McTutorial: A Structured Approach to Teaching MATLAB

Sable Technical Report No. sable-2014-03

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August 2014

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Abstract

Learning how to program has increasingly become a more important skill for non-programmers in the tech industry or researchers outside of computer science. Newer programming languages such as MATLAB language have grown into industrial strength languages, and many industries and academic fields outside of math and computer science have found uses for it. Thus, it is essential for many more people to learn MATLAB. However, many people often learn it without fundamental knowledge in programming concepts that are rooted in computer science. Thus, a new tutorial, McTutorial addresses this issue.

1 Introduction

MATLAB is language that must be learned by many scientists and engineers. It is a powerful language that suits many scientific needs, from numerical computing to algorithm-prototyping to graphics.

It is thought that the best programming practices come from an understanding of underlying computer science concepts, such as memory and algorithm efficiency. However, many scientists and engineers never get training in computer science. This leads an abundance of poor programming practices in many programs used for research and in industry.

Thus, McTutorial was conceived to address this issue. Most scientists and engineers begin their education in school, so this tutorial is aimed at students at the beginning of their programming careers. However, it can be used by anyone who has access to MATLAB and a basic understanding of linear algebra.

The tutorial itself is our main contribution, as a resource to beginners to MATLAB and programming. Within the tutorial, there are many examples for the users to learn from, but also for educators to take from and adapt. Educators can also take the compiled command list for a subset of MATLAB that is ”safe” to use for a computer science focused programming curriculum.

The structure of the tutorial is as follows:

1. Basics of MATLAB and Programming: This section familiarizes the learner with the MATLAB user interface and with basic commands. In addition, basic programming structures are covered.

2. Programming Concepts in MATLAB: This section builds on the first section to teach essential programming concepts, which are rooted from a computer science perspective.

3. Appendices: This section includes the glossary and MATLAB command list for further explanation and later on, for quick reference.

Please note that this tutorial was created to be extensible, and has been made to easily add more chapters. Read the Future Work section to find out more.

For now, this tutorial has two forms, a printable pdf and an HTML version, available on the Sable website: `http://www.sable.mcgill.ca/mclab/projects/mctutorial/`

The rest of the paper continues by detailing the design and content selection of the tutorial itself (Sections 2-3), with further discussion of the format of the tutorial (Section 4), related work (Section 5), and potential future work (Section 6). Finally, we finish with conclusions (Section 7).

2 Format

In the construction of a user-centric system like McTutorial, it is important to consider its design. This means considering structure and usability, because poor structure can lead to frustration with the interface. This frustration detracts from the purpose of the system: to teach.

To address this, the structure of McTutorial was carefully designed. This section of the paper discusses the various decisions made to make McTutorial as easy to learn from as possible.

At the highest level, McTutorial is currently split into two sections, programming basics and programming concepts. The first section is meant to lay the foundation for the skills needed for the second section. As well, this division sets up the content for the lessons within the each section.

Within each section are several lessons. Each lesson has one main topic that it is centred around. This allows the learner to focus on that one concept for the lesson. As well, small lessons correspond to a less dense, more readable format. Afterwards, the learner can easily reference back to it, if needed.

Inside each lesson, code examples are interspersed throughout. This gives the learner something to follow along with during the lesson. Programming is learned by doing, so having examples to try encourages the learner to start practicing right away. Visually, the code examples are contained in boxes, in order to distinguish them from the rest of the text. This way, the code is easier to read when the learner is trying to type it in their MATLAB session.

Additionally, in the script and function lessons, the examples are oriented around solving a specific problem. Much of the programming engineers and scientists face is like this. Hence, practicing how to use programming to create solutions is something these two lessons emphasize. It forces the learner to start thinking with a problem-solving mindset, something that is essential in programming.

Throughout the tutorial are boldface words. These are essential vocabulary words, which are collected in a glossary at the end of the tutorial. These boldface words function to highlight important words and concepts in blocks of text, where they can be lost. Clicking the word brings the user to the definition at the back, for quick reference. In addition, MATLAB commands are set in a different font to emphasize them. These are also collected linked to an appendix.

