Instructions for master thesis students

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Abstract

These notes contain my subjective instruction and recommendations for master students, but they apply equally well to PhD students. They are a work in progress and by no means complete. In their current state, they focus on thesis work and report writing.

Contents

1 Introduction

Writing a master thesis means a lot of work and for many students a very interesting time. This document contains instructions and recommendations on the working process and the thesis writing. It is my intention that the students who follow these instructions will have a smoother work flow and thesis writing. The document is primarily written for students who are writing their master or bachelor thesises in quantitative sciences like mathematics, signal processing, physics or computer science. All instructions might not be applicable to all departments at every university due to conventions or formal requirements, e.g., on the structure of the report. It is written based on my personal experiences and preferences, and within the formal requirements at the Department of Mathematical Sciences at Chalmers and the University of Gothenburg. Since I believe that it can be useful for other students and their supervisors, I make it freely available.

2 The thesis work

When evaluating a thesis work after completion there are often lessons about what could or should have been done differently. This section is an attempt to serve students these accumulated learnings in order to reduce the risk to redo the well known misstakes and having a better chance of getting a good start.

2.1 The writing process

The final result of the project is a nicely written scientific report. There are at least three very good reasons to start writing from start. I devote one subsection to each of these.

2.1.1 Learning to write

I have not yet supervised a single student who has reached a maturity in scientific writing, sufficient to write a well written master thesis report, without an iteration with the supervisor. It sometimes happens that students get overwhelmed by the amount of comments and iterations needed to get the report in a good shape. An important and necessary part of writing a master thesis is thus to learn to write. Theoretical background chapter(s) can and should be written early. This gives an excellent opportunity for an early iteration with the supervisor, that makes you as a student grow in your writing skills. One of the most common misstakes is to wait with the report writing until the last month. Doing so you lose the mentioned opportunity to improve gradually and the iteration can be overwhelming for both the student and the supervisor. Eventually, due to lack of time at the end, there can be a need to end the iteration before the thesis has reached a good enough state, or ambitious students with high standards need an extra month or two, which is both unfortunate.

2.1.2 Writing to learn

Writing is a great tool to enhance learning. In order to formulate an abstract concept or theory in a written form, you necessarily need to reach a higher level of understanding than if you rely on your memory, sketchy notes or high-level code. This gives a second great reason for start writing the theory chapter(s) early. To push this learning technique even further, I encouraged you to write material in LaTeX that you are not certain will end up in the final report, just for the sake of learning. In the literature study it is, for instance, a very good technique to summarise research articles. Some students write weekly summaries of their work. This is good but should be interesting to read and not only a list of details.

2.1.3 Writing to boost feedback

The third and final reason for writing throughout the entire work is the communicative value it has with the supervisor(s). Being left out solely to oral communication leaves room for misunderstandings. By formulating theory, methods, experiments, etc. with details the supervisor will be able to spot misconceptions or weaknesses directly and the student will get early feedback and not need to work too long with erroneous settings that could had been spotted by clear communication. While material intended for the final report should be nicely written, writing the details of experiments in the process of working, can be done with a table or similar, as long as it is clear. Writing weekly summaries of your work is a good way to communicate your work.

2.2 Being supervised

Both supervisors and students are individuals. No collaborations between a student and a supervisor are the same and should not be. Some students write weekly reports on their progress and for other this seems too much of a formality or control function.

Some students want weekly meeting, while other want meetings on demand. Regardless of the differences, by experience, a common factor for successful collaborations reads communication and this is the core of this section.

2.2.1 Expectations between supervisor and student

A key for successful student and supervisor collaboration is communication and having agreed on expectations. Reasonable expectations on a supervisor in my view are:

- Research is an activity concerned with learning from mistakes. The supervisor is expected to be respectful and provide an environment where the student feels safe to commit mistakes.
- Since the supervisor has agreed to supervise, he or she has, with exceptions, time for the supervision. Feedback should be relatively quick.
- The supervisor is a researcher. Adequate support on scientific matters is expected.
- If the thesis topic is within the supervisor's domain of expertice, a corresponding level of the supervision is expected.
- If the thesis topic is outside the supervisor's domain of expertice, a curiosity and will for joint learning is expected from the supervisor's side.
- The supervisor is never expected and should not write parts of, or edit, the report.

Maybe you as student has more or other expectations. It is then important to communicate these early.

