UNIVERSITÄT ZU LÜBECK
INSTITUTE FOR ELECTRICAL ENGINEERING IN MEDICINE

A Novel Algorithm for Electrical Engineering in Medicine

Ein neuer Algorithmus für die Medizinische Elektrotechnik

Masterarbeit
im Rahmen des Studiengangs Informatik der Universität zu Lübeck

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Lübeck, den 1. April 2020

Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne die Benutzung anderer als der angegebenen Hilfsmittel selbstständig verfasst habe; die aus anderen Quellen direkt oder indirekt übernommenen Daten und Konzepte sind unter Angabe des Literaturzitats gekennzeichnet.

Lübeck, den 1. April 2020

Abstract

This is the place for a very short abstract about your work. It should offer the reader an overview about the scope of the work and the attained results – after reading this, a reader should be able to judge whether reading this thesis might prove beneficial to him. So take care about its length and comprehensibility. For the present document, such an abstract could look like this:

This work gives a short introduction to the typesetting tool LaTeX and points out its advantages for writing a scientific thesis. Additionally, several more general hints on how to write a bachelor's thesis, master's thesis or project work are given, concerning structure, contents and representation.

Kurzzusammenfassung

An diese Stelle kommt eine Kurzzusammenfassung der Arbeit. Dies sollte eine Übersetzung des englischen Abstracts sein.

Contents

1 Introduction

You've just started your project work, your bachelor or master's thesis. Maybe you've already achieved some results like experiments, algorithms, methods or you've made some handwritten notes. Now you wonder how to put that on paper? This document is both a manual on how to write a thesis as well as a template that you can use for your own thesis. Once you've read this document and checked out the accompanying LaTeX-files from which it is generated, you should be able to produce your own scientific work, in a professional and visually appealing form. If you have any feedback (positive or negative) regarding this document, please let me know!

Eike Petersen, May 2018
(eike.petersen@uni-luebeck.de)

FiXme Note: This is a FixMe Note that tells you to complete the introduction of your thesis. To see how this is achieved, see `introduction.tex`. You can use FixMe to help you organizing your thesis writing process, if you like. For more information see the FiXme manual [5].

1.1 Previous Works

This section should contain a quick overview of the previous results of other researchers or students relevant to your thesis project. It serves to clearly position the results of your thesis in relation to other works, and to clarify the novelty of your work in comparison to previous approaches. Normally, this section should span between a half and one page.

1.2 Thesis outline

This work is structured in two sections. Chapter 2 describes how to produce a LaTeX-file using some illustrative examples. Chapter 3 gives a short introduction to scientific writing techniques.

2 Materials and Methods

This chapter deals with background information relevant for your thesis, including physiological background, existing research on the topic, and mathematical and other preliminaries required to understand the novel concepts presented in the following chapter. It is also often called *Fundamentals* or *Background*.

2.1 LaTeX's Features

This section gives some useful hints to write a thesis with LaTeX. It is important to know that LaTeX is not a WYSIWYG (what you see is what you get) program like other text editors, such as Microsoft Word. Instead, it much more resembles a programming language, in which you construct your text by proper usage of syntax. The "source code" is your LaTeX file (`.tex`).

As in other programming languages, it is possible to insert comments in LaTeX that are not visible in the final text. Line wraps are not of importance while writing the text, since they are created during compilation. Therefore, formatting with LaTeX is not a big deal and should not take a lot of time, if all the logical relations are correct.

One of the big advantages of LaTeX is its strong support for typesetting mathematical formulas. Using the logical referencing of your formulas, those references are always correct, even if you change the position of the formulas. Furthermore the print quality you achieve with LaTeX formulas is hardly matched by any other program, let alone free of charge! Citing other works and providing a nicely compiled list of references is very easy in LaTeX, as well.

The following text is not very meaningful on its own, but if you read the source code at the same time, it is easy to understand how different elements are constructed. You should try to compile the file yourself and compare the results. If there are any differences, check if your LaTeX configuration is correct.

2.2 Getting started with Latex

To get started with Latex, you need...

