UNIVERSITAT DE BARCELONA

FUNDAMENTALS OF DATA SCIENCE MASTER'S THESIS

Man-made Structures Detection from Space

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in the

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UNIVERSITAT DE BARCELONA

Abstract

Facultat de Matemàtiques i Informàtica

Man-made Structures Detection from Space

by Eduard RIBAS FERNÁNDEZ

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too…

Acknowledgements

The acknowledgments and the people to thank go here, don't forget to include your project advisor…

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Chapter 1

Introduction

1.1 Problem introduction, satellites, Satellogic, motivation

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1.1.1 Subsection 1

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1.2 Previous work, literature

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Chapter 2

Neural Networks

2.1 Neural Networks

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2.2 Convolutional Neural Networks

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Chapter 3

Building Datasets

In this chapter, we will give an overview of existing (labelled) aerial imagery datasets and outline the reasons why none of them is suitable for our investigation. Following this discussion, we will describe two approaches for obtaining our own labelled dataset.

3.1 Requirements and Considerations

Before we go into the presentation of existing labelled datasets we discuss the requirements that the dataset needs to fulfill in order to serve for the investigation in this thesis project. As a refresher, we want to detect human impact on aerial images and determine the dependency on resolution per pixel of a chosen evaluation metric. Ideally, the range for the resolutions should scale from a few tens of centimeters to a few tens of meters, whereas the images with low resolution can be generated from the high resolution images by downsampling. Having in mind previous arguments, we mainly need to consider three aspects.

First, we need to have imagery data with labels that can be used to clearly distinguish between existing and non-existing human impact, respectively. This impact might be classified pixel wise, or as binary classification for the entire image, or as multi-class classification that can be translated into binary labelling. Second, we need a balanced dataset of approximately the same number of images for both labels, and variations of the images as large as possible with respect to different terrains. Third, the images need to have a resolution per pixel which is equal or better than 1m. Also, the height and width of the images should measure at least 500×500 pixels, so that one has enough room for downsampling.

3.2 Existing Datasets

In table **??** we have summarized the most relevant remote sensing datasets with ground truth labels, that can be found in literature. The table lists the name of the dataset together with the bibliographic reference. It also details the data source for the images. Further it contains a description about the number of images, the resolution of the images, the size (in pixel) of the images where images are squared, and the number of categories.

The datasets were collected using different publicly available data sources. These range from pure low resolution satellite imagery (Sentinel-2) to high-resolution images taken with an aircraft (USGS) to a mix of different image sources (Google Earth).

The satellite images have a resolution of equal or larger than 10 m and they are collected with the Sentinel-2 satellites of the European Earth observation program Copernicus. Although the datasets from this source (BigEarthNet and EuroSat) are comparatively large, they do not suffice for our purpose, because the resolution is not good enough and the images are too small.

name	source	images	resolution (m)	size (pixel)	categories
BigEarthNet [**sumbul2019**]	Sentinel-2	590,326	10, 20, 60	120, 60, 20	~ 50
EuroSAT [**helber2017**]	Sentinel-2	27,000	10	64	10
UCMerced [**yang2010**]	USGS	2100	0.3	256	21
DeepSat [**basu2015**]	USGS	405,000	1	28	6
AID [**xia2016**]	Google Earth	10,000	0.5 - 8	600	30
PatternNet [**zhou2017**]	Google Earth	30,400	0.06 - 4.69	256	38

TABLE 3.1: Publicly available remote sensing datasets with labels.

The USGS National Map Urban Area Imagery collection (*see link*) was utilized to collect remote sensing datasets in the two works UCMerced and DeepSat, where the former is the dataset that comes closest to our requirements. It has 21 categories of which only 2 belong to images without human impact, while the other 19 show human impact. The DeepSat dataset unfortunately consists of image patches which are only 28×28 large, so that we aren't able to study these images as a function of resolution.

