The Perfect Thesis

Content, Structure, and Layout

LaTeX Template

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Structure, Content and Layout

Generic Thesis Template

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About this template

This document, along with the source code, is meant to be a self-explanatory generic thesis template, to be used in any field. It is implemented in LaTeX, the most popular, advanced, flexible, and comprehensive documentation system in natural sciences. However, the document as such could be implemented with other tools, as well.

The thesis covers both structure, content, and layout. No prior LaTeX knowledge is required, since much emphasis has been put on making it user friendly and fairly tampering proof.

The suggested structure is based on the widely used model (Introduction, Methods, Results, And Discussion)[1]. The student may of course deviate from the structure and recommended content for each chapter. In particular, the chapters describing the main bulk of work done in the research project (Chapters 3, 4, and 5), should be customized to fit the specific topic of your project, both regarding chapter titles and content. You may, of course, consider merging some of the chapters, and/or add more chapters.

The template is based on the author's personal experiences as a research scientist and lecturer during the last 25 years[2], various online resources, and the "The Mayfield Handbook of Technical and Scientific Writing" [2][3].

For technical details, see Appendix A.

For updates and advice regarding this template, and similar templates for Microsoft Word and LibreOffice Writer, follow the Thesis Templates Facebook group[4].

Finally: Comments, bug reports, and suggestions are highly welcome[5]!

Gunnar Misund
Halden, February 15, 2021

[1] en.wikipedia.org/wiki/IMRAD
[2] www.ia.hiof.no/~gunnarmi
[3] www.mhhe.com/mayfieldpub/tsw/home.htm
[4] https://www.facebook.com/groups/693636154649756
[5] gunnar.misund@hiof.no

Abstract

An abstract is a brief summarizing statement, not more than one page. It gives the reader a synopsis of the research problem, method, results, and conclusions of your document. The abstract takes the form of a single paragraph and should not contain cross references or citations. Abstracts are sometimes collected into volumes and must be able to stand alone. They may be read by parties trying to decide whether or not to read the main document, or for getting a broad picture before starting on the report. If you describe the content of each main chapter, and bind it nicely together, you're done. You should not have any information in the abstract that is not found in any of the main chapters. It is common to close the abstract with a few well carefully selected keywords. Obviously, the abstract is the last thing you do in your project.

Here is an example of a short and concise abstract [6]:

> This thesis presents an evaluation of a set of 3D Scene Graph APIs for Java. The work consists mainly of two parts: Defining a methodology for comparing the APIs, and then applying the proposed methodology to the APIs. An overview of the available 3D Scene Graph APIs in Java is presented, and a selection of these are chosen for the evaluation. The APIs subjected to the evaluation are Java 3D, Ardor3D and jMonkeyEngine3. The proposed methodology focuses on the comparison on four different aspects. These are: *Project Management and Technical Infrastructure, System Architecture, System Features and Capabilities, and System Performance*. The results from applying the evaluation method show that none of the APIs were superior to the others in all respects. The results identify strengths and weaknesses with each API, that indicate which use cases each API might be better suited for.

Keywords: Scene Graph, API, Evaluation, Java, 3D Graphics, OpenGL, Java3D, jMonkeyEngine3, Ardor3D

Acknowledgments

In a thesis, it is common to mention the assistance of people whose help was crucial but not extensive enough to warrant their being listed as co-authors. Thesis advisors, technicians, and colleagues who gave advice or time are all candidates for the acknowledgments section. Patient family members are also frequently thanked.

Prerequisites (Optional)

You may say something about what kind of knowledge and background the reader should have to get the most from reading your thesis.

Contents

List of Figures

List of Tables

List of Code

Chapter 1

Introduction

The introduction to your document should lead your readers into your report and give them an idea of what to expect. You should begin with a general statement about the topic before moving on to specific issues. This strategy will help make the content accessible to your readers, especially those who are not specialists in the field. Illustrations, like Figure 1, often help to introduce the reader to the problem (from [3]).

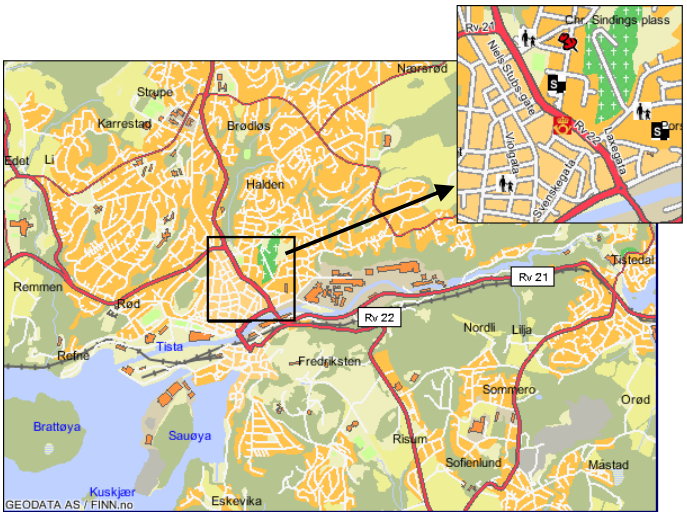

Figure 1.1: Example of a window query in a map (map from www.finn.no)

In the introduction, you should do the following, in approximately this order:

- State the subject of your document as clearly as possible, and briefly explain why you are doing it (motivation)
- Provide necessary and relevant background information (you will elaborate on this matter in Chapter 2, Analysis)
- Define the problem you are addressing, your approach to the problem, and why this problem is important
- Define the scope of your work (in particular limitations and things you will *not* deal with)
- Describe your research method, i.e., how you are going to proceed to answer your research question
- Give an outline of the rest of the document

You should think of the introduction as the foundation of your master work, and accordingly you should put considerable efforts in getting it right.

1.1 Background and motivation

Here you will describe the topic of your research in broad terms, so that even your grandfather should be able to get the general picture. If you are cooperating with a company, research institute, etc., they should also be introduced. It is also important that you explain *why* your topic is interesting and worth researching.

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1.1.1 Research question/Problem statement/Objectives

Every academic paper needs a clearly stated goal, concisely describing its purpose. The formulation depends on the type of document. Here we will see how it can be done in a bachelor's and master's thesis. You should put considerable effort in describing your goals, since they will be governing the rest of your work. However, goals may change during the projects, and may need revision now and then.

Bachelor A bachelor project is generally more practically oriented than a master's thesis. Often, the pro-ject has an external project owner, like a company or an institution. The

goal will be to provide something that can gain the project owner in some way. Hence, it is important to formulate the effects project owner want to achieve. Objectives often starts with "To…". The following is from a project developing a social trading app for exchanging used books [8]:

Objective 1 To connect people that enjoy books with each other.

Objective 1.1 To connect people that enjoy books with each other.

Objective 1.2 To lessen the environmental effect that printing a new book has.

If the bachelor project is more theoretically oriented, the goals could be stated as in a master's thesis, as described in the following section.

Master A research question[1] is a formal statement of the goal of a study. The research question should clearly and concisely state what the study will investigate or attempt to prove. Good research questions help to focus the research and the writing by providing a red thread through the project and the report.

The research question will surface both in the analysis of the problem, the choice of methods, the design and implementation of the project, and, most importantly, it will be revisited in the discussion and conclusion parts of the report.

The following example is from [7]:

> As mentioned, opportunities arise with smart-phones for providing feedback on electricity consumption when coupled with a smart meter. A display such as the eWave, shown in Figure 1.2, requires that a user take it upon themselves to check their consumption regularly. An application that notifies the user when consumption is high on a device that, for most parts of the day, is within reach of its owner does not require this initiation. However, it is not certain how such notifications will affect or be perceived by users. Further on in the report I attempt to shed some light on this. My research question consists of two parts. First, I wish to shed some light on the user experience:
>
> **RQ 1** Given immediate feedback on changes in the electricity consumption through their mobile phone, how do users respond?
>
> Secondly, I wish to see if there is a trend towards a lowering of the electricity consumption peak:
>
> **RQ 2** What impact does a mobile phone assistant have on electricity consumption patterns in an effect-based billing situation?
>
> **RQ 2.1** You may elaborate in a secondary research question.

1.1.2 Method

Here you shall explain how you are going to find answers to the research questions. The research method should be treated in more detail later in the report. Here is an example from [5] (it is somewhat sketchy, it is OK to be more detailed than this):

[1] It is common with more than one question

Figure 1.2: The eWave display being offered to Fredrikstad Energi's customers. The display is 7 inches across, and is based on the Android platform (photo by Odin Media).

The concept described in this thesis has evolved throughout the work with it, taking on an explorative approach. This process has been incremental using several rounds of iteration before ending up as a working prototype tested in a real-life setting, involving potential end users throughout the design. The below mentioned methods have been used in the process:

- Identification of research objectives
- Literature and case studies
- Development of mock-up videos
- Implementation of a high-fidelity prototype
- Field test and interview
- Testing the prototype on real representative users

1.1.3 Deliverables

Here you describe the tangible outcomes of your projects. This obviously includes the thesis, in addition to software, prototypes and such.

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1.2 Report Outline

The last point in the introduction is an outline of the rest of the report, for example like this (from [3]):

> Chapter 2 provides background information on range search and line simplification. In the section concerning range search, several data structures and algorithms are presented. The second section describes some of the different techniques developed for performing completely automated line simplification procedures. Finally, another proposed approach to combining the two problems is presented.
>
> The third chapter gives a general description of the PST and what it can be used for. The interval stabbing problem is an important aspect of the work presented in this thesis, and the third chapter explains how to solve this with a PST. Next, the interval stabbing problem is expanded to a "grid stabbing problem", which also can be solved using a PST, and the reason for this is described. Chapter 4 gives a detailed description of the new data structure and the search methods that have been developed. After this, theoretical analyses are provided. This chapter also explains how an external version of it has been implemented, along with empirical test results to support the theory.
>
> Chapter 5 presents suggestions for further work. Some work on the suggestions that are made has already been conducted, and this work is also described in this chapter. Finally, there is a chapter providing discussions and conclusions to whether or not the problem can be solved using the approach presented in this thesis.

Chapter 2

Analysis (Generic title)

This chapter describes the practical and theoretical foundation of your project. Basically, there are two aspects you should focus on, your research topic, and related work (literature and projects).

2.1 Research topic (generic title)

Here you will describe the thesis topic in sufficient detail to work out the details of your project, so that the reader gets a perfectly clear picture of the settings of your project. It is important to define your scope, and perhaps narrow down a broad subject. Also, if there are such, describe constraints and requirements you need to follow. If your work is part of a larger project, or if you are cooperating with an external company or research institute, this is the place to tell the reader about that.

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2.2 Related work (generic title)

It is important that you relate your work to relevant research and projects, and base your work solidly on existing literature. In particular, you must highlight related work that are directly relevant for your project, for instances if you want to extend earlier research, or to use specific results from other projects.

You should also discuss alternative research methods that have been used to research similar problems.

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2.3 Methods (generic title)

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Sed eleifend, eros sit amet faucibus elementum, urna sapien consectetuer mauris, quis egestas leo justo non risus. Morbi non felis ac libero vulputate fringilla. Mauris libero eros, lacinia non, sodales quis, dapibus porttitor, pede. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Morbi dapibus mauris condimentum nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Etiam sit amet erat. Nulla varius. Etiam tincidunt dui vitae turpis. Donec leo. Morbi vulputate convallis est. Integer aliquet. Pellentesque aliquet sodales urna.

Nullam eleifend justo in nisl. In hac habitasse platea dictumst. Morbi nonummy. Aliquam ut felis. In velit leo, dictum vitae, posuere id, vulputate nec, ante. Maecenas vitae pede nec dui dignissim suscipit. Morbi magna. Vestibulum id purus eget velit laoreet laoreet. Praesent sed leo vel nibh convallis blandit. Ut rutrum. Donec nibh. Donec interdum. Fusce sed pede sit amet elit rhoncus ultrices. Nullam at enim vitae pede vehicula iaculis.

Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Aenean nonummy turpis id odio. Integer euismod imperdiet turpis. Ut nec leo nec diam imperdiet lacinia. Etiam eget lacus eget mi ultricies posuere. In placerat tristique tortor. Sed porta vestibulum metus. Nulla iaculis sollicitudin pede. Fusce luctus tellus in dolor. Curabitur auctor velit a sem. Morbi sapien. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Donec adipiscing urna vehicula nunc. Sed ornare leo in leo. In rhoncus leo ut dui. Aenean dolor quam, volutpat nec, fringilla id, consectetuer vel, pede.