1. a tool that generates a PDF file out of a bunch of *.tex and *.bib files. In Windows, this is typically `MikTex` (`http://miktex.org/download`).

2. a text editor. This can be as simple as `Notepad++` (`https://notepad-plus-plus.org/`), but many would recommend an IDE that provides further convenience features. `TexMaker` (`http://www.heise.de/download/texmaker.html`) and `TexStudio` (`http://www.texstudio.org/`) are two well-known examples.

If you have these two installed on your PC, you're ready to go! There is a wealth of references and tutorials on the internet that deal with Latex. What follows is a small list compiled based on my personal preferences.

- ShareLatex currently provides - to my taste - the best introduction and reference on a number of Latex-related topics: `https://www.sharelatex.com/learn`.

- Latex-Wikibooks often prove useful if you're really looking for a reference of the available symbols, e.g. `https://en.wikibooks.org/wiki/LaTeX/Mathematics` or `https://en.wikibooks.org/wiki/LaTeX/Tables`.

- There is a neat little online tool available, which provides users with hints on available Latex commands based on the user's drawing of the desired symbol: `http://detexify.kirelabs.org/classify.html`.

- Malte Schmitz from the Universität Lübeck also provides good introductory material in German: `http://www.mlte.de/layout`.

2.3 Figures in Latex

Figures should represent an essential component of your thesis, as they are excellent tools for effectively communicating information on complex issues to your reader. While it is not easy to create visually appealing figures that represent information in the most accessible way, this is a skill that can be learned over time by reading

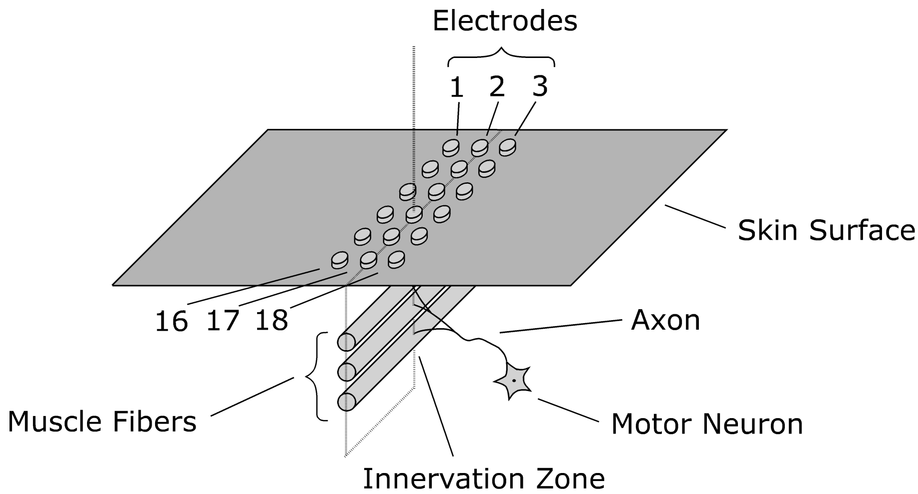


Figure 2.1: Schematic of the geometry in single fiber action potential (SFAP) measurements of human muscle fibers. Shown are three muscle fibers at different depths in the muscle tissue, and a regular grid of 18 recording electrodes on the skin surface. This figure has been produced using the `Inkscape` software.

various tutorials on the topic, carefully examining the works of other authors, and always reviewing one's own figures critically in this regard. For some pointers on how to create good scientific figures, refer to, e.g., Few [4], Rougier, Droettboom, and Bourne [13], Tufte [14], and Ware [15]. A very quick and short introduction to clean and clear figure design is provided in, e.g., `https://youtu.be/UuL6wPGTJZQ`. In the following, the rather technical aspect of how to generate and include figures in Latex will be considered, and several options will be discussed.

Figure 2.1 shows a schematic of the geometry of of single fiber action potential (SFAP) detection. Note the extensive figure caption: many readers will first skim through your thesis and look at the figures, which should hence be as self-explanatory as possible.

