Aalto University
School of Science
Degree Programme of Computer Science and Engineering

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Using Big Data Analytics for Measuring Energy Consumption Patterns:

An end to end data analytics platform in use for energy efficiency

Master's Thesis
Espoo, June, 2014

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Instructor: Sanja Scepanovic M.Sc. (Tech.)

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ABSTRACT OF
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A dissertation or thesis is a document submitted in support of candidature for a degree or professional qualification presenting the author's research and findings. In some countries/universities, the word thesis or a cognate is used as part of a bachelor's or master's course, while dissertation is normally applied to a doctorate, whilst, in others, the reverse is true.

!FIXME **Abstract text goes here (and this is an example how to use fixme).** FIXME! Fixme is a command that helps you identify parts of your thesis that still require some work. When compiled in the custom `mydraft` mode, text parts tagged with fixmes are shown in bold and with fixme tags around them. When compiled in normal mode, the fixme-tagged text is shown normally (without special formatting). The draft mode also causes the "Draft" text to appear on the front page, alongside with the document compilation date. The custom `mydraft` mode is selected by the `mydraft` option given for the package `aalto-thesis`, near the top of the `thesis-example.tex` file.

The thesis example file (`thesis-example.tex`), all the chapter content files (`1introduction.tex` and so on), and the Aalto style file (`aalto-thesis.sty`) are commented with explanations on how the Aalto thesis works. The files also contain some examples on how to customize various details of the thesis layout, and of course the example text works as an example in itself. Please read the comments and the example text; that should get you well on your way!

Keywords: big data, energy, smart grid,energy efficiency, hadoop, analytics,machine learning, classification, CIVIS

Language: English

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I wish to thank all students who use LaTeX for formatting their theses, because theses formatted with LaTeX are just so nice.

Thank you, and keep up the good work!

Espoo, June, 2014

Hussnain Ahmed

Abbreviations and Acronyms

2k/4k/8k mode	COFDM operation modes
3GPP	3rd Generation Partnership Project
ESP	Encapsulating Security Payload; An IPsec security protocol
FLUTE	The File Delivery over Unidirectional Transport protocol
e.g.	for example (do not list here this kind of common acronymbs or abbreviations, but only those that are essential for understanding the content of your thesis.
note	Note also, that this list is not compulsory, and should be omitted if you have only few abbreviations

Contents

Chapter 1

Introduction

In modern era we have seen phenomenal increase in human dependency on information and communication technology (ICT) enabled products and services. It has transformed the way of life on the planet. From fulfilling very basic physiological needs like health and food to the human needs of communicating with others and being part of wider social groups, we need and depend on ICT. There are many research areas and opportunities that are emerging as bi-products of this continuous transformation. One of them is the availability of digital traces of human activities. With every instance of use of these services we produce a digital trace that can be recorded and analysed. Big Data is a term that is being widely used to refer to these digital traces of human activity. Ubiquity of computing resources, fast and highly mobile connectivity and advent of social media usage has caused a great surge in volumes of data. Realizing the true potentials of data, businesses are not only utilizing it as source of decision making but new revenue lines and opportunities are emerging that are reshaping the business models of many companies around the globe.

To support this transfiguration, we have seen a rapid development in distributed parallel computing, data communication software and machine learning. Industry giants like Google and Yahoo has opened technologies and tools like MapReduce and Hadoop to facilitate these advancement and open source software communities like Apache Software foundation has further developed the tools to provide a complete ecosystem for handling big data and generate insights. The new specialized big data companies like Cloudera and Hortonworks has emerged that has acted as catalyst for this data revolution. In this research we try to formulate a model for end to end big data analytics platform based on these technologies that can ingest data from heterogeneous sources, process it in an efficient way, mine the data to generate the insights based on business logic and then present the information using interactive

visualizations. This thesis includes the development as well as implementation of the mentioned big data platform to perform analysis on real life use case and generate useful insights. The model that we present in this thesis is based on open source software components available free of charge. There are other closed source software alternatives that can fit into the presented model but they are not discussed in this scope of this thesis.

