ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Segmentation of Geometrical Shapes in Aerial Images

Master's Thesis

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April 2018

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Abstract

This example thesis briefly shows the main features of our thesis style,
and how to use it for your purposes.

Acknowledgment

Thanks Mum!

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Chapter 4

Experiments and Results

In this chapter, the entire experimental process is presented, from the acquisition of the ground truth dataset (see section 4.1), to the implementation, training and prediction phases of the R-PolygonRNN (see section 4.2), and finally to the results evaluation and analysis (see section 4.3).

4.1 Ground Truth

Our ground truth dataset consists of satellite images and buildings' coordinates, which are used as inputs and labels respectively when training. In this project, all of the satellite images are collected from Google Static Maps API and all of the latitude and longitude coordinates of the polygon vertices of buildings are collected from OpenStreetMap. For details of the two APIs mentioned above, please refer to subsections 4.1.1 and 4.1.2.

As mentioned in section 3.3, the training phase of our model R-PolygonRNN requires two different kinds of ground truth dataset, areas with multiple bounding boxes for FPN and buildings with geometrical shapes for PolygonRNN, all of which are illustrated in subsection 4.1.3.

Since the whole dataset is collected from two different sources, the problem of inconsistency may exist. Subsection 4.1.4 describes details of the problems in the ground truth dataset, and proposes a solution to adjust the shift between buildings' images and polygons.

4.1.1 Google Static Maps API

Google Static Maps API[1] provides an interface that implements maps as high-resolution images. Users can download customized map based on URL with different parameters, which is sent through a standard HTTPS request.

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[1]`https://developers.google.com/maps/documentation/static-maps/`

The parameters in URL includes the map type (satellite, roadmap, etc.), latitude and longitude coordinates of the image center, the resolution of the image, the zoom level, and the scale. For the usage of the Google Static Maps API, please refer to section A.1 in appendices. Figure 4.1(a) and 4.1(b) shows two types of images can be obtained by Google Static Maps API.

<div align="center">

(a) satellite image   (b) roadmap image   (c) hybrid image

</div>
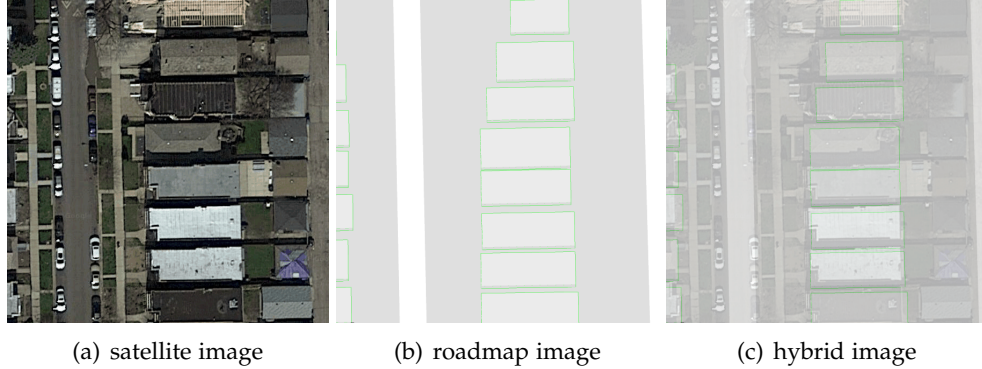
Figure 4.1: Example images downloaded through Google Static Maps API. (a) and (b) are obtained directly by the API, with 41.9399708 degrees north latitude, 87.7380649 degrees west longitude of the center (located in Chicago), both width and height 600 pixels, zoom level 20 and scale 1, but different in map types. (c) is obtained by overlaying (a) with (b), with 75% opacity. It can be clearly seen that the two images cannot match very well.

We would have liked to obtain buildings' coordinates from Google Static Maps API as well, but we find that the API does not provide such information directly. Instead, it gives the styled roadmap images like figure 4.1(b), where querying coordinates requires further corner detection but the boundaries may be still inaccurate (see figure 4.1(c) for example). Thus, this thesis project, only satellite images from Google Static Maps API are used.

4.1.2 OpenStreetMap

OpenStreetMap[2] provides an interface that implements a map as a XML format `.osm` file. The file contains all the information which can be used to recover the map. When the map's bounding box is given, users can retrieve the latitude and longitude coordinates of the buildings' vertices and roads' central lines within the map. For the usage of OpenStreetMap and the format of the `.osm` file, please refer to section A.2 in appendices.