As opposed to fig. 2.1, which is included here as an external graphics file, fig. 2.2 shows a simple electrical schematic that is created completely in Latex, using the `circuitikz` package. This package is based on the powerful `tikz` package which allows for drawing any kind of figure directly in Latex. This bears a number of advantages:

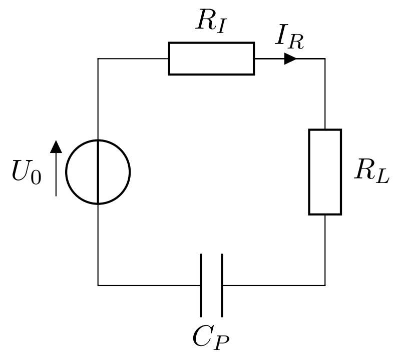


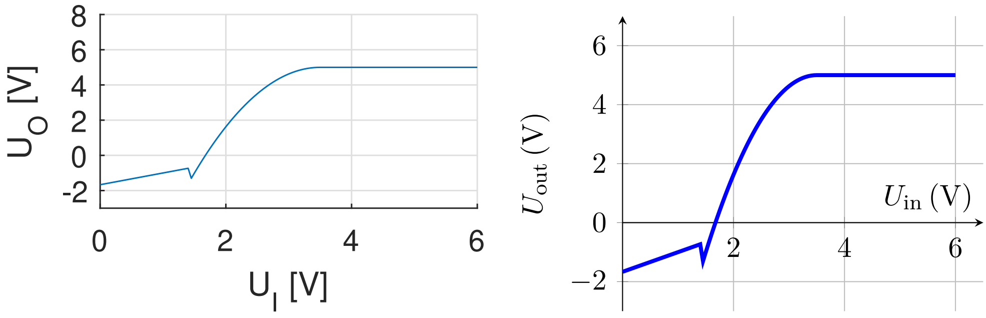
Figure 2.2: A simple electrical circuit, drawn in Latex using the `circuitikz` package. Note how the font type and size are exactly the same as in the normal text body.

- The resulting figures are vector graphics, i.e., they are small (hence not resulting in a final thesis pdf size of several MBs) and generally look good.
- Font style and size is consistent with the rest of the document. This is a major problem when importing figures from other software, e.g., `Matlab`. (Also compare fig. 2.1.)
- Each figure created this way is completely reproducible and configurable in every aspect.

Another package that is also based on the `tikz` package is the `pgfplots` package which enables the user to create plots either completely in Latex, or import data[1] from an external program (e.g., `Matlab` or `Python`) and generate a nice-looking plot from this data using `tikz` (with the advantages mentioned above). Figure 2.3 shows an exemplary comparison of a plot exported directly from `Matlab` and the same data points exported to a data file and plotted using `pgfplots`. (It also shows how to create multiple subfigures inside a single figure.) Figure 2.4 shows an example of a plot that is generated completely in `pgfplots`, without any aid from an external program.

The `pgfplots` package has one drawback, which is at the same time its greatest advantage: it generates *vector graphics*. Vector graphics have a number of significant

[1]For importing data in pgfplots, these are best exported to a `csv` file, e.g. using `csvwrite` in `Matlab` or `numpy.savetxt` or `pandas.DataFrame.to_csv` in `Python`.



(a) (b)

Figure 2.3: The same data points, (a) plotted using `Matlab` and exported to an `.eps` figure file, and (b) exported to a `.csv` file from `Matlab` and plotted using `pgfplots`. Note how the font type and size of all labels in figure (b) agree nicely with those in the rest of the document.

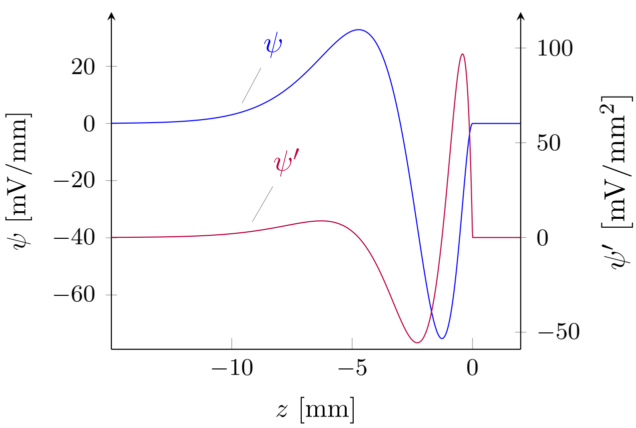


Figure 2.4: Plots of the intracellular action potential (IAP) model function proposed by Rosenfalck [12], generated using the `pgfplots` package. Figure reproduced from Petersen [8].

