OPTIMIZATION IN PRACTICE WITH MATLAB® FOR ENGINEERING STUDENTS AND PROFESSIONALS

Optimization in Practice with MATLAB® provides a unique approach to optimization education. It is accessible to ***junior and senior undergraduate, and graduate students***, as well as industry practitioners. It provides a strongly practical perspective that allows the student to be ***ready to use optimization*** in the workplace. It covers traditional materials, as well as important topics previously unavailable in optimization books (*e.g*., Numerical Essentials – for successful optimization).

Outstanding features include:

- Provides practical applications of real-world problems using **MATLAB**.
- Each chapter includes a ***suite of practical examples and exercises*** that help students ***link the theoretical, the analytical and the computational.*** These include a robust set of real-world exercises.
- Provides ***supporting MATLAB codes*** that offer the opportunity to apply optimization at all levels, from students' term projects to industry applications.
- Offers instructors a comprehensive ***solution manual*** with solution codes along with **lectures in PowerPoint** ***with animations*** for each chapter. The MATLAB m-files are available for download from the book's website.
- ***Instructors have the unique flexibility*** to structure one- or two-semester courses that may range from gentle introductions to highly challenging, for undergraduate or graduate students.

Dr. Achille Messac received his BS, MS and PhD from MIT in Aerospace Engineering. Dr. Messac is a Fellow of the American Institute of Aeronautics and Astronautics (AIAA) and the American Society of Mechanical Engineers. He has authored or co-authored more than 70 journal and 130 conference articles, chaired several international conferences, delivered several keynote addresses, and received the prestigious AIAA Multidisciplinary Design Optimization Award. He has taught or advised undergraduate and graduate students in the areas of design and optimization for more than three decades at Rensselaer Polytechnic Institute, MIT, Syracuse University, Mississippi State and Northeastern University.

Optimization in Practice with MATLAB® for Engineering Students and Professionals

Achille Messac, PhD

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Preface

Contacting the Author Regarding this Book

I am delighted that you are using this book in your study of, or involvement with, optimization. I would very much welcome your comments, particularly regarding this first edition, and any suggestions that you might have for the next edition. For your comments regarding this book, I will be happy to receive your direct email at `OptimizationInPracticeMessac@google.com`.

Book Website

The website `www.cambridge.org/Messac` will be maintained for this book. Information for instructors and students will be separately provided. Software for various problems will be provided in this website. I expect it to be a dynamic website, where the information available will evolve over time to be responsive to readers' requests and feedback.

Book Organization

This book is intended to be used by undergraduate and graduate students in the classroom, or by industry practitioners learning independently. Its organization suits these objectives. Following are messages specifically tailored for students, for industry practitioners and for instructors. The book has five parts:

Part I *Helpful Preliminaries*
Part II *Using Optimization—The Road Map*
Part III *Using Optimization—Practical Essentials*
Part IV *Going Deeper: Inside the Codes and Theoretical Aspects*
Part V *More Advanced Topics in Optimization*

Part I has two chapters that present prerequisite material explaining how to use MATLAB and some useful mathematical information. Most of this book assumes knowledge of undergraduate calculus and elementary linear algebra. The second chapter provides a brief review of the math needed. In **Part II**, three chapters introduce the world of optimization in the form of a road map. This part provides the basics of what should be known about optimization before attempting to use it. In **Part III**, there are five chapters that teach the basic use of optimization. In fact, learning the material up to Part III provides the practitioner with sufficient information for solving practical problems. In doing so, student users will not be experts on how optimization *works under the hood*, so to speak, but will have the ability to use optimization in general practical contexts. Stated differently, while not being an expert about what is *under the hood*, the student will be a pretty good *driver* and should be able to *drive* to the desired destination (*i.e.*, the optimal design). In **Part IV**, three chapters provide a meaningful understanding of the computational and theoretical optimization process for linear programming and nonlinear programming with and without constraints. This is equivalent to learning the basics of what is **under the hood** of a car. **Part V** builds on the first parts of the book to provide a foundation for more advanced studies in optimization. In Part V, we learn optimization at a deeper level, where advanced topics are introduced over six chapters.

A Message to Students

As this book reaches your hands, you may have already signed up to take an optimization course, you may be in your junior or senior year or a graduate student, or you may already be in industry and feel that optimization may be useful to you. Regardless of what the case may be, you probably have two important questions in your mind: (i) Why should I learn optimization? and (ii) Is this a good book for me to use to learn optimization? Let me provide you with some objective comments, together with some subjective thoughts.

