The University of Connecticut **Fall 2009**
Dept. of ESE **KRP**

ECE6437 Computational Methods for Optimization

General Information

2008-2009 Catalog Data:

Three credits, Lecture. Prerequisite: ECE301 Introduction to System Theory.
Content: Computational methods for optimization in static and dynamic problems. Ordinary function minimization, linear programming, gradient methods and conjugate direction search, nonlinear problems with constraints. Extension of search methods to optimization of dynamic systems, dynamic programming.

Instructor:

Prof. Krishna R. Pattipati
Room No.: ITE 350
Phone/Fax: 486-2890/5585
E-mail: krishna@engr.uconn.edu; URL: http://www.ee.uconn.edu/faculty.php?f_id=16

Office hours: Tuesday, 11:00-12:00 Noon or by appointment.

Classes: Time: Tuesday, 6PM-9PM, Location: CUE320.

Text and Major References:

Text: Dimitri P. Bertsekas, Nonlinear Programming, Athena Scientific, Belmont, MA, 1999.

Major References:

1. **(Optional Text)** Jorge Nocedal and Stephen J. Wright, Numerical Optimization, Springer-Verlag, New York, 2006.
2. David G. Luenberger, Linear and Nonlinear Programming, Second edition, Addison-Wesley, 1989.

Course Objective

This course is designed to provide students with a thorough understanding of optimization concepts and methods for several important classes of nonlinear programming problems, as well as the implementation and testing of these methods in software. Our focus will be on robust methods that can solve practical and large problems. Extensions to discrete optimization will also be stressed.

Course Outline

Lecture 1: Introduction and Course Objectives. What is an Optimization Problem? Classification of Optimization Problems, Measures of Convergence, Optimality Conditions for single variable and Multi-variable Functions, Elementary Convexity Theory

Reference: Text: Sec. 1.1, Appendices A and B; [LUE89]: Ch. 1, Ch. 6; [NOC06]: Chapters: 1-2

Lecture 2: Contour maps, Various forms of Generalized Gradient Methods, Line Search Methods (Armijo, Goldstein, Fibionacci, Golden Section)

Reference: Text: Sec. 1.2; [LEU89]: Chapter 7; [NOC06]: Chapters: 2-3

Lecture 3: Quadratic Interpolation, Combined Golden Section Search and Quadratic Interpolation, Convergence of Generalized Gradient Method, Stopping Criteria, Test Problems

Reference: Text: Appendix C, Section 1.3; [LEU89]: Chapter 7; [NOC06]: Chapter 3

Lecture 4: Newton's Method and Quadratic Convergence, Handling Indefinite Hessian using Modified Cholesky Decomposition, Trust Region Methods (Hook Step and Double Dogleg Step), Least Squares Problem and the Gauss-Newton Method, Levenberg-Marduardt Method

Reference: Text: Sections 1.4 and 1.5; [LEU89]: Chapter 7; [NOC06]: Chapter 4

Lecture 5: The conjugate gradient methods, Convergence Analysis, Partial Conjugate Gradient Method, Application to Nonlinear Functions, Pre-conditioned Conjugate Gradient Methods

Reference: Text: Section 1.6; [LEU89]:Chapter 8; [NOC06]:Chapter 5

Lecture 6: Quasi-Newton (Variable Metric, Secant) Methods, Square-root Implementations, DFP and BFGS Updates, Relation to Filtering and Control, Quadratic Termination, Convergence Properties, Scaling, Incremental Methods for Least Squares and Neural Network Training Problems

Reference: Text: Section 1.7; [LEU89]: Chapter 9; [NOC06]: Chapter 6

Lecture 7: Constrained Optimization, Necessary and Sufficient Conditions of Optimality, Equality Constraints, Sensitivity and Economic Interpretation of Lagrange Multipliers

Reference: Text: Sections 2.1, 3.1 and 3.2; [LEU89] Chapter: 10; [NOC06]: Chapter 12

Lecture 8: Inequality Constraints, Karusch-Kuhn-Tucker (KKT) Conditions, Farkas' Lemma, Convex programming Problems and Duality, Saddle Point Theorem, Primal-dual Problems, Fundamental Algorithms for Nonlinear Constrained Optimization (Augmented Lagrangian Methods, Successive Quadratic Programming, Feasible Direction Methods, Solution of Necessary Conditions of Optimality)

Reference: Text: Chapters 2-4; [LEU89] Chapters: 11-14; [NOC06]: Chapters 14 and 15

Lectures 9-10: Penalty and Augmented Lagrangian methods, Primal-dual interpretation of augmented Lagrangian methods

Reference: Text. Ch. 4; [LEU89]: Ch. 12, [NOC06]: Chapter 17

Lecture 11: Successive Quadratic Programming Methods (SQP), Newton and Quasi-Newton versions, A Practical Line Search SQP Method, Solution of Quadratic Programming Problems,

Reference: Text: Chapters 2 and 4; [LEU89]: Ch. 14; [NOC06]: Chapter 18

Lecture 12: Feasible Direction Methods for Constrained Minimization, Manifold Suboptimization Methods (Gradient Projection, Reduced Gradient, Newton-type Methods, Optimization with Simple Constraints, Subgradient methods, Cutting plane methods

Reference: Text: Chapter 2, [LEU89]: Chapter 11; [NOC06]: Ch. 16

Lecture 13: Parallel Optimization Algorithms: Jacobi and Decomposition Methods

Reference: [BER89]

Lecture 14: (If time permits) More on non-differentiable optimization methods, Decomposition methods.