advantages over raster graphics formats like `jpeg` and `png`. However, when there is *a lot* of data points in a figure, and hence a huge amount of vectors is required to accurately represent the figure, vector graphics tend to become very large and very inefficient to generate and view. For such figures, raster graphics are usually preferrable – however, one would still like to achieve things like consistent font size and type between the figure and the surrounding document. One way to achieve this is by using the `gnuplot` software package. `gnuplot` essentially provides a simple scripting language that can be used interactively or script-based to generate, view, and export figures from scratch or using existing data. Figure 2.5 shows a rather sophisticated figure containing EMG signals that has been generated using `gnuplot`. For more information, refer to the accompanying script file `scripts/emg-raw-plots.gp` that generated this figure, and to the `gnuplot` homepage and various tutorials available on the web.

2.4 Referencing

Every statement that you make in your thesis should either be supported by evidence (theoretical or empirical) provided in your thesis, or by citation of an appropriate literature reference. In the present chapter (materials and methods) in particular, you should provide a lot of references, e.g., to scientific articles [2], books [9], book chapters [11], PhD theses [3], or software projects [10] that you used during the creation of your thesis. You must provide a reference whenever you make a statement that is not a result of your own (experimental or theoretical) work, but rather taken from a literary source. When selecting sources to cite, preference should be given to high-quality sources published in respected scientific journals (or books), wherever possible. Moreover, one should always try to cite the original source where a subject was discussed first or an algorithm was proposed first, instead of secondary sources. For example, regarding the infamous Kalman filter, one should always cite the original paper published by Kalman [6] instead of the many papers published later on (variations of) the same subject.

Sometimes, you should explicitly name authors, such as Farina and Rainoldi [2], who wrote a seminal article on the mathematical modelling of electromyography (EMG) measurements (see the Latex source document to see how this textual ref-

