2023 ACC Workshop

Nonlinear Optimization: Techniques for Engineering

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Abstract:

This full-day workshop will be a practical guide for those using multivariable, constraint handling, nonlinear optimization. Although fundamental methods will be revealed, the takeaway will be participants' ability to:

- Define the objective function (cost function).
- Incorporate constraints (either hard or as appropriately weighted penalties).
- Choose an appropriate optimizer for application attributes.
- Choose appropriate convergence criterion and threshold values.
- Choose initialization and number of trials to be confident in finding the global optimum.

The workshop will cover common gradient-based optimization techniques (Steepest Descent, Sequential Line Search, Newton, Levenberg-Marquardt, GRG, etc.) and direct-search techniques (Heuristic, Hook-Jeeves, Particle Swarm, Leapfrogging, Genetic Algorithms, etc.), and both single and multi-objective applications (Pareto Optimal). These are chosen for their utility and/or because they represent the fundamentals of most approaches.

Course examples will represent diverse applications which should be understood by any within the engineering disciplines. Participants will receive course notes and software to provide exercises and access to code. Exercises and code can be implemented in any environment, but Excel/VBA will used as in-workshop examples and exercises. Participants are invited to bring a computer with Excel version 2010 or higher for in-class exploration, and have permission to directly apply the provided software to their specific problems. The material is based on the textbook Engineering Optimization: Applications, Methods, and Analysis, 2018, John Wiley & Sons, ISBN-13: 978-1118936337, ISBN-10:1118936337, 731 pages with supplemental material and software on the companion web site www.r3eda.com.

Most exercises are for 2-dimensional applications for visual understanding of the surfaces and methods, but the methods and techniques are scalable to high dimension. Several N-D examples will be provided.

Rationale:

Optimization means seeking the best outcome or solution, and is a fundamental tool for modeling, model-based control, forecasting, design, analysis and diagnosis, supervisory economic operation, safety, precision, sustainability, and etc. We desire an efficient procedure to find the best solution with minimal computational and experimental effort. Part of this short-course is about the search logic, or the optimizer algorithm.

However, the major challenges in optimization are often not

- the mathematics of the algorithm.

Instead, the major challenges relate to the clear and complete statement of

- the objective function (the outcome you wish to minimize or maximize),
- constraints (what cannot be violated, exceeded, etc.),
- the decision variables (what you are free to change to seek a minimum),
- the model (how DVs relate to OF and constraints),
- the convergence criterion (the indicator of whether the algorithm has found the min or max and can stop, or needs to continue),

and, to choosing

- the DV initialization (what locations, values),
- the number of starts from randomized locations to be confident that the global optimum has been found, and
- the appropriate optimization algorithm (for the function aberrations, for utility, for precision, for efficiency).

This short-course addresses all of those elements.

Prerequisite skills

Any undergraduate engineering or mathematics program should have provided the participant with an adequate experience in calculus, analytical geometry, linear algebra, vector/matrix notation, statistics, and computer programming. The course will review essential topics that are commonly un-remembered from undergraduate courses.

Format:

Full-day. Presentation from laptop computer (need projector and screen). In-class explanations need black/white board or flipchart. Students should have tables for their laptops and course notes.

Presenter:

R. Russell Rhinehart – see bio at the end.

Workshop Schedule:

AM – Session 1

    Introductory Concepts and Definitions
    Gradient based concepts - Cauchy, Incremental Steepest Descent, Newton

Problems and Improvements – Levenberg-Marquardt.
Problems and Constraints
Break

AM – Session 2
Penalty Weighting
Multiple Optima
Multiple Starts

Lunch

PM – Session 1
Convergence Criteria
Surface aberrations – discontinuities, stochastic, narrow valleys
Simple Direct Methods – Heuristic Cyclic, Hook-Jeeves
Multi-Player Direct Methods – Leapfrogging, Particle Swarm

Break

PM – Session 2
Comparisons
Objective Function Formulation

End

Intended Audience:

The workshop is designed for those needing to understand optimization applications. This is a practical guide on the use of best practices from conventional methods, with examples to illustrate the choices and techniques. Supporting theory will be addressed, but the take-away will be the ability to specify objective functions, include constraints, select an appropriate optimizer, and specify initialization and convergence criteria.

The intended audience is engineering employees, students, and faculty who use nonlinear optimization techniques.

Expected Enrollment:

Based on past offerings, I suspect there will be about 10 participants, roughly 1/3 students, 1/3 faculty, and 1/3 from industry. I also plan on doing my own marketing to professional and university groups in the San Diego area.

Completeness:

I'd like to include more topics, but it's only a one-day workshop. I believe that with the basic concepts from the workshop, individuals will have the ability to understand the more advanced techniques. There are next generation optimizers (like ant colony, differential evolution, simulated annealing, or genetic algorithms), there are build-on techniques for the objective functions (like maximum likelihood for regression, or minimizing the probability or undesired outcomes), next levels in the decision variables (like random keys for sequencing of class variables), and a variety of techniques for determining convergence (like steady state). I can't cover everything, but hopefully can provide the grounding so that participants can independently move in the other directions.

Presenter Bio:

This workshop will be presented by Russ Rhinehart.

Dr. R. Russell Rhinehart, has experience in both industry (13 years) and academe (31 years). He was Head of the School of Chemical Engineering at Oklahoma State University for 13 years and retired in 2016 to shift his career toward professional education. Russ was a president of the American Automatic Control Council and Editor-in-Chief of ISA Transactions. He is a Fellow of both AIChE and ISA, a CONTROL Automation Hall of Fame inductee, and received numerous teaching and innovation recognitions.

His 1968 B.S. in Chemical Engineering and subsequent M.S. in Nuclear Engineering are both from the University of Maryland. His 1985 Ph.D. in Chemical Engineering is from North Carolina State University.

He is coauthor of the textbook Applied Engineering Statistics, author of three other books: Nonlinear Regression Modelling for Engineering Applications (Modelling, Model Validation, and Design of Experiments), of Nonlinear Control (how to use first-principles models in control), and of Engineering Optimization (Applications, Methods and Analysis). The last book is the basis of this short course. He authored six handbook chapters on modeling, uncertainty, process control, and optimization; and published over 270 articles.

Russ also developed short courses for industrial participants offered through ISA or directly to companies related to statistical process control, instrument and control systems, modeling, and model-based control. He has developed a web site to support his aim to disseminate best-in-class public-domain techniques for modeling, optimization, and control. You are invited to visit www.r3eda.com.