Reference: Text: Ch. 6; [LUE84]: Ch. 13.

Grading:

Homework Assignments	40%
Programming Assignments	20%
Review Paper Presentation	5%
Take home Mid-term	15%
Term Project	20%
Total	100%

Additional Information:

- Starting with October 6 Lecture, each lecture will be divided into two parts. The first 2.5 hours will be used to present course materials, and the remaining 0.5 hour will be used for students to present reviews of recent journal publications.

- Paper reviews should be based on relevant and recent (2004 and up) journal articles from, e.g., Mathematical Programming1 Mathematical Programming Studies, Operations Research, Management Science, SIAM Journal on Optimization, Journal of Optimization Theory and Applications, Computational Optimization and Applications.

- Term projects can be performed in teams of two students on relevant optimization topics. Topics could be related to research, or based on at least two recent journal articles. **Numerical implementation** and **testing** are a must.

- Term project **proposals** are due on **Tuesday October 6**, presentations are scheduled on **Tuesday December 15** from 6 PM to 9 PM, and final reports are due on **the same day**.

- Programming can be done in any language.

References:

[AVR76] Mordecai Avriel, Nonlinear Programming: Analysis and Methods, Prentice-Hall, Englewood Cliffs, N.J., 1976.

[BAZ79] Mokhtar S. Bazaraa, H. D. Sherali, and C. M. Shetty, Nonlinear Programming Theory and Algorithms, Wiley, 1993, second edition.

[BER82] Dimitri P. Bertsekas, Constrained Optimization and Lagrange Multiplier Methods, Academic Press, 1982.

[BER89] Dimitri P. Bertsekas, and J. N. Tsitsiklis, Parallel and Distributed Computation: Numerical Methods, Prentice-Hall, 1989.

[BER95] Dimitri P. Bertsekas, Nonlinear Programming, Athena Scientific, Belmont, MA, 1999.

[BET97] D. Bertsimas and J.N. Tsitsiklis, Introduction to Linear Optimization, Athena Scientific, Belmont, MA, 1997.

[BOL99] V. Boltyanski, H. Martini and V. Soltan, Geometric Methods and Optimization Problems, Kulwer Academic, Boston, MA, 1999.

[CHO96] Edwin K. P. Chong and S. H. Zak, An Introduction to Optimization, Wiley-Interscience, 1996.

[CLA90] Frank H. Clarke, Optimization and Nonsmooth Analysis, Society for Industrial and Applied Mathematics, 1990.

[DEN83] J. E. Dennis, Jr., and R. B. Schnabel, Numerical Methods for Unconstrained Optimization and Nonlinear equations, Prentice-Hall, Englewood Cliffs, N.J., 1983.

[EIS87] H. A. Eiselt, G. Pederzoli, and C. L. Sandblom, Continuous Optimization Models, de Gruyter, 1987.

[FAN93] Shu-Cherng Fang and S. Puthenpura, Linear Optimization and Extensions, Theory and Algorithms, Prentice Hall, 1993.

[FLE87] Roger Fletcher, Practical Methods of Optimization, second edition, Wiley Interscience, 1987.

[GIL90] Philip E. Gill and M. H. Wright, Numerical Linear Algebra and Optimization, Addison- Wesley, 1990.

[GIL81] Philip E. Gill , W. Murray, and M. H. Wright, Practical Optimization, Academic Press, New York, 1981.

[HAG96] Martin T. Hagan, H. B. Demuth, and M. Beale, Neural Network Design, PWS Publishing Company, 1996.

[HIR93] Jean-Baptiste Hiriart-Urruty and Claude Lemarechal, Convex Analysis and Minimization Algorithms, Vols. I and II, Springer-Verlag, 1993.

[LUE89] David G. Luenberger, Linear and Nonlinear Programming, second edition, Addison- Wesley, 1989.

[MAN95] O.L. Mangasarian, Nonlinear Programming, SIAM, Philadelphia, 1995.

[MCC83] Garth P. McCormick, Nonlinear Programming: Theory, Algorithms, and Applications, Wiley, 1983.

[MIN86] M. Minoux, Mathematical Programming: Theory and Algorithms, Wiley, 1986.

[MOR93] J. J. More and S.J. Wright, Optimization Software Guide, Society for Industrial and Applied Mathematics, 1993

[NEM88] George L. Nemhauser and L. A. Wolsey, Integer and Combinatorial Optimization, Wiley, 1988.

[NEM89] George L. Nemhauser, A. H. G. Rinnooy Kan and M. J. Todd, eds., Optimization, North-Holland, 1989.

[NES94] Yurii Nesterov and A. Nemirovskii, Interior-Point Polynomial Algorithms in Convex Programming, Society for Industrial and Applied Mathematics, 1994.

[NOC06] Jorge Nocedal and Stephen J. Wright, Numerical Optimization, Springer-Verlag, New York, 2006, Second Edition.

[PAR93] Panos M. Pardalos, Complexity in Numerical Optimization, World Scientific, 1993.

[POL97] E. Polak, Optimization: Algorithms and Consistent Approximations, No. 124 in Applied Mathematical Sciences, Springer, 1997.

[RAO96] Singiresu S. Rao, Engineering Optimization, Theory and Practice, third Edition, Wiley-Interscience, 1996.

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[SHA79] Jeremy F. Shapiro, Mathematical Programming: Structures and Algorithms, Wiley, 1979.

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[YE97] Y. Ye, Interior Point Algorithms: Theory and Analysis, Wiley Interscience, New York, 1997.