This thesis is also part of European Union CIVIS- Cities as drivers of social change project under 7th framework. CIVIS project focuses on adaption of ICT tools and techniques for low carbon smart energy grid, distributed energy and information flow. The use of pervasive ubiquitous computing is driving the smart energy solutions. Combined with internet of things (IoT) for home/building automation, smart commuting, and remote monitoring is becoming the basis for energy conservation and energy efficiency. All the smart energy devices as part of this ecosystems generates high volumes of data, that needs to be instantaneously transferred, stored, analysed and visualized for knowledge discovery and improvements of services for the goal of achieving high energy efficiency. The platform that was developed as part of this thesis has the capability to automate the whole process.

Energy usage pattern detection, classification of buildings on basis of energy efficiency and a prediction model for energy consumption per household will be the use cases for validating the developed big data analytics platform. These use cases also provide the basis for designing, planning and implementing schemes for improving energy related services for sake of achieving higher efficiency in both production and usage that contributes to cause of green environment in terms of less C02 emissions. The insight generated from these use cases can also help in educating the consumer about benefits of energy conservation and spread the awareness about behavioural changes that can benefit society as well as individuals themselves.

This master thesis is also supported by VTT, Technical Research Centre of Finland as part of their Green Campus initiative that focuses on use of ICT based solutions for innovative energy management and control systems capable to optimize the consumption without compromising the indoor environment. VTT is also a supporter and partner of CIVIS project. VTT has installed specialized smart devices in selected test sites that are the buildings owned by Aalto University. VTT has contributed to this thesis by providing the data generated by these smart devices. VTT has also helped in scoping for the use cases for energy efficiency by the experience and the knowledge they have from the related projects and research.

In a nutshell, this thesis focuses on providing a solution for collecting, storing, analysing and visualizing data generated by smart energy device for generating insights about energy consumption patterns and discovering the

performance of different building units in terms of energy efficiency. This thesis also provides the models for knowledge discovery that can be used to improve energy efficiency at both producers and consumers ends. The big data analytics platform developed as part of this thesis is not limited to be used only for energy efficiency. It has the capability of handling other big data uses cases as well but we shall discuss its use for energy pattern detection and usage efficiency only in scope of this thesis report.

1.1 Problem statement

Energy conservation is required to reduce C02 emissions from energy production and usage. To achieve this goal we need to understand and improve the energy efficiency on both producer and consumer end. ICT enabled smart energy grids and devices are being rolled out globally to measure energy consumption and improve on energy efficiency. These smart devices produce high volumes of data that may or may not be predicted and planned at time of setting up the infrastructure. The data generated by different devices comes in different formats. For knowledge discovery from this data it is required to collect, store analyse the data and then visualize the generated insights so the information can be understood efficiently. The challenge gets even tougher when data needs to be collected and analysed in real time. Then with the time, volume of data and scope of analysis is expected to increase. So to cater for all this a highly scalable and flexible data analysis platform is required that can automate the whole process. This platform needs to be very cost effective for global adaptation.

In scope of this research we provide a model for big data analytics platform that can provide the solution for these requirements. We also implement the proposed model and test it with real life energy smart devices data and use cases. The proposed solution is based on open source components that can be deployed on general purpose commercially available, hence it is very cost effective. The proposed platform can be scaled according to data volumes and additional functional components can be integrated as per the scope of analysis.

1.2 Helpful hints

Read the information from the university master's thesis pages [2] before starting the thesis. You should also go through the thesis grading instructions [1] together with your instructor and/or supervisor in the beginning of

your work.

1.3 Structure of the Thesis

You should use transition in your text, meaning that you should help the reader follow the thesis outline. Here, you tell what will be in each chapter of your thesis.

Chapter 2

Background

The problem must have some background, otherwise it is not interesting. You can explain the background here. Probably you should change the title to something that describes more the content of this chapter. Background consists of information that help other masters of the same degree program to understand the rest of the thesis.

Transitions mentioned in Section 1.3 are used also in the chapters and sections. For example, next in this chapter we tell how to use English language, how to find and refer to sources, and enlight different ways to include graphics in the thesis[5].