Nulla malesuada risus ut urna. Aenean pretium velit sit amet metus. Duis iaculis. In hac habitasse platea dictumst. Nullam molestie turpis eget nisl. Duis a massa id pede dapibus ultricies. Sed eu leo. In at mauris sit amet tortor bibendum varius. Phasellus justo risus, posuere in, sagittis ac, varius vel, tortor. Quisque id enim. Phasellus consequat, libero pretium nonummy fringilla, tortor lacus vestibulum nunc, ut rhoncus ligula neque id justo. Nullam accumsan euismod nunc. Proin vitae ipsum ac metus dictum tempus. Nam ut wisi. Quisque tortor felis, interdum ac, sodales a, semper a, sem. Curabitur in velit sit amet dui tristique sodales. Vivamus mauris pede, lacinia eget, pellentesque quis, scelerisque eu, est. Aliquam risus. Quisque bibendum pede eu dolor.

2.4 Tools (generic title)

Sed mattis, erat sit amet gravida malesuada, elit augue egestas diam, tempus scelerisque nunc nisl vitae libero. Sed consequat feugiat massa. Nunc porta, eros in eleifend varius, erat leo rutrum dui, non convallis lectus orci ut nibh. Sed lorem massa, nonummy quis, egestas id, condimentum at, nisl. Maecenas at nibh. Aliquam et augue at nunc pellentesque ullamcorper. Duis nisl nibh, laoreet suscipit, convallis ut, rutrum id, enim. Phasellus odio. Nulla nulla elit, molestie non, scelerisque at, vestibulum eu, nulla. Ut odio nisl, facilisis id, mollis et, scelerisque nec, enim. Aenean sem leo, pellentesque sit amet, scelerisque sit amet, vehicula pellentesque, sapien.

Sed consequat tellus et tortor. Ut tempor laoreet quam. Nullam id wisi a libero tristique semper. Nullam nisl massa, rutrum ut, egestas semper, mollis id, leo. Nulla ac massa eu risus blandit mattis. Mauris ut nunc. In hac habitasse platea dictumst. Aliquam eget tortor. Quisque dapibus pede in erat. Nunc enim. In dui nulla, commodo at, consectetuer nec, malesuada nec, elit. Aliquam ornare tellus eu urna. Sed nec metus. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Phasellus id magna. Duis malesuada interdum arcu. Integer metus. Morbi pulvinar pellentesque mi. Suspendisse sed est eu magna molestie egestas. Quisque mi lorem, pulvinar eget, egestas quis, luctus at, ante. Proin auctor vehicula purus. Fusce ac nisl aliquam ante hendrerit pellentesque. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Morbi wisi. Etiam arcu mauris, facilisis sed, eleifend non, nonummy ut, pede. Cras ut lacus tempor metus mollis placerat. Vivamus eu tortor vel metus interdum malesuada.

Sed eleifend, eros sit amet faucibus elementum, urna sapien consectetuer mauris, quis egestas leo justo non risus. Morbi non felis ac libero vulputate fringilla. Mauris libero eros, lacinia non, sodales quis, dapibus porttitor, pede. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Morbi dapibus mauris condimentum nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Etiam sit amet erat. Nulla varius. Etiam tincidunt dui vitae turpis. Donec leo. Morbi vulputate convallis est. Integer aliquet. Pellentesque aliquet sodales urna.

Nullam eleifend justo in nisl. In hac habitasse platea dictumst. Morbi nonummy. Aliquam ut felis. In velit leo, dictum vitae, posuere id, vulputate nec, ante. Maecenas vitae pede nec dui dignissim suscipit. Morbi magna. Vestibulum id purus eget velit laoreet laoreet. Praesent sed leo vel nibh convallis blandit. Ut rutrum. Donec nibh. Donec interdum. Fusce sed pede sit amet elit rhoncus ultrices. Nullam at enim vitae pede vehicula iaculis.

Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Aenean nonummy turpis id odio. Integer euismod imperdiet turpis. Ut nec leo nec diam imperdiet lacinia. Etiam eget lacus eget mi ultricies posuere. In placerat tristique tortor. Sed porta vestibulum metus. Nulla iaculis sollicitudin pede. Fusce luctus tellus in dolor. Curabitur auctor velit a sem. Morbi sapien. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Donec adipiscing urna vehicula nunc. Sed ornare leo in leo. In rhoncus leo ut dui. Aenean dolor quam, volutpat nec, fringilla id, consectetuer vel, pede.

Nulla malesuada risus ut urna. Aenean pretium velit sit amet metus. Duis iaculis. In hac habitasse platea dictumst. Nullam molestie turpis eget nisl. Duis a massa id pede

dapibus ultricies. Sed eu leo. In at mauris sit amet tortor bibendum varius. Phasellus justo risus, posuere in, sagittis ac, varius vel, tortor. Quisque id enim. Phasellus consequat, libero pretium nonummy fringilla, tortor lacus vestibulum nunc, ut rhoncus ligula neque id justo. Nullam accumsan euismod nunc. Proin vitae ipsum ac metus dictum tempus. Nam ut wisi. Quisque tortor felis, interdum ac, sodales a, semper a, sem. Curabitur in velit sit amet dui tristique sodales. Vivamus mauris pede, lacinia eget, pellentesque quis, scelerisque eu, est. Aliquam risus. Quisque bibendum pede eu dolor.

2.5 Summary (Optional)

Sometimes, in particular when the chapters are quite long, they are ended with short summaries.

Chapter 3

Design / Planning (Generic title)

Here you will explain in detail how you will design you project in order to answer the research question(s). The contents of this chapter will rely heavily on the thesis topic.

Etiam suscipit aliquam arcu. Aliquam sit amet est ac purus bibendum congue. Sed in eros. Morbi non orci. Pellentesque mattis lacinia elit. Fusce molestie velit in ligula. Nullam et orci vitae nibh vulputate auctor. Aliquam eget purus. Nulla auctor wisi sed ipsum. Morbi porttitor tellus ac enim. Fusce ornare. Proin ipsum enim, tincidunt in, ornare venenatis, molestie a, augue. Donec vel pede in lacus sagittis porta. Sed hendrerit ipsum quis nisl. Suspendisse quis massa ac nibh pretium cursus. Sed sodales. Nam eu neque quis pede dignissim ornare. Maecenas eu purus ac urna tincidunt congue.

Donec et nisl id sapien blandit mattis. Aenean dictum odio sit amet risus. Morbi purus. Nulla a est sit amet purus venenatis iaculis. Vivamus viverra purus vel magna. Donec in justo sed odio malesuada dapibus. Nunc ultrices aliquam nunc. Vivamus facilisis pellentesque velit. Nulla nunc velit, vulputate dapibus, vulputate id, mattis ac, justo. Nam mattis elit dapibus purus. Quisque enim risus, congue non, elementum ut, mattis quis, sem. Quisque elit.

Maecenas non massa. Vestibulum pharetra nulla at lorem. Duis quis quam id lacus dapibus interdum. Nulla lorem. Donec ut ante quis dolor bibendum condimentum. Etiam egestas tortor vitae lacus. Praesent cursus. Mauris bibendum pede at elit. Morbi et felis a lectus interdum facilisis. Sed suscipit gravida turpis. Nulla at lectus. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Praesent nonummy luctus nibh. Proin turpis nunc, congue eu, egestas ut, fringilla at, tellus. In hac habitasse platea dictumst.

Vivamus eu tellus sed tellus consequat suscipit. Nam orci orci, malesuada id, gravida nec, ultricies vitae, erat. Donec risus turpis, luctus sit amet, interdum quis, porta sed, ipsum. Suspendisse condimentum, tortor at egestas posuere, neque metus tempor orci, et tincidunt urna nunc a purus. Sed facilisis blandit tellus. Nunc risus sem, suscipit nec, eleifend quis, cursus quis, libero. Curabitur et dolor. Sed vitae sem. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Maecenas ante. Duis ullamcorper enim. Donec tristique enim eu leo. Nullam molestie elit eu dolor. Nullam bibendum, turpis vitae tristique gravida, quam sapien tempor lectus, quis pretium tellus purus ac quam. Nulla facilisi.

Duis aliquet dui in est. Donec eget est. Nunc lectus odio, varius at, fermentum in, accumsan non, enim. Aliquam erat volutpat. Proin sit amet nulla ut eros consectetuer cursus. Phasellus dapibus aliquam justo. Nunc laoreet. Donec consequat placerat magna.

Duis pretium tincidunt justo. Sed sollicitudin vestibulum quam. Nam quis ligula. Vivamus at metus. Etiam imperdiet imperdiet pede. Aenean turpis. Fusce augue velit, scelerisque sollicitudin, dictum vitae, tempor et, pede. Donec wisi sapien, feugiat in, fermentum ut, sollicitudin adipiscing, metus.

Donec vel nibh ut felis consectetuer laoreet. Donec pede. Sed id quam id wisi laoreet suscipit. Nulla lectus dolor, aliquam ac, fringilla eget, mollis ut, orci. In pellentesque justo in ligula. Maecenas turpis. Donec eleifend leo at felis tincidunt consequat. Aenean turpis metus, malesuada sed, condimentum sit amet, auctor a, wisi. Pellentesque sapien elit, bibendum ac, posuere et, congue eu, felis. Vestibulum mattis libero quis metus scelerisque ultrices. Sed purus.

Donec molestie, magna ut luctus ultrices, tellus arcu nonummy velit, sit amet pulvinar elit justo et mauris. In pede. Maecenas euismod elit eu erat. Aliquam augue wisi, facilisis congue, suscipit in, adipiscing et, ante. In justo. Cras lobortis neque ac ipsum. Nunc fermentum massa at ante. Donec orci tortor, egestas sit amet, ultrices eget, venenatis eget, mi. Maecenas vehicula leo semper est. Mauris vel metus. Aliquam erat volutpat. In rhoncus sapien ac tellus. Pellentesque ligula.

Cras dapibus, augue quis scelerisque ultricies, felis dolor placerat sem, id porta velit odio eu elit. Aenean interdum nibh sed wisi. Praesent sollicitudin vulputate dui. Praesent iaculis viverra augue. Quisque in libero. Aenean gravida lorem vitae sem ullamcorper cursus. Nunc adipiscing rutrum ante. Nunc ipsum massa, faucibus sit amet, viverra vel, elementum semper, orci. Cras eros sem, vulputate et, tincidunt id, ultrices eget, magna. Nulla varius ornare odio. Donec accumsan mauris sit amet augue. Sed ligula lacus, laoreet non, aliquam sit amet, iaculis tempor, lorem. Suspendisse eros. Nam porta, leo sed congue tempor, felis est ultrices eros, id mattis velit felis non metus. Curabitur vitae elit non mauris varius pretium. Aenean lacus sem, tincidunt ut, consequat quis, porta vitae, turpis. Nullam laoreet fermentum urna. Proin iaculis lectus.

Sed mattis, erat sit amet gravida malesuada, elit augue egestas diam, tempus scelerisque nunc nisl vitae libero. Sed consequat feugiat massa. Nunc porta, eros in eleifend varius, erat leo rutrum dui, non convallis lectus orci ut nibh. Sed lorem massa, nonummy quis, egestas id, condimentum at, nisl. Maecenas at nibh. Aliquam et augue at nunc pellentesque ullamcorper. Duis nisl nibh, laoreet suscipit, convallis ut, rutrum id, enim. Phasellus odio. Nulla nulla elit, molestie non, scelerisque at, vestibulum eu, nulla. Ut odio nisl, facilisis id, mollis et, scelerisque nec, enim. Aenean sem leo, pellentesque sit amet, scelerisque sit amet, vehicula pellentesque, sapien.

Sed consequat tellus et tortor. Ut tempor laoreet quam. Nullam id wisi a libero tristique semper. Nullam nisl massa, rutrum ut, egestas semper, mollis id, leo. Nulla ac massa eu risus blandit mattis. Mauris ut nunc. In hac habitasse platea dictumst. Aliquam eget tortor. Quisque dapibus pede in erat. Nunc enim. In dui nulla, commodo at, consectetuer nec, malesuada nec, elit. Aliquam ornare tellus eu urna. Sed nec metus. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

Phasellus id magna. Duis malesuada interdum arcu. Integer metus. Morbi pulvinar pellentesque mi. Suspendisse sed est eu magna molestie egestas. Quisque mi lorem, pulvinar eget, egestas quis, luctus at, ante. Proin auctor vehicula purus. Fusce ac nisl aliquam ante hendrerit pellentesque. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Morbi wisi. Etiam arcu mauris, facilisis sed, eleifend non,

nonummy ut, pede. Cras ut lacus tempor metus mollis placerat. Vivamus eu tortor vel metus interdum malesuada.