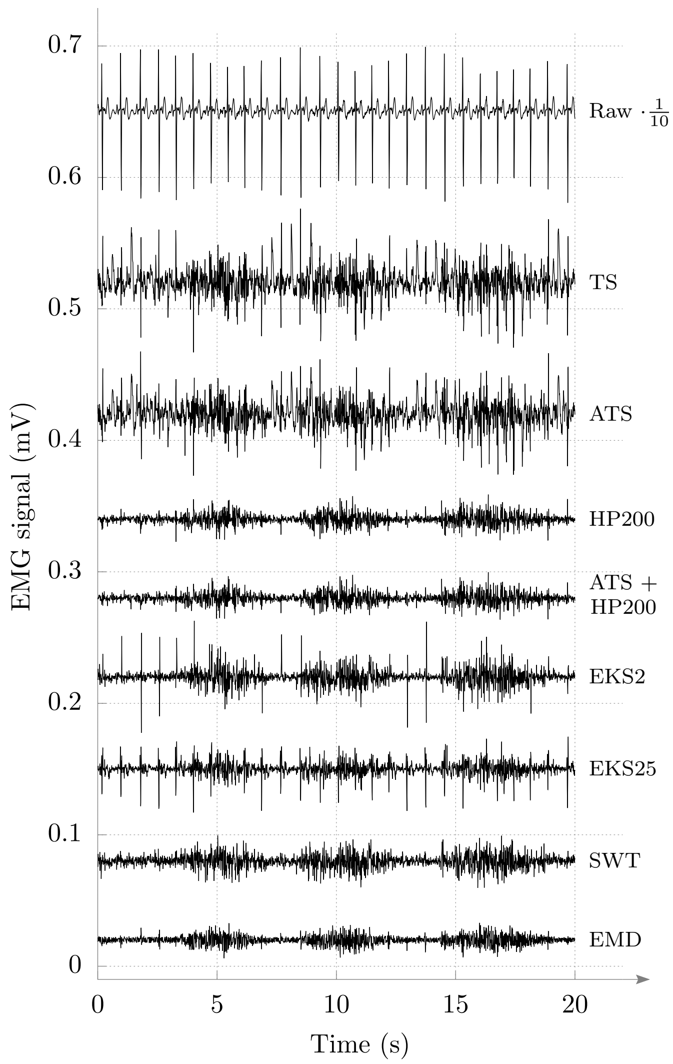


Figure 2.5: Exemplary subset of the measurements taken from subject 7, raw (plotted with a scaling factor of $\frac{1}{10}$) and processed by the various ECG removal algorithms described in the text. All signals are zero-mean, with offsets added for illustrational purposes only. Due to the huge amount of data points, representing this figure in a vector graphics format (using, e.g., `pgfplots`) would be very inefficient. Here, the figure has been produced using the `gnuplot` software in a raster graphics format, while still achieving nice and consistent visual formatting.

erence is created automatically)[2]. In some cases – especially when describing the fundamentals of your research – you will have entire paragraphs that are based on a single, significant reference on the subject you describe. In this case, it is neither necessary nor useful to cite said reference after each phrase. One acceptable solution is to have a phrase in the beginning of the paragraph or section that acknowledges the source and states clearly that the entire following paragraph is based on this source.

Figures may be reproduced from sources, in which case the source must of course be acknowledged accordingly – refer to fig. 2.4 for an example of how this can be done. It is also considered good scientific practice to provide citations for the software packages that you have used, considering that these are often the result of many years of scientific work [10], [16]. Many software packages provide information on how to cite them on their project web pages.

Finally, a bibliography can be created automatically, based on the order in which you have cited sources (see the appendix for an example). This can be achieved using various tools and packages, which all require a separate file (often called `references.bib`) containing bibliographic information on the cited sources. In this template, the `biblatex` package in combination with the `biber` software is used. Usage is simple: After compiling your document once with `pdflatex`, a file `main.bcf` is generated, which essentially contains a list of the cited sources. Next, running `biber main` on the command line combines this generated list with the `.bib` file and generates a new file `main.bcf` that contains the required bibliographic information, using the correct order and citation style. Afterwards, run `pdflatex` again, to incorporate this bibliographic information in the generated document. This process has to be repeated every time a new source is cited in the main document, and each time bibliographic information in the `bib` file is added or changed. Note that there are various software packages available that enable easy handling of bibliographic data and automatic generation of a corresponding `bib` file, e.g. the open source package `JabRef`.

[2]Note how the EMG acronym is clickable and leads to the definition of this acronym in the glossary. This is one of the many features of the `glossaries` package.

2.4.1 This is a subsection

See the source code for how this is achieved.

This is a subsubsection

Note that the different appearance of chapters, sections, subsection and subsubsections can be customized if desired.

2.5 Equations

If you are going to write more than a few equations in your thesis, it is highly recommendable to use macros to define each variable that occurs. This way, if you decide to rename the velocity from v to v_0 (see the source code of this section for how to include mathematical symbols like v in normal text) everywhere in your thesis later on during the process of writing, you will only have to change the definition of the macro used for this variable. For example, in

$$v = \frac{\mathrm{d}x}{\mathrm{d}t} \tag{2.1}$$

and

$$\begin{aligned} a &= \frac{\mathrm{d}v}{\mathrm{d}t} \\ &= \frac{f}{m}, \end{aligned} \tag{2.2}$$

each of the variables is defined using a macro. Always keep in mind that formulas should be treated as a normal part of a sentence and thus can and have to contain punctuation marks! *Never* should any sentence start with a mathematical symbol. Finally, here comes an example of how to reference equations (2.1) to (2.2).

2.6 Pseudo Code

Algorithm 1 is an example of how pseudo code can be represented in Latex. Of course there are, as with anything in Latex, many options available to achieve this goal. Here, the `algpseudocode` package is employed.

