PART 1

HELPFUL PRELIMINARIES

Part I provides prerequisite information for using optimization in practice. Specifically, we need to use software and we need to have some basic knowledge of mathematics. This book uses MATLAB as a computational tool. If you are new to MATLAB or do not know it yet, Chapter 1 will provide you with the preparatory information to get started. If your mathematics knowledge is a bit rusty, Chapter 2 will provide you with the preparatory knowledge for optimization application.

Specifically, the topics presented, with the chapter numbers, are given below:

1. MATLAB® as a Computation Tool

2. Mathematical Preliminaries

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MATLAB® as a Computational Tool

1.1 Overview

Optimization can be viewed as a process that searches methodically for better answers, better solutions, or better designs that a human being may not be able to find through experience, intuition, or courageous trial-and-error. Optimization can be defined as the art of making things better. Interestingly, optimization very often does not simply allow us to do something better, but it may also make it possible to do something that we did not otherwise know how to do. To take full advantage of the power of optimization in practice, there is no choice but to use a computer.

The study of optimization typically takes a theoretical and/or computational approach. The theoretical approach is highly useful when the objective is to develop new optimization methods or to assess how the current methods work [1]. Additionally, the study of optimization often focuses on the understanding of various search algorithms for optimization. A book by Reklaitis and co-authors [2] is an example of methods-based optimization presentation. While these books play an important role in the general study of optimization, we pursue a different approach. The objective of this book takes on a practical perspective. The current interest is in the immediate ability to apply optimization in practice. In order to reach this objective, and to have the ability to apply optimization to real world problems, we use the approach that is almost always required in the application of optimization. We use the power of the computer, in conjunction with the study of different important practical aspects of optimization.

In order readily apply optimization in practice, the focus will be on the computational application of what we will learn, as we learn it. To do so, we use a computational modeling and coding tool that is powerful, easy to use, and one that is widely applied in engineering and other fields. MATLAB is an excellent tool choice and will be used in this book. MATLAB has arguably become the most popular tool for computational modeling worldwide. Using MATLAB will enable you to optimize both simple and complex systems or designs with effectiveness and efficiency.

MATLAB is a registered trademark of The MathWorks, Inc.

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This chapter provides a brief introduction to MATLAB, which is primarily for those who have little or no experience with MATLAB. Previous users of MATLAB may find this introduction to be a useful review and a way to learn about the MATLAB optimization capabilities. This chapter has six sections. Section 1.2 defines MATLAB. Section 1.3 provides a basic introduction of MATLAB, while Sec. 1.4 goes beyond the basics. Section 1.5 focuses on the MATLAB plotting capabilities. In Sec. 1.6, the MATLAB nonlinear and linear optimization capabilities are introduced. For historical reasons, the terminology "linear programming" and "nonlinear programming" is often used synonymously with "linear optimization" and "nonlinear optimization," respectively. In Sec. 1.7, a list of useful functions is presented.

1.2 MATLAB Preliminaries—Before Starting

This section provides useful information about MATLAB as a software tool. It includes the following components:

1. What is MATLAB?
2. Why MATLAB?
3. MATLAB Toolboxes
4. How to Use MATLAB in This Book?
5. Acquiring MATLAB
6. MATLAB Documentation
7. Other Software for Optimization

1.2.1 What Is MATLAB?

MATLAB is a very popular high level language for computation. It is used extensively both in industry and in universities worldwide. It is much easier to use than other popular programming languages such as Fortran or C. It takes a very short time to start becoming productive with MATLAB. Mathematical expressions are evaluated much the same way as they would be written in text form. MATLAB is used for a wide variety of activities, including computation, algorithm development, modeling, simulation, prototyping, data analysis, visualization, engineering graphics, and graphical user interface building (Ref. [3]).

In this book, the use of MATLAB is limited to the context of the application of optimization. In doing so, we will be able to optimize practically any system. This is because the MATLAB environment is very powerful. We will be able to optimize any system that is modeled in the MATLAB computational environment using this newly acquired optimization knowledge.

Over the years, various parties have developed MATLAB tools that are applicable to specific fields. These tools essentially constitute a set of functions that work together to perform powerful tasks in specific technical areas, such as control, dynamics, financial analysis, and signal processing. Some are available through private parties, while others are available through the MATLAB developer (The MathWorks, Inc.) [4]. Information concerning MATLAB can be obtained from its developer or at the website www.mathworks.com.

MATLAB is organized as a collection of several independent components that work together harmoniously. The central component is the basic MATLAB software, which can be used for most general computation and algorithm development. When the needs become more advanced and specific, we acquire MATLAB Toolboxes. These toolboxes are a collection of MATLAB function codes that perform tasks in given technical areas. To perform advanced optimization, the basic MATLAB software is needed, together with the "Optimization" Toolbox.