Sed eleifend, eros sit amet faucibus elementum, urna sapien consectetuer mauris, quis egestas leo justo non risus. Morbi non felis ac libero vulputate fringilla. Mauris libero eros, lacinia non, sodales quis, dapibus porttitor, pede. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Morbi dapibus mauris condimentum nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Etiam sit amet erat. Nulla varius. Etiam tincidunt dui vitae turpis. Donec leo. Morbi vulputate convallis est. Integer aliquet. Pellentesque aliquet sodales urna.

3.1 Summary (Optional)

Chapter 4

Implementation (Generic title)

This is where you describe what you actually did in your research, like field studies, experiments, implementations, media productions, interviews, etc.

Proin non sem. Donec nec erat. Proin libero. Aliquam viverra arcu. Donec vitae purus. Donec felis mi, semper id, scelerisque porta, sollicitudin sed, turpis. Nulla in urna. Integer varius wisi non elit. Etiam nec sem. Mauris consequat, risus nec congue condimentum, ligula ligula suscipit urna, vitae porta odio erat quis sapien. Proin luctus leo id erat. Etiam massa metus, accumsan pellentesque, sagittis sit amet, venenatis nec, mauris. Praesent urna eros, ornare nec, vulputate eget, cursus sed, justo. Phasellus nec lorem. Nullam ligula ligula, mollis sit amet, faucibus vel, eleifend ac, dui. Aliquam erat volutpat.

Fusce vehicula, tortor et gravida porttitor, metus nibh congue lorem, ut tempus purus mauris a pede. Integer tincidunt orci sit amet turpis. Aenean a metus. Aliquam vestibulum lobortis felis. Donec gravida. Sed sed urna. Mauris et orci. Integer ultrices feugiat ligula. Sed dignissim nibh a massa. Donec orci dui, tempor sed, tincidunt nonummy, viverra sit amet, turpis. Quisque lobortis. Proin venenatis tortor nec wisi. Vestibulum placerat. In hac habitasse platea dictumst. Aliquam porta mi quis risus. Donec sagittis luctus diam. Nam ipsum elit, imperdiet vitae, faucibus nec, fringilla eget, leo. Etiam quis dolor in sapien porttitor imperdiet.

Cras pretium. Nulla malesuada ipsum ut libero. Suspendisse gravida hendrerit tellus. Maecenas quis lacus. Morbi fringilla. Vestibulum odio turpis, tempor vitae, scelerisque a, dictum non, massa. Praesent erat felis, porta sit amet, condimentum sit amet, placerat et, turpis. Praesent placerat lacus a enim. Vestibulum non eros. Ut congue. Donec tristique varius tortor. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Nam dictum dictum urna.

Phasellus vestibulum orci vel mauris. Fusce quam leo, adipiscing ac, pulvinar eget, molestie sit amet, erat. Sed diam. Suspendisse eros leo, tempus eget, dapibus sit amet, tempus eu, arcu. Vestibulum wisi metus, dapibus vel, luctus sit amet, condimentum quis, leo. Suspendisse molestie. Duis in ante. Ut sodales sem sit amet mauris. Suspendisse ornare pretium orci. Fusce tristique enim eget mi. Vestibulum eros elit, gravida ac, pharetra sed, lobortis in, massa. Proin at dolor. Duis accumsan accumsan pede. Nullam blandit elit in magna lacinia hendrerit. Ut nonummy luctus eros. Fusce eget tortor.

Ut sit amet magna. Cras a ligula eu urna dignissim viverra. Nullam tempor leo porta ipsum. Praesent purus. Nullam consequat. Mauris dictum sagittis dui. Vestibulum sollicitudin consectetuer wisi. In sit amet diam. Nullam malesuada pharetra risus. Proin lacus arcu, eleifend sed, vehicula at, congue sit amet, sem. Sed sagittis pede a nisl.

Sed tincidunt odio a pede. Sed dui. Nam eu enim. Aliquam sagittis lacus eget libero. Pellentesque diam sem, sagittis molestie, tristique et, fermentum ornare, nibh. Nulla et tellus non felis imperdiet mattis. Aliquam erat volutpat.

Vestibulum sodales ipsum id augue. Integer ipsum pede, convallis sit amet, tristique vitae, tempor ut, nunc. Nam non ligula non lorem convallis hendrerit. Maecenas hendrerit. Sed magna odio, aliquam imperdiet, porta ac, aliquet eget, mi. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Vestibulum nisl sem, dignissim vel, euismod quis, egestas ut, orci. Nunc vitae risus vel metus euismod laoreet. Cras sit amet neque a turpis lobortis auctor. Sed aliquam sem ac elit. Cras velit lectus, facilisis id, dictum sed, porta rutrum, nisl. Nam hendrerit ipsum sed augue. Nullam scelerisque hendrerit wisi. Vivamus egestas arcu sed purus. Ut ornare lectus sed eros. Suspendisse potenti. Mauris sollicitudin pede vel velit. In hac habitasse platea dictumst.

Suspendisse erat mauris, nonummy eget, pretium eget, consequat vel, justo. Pellentesque consectetuer erat sed lacus. Nullam egestas nulla ac dui. Donec cursus rhoncus ipsum. Nunc et sem eu magna egestas malesuada. Vivamus dictum massa at dolor. Morbi est nulla, faucibus ac, posuere in, interdum ut, sapien. Proin consectetuer pretium urna. Donec sit amet nibh nec purus dignissim mattis. Phasellus vehicula elit at lacus. Nulla facilisi. Cras ut arcu. Sed consectetuer. Integer tristique elit quis felis consectetuer eleifend. Cras et lectus.

Ut congue malesuada justo. Curabitur congue, felis at hendrerit faucibus, mauris lacus porttitor pede, nec aliquam turpis diam feugiat arcu. Nullam rhoncus ipsum at risus. Vestibulum a dolor sed dolor fermentum vulputate. Sed nec ipsum dapibus urna bibendum lobortis. Vestibulum elit. Nam ligula arcu, volutpat eget, lacinia eu, lobortis ac, urna. Nam mollis ultrices nulla. Cras vulputate. Suspendisse at risus at metus pulvinar malesuada. Nullam lacus. Aliquam tempus magna. Aliquam ut purus. Proin tellus.

Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Donec scelerisque metus. Maecenas non mi ut metus porta hendrerit. Nunc semper. Cras quis wisi ut lorem posuere tristique. Nunc vestibulum scelerisque nulla. Suspendisse pharetra sollicitudin ante. Praesent at augue sit amet ante interdum porta. Nunc bibendum augue luctus diam. Etiam nec sem. Sed eros turpis, facilisis nec, vehicula vitae, aliquam sed, nulla. Curabitur justo leo, vestibulum eget, tristique ut, tempus at, nisl.

Nulla venenatis lorem id arcu. Morbi cursus urna a ipsum. Donec porttitor. Integer eleifend, est non mattis malesuada, mi nulla convallis mi, et auctor lectus sapien ut purus. Aliquam nulla augue, pharetra sit amet, faucibus semper, molestie vel, nibh. Pellentesque vestibulum magna et mi. Sed fringilla dolor vel tellus. Nunc libero nunc, venenatis eget, convallis hendrerit, iaculis elementum, mi. Nullam aliquam, felis et accumsan vehicula, magna justo vehicula diam, eu condimentum nisl felis et nunc. Quisque volutpat mauris a velit. Pellentesque massa. Integer at lorem. Nam metus erat, lacinia id, convallis ut, pulvinar non, wisi. Cras iaculis mauris ut neque. Cras sodales, sem vitae imperdiet consequat, pede purus sollicitudin urna, ac aliquam metus orci in leo. Ut molestie ultrices mauris. Vivamus vitae sem. Aliquam erat volutpat. Praesent commodo, nisl ac dapibus aliquet, tortor orci sodales lorem, non ornare nulla lorem quis nisl.

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4.1 Summary (Optional)

Chapter 5

Results / Testing / Evaluation (Generic Title)

You now present the outcomes of the actual research work described in the previous chapter, as suggested in [2]:

> In the results section of a report, describe all appropriate information produced by the research procedures. Simply present data and estimates of their accuracy. Save the explanation and interpretation of these findings for the discussion section, which usually follows the results section. In short documents, however, the results and discussion sections may be combined into a single section.
>
> Results sections make extensive use of graphs and figures to present data effectively. Order information by its importance to your audience's purpose in reading the document. State all significant findings in the text, referring to tables and graphs displaying all significant data. If the study has produced a large amount of raw data, do not present all of it in the results section. Instead, present only the information most appropriate to your audience's purpose in reading the document, summarizing other key information in graphs and figures. If appropriate, include your raw data in an appendix, referring to them within your text.

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5.1 Summary (Optional)

Chapter 6

Discussion

You will now discuss and reflect over the results and findings described in the previous chapter. Were they as you expected? How are your findings compared to relevant research? What is the significance of your results? What do you think is your main contribution to the research field? Have your research questions been fully answered? Was it a good choice of research method? Is there anything you would have done differently, in retrospect?

6.1 Summary (Optional)

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Chapter 7

Conclusion

Some readers of documents, particularly managers, will sometimes not read the entire document but, instead, focus on the conclusion. Hence, this part of the report should summarize all essential information necessary for your audience's purpose.

In some sense the conclusion is a summary of the discussion chapter. You must relate your findings to the research questions stated in the introduction, in other words, present the short version of the answer to the research question. You should also summarize clearly what the report does and does not demonstrate, and what you think is your main contribution to scientific community.

Finally, it is often appropriate to include specific recommendations for future research. Sometimes these recommendations will constitute a separate section.

The conclusion should be relatively short, a page or two is fine.

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tempus eu, arcu. Vestibulum wisi metus, dapibus vel, luctus sit amet, condimentum quis, leo. Suspendisse molestie. Duis in ante. Ut sodales sem sit amet mauris. Suspendisse ornare pretium orci. Fusce tristique enim eget mi. Vestibulum eros elit, gravida ac, pharetra sed, lobortis in, massa. Proin at dolor. Duis accumsan accumsan pede. Nullam blandit elit in magna lacinia hendrerit. Ut nonummy luctus eros. Fusce eget tortor.

Ut sit amet magna. Cras a ligula eu urna dignissim viverra. Nullam tempor leo porta ipsum. Praesent purus. Nullam consequat. Mauris dictum sagittis dui. Vestibulum sollicitudin consectetuer wisi. In sit amet diam. Nullam malesuada pharetra risus. Proin lacus arcu, eleifend sed, vehicula at, congue sit amet, sem. Sed sagittis pede a nisl. Sed tincidunt odio a pede. Sed dui. Nam eu enim. Aliquam sagittis lacus eget libero. Pellentesque diam sem, sagittis molestie, tristique et, fermentum ornare, nibh. Nulla et tellus non felis imperdiet mattis. Aliquam erat volutpat.

Vestibulum sodales ipsum id augue. Integer ipsum pede, convallis sit amet, tristique vitae, tempor ut, nunc. Nam non ligula non lorem convallis hendrerit. Maecenas hendrerit. Sed magna odio, aliquam imperdiet, porta ac, aliquet eget, mi. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Vestibulum nisl sem, dignissim vel, euismod quis, egestas ut, orci. Nunc vitae risus vel metus euismod laoreet. Cras sit amet neque a turpis lobortis auctor. Sed aliquam sem ac elit. Cras velit lectus, facilisis id, dictum sed, porta rutrum, nisl. Nam hendrerit ipsum sed augue. Nullam scelerisque hendrerit wisi. Vivamus egestas arcu sed purus. Ut ornare lectus sed eros. Suspendisse potenti. Mauris sollicitudin pede vel velit. In hac habitasse platea dictumst.