In addition, certain lessons include images to help explain a concept or orient the learner. For example, the lesson on the MATLAB user interface includes many screen shots to guide the learner. As well, images can aid learners with a more visual learning style. Other style learners can also use images to look at the concept in a different way. For example, in explaining assignment, an image is used to give a graphical description of the concept.

Finally, some lessons include more information than just the basics. This is intended to explain deeper concepts to more advanced learners, or to pique the interest of more inquisitive learners. Generally, the information illuminates specific idiosyncrasies of MATLAB, but are interesting enough to include.

3 Basics

The goal of this chapter is to introduce the learner to MATLAB and basic programming essentials. The focus is on what features will allow the learner to be productive, but also able to learn the programming concepts introduced in the next chapter. This chapter lays down the foundation for the learner's MATLAB programming career, so things like commands, functions, and structures are introduced.

The topics in the chapter are introduced in an incremental fashion. This way, the learners will encounter what they need to know before they learn a new topic. For example, the user interface is described before the lessons on scripts and functions. This avoids unnecessary frustration due to unfamiliarity.

The rest of the chapter elaborates on the content choices and design decisions of the first chapter of McTutorial.

3.1 Lesson 1: User Interface Introduction

The aim of this chapter is to familiarize the learner with the MATLAB Desktop. New tools can be intimidating, so this lesson allows for a gentle introduction to the environment.

To avoid confusion, the focus in this chapter is the four main frames of the default MATLAB Desktop layout: Command Window, Command History, Workspace, and Current Folder. The other options in the toolbar are ignored in order to emphasize usage of the four frames the learner will be using throughout the tutorial.

Each frame is introduced one-by-one, in order to highlight the uses of each frame individually. This also allows the learner to easily refer back to each frame's usage. Sprinkled into each subsection are helpful tips to improve productivity. For example, in the Command History subsection, smart recall is introduced, in order for the learner to easily modify and repeat new commands.

As well, the learner is introduced to a few emacs bindings, which are the standard in MATLAB. These are included because many people are used to using Windows bindings for common file operations such as saving, cutting, and pasting. Thus, the new set of bindings can frustrate and impede learning if it is never addressed.

Finally, since this chapter is a survey of the basics of MATLAB, deeper concepts are left to later lessons. This is signalled to the learner, so as to inform them of what is ahead.

N.B. This lesson is based on MATLAB2013a, full version. This may need to be updated in the future.

3.2 Lesson 2: Calculations

This lesson aims to get the learner to start using MATLAB as a tool for calculations.

To begin, the learner is introduced to variables for the first time. Part of aims of McTutorial are to be frank about the computer science concepts in programming. Hence, essential details about variables are explained, such as variable assignment and declaration.

Another important discussion in this lesson is about operator precedence. This is a concept taught in secondary school education, but not always reviewed later on. A lack of understanding of precedence can cause sneaky bugs in programs, and precedence rules can vary across different programming languages. Therefore, it is essential to introduce it here.

This lesson does not solely focus on programming concepts. The learner is encouraged to direct their attention to more than one frame in the Desktop. This allows the learner to practice using all of the frames to help them. In addition, various entry methods for the Command Window are shown, in order for the learner to be aware of different styles. This is intended to help them read other sources of MATLAB code.

3.3 Lesson 3: Numbers

The goal of this lesson is to introduce memory and explain various number concepts, such as floating point, order of operations, and special values. The content choices for this chapter were some of the most difficult to make in McTutorial, because memory could make up a whole different chapter. Thus, this lesson aims to introduce numbers in MATLAB with a good balance of theoretical and practical components.

To begin, some practical elements. The learner is instructed on how to change the display of numbers. MATLAB has many ways to display numbers, including the default four decimal format, and the long 16 decimal format. This ability to switch between displays can confuse the learner as to what is actually being stored in memory. Thus, this leads to a theoretical discussion on the storage of numbers in memory, especially with regards to precision. Precision is a topic of importance for scientists and engineers, because calculations that are off can have a huge impact in the physical world. Even in MATLAB, using an `NaN` value in your matrix can cause bugs. That's why it is discussed so early in McTutorial.