MATLAB can be acquired in the form of professional and educational versions [4]. The latter has some reduced capabilities, but should be able to perform most required tasks for moderately sized problems.

1.2.2 Why MATLAB?

It is important to keep in mind that MATLAB is in no way required to perform computational optimization. Several other codes could be used to perform all of the tasks for which MATLAB can be used. However, for the purpose of this book, MATLAB is an excellent choice. It is also a recommended software for future activities after completing the study of optimization using this book. Related information is also discussed in the Preface.

1.2.3 MATLAB Toolboxes

MATLAB Toolboxes provide useful functions for research and development in technical fields. Specific tasks can be performed using these toolboxes to satisfy users' requirements through user-friendly commands or visual interfaces. These toolboxes are convenient to use, as well as powerful. They provide functions that can be called by the MATLAB code written by users. The toolboxes support various functionalities for a broad range of applications. They are available for applications in (1) parallel computing, (2) mathematics, statistics, and optimization, (3) control system design and analysis, (4) signal processing and communications, (5) image processing and computer vision, (6) test and measurement, (7) computational finance, (8) computational biology, and (9) database connectivity and reporting. A complete list of MATLAB Toolboxes is available at the MathWorks website. The list includes the following toolboxes.

1. Parallel Computing
   - Parallel Computing Toolbox
2. Math, Statistics, and Optimization
   - Symbolic Math Toolbox
   - Partial Differential Equation Toolbox
   - Statistics Toolbox
   - Curve Fitting Toolbox
   - Optimization Toolbox
   - Global Optimization Toolbox

- Neural Network Toolbox
- Model-Based Calibration Toolbox

3. Control System Design and Analysis

    - Control System Toolbox
    - System Identification Toolbox
    - Fuzzy Logic Toolbox
    - Robust Control Toolbox
    - Model Predictive Control Toolbox
    - Aerospace Toolbox

4. Signal Processing and Communications

    - Signal Processing Toolbox
    - DSP System Toolbox
    - Communications System Toolbox
    - Wavelet Toolbox
    - Fixed-Point Toolbox
    - RF Toolbox
    - Phased Array System Toolbox

5. Image Processing and Computer Vision

    - Image Processing Toolbox
    - Computer Vision System Toolbox
    - Image Acquisition Toolbox
    - Mapping Toolbox

6. Test and Measurement

    - Data Acquisition Toolbox
    - Instrument Control Toolbox
    - Image Acquisition Toolbox
    - OPC Toolbox
    - Vehicle Network Toolbox

7. Computational Finance

    - Financial Toolbox
    - Econometrics Toolbox
    - Datafeed Toolbox
    - Database Toolbox
    - Financial Instruments Toolbox

8. Computational Biology

    - Bioinformatics Toolbox

9. Database Connectivity and Reporting

    - Database Toolbox

MATLAB users can develop unique toolboxes for specific purposes. Many of these user-developed toolboxes are available online for download and use.

This book focuses on optimization using MATLAB Toolboxes. The optimization toolbox and the Global Optimization Toolbox are used for the study of optimization.

To access the MATLAB Toolboxes, you can click the APPS tab (Fig. 1.1) at the top menu of the MATLAB Desktop. The toolboxes have graphical user interfaces. A more advanced way to use the MATLAB Toolboxes is to call their functions using MATLAB codes. In this book, different MATLAB optimization functions are used to solve different types of problems.

1.2.4 How to Use MATLAB in this Book

This book provides a brief introduction to MATLAB to help with the initial use of MATLAB. Also provided is information regarding how to perform optimization using MATLAB. When it is deemed helpful and practical, the actual MATLAB code will be provided. By examining these preliminary coding examples, it will become clear how to write other more complicated code. Some code will be provided in the text, while others will be provided in the media device that accompanies this book. It is assumed that the PC Windows version of MATLAB 2013 is being used. The distinctions between the different platform versions of MATLAB are minor. The basic code is almost always identical across platforms, except for some tasks, such as file manipulations.

1.2.5 Acquiring MATLAB

MATLAB is widely available in most engineering firms and universities, as well as many financial institutions. It can be purchased from the MATLAB developer [4]. This book makes use of the basic MATLAB software and of the optimization toolbox software. Both are required to perform the computational portion of this book. It should also be noted that several other software options can be used to do this computational optimization work.

1.2.6 MATLAB Documentation

Several forms of documentation are available for the MATLAB user. An abundance of information is available on the web and on the developer's website. Several books that document the different components of MATLAB are sold by The MathWorks. Many of these books can also be downloaded from The MathWorks' website [4].