Suspendisse erat mauris, nonummy eget, pretium eget, consequat vel, justo. Pellentesque consectetuer erat sed lacus. Nullam egestas nulla ac dui. Donec cursus rhoncus ipsum. Nunc et sem eu magna egestas malesuada. Vivamus dictum massa at dolor. Morbi est nulla, faucibus ac, posuere in, interdum ut, sapien. Proin consectetuer pretium urna. Donec sit amet nibh nec purus dignissim mattis. Phasellus vehicula elit at lacus. Nulla facilisi. Cras ut arcu. Sed consectetuer. Integer tristique elit quis felis consectetuer eleifend. Cras et lectus.

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Glossary

LaTeX A mark up language specially suited for scientific documents.LaTeX was developed by Leslie Lamport in 1984, and is basically a collection of macros written in TeX, invented by Donald Knuth, one of the giants of computer science. 37, 48

Mathematics Mathematics is what mathematicians do. 37

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Appendix A

How to use this template

This document is a generic thesis template covering both structure, content, and layout, to be used as a starting point for bachelor's, master's, and PhD theses in any field. It is implemented in the LaTeX typesetting markup language, which in particular is suitable for documents including Mathematics and scientific notation, and is considered the gold standard in natural sciences, however commonly used in other settings.

The template is implemented as a document class, `thesistemplate`, with the following options:

`draft` Turns off graphics rendering and micro-formatting stuff, and turns on todo notes. Affects page breaking.

`cover` Custom cover page, must be provided as an Layout/coverpage.PDF in A4 size. Otherwise a standard HiØ (Høgskolen i Østfold) cover is generated.

`word` Word-like paragraph formatting, no indentations, air between paragraphs, and ragged right margin. Otherwise standard LaTeX paragraph formatting (as you also find it in most books, papers, and formal documents).

`sans` Sans serif fonts, otherwise standard LaTeX font (Computer Modern).

First of all, it outlines a recommended structure of the thesis, and provides guidelines for the content of each part. In addition, it serves as a concrete example of how this can be accomplished by using LaTeX. Use the template by gradually populating the files with your own content, and perhaps modify the structure to suit your project. The template is designed to be rather self-explanatory, and all of the features you need are present somewhere in the source code, so you will come a long way by cutting and pasting.

It is assumed that the user has (or provides herself with) some basic knowledge of LaTeX. There are numerous good tutorials online[1], but I warmly recommend the original documentation: "LaTeX: A Document Preparation System" (Figure A.1) [1]. LaTeX is basically a collection of macros written in TeX. This system, which is a low level tool for digital typesetting, is known for producing scientific documents of unprecedented quality. It was developed by Donald Knuth, one of the giants in computer science.

The template is intended to use with Overleaf[2], where it works out of the box.

[1] `latex-project.org` is a good starting point

[2] `overleaf.com`

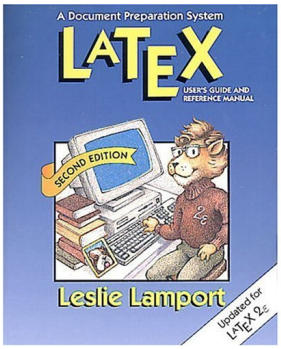


Figure A.1: The LaTeX "bible", 2. edition

However, it can be used locally on your machine, using one of the many good LaTeX editors, and there are many possibilities for the Emacs users[3]. Personally, I use *texmaker*[4] for OSX, and *Kile*[5] for Ubuntu. MS users may try *WinEDT*[6].

A.1 Language settings

The template is using the `polyglossia` package, for enabling easy use of different languages, including native UTF-8 support. You may make multi-language documents [7]. You set the main language for instance like this (in the preamble, before `\begin{document}`):

```
\setdefaultlanguage[variant=bokmal]{norwegian}
```

See [9, p. 6][8] for supported languages, including variants.

A.2 Chapters/Sections/Paragraphs

As any document, the template is a collection of chapters, sections, subsections, subsubsections and paragraphs. By default subsubsections and paragraphs are not numbered or included in the table of contents.

These structural parts contain plain text and/or graphical elements like figures and tables. Plain text is commonly structured by *paragraphs*. Paragraphs are generated by one or more *empty lines*[9].

Chapters have *sections*, which may contain *subsections*, and the next level is *subsubsection*. Finally we have a special type of *paragraph*.

Please note that it is considered good practice to have some text before you go to a lower section level, for instance, do not go directly from a chapter to a section, and, in general, do not skip levels, like going from a section to a subsubsection.

Below follows examples of all these constructs.

[3] `www.gnu.org/software/emacs`

[4] `www.xm1math.net/texmaker/`

[5] `kile.sourceforge.net`

[6] `www.winedt.com`

[7] `www.overleaf.com/learn/latex/Multilingual_typesetting_on_Overleaf_using_polyglossia_and_fontspec`

[8] `https://ctan.uib.no/macros/unicodetex/latex/polyglossia/polyglossia.pdf`

[9] Correspondingly, when there are two or more consecutive whitespaces in the text, these will treated as one single whitespace.

A.3 Section

This is a section. Suspendisse vitae elit. Aliquam arcu neque, ornare in, ullamcorper quis, commodo eu, libero. Fusce sagittis erat at erat tristique mollis. Maecenas sapien libero, molestie et, lobortis in, sodales eget, dui. Morbi ultrices rutrum lorem. Nam elementum ullamcorper leo. Morbi dui. Aliquam sagittis. Nunc placerat. Pellentesque tristique sodales est. Maecenas imperdiet lacinia velit. Cras non urna. Morbi eros pede, suscipit ac, varius vel, egestas non, eros. Praesent malesuada, diam id pretium elementum, eros sem dictum tortor, vel consectetuer odio sem sed wisi.

Sed feugiat. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Ut pellentesque augue sed urna. Vestibulum diam eros, fringilla et, consectetuer eu, nonummy id, sapien. Nullam at lectus. In sagittis ultrices mauris. Curabitur malesuada erat sit amet massa. Fusce blandit. Aliquam erat volutpat. Aliquam euismod. Aenean vel lectus. Nunc imperdiet justo nec dolor.

Etiam euismod. Fusce facilisis lacinia dui. Suspendisse potenti. In mi erat, cursus id, nonummy sed, ullamcorper eget, sapien. Praesent pretium, magna in eleifend egestas, pede pede pretium lorem, quis consectetuer tortor sapien facilisis magna. Mauris quis magna varius nulla scelerisque imperdiet. Aliquam non quam. Aliquam porttitor quam a lacus. Praesent vel arcu ut tortor cursus volutpat. In vitae pede quis diam bibendum placerat. Fusce elementum convallis neque. Sed dolor orci, scelerisque ac, dapibus nec, ultricies ut, mi. Duis nec dui quis leo sagittis commodo.

A.3.1 Sub section

This is a sub section. Aliquam lectus. Vivamus leo. Quisque ornare tellus ullamcorper nulla. Mauris porttitor pharetra tortor. Sed fringilla justo sed mauris. Mauris tellus. Sed non leo. Nullam elementum, magna in cursus sodales, augue est scelerisque sapien, venenatis congue nulla arcu et pede. Ut suscipit enim vel sapien. Donec congue. Maecenas urna mi, suscipit in, placerat ut, vestibulum ut, massa. Fusce ultrices nulla et nisl.

Etiam ac leo a risus tristique nonummy. Donec dignissim tincidunt nulla. Vestibulum rhoncus molestie odio. Sed lobortis, justo et pretium lobortis, mauris turpis condimentum augue, nec ultricies nibh arcu pretium enim. Nunc purus neque, placerat id, imperdiet sed, pellentesque nec, nisl. Vestibulum imperdiet neque non sem accumsan laoreet. In hac habitasse platea dictumst. Etiam condimentum facilisis libero. Suspendisse in elit quis nisl aliquam dapibus. Pellentesque auctor sapien. Sed egestas sapien nec lectus. Pellentesque vel dui vel neque bibendum viverra. Aliquam porttitor nisl nec pede. Proin mattis libero vel turpis. Donec rutrum mauris et libero. Proin euismod porta felis. Nam lobortis, metus quis elementum commodo, nunc lectus elementum mauris, eget vulputate ligula tellus eu neque. Vivamus eu dolor.

Sub sub section

This is a sub sub section. Nulla in ipsum. Praesent eros nulla, congue vitae, euismod ut, commodo a, wisi. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Aenean nonummy magna non leo. Sed felis erat, ullamcorper in, dictum non, ultricies ut, lectus. Proin vel arcu a odio lobortis euismod. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Proin ut est. Aliquam odio. Pellentesque massa turpis, cursus eu, euismod nec, tempor congue, nulla.

Duis viverra gravida mauris. Cras tincidunt. Curabitur eros ligula, varius ut, pulvinar in, cursus faucibus, augue.

Nulla mattis luctus nulla. Duis commodo velit at leo. Aliquam vulputate magna et leo. Nam vestibulum ullamcorper leo. Vestibulum condimentum rutrum mauris. Donec id mauris. Morbi molestie justo et pede. Vivamus eget turpis sed nisl cursus tempor. Curabitur mollis sapien condimentum nunc. In wisi nisl, malesuada at, dignissim sit amet, lobortis in, odio. Aenean consequat arcu a ante. Pellentesque porta elit sit amet orci. Etiam at turpis nec elit ultricies imperdiet. Nulla facilisi. In hac habitasse platea dictumst. Suspendisse viverra aliquam risus. Nullam pede justo, molestie nonummy, scelerisque eu, facilisis vel, arcu.

Paragraph This is a titled paragraph. Please note the difference between the standard paragraphs produced by blank lines, and this type, which is the lowest level of elements with titles.

Curabitur tellus magna, porttitor a, commodo a, commodo in, tortor. Donec interdum. Praesent scelerisque. Maecenas posuere sodales odio. Vivamus metus lacus, varius quis, imperdiet quis, rhoncus a, turpis. Etiam ligula arcu, elementum a, venenatis quis, sollicitudin sed, metus. Donec nunc pede, tincidunt in, venenatis vitae, faucibus vel, nibh. Pellentesque wisi. Nullam malesuada. Morbi ut tellus ut pede tincidunt porta. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam congue neque id dolor.

Donec et nisl at wisi luctus bibendum. Nam interdum tellus ac libero. Sed sem justo, laoreet vitae, fringilla at, adipiscing ut, nibh. Maecenas non sem quis tortor eleifend fermentum. Etiam id tortor ac mauris porta vulputate. Integer porta neque vitae massa. Maecenas tempus libero a libero posuere dictum. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aenean quis mauris sed elit commodo placerat. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Vivamus rhoncus tincidunt libero. Etiam elementum pretium justo. Vivamus est. Morbi a tellus eget pede tristique commodo. Nulla nisl. Vestibulum sed nisl eu sapien cursus rutrum.

A.4 Figures, tables, equations, etc.

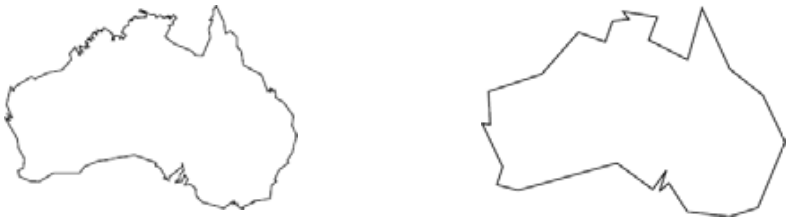
Please see the source code (`how-to.tex`) for details on the implementation of these elements.

In general, figures and tables shall be numbered, and have a caption. Numbered figures and tables *must* be referenced at least once in the text. Equations and similar elements should also be numbered, but they are not always referred to.

Figures, tables, equations, and similar constructs are so-called *floats*. This means that LaTeX will place them in a position that is "best", taking many aspects into consideration. The result is that the elements may not be positioned exactly where the author wants (in particular when you have many floats near each other, like in text you are reading now), and novice user may find this frustrating (see Section A.14). Remember to include empty lines in the source before and after a float.

Figures are most often produced from files in common graphics formats (like PDF, png, jpg, etc). You can use a single image file, as in Figure A.1, or you can combine several images, see Figure A.2, consisting of Figures A.2(a) and A.2(b).

The template provides two short-hand commands for including graphics. Figure A.4 is produced with the `floatingfigure` command, which let LaTeX to treat it like a floating



(a) input (b) output

Figure A.2: Input and result from running the Douglas-Peucker line simplification algorithm (from [3])

object, placing it at at the "best" location. The first argument is the filename, the second gives the width as a fraction of the text width, and the last sets the caption.