Why should you learn optimization? The truth is this. If you are an engineer or about to become one, if you are a financial analyst, or if you deal with numbers to determine how desirable or undesirable the performance of a system or a design is, then optimization will almost certainly be able to help you do a better job—without fail. Optimization applies to most engineering activities, management operations activities and numerous other fields where performance (or *goodness*) can be numerically quantified.

More importantly, if you are trying to design a system that must perform a certain way, you have unsuccessfully tried all that you know, and you have already asked the experts for help without success, then there is a good chance that optimization will help you succeed. Interestingly, it would not be at all surprising that the expert may find it too difficult to obtain an adequate answer, when optimization can be successfully used to find one. This is, in part, because optimization can intelligently examine thousands of design alternatives in less time than it takes the expert to examine a single design alternative. Optimization can also perform an intelligent search in a complex environment that may not be clear to the human mind. Optimization essentially makes it obsolete to engage in the typical trial-and-error process, as we search for a good design.

The following are some important comments regarding the rapidly growing popularity of optimization in recent years, and about how this book offers a unique approach to bringing optimization to a broader audience.

Until recently, *the cost of computing* was a critical issue that hindered the broad application of optimization. Fortunately, with the revolutionary decrease in the cost of computing in recent years, a desktop computer is often all that is needed to solve many practical optimization problems—making the application of optimization dramatically more practical.

The application of optimization in practical settings is increasingly becoming commonplace. A growing number of software developers have begun to include optimization capabilities as they respond to growing demand. They realize that it is not sufficient to determine how a structure deforms under given loads. It is also important, and of interest, to *discover* how to change the design in order to reduce that deformation. Optimization provides a reliable and systematic way to obtain this reduction. Importantly, this powerful benefit of optimization applies to a plethora of analysis software in engineering, management, finance and numerous other fields.

Let us now turn our attention to the second question: Is this a good book for you to use to learn optimization? This book will provide you with a unique combination of desirable attributes. It will provide you with the knowledge to start using optimization software in general. In particular, you will have the ability to use MATLAB for this purpose with effectiveness and efficiency. *Note that any other optimization software could have been used, but we use MATLAB for its broad popularity, effectiveness and convenience*.

This book focuses primarily on the material that is required for the practical application of optimization: more time spent on the computational analysis and optimization of real-world problems, and less time on the inner theory and mathematics of optimization. This approach is beneficial to students who wish to initiate research studies in optimization, as well as to those students who primarily wish to use optimization for practical purposes. This book is explicitly intended to teach you *how to use optimization successfully*, and to do so while avoiding unnecessary mathematics. The first parts of this book can be used for a one-semester course that is fully accessible to junior-level undergraduate students. Those interested in advanced topics are referred to Part V of this book.

To make this practical learning possible, after the preparatory material of Part I, realistic solution approaches that involve the use of a computer are provided in Part II. With our ability to use an optimization and modeling code, such as MATLAB, we will be able to readily apply what we learn to real-life problems. The approaches do not fundamentally change with different optimization codes. The changes that occur from problem to problem are readily handled with any optimization code, such as the size and other generic features of the problem. MATLAB is an easy-to-use and very popular software that is useful in all areas of engineering. It is also used in a growing number of non-engineering fields. If you don't yet know MATLAB, that is fine. You will learn it as we go along. The first chapter of this book provides an introduction to MATLAB that focuses on the material that we will need.

Your prospective learning of optimization in a way that focuses on practical applications is timely in view of the increasingly computational world. It will prove to be an important component of your education. Ultimately, learning optimization will provide you with a truly powerful tool to do things more successfully than could be done without optimization.

A Message to Industry Practitioners

To obtain an overall idea about the objectives and intent of this book, I suggest that you also read the messages to students and instructors. Regarding the particular needs of industry practitioners, this book is deliberately designed to quickly get to the point. Many software products are coming to market with optimization capabilities, and it is wise to acquire the appropriate background to start using these capabilities. This book directly provides the required knowledge in a way that is unencumbered by unnecessary math, and focuses on such practical aspects as: (i) How do I make my design lighter, stronger and cheaper? (ii) Once I get an answer from my analysis code, what is the next step to improving that answer?