The datasets using Google Earth as data source are collected using either the Google Earth or the Google Maps API. These images vary in resolution as well as in their original data provider since Google accesses several data sources. Both datasets, the AID and the PatternNet dataset, have about 30 categories with several images in each category. Here, different categories have different resolutions per pixel, and again most of the categories relate to urban areas so that we do not have sufficient images without human impact. Even the categories that in principle should not show human influence contain images that break this rule.

Overall, the main issue with these datasets stems from the fact that non of them was collected with the purpose to analyze the human footprint and therefore they are very unbalanced, and do not contain sufficient variety of images for the classes without human influence. Therefore, we decided to collect and label images by ourselfes. In our first approach we used the Google Maps API, and in our final approach we used datasets from the USGS Aerial Imagery collection.

3.3 Google Maps

Google has a public API that allows for querying images from their service Google Maps. In its most basic form, the API accepts as input parameters a lattitude and longitude, a zoom, and the number of pixels to return. Given this set of parameters one can calculate the resolution per pixel (see [**gmaps_res_per_m**]), which is given by

$$\frac{meter}{pixel} = \frac{156543.03392 \cdot cos(\frac{lattitude \cdot \pi}{180})}{2^{zoom}}. \tag{3.1}$$

3.4 USGS, Land Cover

3.4.1 Getting the Data

To be able to construct a balanced and representative dataset we first decided to focus on images of the United States, which allows for a large variety of different terrains. We then used as data source the Aerial Imagery datasets from USGS Earth-explorer (*see link*) which we combined with information about Land Cover and Land Use available from the USGS Land Cover Viewer (*see link*).

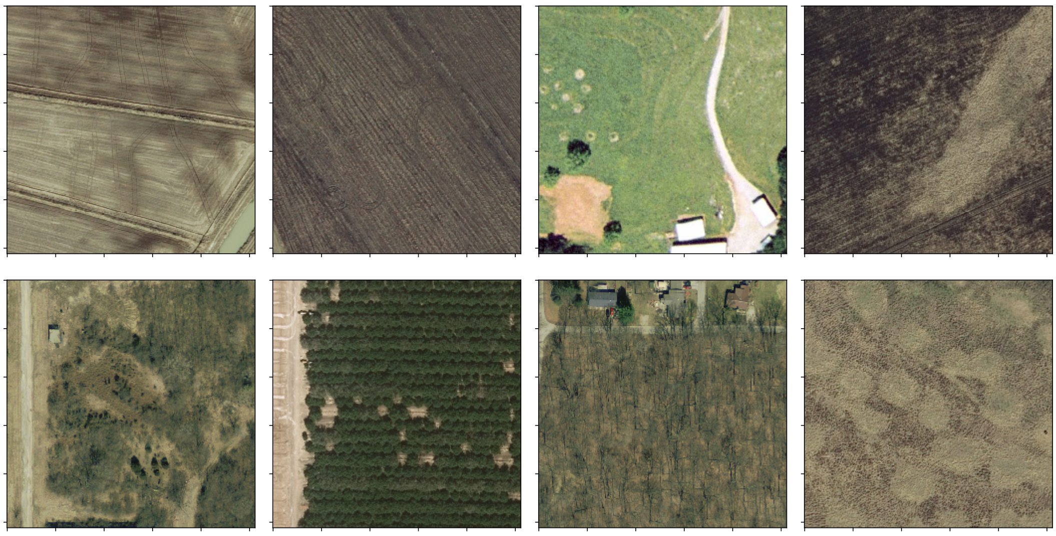

FIGURE 3.1: **Example images of category Agricultue.** All images in this figure show clear signs of human impact. The images have a size of 512 $\times$ 512 pixels and a resolution of 0.3m per pixel.