Figure A.3: A figure produced by the `floatingfigure` command

Despite of beeing typed directly after the floating figure, note that this text may for example appear prior to the figure in the PDF.

Ut lectus lectus, ultricies sit amet, semper eget, laoreet non, ante. Proin at massa quisnunc rhoncus mattis. Aliquam lorem. Curabitur pharetra dui at neque. Aliquam eu tellus. Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

The `fixedfigure` command forces the graphics to be placed exactly where it is located in the text [10], as in Figure A.4.

[10] Be careful, this could cause some strange effects.

Figure A.4: A figure produced by the `fixedfigure` command

After inserting a fixed figure, this text should appear directly after the figure in the PDF.

Ut lectus lectus, ultricies sit amet, semper eget, laoreet non, ante. Proin at massa quisnunc rhoncus mattis. Aliquam lorem. Curabitur pharetra dui at neque. Aliquam eu tellus. Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

Ut lectus lectus, ultricies sit amet, semper eget, laoreet non, ante. Proin at massa quisnunc rhoncus mattis. Aliquam lorem. Curabitur pharetra dui at neque. Aliquam eu tellus. Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

Ut lectus lectus, ultricies sit amet, semper eget, laoreet non, ante. Proin at massa quisnunc rhoncus mattis. Aliquam lorem. Curabitur pharetra dui at neque. Aliquam eu tellus. Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc. Ut lectus lectus, ultricies sit amet, semper eget, laoreet non, ante. Proin at massa quisnunc rhoncus mattis. Aliquam lorem. Curabitur pharetra dui at neque. Aliquam eu tellus. Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

If you want to wrap text around an illustration, the `wrapfig` package can be used [11] , as demonstrated in Figures A.6 and A.5.

Ut lectus lectus, ultricies sit amet, semper eget, laoreet non, ante. Proin at massa quisnunc rhoncus mattis. Aliquam lorem. Curabitur pharetra dui at neque. Aliquam eu tellus. Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

Ut lectus lectus, ultricies sit amet, semper eget, laoreet non, ante. Proin at massa quisnunc rhoncus mattis. Aliquam lorem. Curabitur pharetra dui at neque. Aliquam eu tellus. Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi

[11] The environment should be placed so as to not run over a page break, that could cause that the figure overlaps the text.

nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

Figure A.5: Wrapped figure placed near the outer margin

Figure A.6: Wrapped figure placed near the inner margin

Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

Aenean tempus, felis vitae vulputate iaculis, est dolor faucibus urna, in viverra wisi nequenon risus. Fusce vel dolor nec sapien pretium nonummy. Integer faucibus massa ac nullaornare venenatis. Nulla quis sapien. Sed tortor. Phasellus eget mi. Cras nunc.

Tables have a relatively steep learning curve. Still, simple tables, like Table A.1, are relatively easy to make. A more complex example is demonstrated in Table A.2[12].

X		
	X	
		X

Table A.1: Simple table

Combination	**Included Optional Steps**			
	1	**2**	**3**	**4**
1	X			
13			X	X
14				X
15	Nano Particles Deposited, Not Sintered			
16	Only Grinded Wafer 1, No Particles Deposited, Not Sintered			
17	Only Grinded Wafer 2, No Particles Deposited, Not Sintered			

Table A.2: Complex table

Within mathematics and natural sciences there is a common belief that LaTeX is unrivaled when it comes to typesetting formulas, equations, and complex specialized notation, as the following examples demonstrate.

[12] An easy workaround is to generate the table in a spread sheet program, export to an image or PDF file and include as graphics.

You can have inline equations, like this: $\alpha = \beta\gamma\delta$, or you can typeset them as numbered floats, as in Equation A.1.

$$\alpha = \beta\gamma\delta \tag{A.1}$$

Equation A.2 is a bit more complicated:

$$I_{zz} = \int_{-b/2}^{b/2} \int_{-h/2}^{h/2} y^2 dy dx = \frac{bh^3}{12} \tag{A.2}$$

There are loads of special characters, like $\approx$, $\pm$, $\times$, $\div$, $\propto$, $\leq$, $\geq$, $\ll$, $\gg$, $\neq$, ∇, $\Re$, $\Im$, $\flat$, $\sharp$, ∂, ∞, and $\heartsuit$.

See the next section for a complete example of a mathematical proof.

A.5 Proof of the Area of a Circle Formula

Here follows a complete proof of a theorem.

Theorem 1 *The area of circle with radius r is πr^2.*

Proof: The equation of a circle centered at the origin is

$$x^2 + y^2 = r^2,$$

where r is the radius. We write y in terms of the variable x and the constant r:

$$\frac{x^2}{r^2} + \frac{y^2}{r^2} = 1$$

$$\frac{y}{r} = \sqrt{1 - \frac{x^2}{r^2}}$$

$$y = r\sqrt{1 - \frac{x^2}{r^2}}$$

By symmetry, the area of a circle centered at the origin is four times the area of the circle between $(0, 0)$ and $(r, 0)$ above the x-axis. We can integrate to find the area (A):

$$A = 4r \int_0^r \sqrt{1 - \frac{x^2}{r^2}}\, dx$$

To evaluate the antiderivative of $\sqrt{1 - \frac{x^2}{r^2}}$, we make the substitutions:

$$x = r \sin\theta$$

$$\theta = \arcsin \frac{x}{r}$$

$$dx = r \cos\theta\, d\theta$$

Thus, our integral becomes:

$$A = 4r \int_0^r \sqrt{1 - \frac{x^2}{r^2}}\, dx = 4r \int_0^{\pi/2} r\sqrt{1 - \sin^2\theta} \cos\theta\, d\theta$$

We can use the trigonometric identity $1 - \sin^2\theta = \cos^2\theta$:

$$A = 4r\int_0^{\pi/2} r\sqrt{1-\sin^2\theta}\cos\theta\,d\theta = 4r^2\int_0^{\pi/2}\cos^2\theta\,d\theta$$

We then apply $\cos^2\theta = \frac{1}{2}(1+\cos 2\theta)$:

$$\begin{aligned}
4r^2\int_0^{\pi/2}\cos^2\theta\,d\theta &= 4r^2\int_0^{\pi/2}\frac{1}{2}(1+\cos 2\theta)\,d\theta \\
&= 2r^2\theta\Big|_0^{\pi/2} + 2r^2\int_0^{\pi/2}\cos 2\theta\,d\theta \\
&= \pi r^2 + 2r^2(\sin 2\theta)\Big|_0^{\pi/2} \\
&= \pi r^2
\end{aligned}$$

Thus, the area of a circle with radius r is πr^2. ■

A.6 Listings and other *environments*

You can apply specialized layout by using *environments*. Environments are constructed like this:

```
\begin{some-environment}
The text and other contents goes here
\end{some-environment}
```

The most common environments are the following three different list types[13]. First, the bullet list:

- First item
- Second item
- Third item

Then, the enumerated list:

1. First item
2. Second item
3. Third item

And finally the decription list:

First item First description Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellentesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

[13] Here we are using compact versions of the standard lists, which tend to produce to much "air"

Second item Second description
Third item Third description

Needless to say, as anything else in LaTeX, these lists can be customized to your liking.

A.7 Source code

Large chunks of code should be placed in an appendix, but smaller pieces may be listed in the main part. We here demonstrate two ways of doing this.

In Listing A.1 we have included code from a separate file.

```
/******************************************************************************
 *  Compilation:  javac Hanoi.java
 *  Execution:    java Hanoi N
 *
 *  Solves the Towers of Hanoi problem on N discs. The discs are labeled
 *  in increasing order of size from 1 to N and the poles are labeled
 *  A, B, and C.
 *
 ******************************************************************************/

public class Hanoi {

    // move n smallest discs from one pole to another, using the temp pole
    public static void hanoi(int n, String from, String temp, String to) {
        if (n == 0) return;
        hanoi(n-1, from, to, temp);
        System.out.println("Move disc " + n + " from " + from + " to " + to);
        hanoi(n-1, temp, from, to);
    }

    public static void main(String[] args) {
        int N = Integer.parseInt(args[0]);
        hanoi(N, "A", "B", "C");
    }
}
```

Listing A.1: Recursive solution of Towers of Hanoi

Listing A.2 is generated by copying and pasting from the same file.

```
// move n smallest discs from one pole to another, using the temp pole
 public static void hanoi(int n, String from, String temp, String to) {
     if (n == 0) return;
     hanoi(n-1, from, to, temp);
     System.out.println(''Move disc '' +n+ '' from '' +from+ '' to '' +to);
     hanoi(n-1, temp, from, to);
}
```

Listing A.2: Core of the recursive solution of Towers of Hanoi

A.8 Cross-references and bibliography

As mentioned earlier, all non-text elements should be numbered, and should be referenced to at least once in the text. This is what is called *cross-referencing*, and is easily accomplished. First we need to attach a label to the element: `\label{type:name}`. Then we use this label in the reference: `\ref{type:name}`. The reference is only a number, so we usually add the element type as a capitalized prefix, for instance like his: `Figure \ref{fig:lamport}}`, which produces: Figure A.1.

When you need a reference to an item in your bibliography (books, articles, web sites etc), you need to use one or more "database" files, which are plain texts files with bibliography items formatted according to certain rules. These files have the extension `.bib`, and must be included in the the preamble in the main file. An example of a correctly formatted bibliography item is found in A.3.

```
@book{perelman97mht,
author = {Perelman, Leslie and Barrett, Edward},
title = {{The Mayfield Handbook of Technical and Scientific Writing}},
year = {1997},
edition = {1},
publisher = {McGraw-Hill, Inc.},
address = {New York, NY, USA},
}
```

Listing A.3: BibLaTeX entry

This format is called *BibTeX*, and all the academic search engines, including *Google Scholar*, export to this format. When referencing, you use this command: `\cite{perelman97mht}` and you get: [2]. If you want to specify page(s), use `\cite[p. XX]{perelman97mht}`, which results in [2, p. XX].

To build the bibliography, run `\printbibliography[heading=bibintoc]`, which also places an entry in the table of contents. BibLaTeX generates the bibliography only from the references in the document (and not from all the items in the `.bib` files).

The different scientific communities have their own guidelines for how to format the entries in the bibliography, and how to format the references in the document. You decide which style to use with the command `\citationstyle{ieee}` in the preamble in the main file.

There are many options for creating specialized bibliography, for instance multiple bibliographies[14].

There are several tools for creating and maintaining bibliography databases that export BibLaTeX files, both standalone programs, plugins to editors and browsers, and cloud based services[15]. I recommend to use such reference managers, in particular the online versions which, when shared, enable collaborative writing.

[14] `www.overleaf.com/learn/latex/bibliography_management_with_biblatex`
[15] For instance, check out `zotero.org`

A.9 Glossary and Index

You may also make a glossary page, where the terms have descriptions and lists of pages they occur on. You need to provide the terms and their descriptions in the preamble, for instance in a separate file, see `glossary.tex`. An entry looks like this:

```
\newglossaryentry{maths}
{
    name=mathematics,
    description={Mathematics is what mathematicians do}
}
```

The terms are marked in the text like this:
`\gls{latex}`
which generates LaTeX. The glossary is produced by including `\\printglossaries` in the main file, and run `makeglossaries` when compiling.

The result in the glossary will be something like this:
"mathematics Mathematics is what mathematicians do. 1, 29".

An index is made by marking words, for instance , like this
`\index{IMRAD}`

The index page is then produced by including `\printindex` in the main file, and running the following sequence[16]:

```
xelatex main
makeindex main
xelatex main
```

The entry in the index page will then be:
"IMRAD, 48".

A.10 Fonts

For every LaTeX distribution, there is a default set of fonts. It is possible to customize this setup. Normally, there is no need for this. Nevertheless, to change the fonts for the whole document, use the following command in the preamble:

`\usepackage[lining,light,default]{sourcesanspro}` with the name of the typeface and the appropriate options[17].

However, size, weight, style, and typeface may be manipulated using standard commands.

Font size First of all, you decide in the preamble the default font size for your document. The `documentclass` takes the parameters `10pt`, `11pt`, or `12pt`. Locally, you can change the style by these commands, that resizes the font *relatively* to the default size:

tiny
scriptsize
footnotesize

[16] Overleaf does this automatically when compiling.