MATLAB documentation books can be downloaded from the website [4]. The powerful capabilities of the MATLAB graphics are presented in the book entitled *MATLAB Graphics* [5]. A book entitled *MATLAB Primer* provides a handy documentation of MATLAB [6] and, for the novice, a good basic introduction of MATLAB is given in the book entitled *Basics of MATLAB and Beyond* (Ref. [7]) or *Getting Starter with MATLAB: a Quick Introduction for Scientists and Engineers* (Ref. [8]). We note that the information provided here is fluid and dynamic. A visit to the developer's website [4] and a web search will provide the latest information.

1.2.7 Other Software for Optimization

MATLAB is not unique in its ability to perform computational optimization. It is chosen here because it is a highly effective software that is user-friendly and widely used. The skills that will be developed are useful in numerous other fields.

By using the MATLAB Toolboxes, it is possible to perform optimization in a number of different technical areas. This is because these toolboxes provide the means to model the performance behavior of the pertinent systems.

In certain situations, it is more appropriate to use other software, either independently or in conjunction with MATLAB. When used in conjunction with MATLAB, the external interface capability of MATLAB is used. Pertinent documentation is available from the MATLAB help menu or from The MathWorks' website.

There is a plethora of optimization software available to perform optimization independently. A book entitled *Optimization Software Guide* [9] catalogs a large number of these software tools. Notable optimization software products in the area of structural optimization are GENESIS [10], MSC/Nastran [11], and Altair [12]. Genesis was explicitly developed for the purpose of structural optimization and is considered a powerful tool.

1.3 Basics of MATLAB—Getting Started

This section provides a brief description of how to get around MATLAB and of how to use MATLAB at an introductory level. Specifically, the following topics are presented:

1. **Starting and Quitting Matlab**
2. **Matlab Desktop:** Basic MATLAB Graphical User Interface
3. **Matrices and Variables:** Matrices and Variables Operations
4. **Expressions:** Evaluations of Mathematical Expressions
5. **Control Flow Statements:** Using the `for` loop, the `while` loop, the `if` statement, and others
6. **Input and Output, Directories, and Files:** Input and Output of Data and Editing Commands, Directories, and Files
7. **Script File:** File that has MATLAB Commands
8. **Function File:** MATLAB File that Performs Independent Tasks
9. **Plotting:** Elementary Plotting Capabilities of MATLAB

1.3.1 Starting and Quitting MATLAB

To start MATLAB in Microsoft Windows, double-click on the MATLAB icon on the Windows desktop. MATLAB can also be started by selecting MATLAB from the `Start` menu. On a UNIX platform, type `matlab` at the operating system prompt. Once MATLAB is launched, a MATLAB Desktop appears on the screen.

To quit MATLAB, click on the top right close window button (Fig. 1.1). Alternatively, select `Exit` from the `File` menu in the desktop, or type `exit` or `quit` in the Command Window.
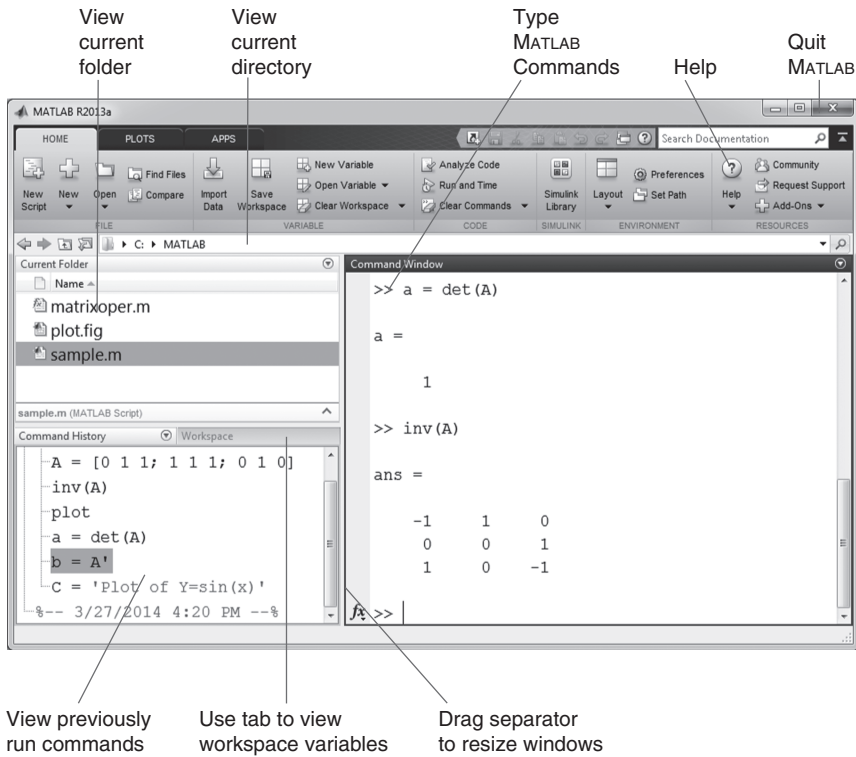
Figure 1.1. MATLAB Desktop

1.3.2 MATLAB *Desktop: Its Graphical User Interface*

The MATLAB Desktop (Fig. 1.1) appears when MATLAB is started. It provides a Graphical User Interface (GUI) that facilitates various MATLAB functions, such as managing files, variables, and applications.