Another important concept introduced in this chapter are built-ins. Engineers and scientists shouldn't be writing code for common operations that are already written and available. Hence, McTutorial aims to introduce them early. This is actually something MATLAB excels in, as most of their built-ins are given intuitive names. For example, the operation `size(A)` gives the size of a matrix, and `zeros(n)` gives a matrix of zeroes of size n.

Nesting of operations is also introduced here, to show that math functions can be combined. The nesting operations are carefully introduced with increasing complexity, beginning with math operations and scaling to math functions combined with operations. This is to ensure the learner understands what order nested functions are evaluated in, a concept that may not be intuitive. This sets the tutorial up for later, when other types of functions are combined.

Finally, a few MATLAB number idiosyncrasies are explained. First, `i` and `j` as imaginary numbers. An introduction to these numbers introduces the learner to the manipulation of complex numbers in MATLAB. As well, it sets up an apt segue-way into the `which` command. This command is essential for beginners to keep track of what their variables are, especially while working in the dynamic environment of the Command Window. In addition, `NaN` and `Inf` are introduced, so the learner can recognize them, and work with them appropriately.

Overall, this lesson covers many introductory concepts related to numbers and memory, starting with number representation and memory, then moving on to MATLAB specifics, such as built-ins, nesting and special values.

3.4 Lessons 4-6: Vectors and Matrices

At this point, a couple of essential structures in MATLAB need to be taught: vectors and matrices. Since MATLAB is an array-based language, the next three lessons aim to give the learner a good working knowledge of vectors and matrices. In addition, these lessons introduce many related functions that engineers and scientists commonly use.

In the lesson on vectors, the `size` function is introduced to link the familiar single values used in the tutorial so far, to the new concept: vectors. Intuitively, the next step is to teach matrix creation. Here, the learner is also exposed to the different ways matrices are created. The new function command is also used in this context, to showcase its versatility.

Next, vector manipulations are covered through carefully chosen examples. The examples are meant to be simple, but also to cover a range of situations. For example, there is an example that uses a matrix with fraction inputs. Again, this is meant to give the learner exposure to types of code they may encounter.

In the multiplication section, the learner is given a reminder of how matrix multiplication works, even though a basic understanding of linear algebra is assumed for this tutorial. Additionally, this situation exposes the learner to error messages. This is something that is often overlooked in other tutorials. However, reading and using error messages is an excellent troubleshooting skill for programmers to have, which is why error messages are explicitly discussed in this tutorial.

Continuing on, a few more essential operations are covered, such as transpose and division. This section also introduces the "dot operator;, which distinguishes matrix operations from array operations (element-by-element operations). This can be a major source of confusion for learners, so examples for each major operation are included. Another sticky point that is stressed is the distinction between scalar multiplication and matrix multiplication.

The first matrix lesson progresses like the vector lesson. It uses the foundation created in the vector lesson to teach basic matrix operations, such as array operations and scalar multiplication. Since the new information is linked to concepts already taught in the previous lesson, there is room here to introduce more useful functions. These functions include `min` and `max`, as well as `zeros` and `ones`. The latter two are especially important for beginners to get accustomed to using, in order to maximize efficiency of programs using large matrices.

The second matrix lesson delves deeper into the matrix manipulations that are possible in MATLAB, with a focus on subscripting. Originally, these operations were going to be included in one matrix basics lesson. However, the material proved to be too much for one lesson, and after the edit, the lessons in this chapter are more consistent in size.

Like the previous lessons, this one gives many examples to expose the learner to the different methods one can use to take advantage of MATLAB subscripting capabilities. Subscripting is useful in increasing the speed of a program that creates many simple matrices. In addition, a couple useful functions (`subm` and `linspace`) are introduced to continue the learner's exposure to new functions.

3.5 Lessons 7-8: Scripts and Functions

The last two lessons of this chapter introduce user-created scripts and functions These structures that are often underused by many scientists and engineers, even if they have programmed a lot.