2.1 Smart grids

Energy industry across the globe is facing numerous challenges. There is a huge pressure from regulatory authorities and environmental organizations to reduce carbon foot print, expand their renewable energy portfolios, and take energy conservation measures. The demand response (DR)[1] and its impacts on consumer behaviour requires rapid adaptations in energy service providers business models. According to United States Federal Energy Regulatory Commission (FERC) , "Demand response can provide competitive pressure to reduce wholesale power prices; increases awareness of energy usage; provides for more efficient operation of markets; mitigates market power; enhances reliability; and in combination with certain new technologies, can support the use of renewable energy resources, distributed generation, and

[1]Demand Respose(DR); Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.

advanced metering. Thus, enabling demand-side resources, as well as supply-side resources, improves the economic operation of electric power markets by aligning prices more closely with the value customers place on electric power"[4]. Traditionally, power system participants have been strictly producers or consumers of electricity. The demand response and reliability issue with conventional electric power distribution models on consumer side are causing a major trend in motivating consumers to produce electricity at domestic level mostly using the renewable energy production methods. " Prosumer" is an emerging term used for an economically motivated entity that: [8]

- Consumes, produces, and stores power,
- Operates or owns a power grid small or large, and hence transports electricity, and
- Optimizes the economic decisions regarding its

The current energy grids support unidirectional distribution models and are centralized in nature. They are very limited to handle the prosumer needs. Line loses and hierarchical topology makes them less reliable. They usually become bottle neck when rapid adaptations are required for demand response. Farhangi, 2010 define smarts grids as "The next-generation electricity grid, expected to address the major shortcomings of the existing grid. In essence, the smart grid needs to provide the utility companies with full visibility and pervasive control over their assets and services. The smart grid is required to be self-healing and resilient to system anomalies. And last but not least, the smart grid needs to empower its stakeholders to define and realize new ways of engaging with each other and performing energy transactions across the system" [7].

In our research, we used data collected from smart metering devices as part of a pilot smart grid project. The data was used to generate analysis that recommends improvement for both demand and supply side to achieve energy efficiency as well as provide understanding to enable correct decision to adapt for demand response.

2.2 CIVIS Poject

CIVIS is the abbreviated name for "Cities as drivers of social change" project under European Union 7th framework. It is a part of the programme for optimising energy systems in smart cities. CIVIS project is a collaborative

effort of 10 European universities) [2]. It aims to embed the social aspect into the advancements of energy technology. To unleash the full potential of this vision, smart grids need to be coupled with broader social and cultural considerations and understood as complex socio-techno-economic systems with multiple decision making layers that are in effect at the physical, cyber, social, and policy [6].

ICT acts as one of the main enabler of smart grids, distributed and bidirectional information flow models. On the other hand ICT also provides a lot of new mediums for social aggregation e.g. internet based social media. CIVIS projects tends to connect these two different dimensions with innovative ICT solutions. An integrated approach to energy efficiency is the basic manifesto of CIVIS project. [6]

Understanding energy usage patterns and benchmarking energy efficiency performance of small units within cities are some preliminary items in list of CIVIS objectives. Within scope of our research we analyze energy data to understand the consumption patterns and try to evaluate various factors that can effect directly or indirectly on the usage patterns. We also try to classify the building on basis of energy efficiency and try to test the sensitivity of energy efficiency with respect to factors that can cause shift in usage patterns. For the CIVIS project aim of social aspect integration, we also present an ICT application framework that can be used to collect and analyse social media data. However the analysis of that data is not within the scope of this research.

2.3 Green Campus Initiative

Green campus initiative is a project by VTT "Technical Research Centre of Finland" . It is part of EcoCampus 2030 program. EcoCampus is an attempt to contribute to increased energy efficiency in districts and buildings by innovative management and control systems capable to optimize the local consumption without compromising the indoor environment, occupant comfort and building performance, and by introducing new ICT enabled business models [13]. The vision of the program is to realize a net zero energy model for a world class research, development and educational facility. Program focuses on co-designing this model with user by educating them and then

[2] 1. Associazione Trento RISE, Italy 2. Aalto university, Finland 3. Imperial College London, UK 4. ENEL Foundation, Italy 5. Instituto Superior TÃ©cnico, Portugal 6.Karlsruhe Institute of Technology, Germany 7.Kungliga Tekniska Hogskolan, Sweden 8.SANTER REPLY SpA Italy 9.Nederlandse Organisatie voor toegepast Natuurwetenschappelijkonderzoek, Netherlands 10. Delft University of Technology,Netherlands

collecting feedbacks for improvement. The main aim is to gain energy efficiency by building infrastructure in the building units that can make them self sustain for future requirements. The aim is build to build a performance based ecosystem that can help both consumers and producers to adapt with demand response.