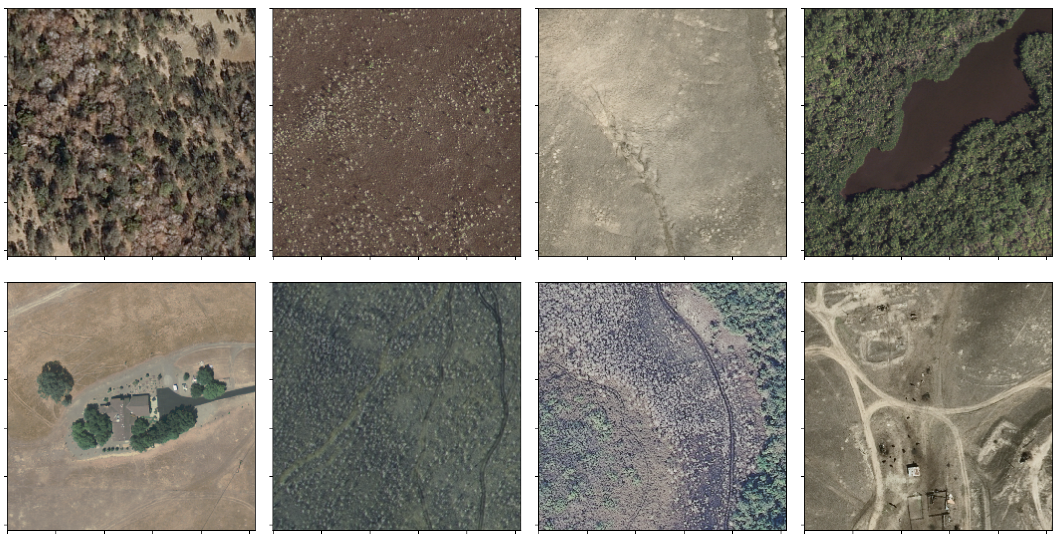

FIGURE 3.2: **Example images of category Shrubland-grassland.** The images in the first row do not contain any human influence, while the images in the second row show influence by humans. The images in this figure have a size of 512 $\times$ 512 pixels and a resolution of 0.3m per pixel.

When looking for images we excluded cities and highly developed urban areas, and instead focussed on unpopulated areas. Specifically, we limited our image search to the four Land Use categories Agriculture, Shrubland-Grassland, Semi-Desert, Forest-Woodland that can be found in the USGS Land Cover Viewer. Note

FIGURE 3.3: **Example images of category Forest-woodland.** The images in the first row do not contain any human influence, while the images in the second row show influence by humans. The images in this figure have a size of 512 × 512 pixels and a resolution of 0.3m per pixel.