Algorithm 1 Euclid's algorithm

procedure EUCLID(a, b) ▷ The g.c.d. of a and b
    $r \leftarrow a \bmod b$
    while $r \neq 0$ **do** ▷ We have the answer if r is 0
        $a \leftarrow b$
        $b \leftarrow r$
        $r \leftarrow a \bmod b$
    end while
    return b ▷ The gcd is b
end procedure

3 Concept

This chapter describes the novelty that you have created during the making of your thesis. This novelty might be an experimental apparatus, a novel algorithm, or a thorough analysis of something. You may here reuse the background information presented in the previous chapter.

There is a wealth of guides available on thesis writing; one that I'd like to point out here because of its conciseness and direct availability is *Clarity in technical reporting* [7], an old yet still valid guide on the subject, originally created for internal use at NASA.

3.1 Thesis writing strategies

3.1.1 Have a plan before you start

Before starting to write any paragraph of full text in your thesis, you should know the contents of every chapter of your thesis to a high degree of detail. Otherwise, you will find yourself rewriting and maybe even dumping large parts of what you wrote earlier. Create a detailed outline of the story you want to tell in your thesis, and make it clear to yourself how each chapter contributes to this central story (also see below for general tips on structuring your thesis well). It also helps to collect and create explanatory figures early on that can help you identify the concepts you need to explain in your thesis.

Once you have a very detailed draft of your thesis *withoug having written any full sentences*, and you have discussed this draft in detail with your supervisor, doing the actual writing will be much, much easier than if you started right away. It will also reduce the chance of your supervisor telling you to rewrite large parts of your thesis. For a more detailed discussion of this writing strategy, also refer to Carlis [1].

3.1.2 Reproducible research

Reproducible research is a term that has gained a lot of attention recently. It describes research that is easily reproducible by yourself, as well as others. Note that many common research practices are not easily reproducible at all, e.g.

- Saving figures you somehow created interactively in `Matlab` – instead of saving a script file that reliably reproduces this figure.
- Saving statistics calculated from measured data, or modified data (e.g. smoothed signals, or with outliers removed) – instead of saving a script file that performs the desired operations.
- Changing a results table in your report according to new results obtained during interactive analysis – instead of saving a script file that automatically generates the data in the table, using the most current version of your software.

Keeping your work reproducible is not only useful for others, but also (and especially) for yourself: It makes sure that all parts of your work (data, analysis, report, etc.) are always in sync. Furthermore, you can, e.g., easily update all figures in your thesis a week before the deadline – which may be a nightmare if you created all of these figures manually and cannote reproduce them easily. A good introduction to the steps required to keep your work reproducible can be found at `http://kbroman.org/steps2rr/`.

3.2 Structure

The general structure of your text depends on the particular subject and your personal preferences. A reader following your text should at each point in your thesis feel like you are telling him a consistent story. In particular, ask yourself the following questions:

- What is your main contribution to the scientific community?
- Which concepts and background knowledge do you need to provide for the reader to be able to understand your contribution and its relevance?

- Which would be a sensible and natural ordering of the concepts that you need to explain?

Always keep in mind that the structure of your text should feel natural to a reader, not leaving him or her wondering what on earth this new topic has to do with anything he's read so far.

Start your scientific text with an introduction, that

- introduces the subject,
- specifies the topic,
- reflects on the problem that you are going to consider,
- defines the purpose of the work,
- explains the line of reasoning
- sketches the structure of the work.

Keep in mind that there are some readers that only read the introduction and conclusion of your work and base their decision on whether the work bears any interest for them only on these parts. To make that decision, they need to get all relevant information from those two chapters. Hint: Look at other work with a focus on that question.

For the main part of your work, there are no general rules. Among others, the order of your chapters should depend on whether your work has a rather theoretic, methodical or experimental focus. The length of each chapter does not necessarily need to be proportional to the amount of time you have spent on solving the respective problems. Sometimes it takes one week to debug a piece of code, which nevertheless should not be explained excessively.

Your work concludes with a summary of your results. Have a look at your introduction: how you have specified the problem there? Do your results solve the problem? Do not present any further results here that have been not presented in the main part. As such, always clearly separate the presentation and the discussion of results.