Green campus initiative is a pilot project for EcoCampus program in which VTT has installed smart devices inside Aalto University, Finland campus building in cities of Espoo and Helsinki. These specialized devices contained smart metering for energy consumption and indoor environment monitoring sensors. The data used for analysis in our research was collected from 100 buildings as test sites. The data includes hourly consumption of electricity and electricity used for heating. For one of the test sites VTT provided us the data with the details up to use of respective electric devices used in that site. This was achieved using smart NIALM [3][11] meters that can distinguish between different electric devices used on basis of their signal thumb print.

Apart from providing the data, VTT green campus researchers have also helped us in formulating the use cases for this thesis research.

2.4 Big Data Analytics

Big data analytics is application of advance data analytics techniques on large volumes of data. Advance analytics is a generalized term used for data analysis techniques like statistical analysis, data mining, machine learning, natural language processing, text mining and data visualization etc [15]. Although volume of the data is a widely used factor for qualification of a data set as big data but when it come to big data analytics there few other important attributes i.e. variety, velocity, valuation and veracity. The concept of 3Vs (volume, variety and velocity) of data was first given by an analyst, Doug Laney from Gartner in a 2001 MetaGroup research publication, "3D data management: Controlling data volume, variety and velocity"[14]. Gartner used this concept to formulate a data magnitude index that can support decision making for selection of the solutions for tackling big data challenge on use case base. This concept is shown in Figure 2.1 below

Number 0 to 3 represents the scale of data that you perceive on each dimension. Adding them together for a big data case can provide the data magnitude index. This method provides some basis for quantifying the data

[3] NIALM stands for non-intrusive appliance load monitoring, is a process for analysing changes in the voltage and current going into a house and deducing what appliances are used in the house as well as their individual energy consumption

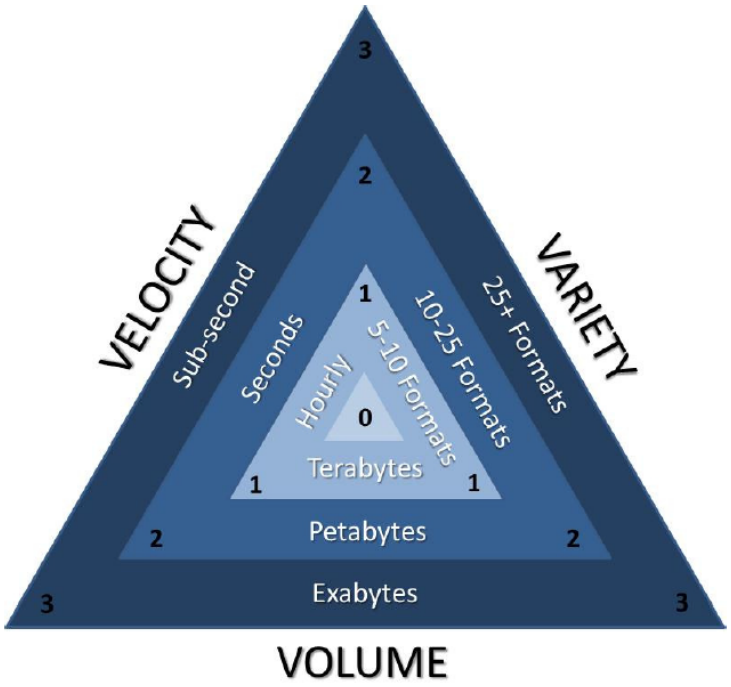


Figure 2.1: Gartner 3Vs of data and data magnitude index.

for big data qualification, However it is not providing a definitive model as it allows presumptions to scale the data. Valuation and veracity are two other factors that are being used widely along with Gartner's 3V. Valuation supports the decision making by considering the value of outcomes against the efforts required to collect, manage, process and analyse huge amounts of data. While veracity refers to ambiguity in the data that can cause complexity. There is no standard definition of big data but most of the attempts to define big data can be associated with these five factors that we have discussed.