The coordinates obtained by the API is the original latitude and longitude coordinates of the buildings' vertices, which cannot be directly used for training. We need to convert them to relative pixel coordinates with regards to an given satellite image.

---

[2]https://www.openstreetmap.org/

As a matter of fact, every fixed point on the earth can correspond to a unique pixel on the map at a specific zoom level. This projection process can be regarded as a function. Since we have already known the relative pixel coordinates of the image center (half width and half height), the projection for an arbitrary point with given latitude and longitude coordinates can be therefore computed. This process can be described as following equations.

$$(c_x, c_y) = (\frac{w}{2}, \frac{h}{2}) = f(c_{lon}, c_{lat}, z) + (\Delta_x, \Delta_y), \tag{4.1}$$

$$(p_x, p_y) = f(p_{lon}, p_{lat}, z) + (\Delta_x, \Delta_y), \tag{4.2}$$

where f is the function that projects latitude and longitude coordinates to global pixel coordinates (see A.3 in appendices for more details), c is the image center, p is an arbitrary point, the subscripts x, y, lon, lat mean the relative pixel and longitude and latitude coordinates respectively, z is the zoom level, Δ is the translation constant from the global to the relative pixel coordinate system. Thus, we have

$$(p_x, p_y) = f(p_{lon}, p_{lat}, z) - f(c_{lon}, c_{lat}, z) + (\frac{w}{2}, \frac{h}{2}), \tag{4.3}$$

for any arbitrary point p.

4.1.3 Areas and Buildings

As mentioned in section 3.3, R-PolygonRNN is formed by FPN and PolygonRNN. However, the training phase of these two models requires two different kinds of ground truth dataset.

Areas for FPN   In subsection 3.2.2 we have shown that FPN aims at finding rectangular regions of interests. Thus, training FPN generally requires a relatively large image with several objects in it. When considering our problem, an example of the ground truth can be an area of a city with several bounding boxes. Each box contains a single building, regardless of its tight polygon outline. Figure 4.2 gives an example area for training FPN and its visualized ground truth label.

Buildings for PolygonRNN   In section 3.1 we have mentioned that PolygonRNN can only deal with images with single object, meaning that the bounding box of the object should be first given. Thus, training PolygonRNN generally requires a relatively small image with single object, as well as the information of its polygon outline. When it comes to our problem, an example of the ground truth can be a building with some padding and the pixel coordinates of building's vertices. Figure 4.3 gives example buildings for training PolygonRNN and its visualized ground truth label.

(a) example area   (b) example area with bounding boxes

Figure 4.2: An example area in Zurich for training FPN. (a) is the original satellite image obtained by Google Static Maps API. (b) is (a) covered by multiple bounding boxes of buildings, which is visualized based on the ground truth.

(a)   (b)   (c)   (d)

(e)   (f)   (g)   (h)
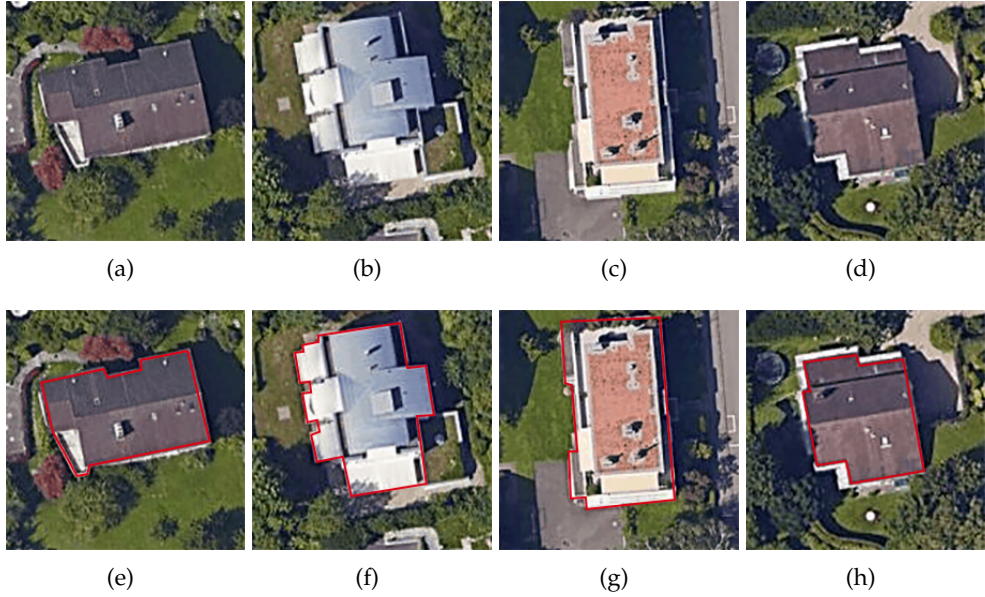
Figure 4.3: Example buildings in Zurich for training PolygonRNN. (a)-(d) are the original satellite images obtained by Google Static Maps API. (e)-(g) are (a)-(d) covered by the corresponding polygons' edges, which are visualized based on the ground truth.