This lack of usage can prevent a programmer from writing anything too complex. Hence, this tutorial exposes the learner to them early on, in hopes of encouraging their abundant use. This tutorial assumes that the learner has a copy of MATLAB, so script/function creation is taught using the MATLAB interface.

To begin, a carefully chosen example script is presented, using concepts from the previous lessons. As usual, the learner is encouraged to follow along. Comments are introduced here, because they can be helpful in explaining code to beginners. In addition, commenting is an excellent habit for scientists and engineers to cultivate, because their code is often shared and read by many people.

To help the learner distinguish that a script is running, the simple function `disp` is introduced. It also makes the introduction of the function `fprintf` easier to do, a little bit later in the lesson. The function `fprintf` also helps to expose the learner to format strings, which are important in displaying results a calculation may provide.

On the more practical side of things, the `help` command is introduced in the scripts lesson. At this point, many functions have been introduced, so the `help` command can help the learner remember what a function does. This also teaches the learner how to look up other functions in the future.

An important point to teaching scripts early is to get the learner to solve one issue at a time. If a program is written entirely in one script, or perhaps even just typed into the interpreter line-by-line, then the programmer cannot write very complex programs. In addition, they will be very inefficient. Hence, exposing the learner to scripts early gets them out of the interpreter, and into using scripts.

In addition to script/function-writing, the learner is given a descriptive example of navigating the file system. Although this is not directly related to being a good programmer, being able to navigate the file system is an essential skill for productivity, and also for code organization. M-files are also explained, because file-naming can sometimes frustrate a beginner.

The function lesson builds off the scripts lesson. Since functions can be intimidating, this lesson is designed to make function-writing feel as close to writing a script as possible. First, the motivation for using functions is outlined. Then, the difference between the two is carefully explained to ward off confusion. Only the essential changes are made to convert the sample code into a function. Finally, a few examples are given.

4 Programming Concepts

The goal of this chapter is to give learners a solid foundation in basic programming concepts. It elaborates on many concepts that are only mentioned in the first chapter. This allows the learner to recall their experience with the material in the first chapter, and build on it in this chapter. For example, variables are introduced in the first chapter, but are talked about in depth in the second chapter.

To further accommodate focus on each concept, each lesson in this section is, in general, shorter than the lessons in the first section. This way, the amount of information in each lesson is kept at a manageable level.

The chapter itself is structured to introduce concepts incrementally, like the first chapter. For example, boolean expressions are introduced before conditional statements, because one needs them to understand how conditional statements work. The same goes for conditional statements with respect to loops.

The rest of this section of the paper will take a closer look at each lesson in the second chapter of the tutorial, with a focus on the content choice and design decisions.

4.1 Lesson 1: Variables

The first lesson in the chapter gives in-depth look at variables. In the first chapter, the focus is on how to use variables. Now, the goal is to teach the learner what is going on behind the scenes. Throughout this lesson, the code examples are kept simple, to focus on the concepts being taught. The first major concepts here are the links between memory, values, and variables.

Since memory is an abstract concept, it is more likely to confuse beginners at first. Thus, the variable, which was introduced before, is used as a starting point for the new concepts. These new concepts are introduced via question-answer format, mimicking the flow of a live lecture.

To emphasize the difference between values and variables, their definitions are carefully given. In addition, their differences are highlighted with a coding example. Finally, expressions are introduced to bring variables and values back to the same level. Since this is still a MATLAB tutorial, the MATLAB variable editor is also explained, so the learner can make use of this feature.

Another concept discussed in this lesson is types. Of course, the quirks unique to MATLAB are described, including its use of the word **Class** instead of type. For types, the learner is made aware that there are many types in MATLAB, but the discussion is limited to that, in order to keep the content manageable for one lesson. Instead, the learner is introduced to a way to check the type of a variable using the MATLAB command `whos`. Here, we can also introduce size and bytes.

Finally, we end with a discussion on scope. This is another abstract concept that can confuse beginners. Hence, it is introduced via the script and function introduced in the first section. This way, two familiar pieces of code are used to explain the new concept. This makes it difficult for the learner to skip to this section or lesson, hopefully ensuring that they take the time to learn what is in the previous section. This discussion on scope also allows the learner to get used to using the MATLAB Workspace window.