As a matter of fact, we are not attempting to provide a definition of big data as part of this thesis or stating any criteria for qualification of a data set as big data. Instead we shall be proposing an advance analytics model that should be capable enough to handle big data as well other smaller data sets on need basis. The modular architecture of the model platform can be tweaked to handle volume, variety, velocity, and veracity on need basis while trying to maximize the valuation for the use case.

Chapter 3

Environment

A problem instance is rarely totally independent of its environment. Most often you need to describe the environment you work in, what limits there are and so on. This is a good place to do that. First we tell you about the LaTeX working environments and then is an example from an thesis written some years ago.

3.1 LaTeX working environments

To create LaTeX documents you need two things: a LaTeX environment for compiling your documents and a text editor for writing them.

3.1.1 Environment

Fortunately LaTeX can nowadays be found for any (modern) computer environment, be it Linux, Windows, or Macintosh. For Linuxes (and other Unix clones) and Macs, I'd recommend *TeX Live* [16], which is the current default LaTeX distribution for many Linux flavors such as Fedora, Debian, Ubuntu, and Gentoo. TeX Live is the replacement for the older *teTeX*, which is no longer developed.

TeX Live works also for Windows machines (at least according to their web site); however, I have used *MiKTeX* [3] and can recommend it for Windows. MiKTeX has a nice package manager and automatically fetches missing packages for you.

3.1.2 Editor

You can write LaTeX documents with any text editor you like, but having syntax coloring options and such really helps a lot. My personal favourite

for editing LaTeX is the *TeXlipse* [12] plugin for the Eclipse IDE [17]. Eclipse is an open-source integrated development environment (IDE) initially created for writing Java code, but it currently has support for editing languages such as C, C++, JavaScript, XML, HTML, and many more. The TeXlipse plugin allows you to edit and compile LaTeX documents directly in Eclipse, and compilation errors and warnings are shown in the Eclipse *Problems* dialog so that you can locate and fix the issues easily. The plugin also supports reference traversal so that you can locate the source line where a label or a citation is defined.

Eclipse is an entire development environment, so it may feel a bit heavy-weight for editing a document. If you are looking for a more light-weight option, check out TeXworks. TeXworks is a LaTeX editor that is packaged with the newer MiKTeX distributions, and it can be acquired from `http://www.tug.org/texworks/`.

And if you are attached to your *emacs* or *vim* editor, you can of course edit your LaTeX documents with them. Emacs at least has syntax coloring and you can compile your document with a key binding, so this may be a good option if you prefer working with the standard Linux text editors.

3.2 Graphics

When you use `pdflatex` to render your thesis, you can include PDF images directly, as shown by Figure 3.1 below.

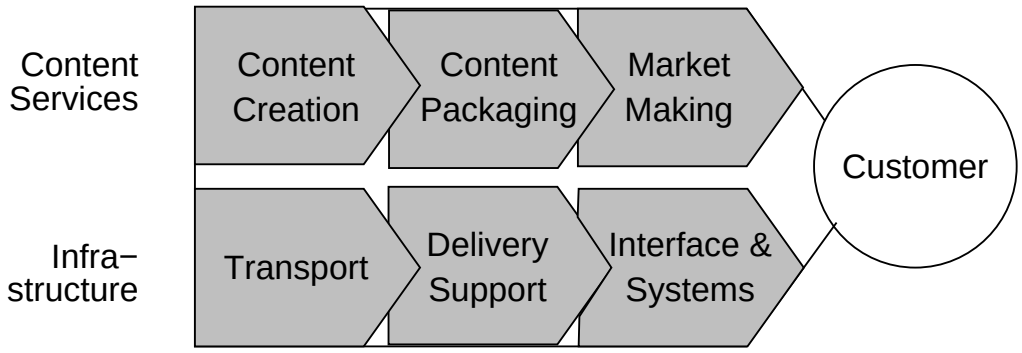


Figure 3.1: The INDICA two-layered value chain model.