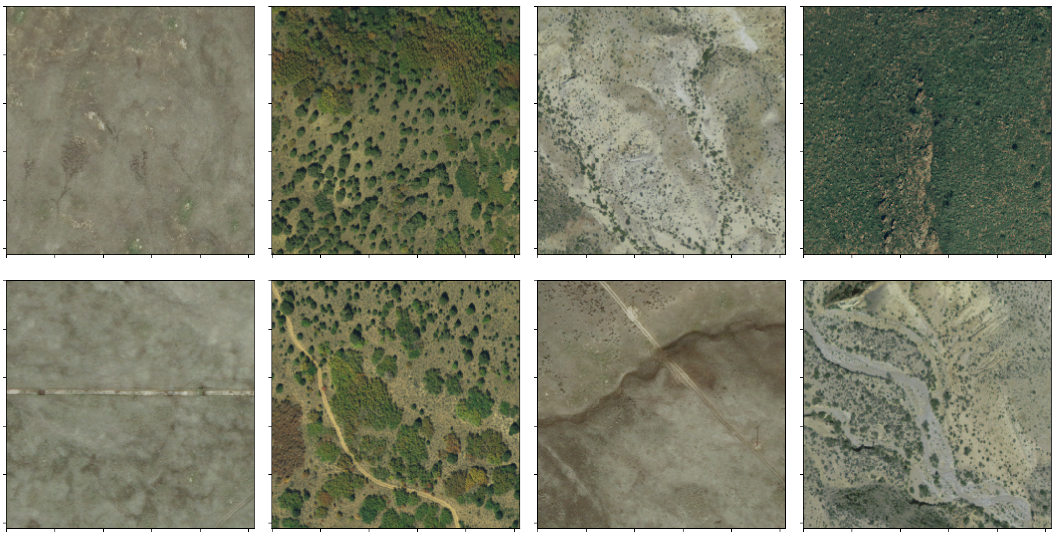

FIGURE 3.4: **Example images of category Semi-desert.** The images in the first row do not contain any human influence, while the images in the second row show influence by humans. The images in this figure have a size of 512 × 512 pixels and a resolution of 0.3m per pixel.

that these categories served as a rough geographic reference to pin down geolocations of interest, in order to guarantee a dataset with a good variety of different terrains. We also found that it is harder to find images without human, which is why we selected many images from national parks. However, within a given area/terrain we always tried to have images with and without impact.

Once an area was pointed out as a region of interest, we located it on USGS Earthexplorer and downloaded images from that area. In particular, we constructed two datasets with $0.3m$ and $1m$ resolution, respectively. The former was taken from the category High Resolution Orthoimagery and the latter from the category National Agriculture Imagery Program (NAIP). Note that the images in these categories usually have a height and a width of several thousand pixels, and hence oocupy a few hundreds of Megabytes of disk space. We cropped smaller images out of the raw images, which will be discussed in more detail in the following section. Overall, we downloaded about 100 images for each dataset.

3.4.2 Data Processing and Labeling

Our data processing pipeline consists of the following steps:

- Download large raw images
- Crop images of size 512×512 pixels
- Label images with either zero (no human impact), one (minimal human impact), two (obvious human impact)
- Degrade images, i.e. reduce number of pixels and thereby resolution per pixel

Let us discuss each of these steps in more detail. Every raw image was processed, whereas the processed images of size 512×512 were saved in a folder named by its category. Note that every raw image resulted in approximately $100 - 150$ processed images, so that we ended up with more than 10,000 images for each dataset.

Within each category of the processed images we labelled a selected portion of the images, by moving them into the folder with the respective label name. The folder structure we used is the following, where pointy brackets ’<parameter>’ indicate a parameter and ’etc’ stands for the three label folders.

```
{raw-images-}usgs-<pixels>-res<resolution>m
├── semi-desert
│   ├── label-0
│   ├── label-1
│   └── label-2
├── agriculture
│   └── label-2
├── shrubland-grassland
│   ├── label-0
│   ├── label-1
│   └── label-2
└── semi-desert
    ├── label-0
    ├── label-1
    └── label-2
```

When labelling we sticked to the following rules. First, we classified images with no human impact at all into the class with label zero, while we classified images with very clear human influence into the class with label two. Ambigious images, i.e. images with minimal human trace were classified into label one. Second, we’ve put major effort into creating datasets that contain images of similar texture spread across all classes. If we for example classified a set of images of a certain forest type into the class with label zero we classified another set of images with a similar forest type, but containing a building or a street, into the class with label two. The same applies for images in class with label one when they contain e.g. a small walking path. We followed the latter rule for all categories except Agriculture. The Agriculture