Finally, you end with an outlook that points out open questions. What should be further analyzed and what are possible follow-up projects? Do not be afraid to point out questions that came to your mind during your research, but you did not have time to properly answer. A good thesis may raise more questions than it clarifies.

3.3 Language

For a very good and readable (and cheap) guide on improving your technical writing skills, refer to Zinsser [17]: *On Writing Well.* Every minute you spend reading this book will be well worth its time.

3.3.1 Correctness

Technical/scientific writing serves a single purpose: to transport information as efficiently as possible. To achieve this, your writing should be as accurate as possible. Do not use colloquial language. Respect the rules of grammar, spelling and punctuation; phrases or words used in the wrong context can lead to misunderstandings or may be hard to understand. It should be clear that the results of your work, e.g., experiments, must be documented precisely and correctly, even though they might have had unexpected outcomes. Otherwise you do not only cause harm to you but any further research.

3.3.2 Comprehensibility

Correctness does not imply comprehensibility. Look at your text from the readers point of view: Consider his or her position, previous knowledge and attitude. Formulate as precisely as possible but not more complicated than necessary. Therefore,

- choose words, that are known;
- use words that are probably unknown, such that their meaning can be deduced from the context, or explain or define them;
- do not construct deeply nested sentences.

3.4 Preparing a scientific presentation

Generally, the same guiding principles that apply to writing a scientific report also apply to the preparation of a scientific presentation: A meaningful structure, clarity, conciseness and correct presentation of contents, including correct referencing of previous works of other scientists. However, in a presentation, the focus should be strongly shifted away from using a lot of text, towards the display of informative figures and diagrams that visually support your oral presentation of concepts and results.

A recent trend in scientific presentation styles has been to move away from the classical „Introduction - Methods - Results - Conclusion“ structure of presentations, and more towards what is called an „Assertion - Evidence“ structure. In this style, slides are usually composed of a title line that displays a meaningful message you would like to convey to your audience („Respiratory Mechanics can be modeled as Electrical Circuits“), instead of a classical caption („Modelling of Respiratory Mechanics“), and supporting visual evidence (i.e., a mechanical and an electrical model of respiratory mechanics), instead of bullet point lists. All further information required to understand the slide is presented orally by the speaker. Scientific studies have shown this style of slides to be more effective in conveying information to the audience than classically designed slides. For more information on this presentation style (and pointers towards the mentioned studies), refer to `http://www.assertion-evidence.com/`.

The following is just a further quick link list compiled to help in creating good scientific presentations.

- `http://www.the-scientist.com/?articles.view/articleNo/28818/title/Pimp-your-PowerPoint/`
- `http://www.northwestern.edu/climb/resources/oral-communication-skills/creating-a-presentation.html`
- `http://www.nextscientist.com/improve-presentation-skills-of-phd-students/`

4 Results

This chapter summarizes the results that you have obtained during experimental validation of the concept presented in the previous chapter. Note that a clear separation between experimental results and their discussion is to be made: Here, only numerical results, performance plots, etc. are to be shown and described. Any interpretation of these results – What do they imply? Which conclusions do you draw? – is to be postponed to the following chapter. This is useful since in the future, some of your interpretations may be clearly known to be false, due to newly acquired knowledge. In this case, however, the data you have collected during your studies may still be very valuable and hence should be easily accessible on its own. Moreover, this provides a very important distinction between objective findings, i.e. experimental measurements that you have obtained or other data, and the inferences that you draw from these data, which may or may not be true.

5 Discussion

Finally, in this chapter, the results presented in the previous chapter are to be discussed and interpreted. Here you may discuss the prospects of your proposed method to solve the problem at hand, and propose alternative solutions.

6 Conclusion

In this final chapter, you provide a concise summary and conclusion of your work.

Acronyms

EMG	Electromyography
IAP	Intracellular Action Potential
SFAP	Single Fiber Action Potential

List of Mathematical Symbols

a	Acceleration
f	Force
m	Mass
v	Velocity
x	Location, spatial variable

List of Figures

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List of Corrections