You can also include JPEG or PNG files, as shown by Figure 3.2.

You can create PDF files out of practically anything. In Windows, you can download PrimoPDF or CutePDF (or some such) and install a printing

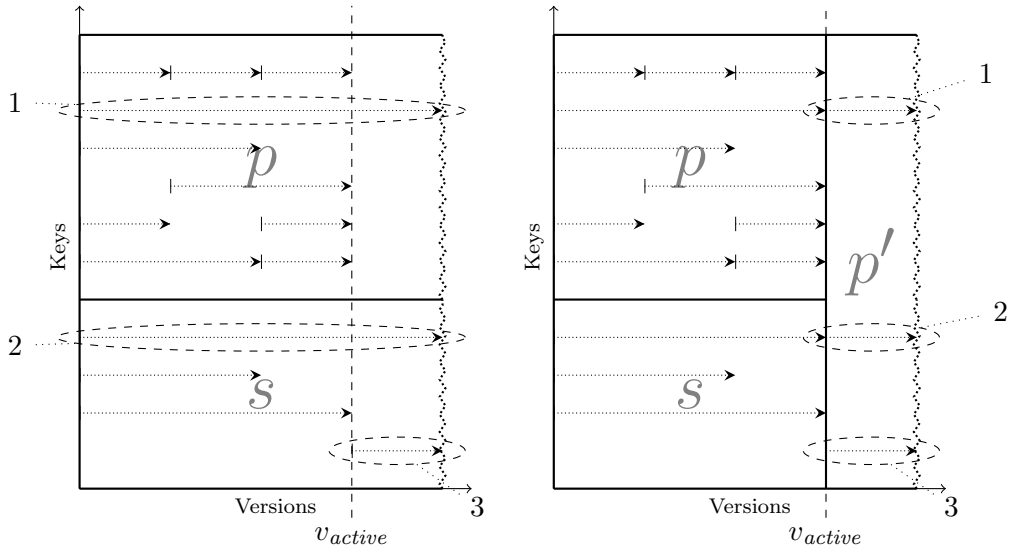
Figure 3.2: Eeyore, or Ihaa, a very sad donkey.

driver so that you can print directly to PDF files from any application. There are also tools that allow you to upload documents in common file formats and convert them to the PDF format. If you have PS or EPS files, you can use the tools `ps2pdf` or `epspdf` to convert your PS and EPS files to PDF.

Furthermore, most newer editor programs allow you to save directly to the PDF format. For vector editing, you could try Inkscape, which is a new open source WYSIWYG vector editor that allows you to save directly to PDF. For graphs, either export/print your graphs from OpenOffice Calc/Microsoft Excel to PDF format, and then add them; or use `gnuplot`, which can create PDF files directly (at least the new versions can). The terminal type is *pdf*, so the first line of your plot file should be something like `set term pdf ...`.

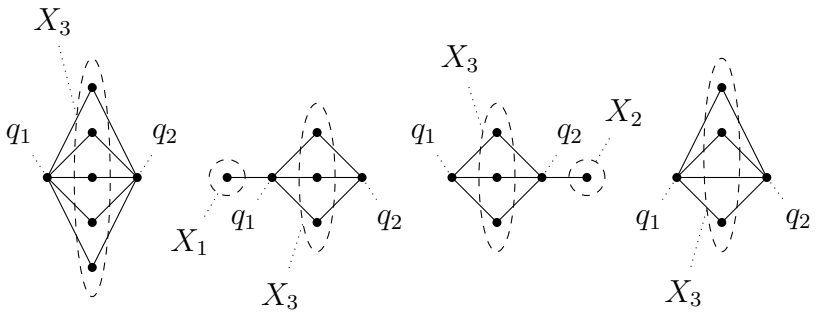
To get the most professional-looking graphics, you can encode them using the TikZ package (TikZ is a frontend for the PGF graphics formatting system). You can create practically any kind of technical images with TikZ, but it has a rather steep learning curve. Locate the manual (`pgfmanual.pdf`) from your LaTeX distribution and check it out. An example of TikZ-generated graphics is shown in Figure 3.3.

