problems will be solved in a mathematical context and a person with a strong applied mathematics background could easily take this course with no knowledge of petroleum engineering. You should not take this course if you are do not have a background in linear algebra and matrix theory; knowledge of basic material like that found in the book by linear algebra book of Strang given below is essential. A prior course in probability theory would be helpful, but I will review the background material you will need for the course so a prior probability course is definitely not essential.

Although no intensive programming is required for the course, you should be able to write some simple Fortran Code. You should be able to get by with basic knowledge of either Matlab or Mathematica. I will provide some code that you will need to use and it will be in Fortran.

Outline:

1. Introduction to Inverse Theory
   (a) The Forward Problem
   (b) The Inverse Problem
   (c) Terminology
2. Examples of Inverse Problems
3. Construction of Estimates — The Method of Backus and Gilbert
4. Construction of Estimates — Finite Dimensional Models
   (a) Solution of the Linear Inverse Problem
   (b) Steady-State Flow as a Linear Inverse Problem
   (c) Resolution
5. Probabilistic Approach to Linearizable Inverse Problems
   (a) Review of probability theory, probability density function, joint, conditional and marginal distributions, Bayes theorem.
   (b) Random processes in function spaces
   (c) The probabilistic solution of an inverse problem

(d) Conditional simulation

6. Sensitivity Coefficients for Nonlinear Problems
7. Maximum a Posteriori Estimate
8. Sampling from the PDF
   (a) Simulation of (Pseudo) Random Numbers
   (b) Rejection Algorithms
   (c) Markov Chain Monte Carlo
   (d) Randomized Maximum Likelihood

Textbook:

Most of the material is from a book I co-authored that will be published by Cambridge University Press in May 2008. Unfortunately, the book is not yet in print. Of the references below, the first four are background references and the last two deal directly with the material in the course. I strongly recommend you buy the book by Menke.

- Press, W. H., Teukolshy, S. A., Vetterling, W. T. and Flannery, B. P.: *Numerical Recipes, the Art of Scientific Computing,* (1992) Cambridge University Press.
- Strang, Gilbert: *Linear Algebra and Its Applications,* Academic Press, New York, 1976.
- Cressie, Noel: *Statistics for Spatial Data,* John Wiley & Sons, New York, 1993.
- Menke, William: *Geophysical Data Analysis: Discrete Inverse Theory,* Academic Press, San Diego, 1989.
- Parker, Robert L.: *Geophysical Inverse Theory,* Princeton University Press, Princeton, New Jersey, 1994.

Grading:

Mid-Term Exam 1: 40%
Short Projects/Homework: 15%
Midterm Exam 2 (final): 45%