[17] For a list of available fonts, see for instance `www.overleaf.com/learn/latex/font_typefaces#Reference_guide`

small
Default: normalsize
large
Large
LARGE
huge
Huge

Font weight (Font series) You can locally change the font weight:
Default: Medium
Bold

Font style (Font shape) The font style may also be locally changed:
Default: Normal (Upright/Roman)
Italic
Slanted
Small caps

Font family Here is how you locally change font family:

- Default: Roman (serif)
- Sans serif
- *Italic*
- **Bold**
- Medium
- *Slanted*
- Upright
- Small caps
- **Bold**

A.11 To-do notes

Many find it useful to use todo-notes. You can place it inline, with
`\todo[inline]{This is an inline note.}`
Or, if you prefer, in the margin with
`\todo[inline]{This is a margin note.}`
The todo notes will only be visible when using the `draft` option in the document class.

A.12 Compilation

Making documents with LaTeX is basically like writing software. This document is produced by compiling a collection of files, all in the same folder. There is a top level file called `main.tex`, which contains commands that decide format, layout etc., or in other words,

the *style*[18]. It also includes the files containing the actual text (in general one file for each chapter).

When using Overleaf, the compilation is done automatically when saving a file in the project, or when issuing the `Recompile` command.

When using the template locally, you may compile it with the appropriate commands in your IDE, or do it from the command line. To generate a PDF file, go to the document folder, and issue the following commands:

1. `xelatex main` (runs through the document, setting up various help files and generates a preliminary PDF)
2. `biber main` (generates the bibliography from the citations)
3. `xelatex main` (includes the bibliography)
4. And finally yet another `xelatex main` to get all cross-references and citations correct.

This process produces a PDF file, `main.PDF`. When printing this particular document, remember to select the double page option.

A.13 Quotes and quotations

LaTeX is picky on quotation marks, to produce correct start and end marks you should type ``` ``a quote'' ```, which produces "a quote". To be on the safe side, use the `\say` command, which also enables nested quotes, like this: "A quotation may have 'nested' quotations".

Quotation marks are used when you want inline quotes. However, longer quotations should be made with the "quote" (or "quotation") environment:

> Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.
>
> Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Remember to always cite the source of a quotation like this.

A.13.1 Troubleshooting

As you may experience when compiling the source code, there might be syntax errors, missing files etc. to be fixed. In Overleaf, error and warning messages are displayed as

[18] Think of HTML and stylesheets …guess where that idea came from …

colored margin markers in the source text, and in the PDF pane. Red flags are indicating errors that Overleaf/LaTeX is not able to fix, thus not able to generate the PDF. These needs to be fixed by you. Overleaf tries to repair minor errors, giving red flags, but still generates the PDF. These errors should also be corrected.

You should also try to fix the orange warnings, but they are not critical. Blue warnings may be ignored, they mostly complain about "overfull" and "underfull" boxes, which in most cases do not affect the final document in any perceivable way.

If stuck, consult the Overleaf troubleshooting pages[19]. In some rare cases you need to delete all temporary help files, if so, go to the bottom of the error/warning pane and choose "Clear cache". If you run the project locally, this is done by deleting all `main.*` files, except `main.tex`.

However, sometimes it can be really tricky to find the source for an error. You should typically search backwards from where the error occurs. Listing A.4 is an example from compiling this document, where the error is misspelling of the LaTeX macro (should be `\LaTeX`, not `\LateX`). The key error message is "`! Undefined control sequence`", followed by a quote of the line where the error has occurred, along with the line number. The name of current file is found a couple of lines above: "`(./how-to.tex`".

```
1  ...
2
3  Overfull \hbox (6.0pt too wide) in paragraph at lines 43--44
4  [][][][][][]
5
6  Underfull \hbox (badness 10000) in paragraph at lines 43--44
7
8  ) (./conclusion.tex [20]
9  Chapter 7.
10 [21]) (./main.bbl [22]) [23] [24]
11 No file main.ind.
12 (./how-to.tex
13 Appendix A.
14 [25]
15 ! Undefined control sequence.
16 l.48 misspelling of the  \LateX
17                         \  macro (should be \verb|\La...
18
19 ?
20 }
```

Listing A.4: LaTeX error output

A.14 Best practice

- First: Focus on *content* and *structure*
- Later: Decide on layout and style
- Use mostly the default settings
- If you need special functionality, look for packages covering your needs
- If you do not find suitable packages, make your own macros

[19] `www.overleaf.com/learn/latex/Errors` and `www.overleaf.com/learn/latex/Questions/Tips_and_Tricks_for_Troubleshooting_LaTeX`

- Learn by 1) asking fellow students, 2) google and cut'n paste, and 3) by sending me an email or come to my office
- Compile frequently
- Commit frequently to your versioning system[20]
- Run spell checks when things start to get complete[21]
- When the document absolutely complete: perform minor fine-tuning (typically to sort out bad placements of floats). Remember that every fix you apply may affect the subsequent layout.

[20] SVN is a good choice, or use any of the many free online services.

[21] Most editors provide built-in spell check functionality (which ignores the markup commands). On Linux platforms you have the ispell and aspell command line tools which can be configured for LaTeX. There are also stand-alone tools around.

Appendix B

Including pages from PDFs

To include a PDF document, or pages from it, use something like this[1]:

```
\includepdf[pages=-,pagecommand={\pagestyle{fancy}}]{Chapters/paper.pdf}
```

which includes the full document, as here[4].

To include parts of, use for example

```
\includepdf[pages={2,5,6},pagecommand={\pagestyle{fancy}}]{Chapters/paper.pdf}
```

or

```
\includepdf[pages={3-5},pagecommand={\pagestyle{fancy}}]{Chapters/paper.pdf}
```

[1] See the package documentation for available options `ctan.uib.no/macros/latex/contrib/pdfpages/pdfpages.pdf`

Users Are Doing It For Themselves: Pedestrian Navigation With User Generated Content

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Abstract

Route planning has over the few past years become common in the context of driving cars and other vehicles. However, with the advent of powerful mobile devices, such as smart-phones, systems helping pedestrians finding their way in complex urban environments have emerged. We present a prototype system for mobile pedestrian navigation, called OurWay*, based on user generated maps and collaborative annotations of network segments. We are particularly concerned with users with various permanent or temporary disabilities, like wheelchair users, or parents pushing baby strollers. By letting users rate the accessibility of locations, the system will compute bespoke routes matching their abilities and preferences. We explore the potential of the concept through a combination of field work and lab trials, using real life data. We also demonstrate that collaboratively collected geodata has promising properties as a foundation for innovative geospatial applications. Initial results indicate that few user annotations are needed to produce good routes.*

1 Introduction

Pedestrian navigation is a challenge in complex urban structures, in particular in unfamiliar territory. For the physically impaired, like wheelchair users or parents with baby strollers, finding and following a reasonable route from one place to another may become difficult, not to say impossible, when encountering barriers like stairways, steep hills and missing sidewalks. Contrary to the related field of car navigation, with its abundance of tools, services and content providers, tools for pedestrian wayfinding are scarce. Notable exceptions can be found in Japan, where the availability and usage of pedestrian mobile route planners in larger cities, such as Tokyo [26, 17], is rapidly increasing. The reason for this, in addition to the widespread use of advanced mobile services, might be the relatively low market penetration of cars, and the comparatively high reliance on public transportation.

Pedestrian wayfinding diverges from car navigation in mainly two aspects:

- Pedestrians are not strictly bound to follow designated roads, paths and sidewalks, but may walk through parks, or take short-cuts through shopping malls. Hence, the underlying transport network becomes more complex, both to generate and to maintain.
- Pedestrians are a more heterogeneous group than car drivers, as car drivers usually are only limited by whether or not there exists a road between given waypoints. Pedestrians may be categorized according to a wide set of criteria, reflecting physical abilities and personal preferences. User profiles also depend on context: a father becomes temporarily disabled when pushing a baby stroller. Accordingly, route planning tools should be able to cope with a variety of user profiles.

Our main strategy for resolving these issues, is to turn to the users themselves. Inspired by the rapidly growing community efforts in phenomena such as wikis, media sharing services and open source software development, we have built a prototype system, called *OurWay*, that enables pedestrians to grade road segments with regards to accessibility, for subsequent use in route planning. Using this mechanism, knowledgeable users, for example people that live and spend time in a particular area, can create feedback and essentially map out their neighborhood. Using this mechanism, users, can draw upon each other's knowledge to quickly find the better paths through town.

We have also leveraged principles and tools for collaborative mapping, by using the OpenStreetMap [22] infrastructure to build the underlying geographic network. The

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users generate the content in the field by using off-the-shelf mobile devices, such as smartphones and Bluetooth GPSs.

The purpose of the paper is twofold. First, we want to explore, on a proof-of-concept basis, how members of a group could benefit from using a collaborative system, such as OurWay, to find good routes in urban environments. Second, we will use this case to demonstrate the potential of user generated mobile content, as the geographic network of streets, sidewalks and paths, along with the individual ratings of accessibility, is built by collaborative efforts in the field, and shared among all users.

In the next section we briefly review a selection of related work. The OurWay prototype is presented in Section 3, and results from the preliminary experiments are given in Section 4. We discuss our findings and propose modifications and extensions of our concept in Section 5, before giving some final remarks in Section 6.

2 Related Work

Route planning for pedestrians is emerging from where classic vehicle routing meets the increased power and versatility of mobile devices. Early commercial efforts include the pioneering DoCo-Navi [26] and the later KDDI's EZ Navi Walk [17]. Karimanzira et al. [15] have looked at using machine learning techniques to generate routes tailored for disabled pedestrians, although the majority of the work in the field has been aimed towards tourist guides and similar [14].

Personalized route planning means that the route planner adapts to the user's specific needs and desires, such as Balke et al.'s prototype [3]. Kawabata et al. propose a context dependent metadata layer over the physical space to generate optimal routes according to the users' preferences [16]. Wuersch and Caduff point out that pedestrians are not confined to the underlying network of streets and sidewalks, but may use open areas like parks and squares. As a consequence, they explore aspects of treating routes as a sequence of waypoints [28].

Collaborative route planning is a variation of personalized route planning that has received little attention from researchers, although research into collaboration in recommender systems has matured (such as [11]). Still, some headway has been made using multiple agents sharing experiences to create a distributed case based reasoning system [20]. Others have looked at collaboration through users offering each other clues, either through direct participation [6] or more indirectly through photographs in geoannotated wikis [5].

To personalize routes, one must somehow capture the user's preferences. Haigh et al. suggest letting users rate routes using an *efficiency* β value to decide whether to reuse old solutions or explore new territory [10], while Akasaka and Onisawa have looked at using fuzzy measures to capture users' preferences, and assign roads sets of attributes based on detailed user input [1, 2]. Rogers and Langley, however, point out that an explicit user model may be too costly to develop and give too few assurances of accuracy to be worthwhile [23]. Examples of explicit pedestrians models are found in [24] and references therein.

Level-of-service (LOS) is a common term in transportation planning and research, and describes systems and methods for modeling suitability, efficiency and other aspects of vehicle transportation. The LOS concept has also been applied to pedestrian domains. Unfortunately, due to regional variations and lack of standards, pedestrian LOS frameworks differ substantially, as evident when comparing for instance the work reported in [19] (US) and [9] (Australia).

In the *MAGUS* project, a comprehensive LOS model for wheelchair users is developed, based on questionnaires, interviews, observations and physical measurements of starting and rolling resistance [4]. The final system is a GIS application, aiming to assist new users and enable better navigation for existing users, and as a means for planners. However, Sobek and Miller point out that the detailed LOS model would be extremely costly to establish and maintain, and that the application requires too much time from the users [25]. MAGUS is implemented with an expensive and proprietary GIS system, and they are of the opinion that this may further limit the practicality of the application.

Based on these observations, Sobek and Miller present an alternative system for route planning for disabled pedestrians, called *U-Access*. They propose simplified models of both level-of-service and users, claiming that this still generate good results. The implementation of the concept is web based, and leverages open geodata standards, thus providing access for users without specialized and expensive software.

In our work we propose an even simpler approach. First, we allow the users to organize themselves based on self-identification, creating groups we can assume share abilities and preferences. Second, we let the users collaboratively generate a simple LOS model based on shared user annotations. Finally, we leverage open standards and open geodata, and implement the prototype as a modular system with open source components.