4.2 Lesson 2: Booleans

The next concept to be covered are booleans. This concept is often combined with the topic of the next chapter: conditionals. However, in the spirit of thorough explanations, this tutorial splits the two concepts over two lessons. This is especially valid for a MATLAB tutorial, because MATLAB allows boolean operators to be used on arrays. This creates situations where a boolean expression is better explained without the context of conditionals.

As usual, the lesson starts small, by explaining logical variables. The MATLAB Workspace is mentioned again, to keep the learner aware of available sources of information about their code. The next step is to explain boolean expressions, along with their corresponding operators. This is done by first explaining the operators, then giving comprehensive examples. The explanation at the beginning can also function as a quick reference for future use.

In general, the examples are crafted to give a sample of typical use, as well as to expose non-intuitive behaviour. This is especially true for comparison of arrays. For the logical operators, tables are used for their orderly presentation that is easy for learners to read. Again, these can be used as a quick reference later on. To keep the learner aware of potential pitfalls, one of the last examples in the lesson results in an error. This also serves as practice in reading error messages, a more practical skill for programmers.

4.3 Lesson 3: Conditionals

This lesson is essential, because it is the learner's first look at control flow. To encourage the problem-solving mindset required in programming, this lesson is set up as a walk-through solution to a given problem. Throughout the this walk-through, the learner is introduced to the pieces needed to solve the problem, including conditional statements and new MATLAB functions.

The conditional statements are introduced in a format similar to the boolean operators. First the general function or structure is described. The format for this general description is uniform for each conditional statement introduced. The language is purposefully verbose, to explain each component of the statement.

Then the statement is used in an example. The example shows the user how the code is used in practice. In this lesson, all the examples tie into the one problem given at the beginning of the lesson. This way, the learner is introduced to using the structure in the context of an actual problem, which mimics the programming they will be doing for their work.

The problem of the lesson, which is to display a message if a given number is even or odd, is very simple, so as not to obscure the topic of the lesson: conditional statements. However, this set-up also allows the user to practice writing scripts, which is a tool that is underutilized by many casual programmers. In addition, this lesson takes the time to introduce a new MATLAB function, the `mod` function. This is intended, in the greater scheme of things, to expose the learner to many helpful MATLAB functions that they may otherwise try writing themselves.

4.4 Lessons 4-5: Loops

After conditional statements, the next logical concept to teach is iteration. One major decision to be made was the order of introduction for the two types of loops. The for-loop has more complex syntax but has a set number of iterations. On the other hand, the while-loop has simple syntax but can be induce infinite iteration. Ultimately, the for-loop was chosen to be taught first because its behaviour is different in MATLAB, compared to other programming languages.

Previously, there was also the decision to split the loops into two separate lessons. In accordance with the split made for booleans and conditionals, the loops are in two different chapters in order to explain each structure more thoroughly. This also keeps each lesson to a shorter length, and makes it easier to refer back to the details of each structure for future reference.

To begin the loop lessons, a motivation for loops is explained. Then, like the lessons on booleans and conditionals, the lessons describe each loop structure in a general way. This explanation is verbose for clarity, and leaves the exact syntax to the examples. For examples, in the case of the for-loop, MATLAB syntax allows for multiple variations of loop declarations, so the code examples are more numerous. In addition, these examples are kept simple, to avoid confusion.

Similar to the conditionals lesson, the two loop chapters feature an example problem that can be solved with the newly introduced structure. This continues the problem-solving theme that started in the first section, and allows the learner to further grasp the utility of scripts.

5 Related Work

The growth of the Web has allowed for learning infrastructure to take a new form online. This provides an excellent platform to reach many potential users, without a high cost to learners or the provider. In this section, we discuss contributions to the design of online tutorials that address the potential learning obstacles a beginner programmer may encounter.