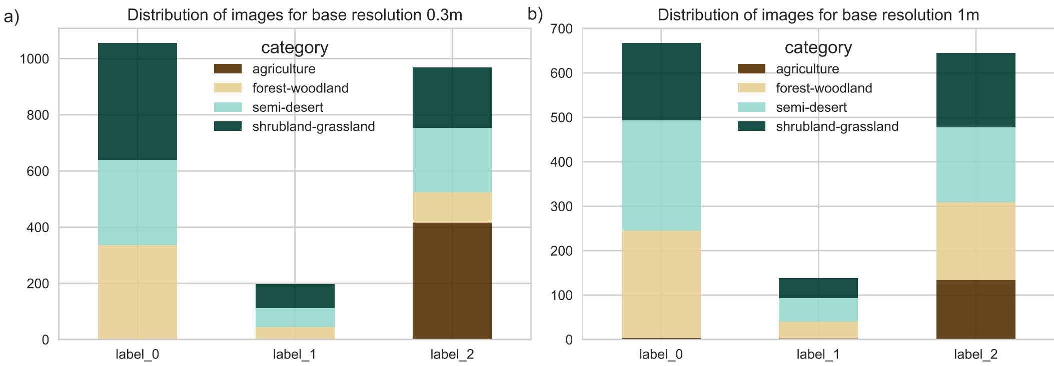

FIGURE 3.5: **Number of images per category and label.** (a) Distribution of images for dataset with resolution of 0.3m per pixel. (b) Distribution of images for dataset with resolution of 1m per pixel.

images all show human influence, and were therefore all classified with label two. By sticking to these rules, we are able to guarantee that the algorithm learns features that relate to human impact, and not to image artefacts such as color or texture.

In Figures **??** - **??** we display sample images for each of the four categories Agriculture, Shrubland-grassland, Forest-woodland and Semi-desert. These images belong to the dataset which has a resolution per pixel of 0.3m. Note that in Figs. **??** - **??** the first row represents images of label zero and the second row shows images that belong to label two. As mentioned above, the images in Fig. **??** all contain human influence.

The distribution of categories and labels is shown in Fig. **??**. Overall, for the 0.3m dataset we classified about 2200 images, and for the 1m dataset we classified about 1450 images. During classification our main goal consisted in creating a balanced dataset between labels zero and two. The minority of images, roughly 10% of all classified images were assigned to label 1. These images were used at random to investigate the behaviour of the Machine Learning classifier, which is discussed in chapter **??** VERIFY.

The last step of the data processing pipeline consisted in downsampling the processed and labelled images, to obtain images with a lower resolution per pixel. We used a Lanczos filter [**duchon1979**] for the sampling, which is based on a sinusoidal kernel. In Fig. **??**) we show a few selected resolutions for an example image from the agriculture category. Note that here we only schematically depict an example in order to illustrate the process. However, in our Machine Learning pipeline the images are downsampled on the fly and the result of this process is not stored on disk.

For this particular image one can observe how certain image features disappear as the image quality is decreased. Above a resolution of around 3m per pixel one is not able anymore to identify the building close to the right corner of the image. The texture of the track that leads up to the building is blurred above a resolution of around 4m per pixel. This shows how different elements in an image are not recognizable anymore once the resolution is worse than their characteristic resolution.