In addition, even if you are not using an analysis software (but can compute the performance of your system), you may ask how to modify your system to improve its performance, and how to do so systematically without the usual manual trial and error. Optimization is a powerful way to accomplish these objectives, and this book provides the required knowledge in a practical and accessible way. As mentioned earlier, those interested in more advanced topics are referred to Part V of this book.

A Message to Instructors

This book takes a novel pedagogical approach to the teaching of optimization. It takes a different perspective regarding what material should be included in a first optimization course; and it provides the means to teach optimization to juniors, seniors, and graduate students who are taking their first course in optimization. The material in this book can be divided into two self-contained one-semester courses. The first course can be offered at the undergraduate or graduate level. At the undergraduate level, Parts I, II, and III could be covered. At the graduate level, (i) Parts II, III, and IV could be nominally covered, (ii) Part II can be covered quickly, (iii) Part V can be covered as part of a challenging first course or as part of a second course, and (iv) a term project could be assigned potentially based on some advanced problems in the book. The problems at the end of each chapter are divided into “Warm-up,” “Intermediate,” and “Advanced,” reflecting their respective levels of difficulty. Some “Graduate Level” problems are provided as well. This flexibility can be exploited to address the diverse skills of students cohorts and of undergraduate/graduate students. The book is structured to provide full flexibility to accommodate the objectives of the instructor, as well as the skills and interests of the students.

Importantly, this book is also structured with the instructor in mind to facilitate the pedagogical process. In particular, the book's website (`www.cambridge.org/Messac`) provides a comprehensive set of materials that support the instructor's needs. A 270-page solution manual is provided. A comprehensive set of lecture materials is provided *in editable form*, which comprises approximately 850 PowerPoint slides, thereby providing the flexibility to suit the instructor's goals and pedagogical style. The book's website is also provided to enrich the coverage of certain topics and to allow us to pose larger practical problems that might not otherwise be considered. The book MATLAB codes are also available in the book's website. The instructor is invited to visit the website and to contact me at `OptimizationInPracticeMessac@google.com` for any suggestions for the website or any other aspects of the book.

This book provides an introduction to the practical application of optimization as a potentially last optimization course. Alternatively, this book can be used as a more accessible introduction to the subject of optimization, to be followed by courses that cover more advanced topics.

Regarding the philosophy of the material covered in this book, we critically assess the need to include candidate topics by asking the question: Is this material needed for someone who primarily wishes to *use* optimization, or is it primarily required for someone who intends to *develop* optimization algorithms? Priority is given to topics that directly contribute to the successful *use* of optimization. For example, is it necessary for an introductory user to learn sequential quadratic programming? Is this knowledge necessary for the successful application of optimization, when robust implementations are broadly available? The book is structured to easily allow the instructor to potentially leave that topic to a second optimization course (using this book), where more theoretically advanced subjects can be presented. This singular philosophy helped prioritize the candidate topics for inclusion (*and where*) in the book. The net result is a text that appreciably departs from tradition, but that we believe makes a novel contribution to the teaching of optimization. It provides the material to teach optimization in the traditional way, but with the flexibility/option to employ a more pragmatic approach that may be more inviting and effective in an introductory undergraduate or graduate first or second course.

A top-level view of the five parts of the book is provided as follows:

Part I *Helpful Preliminaries*

1. MATLAB as a Computation Tool
2. Mathematical Preliminaries

Part II *Using Optimization - The Road Map*

3. Welcome to the Fascinating World of Optimization
4. Analysis, Design, Optimization, and Modeling
5. Introducing Linear and Nonlinear Programming

Part III *Using Optimization - Practical Essentials*

6. Multiobjective Optimization
7. Numerical Essentials
8. Global Optimization Basics
9. Discrete Optimization Basics
10. Practicing Optimization – Larger Examples

Part IV *Going Deeper: Inside the Codes and Theoretical Aspects*

11. Linear Programming
12. Nonlinear Programming with No Constraints
13. Nonlinear Programming with Constraints

Part V *More Advanced Topics in Optimization*

14. Discrete Optimization
15. Modeling Complex Systems: Surrogate Modeling and Design Space Reduction
16. Design Optimization Under Uncertainty
17. Methods for Pareto Frontier Generation/Representation
18. Physical Programming for Multiobjective Optimization
19. Evolutionary Algorithms