Reasonable expectations on the student are:

- The student is expected to drive the project in a positive and curious manner.
- The student is expected to scan the literature for relevant material.
- The student is expected to start writing the thesis report early.
- The student is expected to provide a sufficient level of details about the progress of the work, to enable qualified supervision.
- The student is expected to address the feedback of the supervisor, implement it or argue otherwise.
- The student is expected to grow with feedback and be able to generalise feedback.
- The student is expected to understand that the supervisor and the university (and the company when applicable) expect the report to meet a certain standard.
- The student is expected to understand that occasionally feedback cannot be provided timely.

2.2.2 Supervision throughout the thesis work

During the initial stage of the thesis work, when learning the topic, a great way is for the student to present material from the literature, on the board, to the supervisor, and possibly others. When preparing these presentations, it is natural to write the material down and this way both grow within the field and enhancing communication between student and supervisor. It is important and very useful to get early feedback on the written material. In advanced thesis works, and based on the supervisor's knowledge, it is suitable that the supervisor presents and explains some material for the student.

In a second stage of the thesis work, the student is generating results. Instead of presenting theory, the student is presenting results (possibly of theoretical type), challenges, or problems. It is a good idea to prepare the supervisor in an email if there are questions of more advanced nature, as this gives the supervisor time to think and prepare if necessary. Often, the process of writing the email and formulating the question properly leads to insights and in the best cases to a solution of the problem. If the results are of theoretical nature, it is very natural to use LaTeX as the primary tool and iterating the text with the supervisor. When generating experimental results, it is still important to formulate the experimental setting and use this in the interaction with the supervisor.

In the third and final phase of the thesis work, the type of results to include has been settled (without much uncertainty of the outcome), or results are complete, and it remains to generate the final results and complete the report. This part of the supervision is mainly based on detailed comments on the report, possibly with meetings to explain parts of the written comments.

In all three phases, it is suitable with weekly meetings and communication when needed in between.

3 The report

This section contains concrete instructions on the report writing, based on the knowledge of common misstakes made by students.

3.1 Who is the intended reader?

You should have two intended readers in mind when writing. The first is a student with a similar study background as you, e.g., yourself before starting the project. You should write an interesting and clear text that helps this student to learn what you have learned. The second reader is a senior professional that will easily tell if you have understood concepts or have gaps in your understanding. Your task is to build trust from this second reader and impress him or her. If successful, the reader might continue reading, otherwise, very unlikely.

3.2 Building the story and the flow

A common mistake is to write every section or subsection as an independent text. It might be due to multiple authors or that they were written at different times. In the early writing, this makes sense since the purpose of the writing in that stage is to learn the topic. In the later stage, when the report starts to form, such writing will lead to a bad reading experience. To build an interesting story and get a nice flow in the text it is important to write every new chapter, section, subsection, paragraph, and sentence based on the preceding chapter, section, subsection, paragraph or sentence. Build bridges between them, refer back, and remind the reader about earlier material in order to connect it with the current material. Also give some references to where you are going next (this could be the next paragraph or the next chapter).

3.3 Structure of the report

It is good to sketch out the structure of the report at an early stage. In addition to being a natural starting point for writing, it helps you digest the scope and limitations of the project at a time when the topic is still new and maybe confusing. There is the traditional structure with introduction, theory, method, results, discussion, and future work. Some departments expect it and others do not. An alternative structure is one which is more free, with more descriptive names of chapters. I prefer the latter.

3.3.1 Introduction chapter

The introductory chapter should be interesting and self-contained. It should put the work in its proper context and, on a high level, explain either the results themselves or what type of results have been obtained. Start by expressing the broad picture and continue with more details of what has been achieved in the project. Finally, the results are put in their larger context again, and an outline of the chapters is given. For some projects, it is suitable to formulate limitations. The introduction should reflect the content of the thesis in an adequate way, but the tone in the language can be less formal than in the rest of the thesis, more like that of a popular science text. It is often better not to split the introduction into sections. To catch the reader's attention and make the reader want to continue to read, the value of a high quality introduction should not be underestimated.

3.3.2 Theory chapter(s)

Many reports have a single theory chapter that introduces all theory used throughout the report. This is not necessary, and the theory can be split in more than one chapter. Regardless of the choice, the theory chapters should primarily contain well-known results from literature and not more than is needed for the results. The material should be presented in a formal, clear, and interesting way and not contaminated with references to their application in the thesis, i.e., these chapters should be useful for readers who want to learn the theory itself, regardless of the context. Only in the introductory

paragraphs of chapters and sections, where the purpose of the material is explained, are these connections suitable. While the presentation should be formal, it must also have a story, helping the reader with the logical flow, connecting subsections and concepts to each other. If the logic is hard to follow, the reader will likely give up and find another text to study for the purpose of learning the topic. Formulations like the following one enhance the logical flow: "In Subsection 2.3.1 we introduced the concept of entropy of probability distributions. Here we use entropy as a regularizing term in the optimization problem (2.10). This has been shown in [23] to have the advantage that...".