3 The OurWay Prototype

We have developed a prototype to explore our concept of collaborative pedestrian route planning [12]. The OurWay system is a loose coupling of server and client-side components communicating over the HTTP protocol and exchanging XML formatted data. Figure 1 shows the basic architecture of the system.

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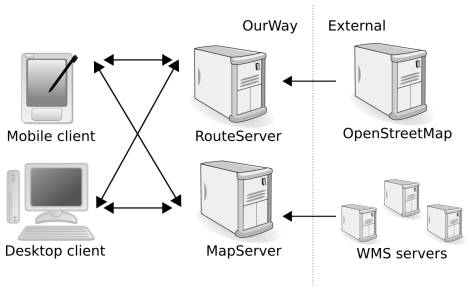

Figure 1: OurWay architecture

3.1 Implementation

OurWay is comprised of two clients and two servers.

Clients The two clients are nearly identical; One is implemented on a smartphone/PDA device, running the Windows Mobile 5 operating system, the other as a desktop C# based application. Their main functionality is to provide a map based user-interface for route planning and user rating of the quality of the streets, sidewalks and paths. In addition, both clients allow the user to create new segments for the underlying geographic network, either semi-automatically by GPS tracking, or manually by drawing on the map.

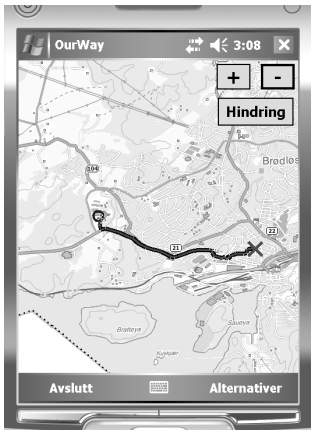

Figure 2: Screenshot of OurWay prototype, running in an emulator

A screenshoot from the mobile client is shown in Figure 2. The buttons labeled plus and minus zoom in and out of the map, while the third button lets the user report feedback. Most other functionality is available throught the two menues at the bottom of the screen. Note that the GUI has not been the focus of this project, and we have therefore not applied any HCI techniques to its design.

Servers The two servers are responsible for providing maps and calculating routes, respectively, in addition to administrative services. The map server is implemented in PHP, while the route server is a Java Servlet.

The Map Server's task is to deliver background maps to the clients, in the form of image tiles. The server transforms the map requests into appropriate calls to a specified geodata provider. We use the Web Map Service (WMS) protocol, initially developed by the Open Geospatial Consortium, and an international standard (ISO) since 2005 [8]. By leveraging this widely used specification, the server can access any WMS based map provider, without changing the implementation.

To reduce the number of WMS calls and speed up delivery, the server maintains a local tile cache based on the clients' positions. In our case, we used both aerial imagery and topographic maps.

The Route sERVER is responsible for calculating and delivering routes based on the supplied user group, start point, and end point. It delivers the routes as an ordered list of geographic points. It also handles ratings from users and assigns these to the relevant edges in the road network during the route calculation. The underlying geometric network is imported from the OpenStreetMap (OSM) server. We explain the route calculation process in some detail in the following section.

3.2 Route Calculation With User Ratings

The central collaborative feature of our prototype application is the rating of accessibility of geographic areas, and the sharing of these ratings inside user groups. Users are able to change groups at any point, and create new groups if they wish. In the current implementation, user groups do not share information, even if the user groups have similar needs.

Users can rate the network used for route planning by pointing out good, bad, or inaccessible points along a route. For instance, if a wheelchair-user comes across a stretch of road where he must get off the sidewalk to circumvent an obstacle, he could mark this point as bad. Even worse, if the wheelchair-user is lead up a road that is simply too steep for him, he could mark the spot inaccessible, and the route planner would never again attempt to route a wheelchair user up that road.

User feedback causes roads to appear shorter or longer than they really are, by applying weights to the corresponding edges in the underlying road graph. This way, the search algorithm will attempt to avoid stretches of road that have received negative feedback. Roads marked as inaccessible will appear prohibitively long and thus never be used by the route planner.

The user feedback is represented as floating point weights. When a route is calculated, an edge in the network is assigned a value equal to its geographic length multiplied

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with any prevailing user feedback assigned to it. Currently, the most negative feedback an edge has been given is the one that is used, although other modes can be imagined, like having the last feedback count, or calculating some average between all user feedbacks.

We have chosen the three weights 0.5, 4.0, and 42000.0. We arrived at the first two weights through informal experimentation, where we found that these worked well for us. The final weight is an arbitrarily large number that effectively renders a road untraversable.

For the purpose of route planning, we consider an edge to be a stretch of road or path or otherwise between two intersections, such that the stretch itself does not contain any intersections. This means that the geometry of the road is not considered when creating the graph of the map, only the topology. Furthermore, it means that negative user feedback offered at the bottom of a very long, winding path up a hill, will make the hill nigh insurmountable, while similar negative feedback for a short road in an urban setting will have a much smaller effect.

The actual search algorithm is the classic A* algorithm for finding an optimal route through a network.

4 Prototype Evaluation

The OurWay prototype was evaluated in an incremental study where we simulated users interacting with the system while we observed the behavior of the prototype. We limited the study to one single user group: normally fit parents with baby strollers. This study was an initial proof-of-concept exercise, focusing mainly on technical aspects.

The study was split into three parts. We first created the geographic network we would use for route planning by gathering map data using the OpenStreetMap infrastructure, as explained in the next section. Then we engaged in a field test, before carrying out systematic lab trials.

4.1 Street Map

The OurWay framework relies on a detailed map of available roads, sidewalks and paths. The clients provide functionality for adding new nodes and edges, however, this is primarily intended for minor updates. Hence, in a practical situation, the system has to be bootstrapped with an initial map with a reasonable level of detail.

However, developing and experimenting with applications depending on real life geospatial data is not trivial. Access to geodata is often expensive[1], and sometimes complicated and cumbersome, due to for instance inefficient distribution systems and problems with interpreting formats and converting data. In particular, the challenge may become overwhelming when trying to integrate data from multiple sources in one single application.

These problems are widely recognized, and several initiatives have emerged to deal with them. On an interoperability level, the perhaps most prominent effort is the Open Geospatial Consortium, which has developed and promoted a family of specifications, some of which have become ISO standards (see e.g., [18] and references therein for details on semantics and interoperability of geodata).

On a content level, the Digital Chart Of The World (DCW), published by United States Defense Mapping Agency (DMA) in 1992 [7], has been, and still is, the most comprehensive dataset with global coverage. The Global Mapping Project is working on product similar to DCW, free for non-commercial use. It is a joint effort, with contributions from national mapping agencies [21].

However, the mentioned open sources provide data on coarse scales, typically 1:1 million, and is unusable for applications dealing with street level problems. During the past years, many initiatives in collaborative content generation, often in the form of wikis, have emerged. The most outstanding example is Wikipedia, which from its start in 2001 has grown from a modest experiment to a highly respected and frequently cited information source on a global scale, outrivalling many traditional encyclopedias.

The Wikipedia concept has as a parallel in the geospatial domain, the OpenStreetMap (OSM) project [22], founded in 2004. OSM provides a complete infrastructure supporting collaborative map making on a global scale, including tools for mobile data acquisition, editing applications, administrative and storage services and browsing and downloading facilities. The OSM data is distributed under a Creative Commons license, which in practice allows any kind of use, as long as OSM is attributed, and that new products are shared under the same conditions.

At the time of writing, OSM has approximately 7500 contributing users, and close to 70 million uploaded GPS points. Several areas and cities, in particular in Great Britain, have reached a coverage making the data usable in various kinds of applications. As an example, the Britain based property search engine Nestoria is providing OSM content as an alternative to Google maps.

For the reasons stated above, OSM became the data provider of choice in the OurWay project. Our main test area was Halden, a small town in Southern Norway, with a population of around 28000. When starting the project, the OSM coverage of Halden was not complete. The authors and a couple of students undertook the task of supplementing the network. We used both GPS tracking, with cars, bikes, and on foot, and tracing on top of high resolution aerial imagery, provided by the local municipality. Figure 3 illustrates the mapping process. The resulting geographic network is a relatively complete map of downtown Halden

[1] A notable exception is US geodata, which, due to legislation on public sector information, is freely available for usage in most applications.

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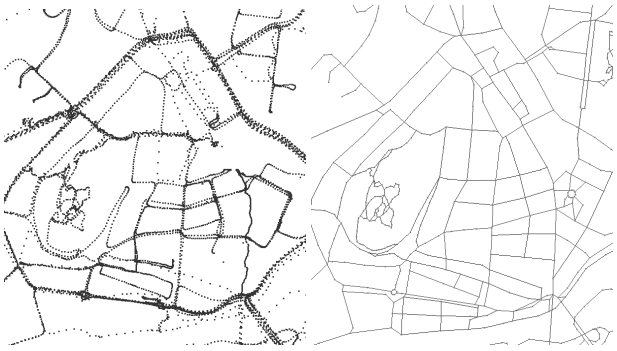

(a) GPS tracks (b) Final geographic network

Figure 3: Mapping Halden the OSM way

(approx. 2 km^2).

The OSM infrastructure provides functionality for categorization of the road networks, in order to enable applications to distinguish between for instance foot paths and highways. However, the OurWay server discard this information, thus treating all parts of the network equally. In this way, all additional information on the usability of the components of the network is provided by the users themselves as feedback in the field.

4.2 Field Work

For the field tests, the main objective was to gather experience as users of the prototype. The authors brought a PDA type smartphone with the prototype installed and a baby stroller. Using OurWay to generate routes, we pushed the stroller through the city-scape, including a fairly hard-to-navigate park with poor trails and steep climbs.

Although the researchers have substantial local knowledge of the test area, the field excursions taught us more about the precise obstacles facing people with baby strollers. We improved our understanding of the local geography and gained some insight into what sort of obstacles would matter to the baby strolling user group.

During the tests, we learned that as a user, it was reasonable to distinguish between only three kinds of accessibility: what was uncomfortable, what was completely inaccessible, and what was experienced as good. The first category would include anything where we felt it was uncomfortable to maneuver. This could include steep climbs as well as roads with poor or confusing sidewalks. By inaccessible, we meant places we were forced to carry the baby stroller, or roads that lacked sidewalks altogether. Positive feedback was given when we came across places we experienced as a relief from the roads around, or where it was especially easy to maneuver.

Further, the field tests provided insight into how to estimate the values of the weights associated with the three categories. Conceptually, these weights are supposed to reduce or increase the actual distances in order to reflect the users' positive and negative experiences. After some trial and error, we decided on the weights 0.5 for a good review, 4.0 for uncomfortable areas, and 42000.0 for an inaccessible point. Estimating parameters like this is notoriously difficult, however, these values yielded satisfactory results in our tests.

An obvious question to ask is under what circumstances users will find themselves motivated to annotate their environment. In a parallel study, we have started to look into different aspects of motivation for use and contribution to this kind of system [13]. Preliminary findings indicate that people are more likely to react to and annotate negative experiences, thus possibly leading to less use of the "good" category of feedback. Further, within some groups, such as those organized in associations for physically disabled, the shared goal of universal access can be a strong motivational factor. Ensuring system trust and information trust is another topic which is key to motivate use of such a navigational tool.

4.3 Lab Trials

The final part of the study was performed in the lab where we used the desktop version of the route planner. Apart from being a technical system test, the main objective was to study how user feedback affected the quality of the proposed routes.

We performed a set of tasks, where we simulated finding and following routes between two waypoints, and giving feedback during the "walks". The simulated user was supposed to belong to a user group with normally fit persons pushing baby strollers.

During each task, we performed a number of iterations, where a route between the given waypoints was generated, based on existing user feedback. We then "walked" the route, and used our local knowledge of the geography and the experience garnered earlier to identify and report comfortable, uncomfortable and inaccessible areas.

The first iteration of each task was carried out with a neutral network, i.e., one that had not received any prior user feedback. We stopped the iterations when there were no need for more feedback, in other words, when the process converged on a stable solution.