A number of studies have looked into the difficulties that face beginner and novice programmers. To this end, Lathinen, Ala-Mutkam, and Jarvinen [3] organized a survey of programming students and teachers. After analysis of this survey, they found that the abstract concepts, along with program construction can cause students many issues, but careful design of instructional material can help. In addition, Milne and Rowe [7] attempt to close the gap between what educators versus beginner programmers find to be difficult programmer concepts in their 2002 study, while Robins, Rountree, and Rountree [8] do the same by reviewing the literature of the educational study of programming.

On the learner side of things, McLoughlin [5] discusses the accommodations that should be taken into account to optimize instructional material for students with different learning styles. The learning styles are a popular topic in research on design of educational material. More specifically, Mestre [2] explores accommodations for learning styles in online learning. Mestre [6] also has a piece that is devoted more closely to usability.

The effectiveness of online tutorials has been a hot topic as their presence online grows. However, Maltby and Whittle [4] have found evidence that the medium for teaching (face-to-face versus online) does not affect the performance of high-achievers. This means a well-designed tutorial can facilitate as much learning as a student-teacher environment if the student is motivated. To add to this, Ally [1] mentions that the medium used to instruct is less important than content and instructional strategy.

6 Future Work

In the original planning of McTutorial, two major sections were to be included, as well as one tutorial-wide feature. Unfortunately due to time constraints and other unforeseen circumstances, these did not make it into the first version of the tutorial. However, they are described here, in anticipation for the expansion of McTutorial.

The first section that was to be included was a style section. Since many scientists and engineers never get formal training in programming, many never learn how to style their code. Coding style exists to keep code as readable as possible. This is to the benefit of the person writing the code, as well as anyone who reads it later on, including those who must expand or fix the program. In fact, good coding style can save time, effort, and money that can diverted into other research or work activities.

Some of the essential style topics to include would be spacing (indentation, list spacing, and code blocks), commenting, and naming (for variables, functions, and scripts).

The second section to be included would be an application section. Since this tutorial is aimed at scientists and engineers, most of their programming, if not all of it, is going to be applied to a specific problem. Therefore, practice solving application-based problems would be very beneficial.

Some essential applications could be complex number operations, plotting graphs, using the debugger, and manipulating graphics. As well, a general example on large datasets would be applicable to a lot of research.

The tutorial-wide feature that is missing is an exercise section at the end of each lesson. This feature would include anywhere from three to ten questions related directly to the current lesson, but also tying in concepts from previous lessons. This would function as a way to cement the lesson content in the learner's head. This supports the assertion that programming is learned by doing. As well, an answer appendix can help the learner check-in on their handle of the information, especially because this tutorial has no other feedback system.

Of course, additions to MATLAB are not limited to the three described above. Further chapters could include more advanced MATLAB programming, such as anonymous functions, or more advanced programming concepts, such as structs.

In addition to expanding the tutorial, McTutorial can be improved through actual use. For now, McTutorial is untested by actual learners, so feedback from users could provide a dearth of information on what can be tweaked.

7 Conclusions

In this report, we have presented McTutorial, a MATLAB tutorial aimed at scientists and engineers. In this tutorial, we aim to teach learners not only how to use MATLAB, but how to program well. To this end, there are many factors that come in to play, and this is what we have discussed in this report.

To begin, structural design of the tutorial. At a high level, the structure of McTutorial splits content into two main chapters: basics and concepts. Within the tutorial, code examples are used to get the learner using MATLAB, as well as problem-solving. In addition, essential vocabulary and MATLAB commands are emphasized to signal their importance to the reader. This vocabulary is then defined in an appendix, along with the list of highlighted MATLAB commands, both for further information, or quick reference.

Next, we explain the content decisions in the two major sections: MATLAB basics and programming concepts. These sections are broken down further into manageable lessons. The first section's contents include lessons on the MATLAB user interface, math operations and numbers, basic MATLAB structures, and scripts and functions. The second section includes lessons on variables and basic programming structures such as boolean values and loops. With these lessons, McTutorial teaches the basics of programming in MATLAB to the learner, with a good grounding in programming concepts.

Finally, we discuss a few specific additions that can be made to improve the tutorial. These include two more sections: a style chapter and an applications chapter. As well, the addition of exercises to each lesson would provide the learner with another excellent way to practice.

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