3.3.3 Method chapter(s)

Between the theory and result chapters, there is often one or more methodology chapters. While the theory chapters are written in a general form, the methodology chapter is the first detailed chapter of the thesis that approaches the specific problem of the thesis. It introduces possible data collection, the data, the specific algorithms, the evaluation metrics, the problems for evaluation, or other methodology used to generate the results of the thesis. Here, specific parameter choices are presented, even though an appendix is sometimes better for this purpose. In this chapter, it is common to introduce abbreviations for objects of study, such as algorithms. Sometimes, it is good to have more than one chapter, e.g., one for data, one for algorithms, and one for problems used for evaluation. Sometimes, it is better to skip the methodology chapter completely. In such cases, it is possible to introduce examples, methods and results in a nice way in the result chapter without losing flow and clarity. If the results of the thesis are of completely theoretical nature, e.g., consisting of mathematical theorems and proofs, it is hard to see what function such a chapter could possibly have.

3.3.4 Result chapters(s)

For experimental-type results, the results are most often figures or tables. The results should be presented in a clear and interesting way. It is not necessary to leave the discussion to a discussion chapter, but it is more interesting to include the discussion in the result chapter(s), as otherwise it might become very dull reading. The connection to a methodological chapter might be slightly challenging, and it is important that the reader does not need to go back to the methodological chapter all the time. To avoid this, it is good to remind the reader of elements of the material in the methodological chapter.

When the results are theorems and proofs, there is usually a natural structure based on the logical flow or the generality of the results. It is often suitable with more than one chapter if the results naturally split into different categories.

3.3.5 Discussion and future work chapter

The author should help the reader already in the result chapter(s) to interpret the results and remark on interesting findings. A discussion chapter, if having one, should instead

lift the results to a higher level, to a larger context. What other methods or theories are there that were not tried or investigated? What could the the underlying reasons be for some surprising finding? Were the assumptions made necessary or is there reason to believe that they can be relaxed? In the case such analysis is done already in the result chapter, then the discussion and future work chapter can be a *summary and outlook* chapter.

The future work section is important and often interesting to read. A rich list of future directions shows that the authors are curious and also can see beyond their work and see the larger picture. A common mistake is to focus too much on details. The authors have been working intensely with the topic for months while the reader in most cases has only skimmed through the report or read parts of it once or twice. Very few readers will thus be able to appreciate very technical future directions and often the authors overestimate the interest in those. Thus try to zoom out and give large and interesting directions.

3.3.6 References

There are different conventions for references. Chose one and be consistent with it. Look at previous reports to see how the references should look. Use a reference management system such as bibtex, biblatex or biber.

3.3.7 Appendix

The appendix is a good place for material which is useful but not central and that might disturb the flow or take focus from the main text. It can contain theory sections with material that might be assumed that the reader knows, but that the authors had to learn during their works. It can also contain lengthy proofs of previously known theory, even though these can often be in the main text too. The authors should adopt according to their intended reader and what the story and main message is.

Model parameters are often suitable for the appendix. So are figures, tables or algorithm environments that give some complementary value but do not quite fit in the main text.

3.4 Scientific English

This section is not a primer in scientific writing. It addresses a few common problems, frequently seen in reports, that I want to help you to avoid from start.

3.4.1 Future tense

In the beginning of the report writing, naturally, all sections are not there and it makes sense to think about "In Section 2 the theory will be presented". On the other hand, when the report is complete, future tense has very little relevance. Never use "will" in the report unless you explicitly discuss the future, e.g. , "autonomous driving will be an

important research topic the next few years" is a legal sentence. To refer to positions in the text, write "below", "above", Section 5, Subsection 4.4, Example 2.4.

3.4.2 Simple and concise

In social sciences complicated language is rewarded. In natural sciences and technology the opposite is true. Use a simple and concise language. Many times sentences are too long and cumbersome to read. Do not hesitate to split too long sentences in two, but also allow variation by avoiding stacking too many short sentences after each other. It is good to use synonyms for a varied language, but technical and scientific words or phrases often have a well defined meaning, and you should *never* try to use synonyms for the sake of a varied language for these ones. If you can remove words from a sentence without corrupting the grammar or making it loose its meaning, then you should do so. This is often possible.