The first time MATLAB starts, the desktop appears as shown in Fig. 1.1, although the desktop may have been customized to contain fewer components. Customize the desktop by opening, closing, moving, docking, and resizing the tools in it. Use Preferences from the File menu to specify features of the desktop. The MATLAB desktop environment provides useful tools that can be used for various purposes.

Command Window

The Command Window (Fig. 1.2) is used to enter variables, evaluate MATLAB commands, and run M-files or functions. M-files are the programs written to run MATLAB functions.

Command History

The Command History window (Fig. 1.3) is used to view previously used functions, copy, and execute selected lines from those functions. The lines entered in the Command Window at the command prompt are logged into Command History.
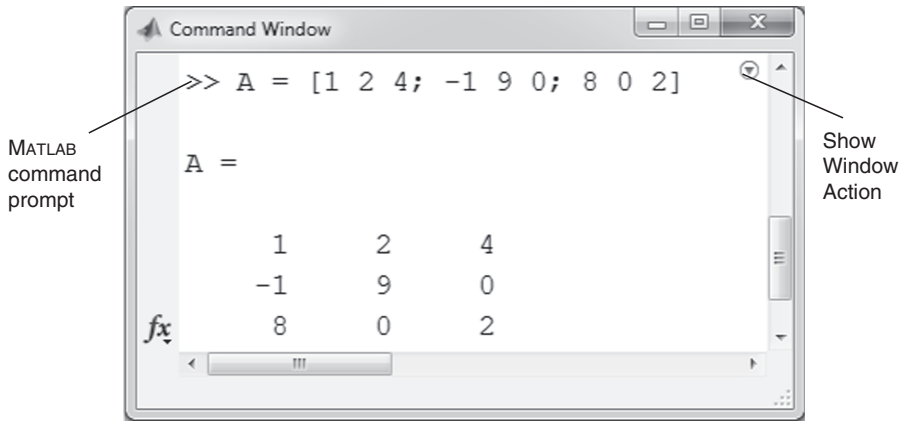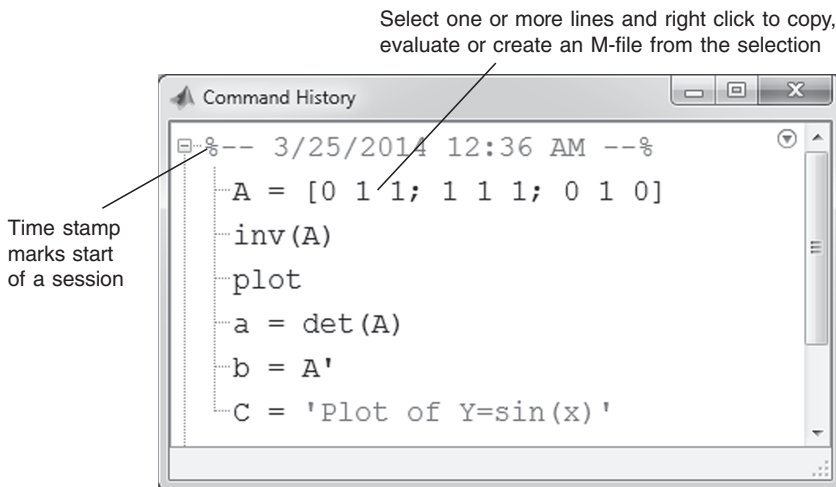
Figure 1.2. MATLAB Command Window

Figure 1.3. MATLAB Command History

Current Directory Browser

The Current Directory browser (Fig. 1.4) can be used to view, open, and make changes to MATLAB related directories and files. You can also use the commands `dir`, `cd`, and `delete` at the command prompt to view, change, and delete directories, respectively. MATLAB uses the current directory and the search path as a reference point to run and save files.

Any file you wish to run must be in the current directory or on the search path. A quick way to change the current directory is to use the `Current Directory` menu in the Desktop shown in Fig. 1.1.

Search Path: MATLAB uses a search path to find and execute the M files/functions you call. It also uses the search path to find other necessary MATLAB files, which are organized in the directories in the file system. By default, the files supplied with