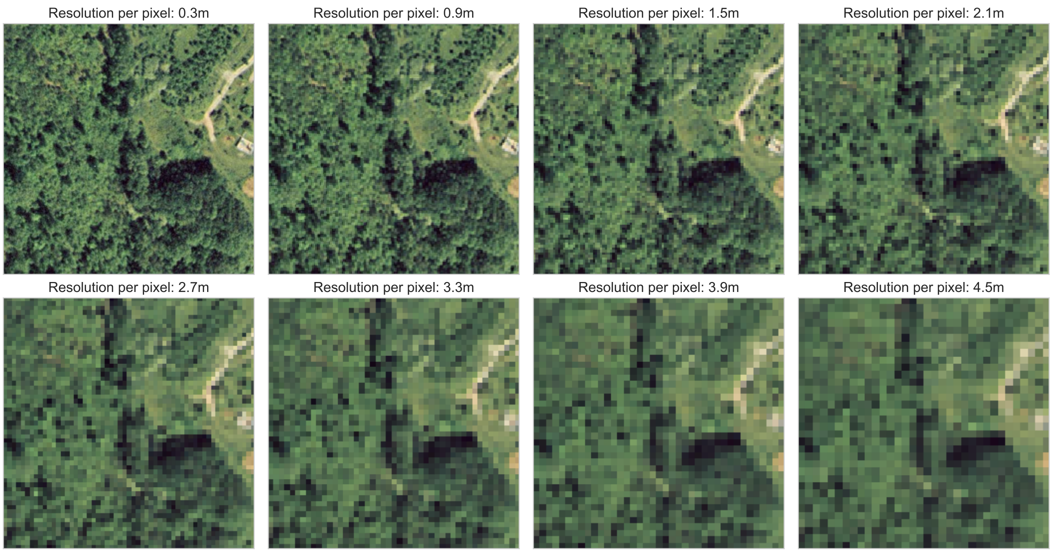

FIGURE 3.6: **Example of image downsampling**. The upper left image has the base resolution, 0.3m per pixel, and a size of 512×512 pixels whereas the lower right image has the worst resolution, 4.5m per pixel, and a size of 34×34 pixels. All intermediate images are downsampled by a factor corresponding to the resolution of the actual image divided by the base resolution. For instance, for the lower right image it is 15.

Chapter 4

Deep Learning Approach

4.1 Features

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4.2 Model

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Chapter 5

Results

5.1 Results

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5.2 Cost and Environment impact

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Chapter 6

Conclusions

6.1 Main Section 1

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Chapter 7

Chapter Title Here

7.1 Welcome and Thank You

Welcome to this LaTeX Thesis Template, a beautiful and easy to use template for writing a thesis using the LaTeX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in LaTeX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

LaTeX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even *heavy* mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on LaTeX to make them look stunning.

7.2 Learning LaTeX

LaTeX is not a WYSIWYG (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for LaTeX is actually a simple, plain text file that contains *no formatting*. You tell LaTeX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use *italic text for emphasis*, I write the `\emph{text}` command and put the text I want in italics in between the curly braces. This means that LaTeX is a "mark-up" language, very much like HTML.

7.2.1 A (not so short) Introduction to LaTeX

If you are new to LaTeX, there is a very good eBook – freely available online as a PDF file – called, "The Not So Short Introduction to LaTeX". The book's title is typically shortened to just *lshort*. You can download the latest version (as it is occasionally updated) from here: http://www.ctan.org/tex-archive/info/lshort/english/lshort.pdf

It is also available in several other languages. Find yours from the list on this page: http://www.ctan.org/tex-archive/info/lshort/

It is recommended to take a little time out to learn how to use LaTeX by creating several, small 'test' documents, or having a close look at several templates on:
http://www.LaTeXTemplates.com

Making the effort now means you're not stuck learning the system when what you *really* need to be doing is writing your thesis.

7.2.2 A Short Math Guide for LaTeX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, "A Short Math Guide for LaTeX". It can be found online here: `http://www.ams.org/tex/amslatex.html` under the "Additional Documentation" section towards the bottom of the page.

7.2.3 Common LaTeX Math Symbols

There are a multitude of mathematical symbols available for LaTeX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page: `http://www.sunilpatel.co.uk/latex-type/latex-math-symbols/`

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the LaTeX command for the symbol you need.

7.2.4 LaTeX on a Mac

The LaTeX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working LaTeX environment and work flow.

MacTeX includes a custom dedicated LaTeX editor called TeXShop for writing your '`.tex`' files and BibDesk: a program to manage your references and create your bibliography section just as easily as managing songs and creating playlists in iTunes.

7.3 Getting Started with this Template

If you are familiar with LaTeX, then you should explore the directory structure of the template and then proceed to place your own information into the *THESIS INFORMATION* block of the `main.tex` file. You can then modify the rest of this file to your unique specifications based on your degree/university. Section **??** on page **??** will help you do this. Make sure you also read section **??** about thesis conventions to get the most out of this template.

If you are new to LaTeX it is recommended that you carry on reading through the rest of the information in this document.

Before you begin using this template you should ensure that its style complies with the thesis style guidelines imposed by your institution. In most cases this template style and layout will be suitable. If it is not, it may only require a small change to bring the template in line with your institution's recommendations. These modifications will need to be done on the `MastersDoctoralThesis.cls` file.