3.5 Mathematics

3.5.1 Typing mathematics

Variables, functions, sets, etc. should be written in a cursive style, e.g., log is the multiplication between the the variables l, o and g. This is default in a LaTeX. When text or abbreviations are used in formulas, they should be written in roman font, e.g., log is the logarithm. The same is true for other words in displays like "minimize" or "maximize". Use `\mathrm` for roman style instead. Parenthesis should not be smaller than what is inside them. Use `\big`, `\Big`, `\Bigg` to enlarge them to desired size. The `\left`, `\right` commands does this automatically but often gives too large parenthesis and requires `\.` in case the start and end parenthesis are located on different lines. For bold face use `\mathbf`. As an example

$$minimize_{x>0} E[\frac{cos(x+\lambda_{out}+X)}{log(x+\lambda_{in})}], \quad X \sim Poisson(r), \tag{1}$$

does not look good, but

$$\underset{x>0}{\text{minimize}}\ \mathbf{E}\left[\frac{\cos(x+\lambda_{\text{out}}+X)}{\log(x+\lambda_{\text{in}})}\right], \quad X \sim \text{Poisson}(r), \tag{2}$$

looks much better. It is convenient to use `\sin, \cos, \log, \min, \max`. For derivatives and integrals write $\mathrm{d}x$ instead of dx and for integrals also a small space before writing `$\int f(x)\,\mathrm d x$`. Please follow these rules.

3.5.2 Logic

There are different conventions for how to write logic. In mathematics statements are often based on the quantors $\exists$ and $\forall$, *there exists* and *for all*. In formal logic, quantors

should always be first, ending with a colon followed by a statement, e.g.,

$$\forall \varepsilon > 0, \exists \delta > 0, \forall x \in \mathbf{R}, \forall y \in (x - \delta, x + \delta) : |f(x) - f(y)| < \varepsilon.$$

The quantor symbols $\exists$ and $\forall$ are seldom suitable in a master thesis and are better written in words. Some authors are consistent in keeping the convention to always have quantors first. Sometimes, like in the above example, this is necessary since there are more than one quantor and the order of them matters. On the other hand it is very common, if the last quantor is $\forall$, that this quantor is written after the statement, e.g., there exists $C > 0$ such that

$$\|u_h(t) - u(t)\| \leq Ch^2 \quad h \in (0, 1),\ t > 0.$$

Notice that the $\forall$ symbol is avoided when doing so. Having an awareness of these logical considerations improves writing skills. Finally, the implication arrow $\Longrightarrow$ and equivalence arrows $\Longleftrightarrow$ are seldom suitable in a master thesis or research paper, but are often better expressed in words.

3.5.3 Theorem environments

There are four theorem environments, namely *proposition*, *theorem*, *corollary* and *lemma*. In logic, a proposition is a statement that is always true, and this fact requires a proof. A particularly important proposition, often a main result, is suitably formulated as a theorem. A less important proposition that still have an interest in itself is formulated as a proposition. A corollary is a proposition that follows, almost immediately or with a minor proof, from another proposition. Finally, a lemma is a proposition with little interest in itself, but instead is formulated to prove something else.

3.6 References and citations

3.6.1 References

To create labels in LaTeX, use `\label`. To refer to a section, subsection, subsubsection, example, remark, theorem or similar use `\ref` and to an equation use `\eqref`. The latter yields parentheses around the reference and the former does not. Use the `heperref` package for clickable links in the references. The first letter in references should be capital, e.g., Section 2, Subsection 2.3, Example 3.2, Inequality (3.1). Do not write "Equation (1.2)" because (1.2) is implicitly understood to be an equation

In the final text, only number equations which you refer to in the text. Do this by including `\mathtoolset{showonlyrefs}` in the header. In the writing and iteration phase, it is practical to have equation numbers everywhere for communication purposes. For displays with multiple lines, in most cases it is best to have one equation number for the display.

4 Working with numerical experiments

The computational sciences provide a multitude of types of numerical results from the computational sciences and domain-specific ways to evaluate and visualize. Therefore, I do not attempt to give any general recommendations on how to present scientific results. Instead, this section simply contains one very important requirement. When you generate numerical results or train models, then **always save the numerical results or model parameters and not only the figures**. Then you can improve the presentation of your results, whether it is figures, tables, or whatever, without running your numerical experiments again, or stay with inferior figures as they cannot be changed. It happens too often in the late iteration that the figures cannot be improved because the output data of a computation were not stored.