Another example of graphics created with TikZ is shown in Figure 3.4. These show how graphs can be drawn and labeled. You can consult the example images and the PGF manual for more examples of what kinds figures you can draw with TikZ.

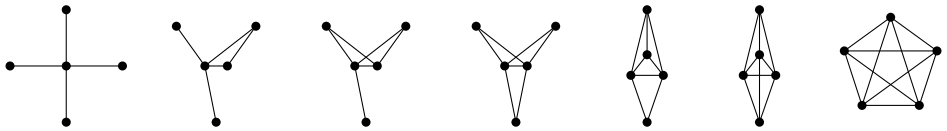


(a) Before (b) After

Figure 3.3: Example of a multiversion database page merge. This figure has been taken from the PhD thesis of Haapasalo [10].



(a) Examples of obstruction graphs for the Ferry Problem



(b) Examples of star graphs

Figure 3.4: Examples of graphs draw with TikZ. These figures have been taken from a course report for the graph theory course [9].

Chapter 4

Methods

You have now stated your problem, and you are ready to do something about it! *How* are you going to do that? What methods do you use? You also need to review existing literature to justify your choices, meaning that why you have chosen the method to be applied in your work.

If you have not yet done any (real) metholodogical courses (but chosen introduction courses of different areas that are listed in the methodological courses list), now is the time to do so or at least check through material of suitable methodological courses. Good methodologial courses that consentrates especially to methods are presented in Table 4.1. Remember to explain the content of the tables (as with figures). In the table, the last column gives the research area where the methods are often used. Here we used table to give an example of tables. Abbreviations and Acronyms is also a long table. The difference is that longtables can continue to next page.

Code	**Name**	**Methods**	**Area**
T-110.6130	Systems Engineering for Data Communications Software	Computer simulations, mathematical modeling, experimental research, data analysis, and network service business research methods, (agile method)	T-110
Mat-2.3170 Simulation (here is an example of multicolumn for tables)		Details of how to build simulations	T-110
S-38.3184	Network Traffic Measurements and Analysis	How to measure and analyse network traffic	T-110

Table 4.1: Research methodology courses

Chapter 5

Implementation

You have now explained how you are going to tackle your problem. Go do that now! Come back when the problem is solved!

Now, how did you solve the problem? Explain how you implemented your solution, be it a software component, a custom-made FPGA, a fried jelly bean, or whatever. Describe the problems you encountered with your implementation work.

Chapter 6

Evaluation

You have done your work, but that's[1] not enough.

You also need to evaluate how well your implementation works. The nature of the evaluation depends on your problem, your method, and your implementation that are all described in the thesis before this chapter. If you have created a program for exact-text matching, then you measure how long it takes for your implementation to search for different patterns, and compare it against the implementation that was used before. If you have designed a process for managing software projects, you perhaps interview people working with a waterfall-style management process, have them adapt your management process, and interview them again after they have worked with your process for some time. See what's changed.

The important thing is that you can evaluate your success somehow. Remember that you do not have to succeed in making something spectacular; a total implementation failure may still give grounds for a very good master's thesis—if you can analyze what went wrong and what should have been done.

[1] By the way, do *not* use shorthands like this in your text! It is not professional! Always write out all the words: "that is".

Chapter 7

Discussion

At this point, you will have some insightful thoughts on your implementation and you may have ideas on what could be done in the future. This chapter is a good place to discuss your thesis as a whole and to show your professor that you have really understood some non-trivial aspects of the methods you used...

Chapter 8

Conclusions

Time to wrap it up! Write down the most important findings from your work. Like the introduction, this chapter is not very long. Two to four pages might be a good limit.

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Appendix A

First appendix

This is the first appendix. You could put some test images or verbose data in an appendix, if there is too much data to fit in the actual text nicely.

For now, the Aalto logo variants are shown in Figure A.1.

(a) In English

(b) Suomeksi

(c) På svenska

Figure A.1: Aalto logo variants