4.3.1 Results

The following results are drawn from experimenting with four navigation tasks. The trips were estimated to be in the range of ten to thirty minutes pushing a stroller at normal speed. The area covered included pedestrian streets, paths

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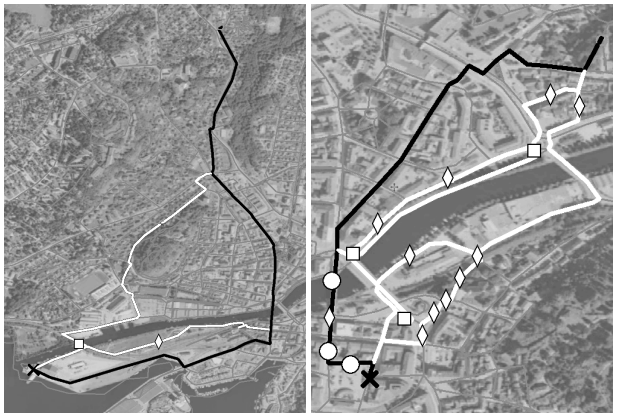
in parks and sidewalks on local and regional highways. In the following we describe each case in some detail.



(a) Task 1 (b) Task 2

Figure 4: Final routes (black) and intermediate routes (white). Inaccessible, inconvenient and good spots are marked with squares, diamonds and circles, respectively. OpenStreetMap network (thin gray lines). Background aerial imagery courtesy of Halden Municipality.

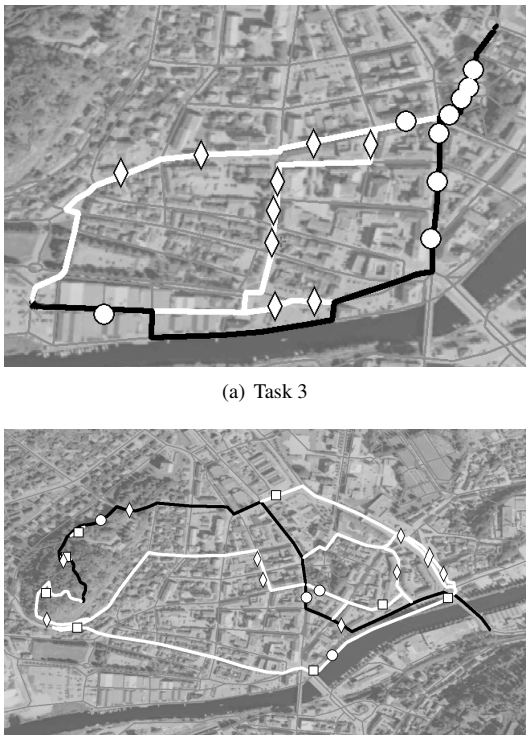
Task 1 The trip starts in a residential area, crosses the town center and ends up in the harbor area. Tista river has to be crossed, see Figure 4(a). The first proposed route mainly follows sidewalks and footways down to the shopping area at the river bank, and then uses a path leading to a bridge that is too narrow for a stroller. Hence, this part of the route is rated inaccessible.

The next route uses another bridge, designated for bikes and pedestrians, resulting in a slightly longer route. It follows a rather cumbersome footway along the river out to the harbor, and this segment is rated uncomfortable.

In the final iteration, the last leg of the route follows sidewalks and crosses open harbor areas. Interestingly, this route is identical to one frequently used by one of the authors. The solution converged after three iterations, including feedback consisting of only two ratings, one on an inaccessible segment, and one on an uncomfortable path.

Task 2 This is a typical 10 minutes walk, from the town square on the south side of the river, to the Porsnes highschool on the other side of the river. The ground between the two waypoints is quite heterogeneous, from dedicated footways to industrial areas and busy streets with sidewalks, as seen in Figure 4(b). To reach a satisfactory route, we made five iterations, with 16 feedbacks, three inaccessible stretches, eleven bad segments and two good parts.

Task 3 This trip is also fairly short, from one shopping mall to another, in a relatively homogeneous mixed shopping/residential city area, with no major obstacles. A good solution was achieved after three iterations. No inaccessible areas were identified, however five segments were rated comfortable, and nine stretches were considered uncomfortable. See Figure 5(a) for details.



(a) Task 3

(b) Task 4

Figure 5

Task 4 This is the most challenging case, estimated 20 minutes through a highly diversified area. It starts in a park with a labyrinth of dirt paths, continues through residential and shopping areas and crosses a regional highway and the river. There are many potentially inaccessible constructs, such as stairways and narrow footpaths in uneven terrain. Not surprisingly, this case needed more iterations to converge than the other tasks. After eight passes, eight reported major obstacles, ten uncomfortable parts and two good ratings, an acceptable route emerged. However, the final solution included one bad segment, marked in the first iteration. The intermediate solutions varied substantially, probing rather a large area all together, as seen in Figure 5(b).

To further analyze the test results, we introduce the *penalty factor*, which is the ratio between a given route between two waypoints and the shortest path computed without user feedback. The penalty factor reflects the additional cost of choosing an alternative route to avoid obstacles and

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unpleasant stretches. Table 1 shows how the penalty factor increases over the iterations in each of the four tasks.

		Iterations						
Task	1	2	3	4	5	6	7	8
1	2554m	1.14	1.16					
2	927m	1.04	1.06	1.09	1.09			
3	770m	1.08	1.10	1.17				
4	1307m	1.07	1.10	1.10	1.10	1.10	1.11	1.12

Table 1: Penalty factor: For each task (row), we give the length in meters of the initial shortest path (first column), and then the computed factor for the following iterations.

It's worth noting that the penalty factor is a conservative measure of the overhead of choosing more comfortable alternatives, considering that avoiding obstacles and inconvenient segments may indeed yield an all together faster route. With this in mind, the penalty factors in our cases seem surprisingly low, in the worst case the best alternative is only 1.16 times longer than the shortest path without user feedback.

One reason for the low penalty factors, is that the urban test area is relatively dense with respect to the underlying network, i.e., there are many and short edges, resulting in a generous solution space, where the algorithm is able to find many alternatives that are relatively similar.

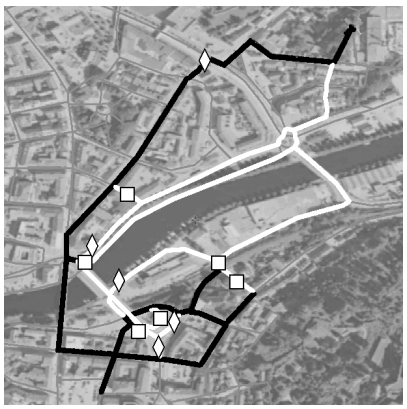

Figure 6: Navigating by trial and error. The ground covered is marked as black, and the proposed, but not used, segments are in white. Annotations are indicated as in Figure 4.

This could lead to the hypothesis that it would be easy for a newcomer to find a good route just by trial and error. To pursue this aspect, we performed an additional experiment, based on Task 2, to simulate this kind of user behavior. We started out with a neutral network, calculated an initial shortest path route, and followed the route until we found an inaccessible or uncomfortable segment. We then reported the point, and asked for a new route, from the current location to the final destination. The procedure was repeated until we reached the target. Not surprisingly, this resulted in a route with numerous backtracking elements, see Figure 6. The penalty factor reached 1.83, significantly higher than the converged route in the corresponding previous experiment (1.09).

The results will be further discussed in the following section.

5 Discussion and Future Work

We chose to carry out the initial round of field testing of the prototype ourself for a handful of reasons. It allowed us to gain first-hand experience as users, giving us valuable insight for the design of a larger study with independent users. Also, it gave us the opportunity to discuss the number of feedback levels and weighting of user feedback, both prerequisites for a larger scale study. Furthermore, as the group consisted of representatives of the case user group, we were able to realistically judge accessibility, giving our findings real value. Finally, continuing the experiments in the lab was made easier and more realistic, since we had our own experiences in mind whilst in the lab.

Our field and lab experiments have led us to several discoveries we consider worthwhile for further research, and some of these will be highlighted the following section.

5.1 Algorithmic Issues

Route distance and the number of iterations to reach route convergence are not correlated, rather the homogeneity and lack of obstacles in an area are determining factors.

It is worth mentioning that a fast convergence of a route planning iteration does not necessarily indicate a high quality route. If there are few alternative routes, a negatively rated segment might be unavoidable, as seen in Figure 5(b), where the final route takes the user through three segments rated as inconvenient. This is of course related to the choice of feedback weights, and a subject for further research.

Proper handling of multiple user feedback on road segments will be crucial to the adaptiveness of the system. In the current prototype, only the most negative feedback on a segment is considered. This leaves the system vulnerable to malicious annotations, since a more positive feedback on the same segment has no effect. Fortunately, experimenting with different ways of handling multiple user feedback is easily achieved by changing the cost function in the route planner. Inspired by wikis, one obvious alternative is to use the last feedback on a segment when calculating the adjusted length. This allows for a more dynamic network, where corrections from users have an immediate effect. This also leads to interesting issues such as edit-wars and malicious edits found in wikis .

In order to enable changes in the underlying road network, it is vital to separate user feedback from the network itself, and rather keep the feedback as point annota-

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tions, associated with network segments at the time of use. Further, this separation allows for points of interest (POIs) from different sources to be integrated in the system. Objectively measured accessibility for street crossings, sidewalks, and roads could be mapped to our pragmatic user feedback model. Further, interest points such as parking spaces, toilets and shopping centers with accessibility information could be included, and allow for route planning with POIs as intermediate goals in a route.

The current prototype handles each user group separately, i.e., there is no sharing of user feedback across the groups. Also, the concept of discrete user groups is open for questioning, since there obviously are differences in perceived quality of the routes between individuals in the group. Alternative ways of handling this include dynamic user groups based on trust networks, and hierarchical groups where some feedback is considered to apply to all groups, with additional feedback within the groups. Using universal access information as a backdrop, each user group could augment and tailor the information to their specific needs.

The experiment results are achieved on a neutral network with no extra information for distinguishing car roads from sidewalks, bridges or stairs. In fact, the prototype will ignore additional metadata information even if provided. Utilizing such information could clearly impact the route planner positively, however the complexity involved in maintaining an unambiguous set of attributes, combined with the positive results of our tests makes our pragmatic approach very attractive.

5.2 Usage Patterns

It is highly likely that the users' perception of the quality of a route segment is linked with the *change* in quality, rather than the objectively measured quality at any given point. Coming from a foot path, it is easier to appreciate a paved sidewalk as good, than if the route generally consisted of paved sidewalks. For this reason, we anticipate that user feedback will tend to appear at points of change in road quality, and to a lesser degree in homogeneous stretches of road.

This is well illustrated by the special case of an inaccessible route segment, where the user will give feedback on the point where it becomes inaccessible, and not have the opportunity to explore the route beyond that point.

In a related study, we are taking on the issue of users' motivation for contributing to a system such as OurWay. Inspired by research on wikis (especially Wikipedia), we are curious to see if users will take responsibility for geographical regions, in the same way that Wikipedia contributors take responsibility for Wikipedia pages on their *watchlist* [27]. This also brings up the need for a visualization method to display changes in an area over time. The non-linearity of geotagged information makes this an interesting issue for further research.

6 Conclusion

In this paper, we presented a collaborative navigation system for pedestrians with varying physical abilities and personal preferences. The OurWay infrastructure enables users to find bespoke routes matching the specific profile of their group.

User participation plays a vital role on two levels in the system. The street network on which the route planning takes place is collaboratively created by OSM contributors. Further, user feedback on route segments makes the route planner adapt to perceived accessibility by users in distinct user groups. The feedback is immediately available for the community using the OneWay services.

Technically, we found the prototype to behave as expected, from each individual component, to the system as a whole. However, our main research objective was to explore the effect of collaboration in route planning, utilizing map making and route feedback tools.

The OpenStreetMap infrastructure enabled us to generate a complete geographic network of the test area with surprisingly small efforts. We used various techniques for creating the OSM data, from field based GPS tracking to tracing features from freely available aerial imagery.

We were able to demonstrate that a relatively small number of annotations was sufficient to generate good bespoke routes, even when starting out with a completely neutral network. This was confirmed both in the field and in our lab trials.

The preliminary findings are promising, and inspires our future work in the direction of user experience trials, studies on user motivation for contribution and use, and issues such as sharing of ratings across user group boundaries, estimation of feedback weights and integration of different data sources.

Part of our initial motivation for creating OurWay was the different requirements for navigation posed by pedestrian users as opposed to car drivers. Nevertheless, it seems obvious that the type of user involvement utilized by OurWay has numerous potential applications, including route planning for different groups of vehicle users. Letting users plan routes along attractive stretches of roads, where attractiveness is defined by a peer group seems to follow naturally from the OurWay concept.

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