7.3.1 About this Template

This LaTeX Thesis Template is originally based and created around a LaTeX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/

Steve's `ecsthesis.cls` was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil's site here: http://www.sunilpatel.co.uk/thesis-template

Sunil's template was made available through http://www.LaTeXTemplates.com where it was modified many times based on user requests and questions. Version 2.0 and onwards of this template represents a major modification to Sunil's template and is, in fact, hardly recognisable. The work to make version 2.0 possible was carried out by Vel and Johannes Böttcher.

7.4 What this Template Includes

7.4.1 Folders

This template comes as a single zip file that expands out to several files and folders. The folder names are mostly self-explanatory:

Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate `.tex` file. An example and template are included in the directory.

Chapters – this is the folder where you put the thesis chapters. A thesis usually has about six chapters, though there is no hard rule on this. Each chapter should go in its own separate `.tex` file and they can be split as:

- Chapter 1: Introduction to the thesis topic
- Chapter 2: Background information and theory
- Chapter 3: (Laboratory) experimental setup
- Chapter 4: Details of experiment 1
- Chapter 5: Details of experiment 2
- Chapter 6: Discussion of the experimental results
- Chapter 7: Conclusion and future directions

This chapter layout is specialised for the experimental sciences, your discipline may be different.

Figures – this folder contains all s for the thesis. These are the final images that will go into the thesis document.

7.4.2 Files

Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by LaTeX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in LaTeX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells LaTeX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by LaTeX. It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell LaTeX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell LaTeX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there. After you put your own information into the *THESIS INFORMATION* block – you have now started your thesis!

Files that are *not* included, but are created by LaTeX as auxiliary files include:

main.aux – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the `main.aux` file. Whereas the `.bib` file contains all the references you have, this `.bbl` file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main `.aux` file.

main.lof – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file. It tells LaTeX how to build the *List of Figures* section.

main.log – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file. It contains messages from LaTeX, if you receive errors and warnings from LaTeX, they will be in this `.log` file.

main.lot – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file. It tells LaTeX how to build the *List of Tables* section.

main.out – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file.

So from this long list, only the files with the `.bib`, `.cls` and `.tex` extensions are the most important ones. The other auxiliary files can be ignored or deleted as LaTeX and BibTeX will regenerate them.

7.5 Filling in Your Information in the `main.tex` File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the `main.tex` file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the third large block titled *THESIS INFORMATION* where you can see the entries for *University Name*, *Department Name*, etc …

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the `http://` for this. If you don't want these to be linked, simply remove the `\href{url}{name}` and only leave the name.

When you have done this, save the file and recompile `main.tex`. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

7.6 The `main.tex` File Explained

The `main.tex` file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the LaTeX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of LaTeX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the *DECLARATION PAGE* block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is *not* done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

Finally, there is the block where the chapters are included. Uncomment the lines (delete the `%` character) as you write the chapters. Each chapter should be written in its own file and put into the *Chapters* folder and named `Chapter1`, `Chapter2`, etc... Similarly for the appendices, uncomment the lines as you need them. Each appendix should go into its own file and placed in the *Appendices* folder.

After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called *authoryear*) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

7.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

One of the most important (and most difficult) things to keep track of in such a long document as a thesis is consistency. Using certain conventions and ways of doing things (such as using a Todo list) makes the job easier. Of course, all of these are optional and you can adopt your own method.

7.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the `oneside` option of the `documentclass` command at the top of the `main.tex` file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of `main.tex`. The spacing can be changed similarly by replacing the `singlespacing` with `onehalfspacing` or `doublespacing`.

7.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in `main.tex`.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

7.7.3 References

The `biblatex` package is used to format the bibliography and inserts references such as this one [**Reference1**]. The options used in the `main.tex` file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication. Multiple references are separated by semicolons (e.g. [**Reference2**, **Reference1**]) and references with more than three authors only show the first author with *et al.* indicating there are more authors (e.g. [**Reference3**]). This is done automatically for you. To see how you use references, have a look at the `Chapter1.tex` source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come *before* the punctuation mark if there is one (such as a comma or period). The same goes for footnotes[1]. You can change this but the most important thing is to keep the convention consistent throughout the thesis. Footnotes themselves should be full, descriptive sentences (beginning with a capital

[1] Such as this footnote, here down at the bottom of the page.

letter and ending with a full stop). The APA6 states: "Footnote numbers should be superscripted, [...], following any punctuation mark except a dash." The Chicago manual of style states: "A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis."

The bibliography is typeset with references listed in alphabetical order by the first author's last name. This is similar to the APA referencing style. To see how LaTeX typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

A Note on bibtex

The bibtex backend used in the template by default does not correctly handle unicode character encoding (i.e. "international" characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in `main.tex`: *`backend=bibtex`* and changing it to *`backend=biber`*. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type `biber main` and biber will compile your bibliography. You can then compile `main.tex` as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with biber instead of bibtex, see here for how to do this for various editors.

7.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\tabhead{Groups} & \tabhead{Treatment X} & \tabhead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8\\
2 & 0.17 & 0.7\\
3 & 0.24 & 0.75\\
4 & 0.68 & 0.3\\
\bottomrule\\
\end{tabular}
\end{table}
```

You can reference tables with `\ref{<label>}` where the label is defined within the table environment. See `Chapter1.tex` for an example of the label and citation (e.g. Table **??**).

7.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the *Figures* folder). The way to insert figures into your thesis is to use a code template like this:

TABLE 7.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

```
\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}
```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.

FIGURE 7.1: An electron (artist's impression).

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly where it should go (in relation to the text) and so LaTeX puts it at the top of the next page. Positioning figures is the job of LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure **??**). The `\caption` command contains two parts, the first part, inside the square brackets is the title that will appear in the *List of Figures*, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The `\decoRule` command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

LaTeX is capable of using images in pdf, jpg and png format.

7.7.6 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, be sure that LaTeX will make it look beautiful, even though it won't be able to solve the equations for you.

The "Not So Short Introduction to LaTeX" (available on CTAN) should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, "A Short Math Guide to LaTeX" and can be downloaded from: `ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf`

There are many different LaTeX symbols to remember, luckily you can find the most common symbols in The Comprehensive LaTeX Symbol List.

You can write an equation, which is automatically given an equation number by LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \tag{7.1}$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by LaTeX. If you don't want a particular equation numbered, use the unnumbered form:

```
\[ a^{2}=4 \]
```

7.8 Sectioning and Subsectioning

You should break your thesis up into nice, bite-sized sections and subsections. LaTeX automatically builds a table of Contents by looking at all the `\chapter{}`, `\section{}` and `\subsection{}` commands you write in the source.

The Table of Contents should only list the sections to three (3) levels. A `chapter{}` is level zero (0). A `\section{}` is level one (1) and so a `\subsection{}` is level two (2). In your thesis it is likely that you will even use a `subsubsection{}`, which is level three (3). The depth to which the Table of Contents is formatted is set within `MastersDoctoralThesis.cls`. If you need this changed, you can do it in `main.tex`.

7.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own `Chapter1.tex` and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

Guide written by —
Sunil Patel: www.sunilpatel.co.uk
Vel: LaTeXTemplates.com

Appendix A

Frequently Asked Questions

A.1 How do I change the colors of links?

The color of links can be changed to your liking using:
`\hypersetup{urlcolor=red}`, or
`\hypersetup{citecolor=green}`, or
`\hypersetup{allcolor=blue}`.
If you want to completely hide the links, you can use:
`\hypersetup{allcolors=.}`, or even better:
`\hypersetup{hidelinks}`.
If you want to have obvious links in the PDF but not the printed text, use:
`\hypersetup{colorlinks=false}`.