4.1.4 Problems and Adjustments

Recall that the satellite images and polygons' coordinates are collected from two different sources, the problem of inconsistency may exist. That is to say, the polygon and the actual building we see in the image may not match well in some cases. This inconsistency is mainly reflected in the following aspects.

General Shift   The figure shows a typical shift example in the dataset.

$$(figure placeholder)$$

Polygon Size   Sometimes the polygon size is different from the actual building size as well. Through rough observation, most of this kind of polygon is smaller than the reality. This is because OpenStreetMap measures the bottom of the building and the aerial image is taken from the top. The roof of the house we see from the top is usually large than the floor area.

$$(figure placeholder)$$

Angle Issue   Some very tall buildings may suffer from the angle issue. This is because the satellite cannot always be vertically right above the building, so the side of these very high buildings will be photographed.

$$(figure placeholder)$$

Adjacent Buildings   Some adjacent buildings will be very close together, and some even share a common roof. Thus, from the satellite image, it is generally difficult to distinguish the boundaries between them. However, these buildings are separated in the dataset of OpenStreetMap. It means that where there are originally edges between buildings, it looks like there is no edge in the image. This would cause the inaccuracy of the bounding boxes, as well as the polygon shapes in the ground truth dataset.

$$(figure placeholder)$$

Problems such as angle issue and adjacent buildings are unsolvable unless the data source can be corrected. What we can improve is to tackle the general shift and the polygon size problem and make the image-polygon pairs more matching. By observing, we can get to some conclusions for a matching image-polygon pair.

- The color variance of image pixels covered by polygon generally reaches the local minimum, because the roof of a building usually has only one color or several similar colors.

- The polygon edges are generally a subset of the output of the edge detection (e.g. Sobel, Canny), which is performed on the image.

- The polygon vertices are generally a subset of the output of the corner detection (e.g. Harris, SIFT), which is performed on the image.

Based on these observations, we propose a brute force shift adjustment method. Briefly, we resize and translate the initial polygon within a certain range, and traverse all the cases to see where the minimum color variance, maximum edge and corner coverage are reached. This method can adjust the shift problem to some extent.

$$(figure placeholder)$$

4.2 Implementation Details

4.2.1 Configuration

building

4.2.2 Training

Furthermore, buildings around the edges of areas are typically ignored

more likely to be incomplete. In this case, the polygon would be clipped by the edges, resulting in new vertices, which can be very hard to compute.

$$(figure placeholder)$$

Although buildings can extract from areas

Therefore, in this project, two different kinds of ground truth dataset are collected separately. batchsizeBuildingareaPolygonRNNbatchsize

4.2.3 Prediction

Beam search

4.3 Experiment Results

Dummy text.

4.3.1 Single Building Segmentation

Dummy text.

4.3.2 Buildings Localization

Dummy text.

4.3.3 R-PolygonRNN

Beam search

Example Subsubsection

Dummy text.

Example Paragraph   Dummy text.

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Chapter 5

Problems and Future Work

Dummy text.

5.1 Problems

Dummy text.

5.1.1 Problem 1

Dummy text.

5.1.2 Problem 2

Dummy text.

Example Subsubsection

Dummy text.

Example Paragraph   Dummy text.

Example Subparagraph   Dummy text.

5.2 Future Work

Dummy text.

5.2.1 Ground Truth

Dummy text.

5.2.2 Training Phase

Dummy text.

5.2.3 Model Generalization

Dummy text.

Chapter 6

Introduction

This is version `v1.4` of the template.

We assume that you found this template on our institute's website, so we do not repeat everything stated there. Consult the website again for pointers to further reading about LaTeX. This chapter only gives a brief overview of the files you are looking at.

6.1 Features

The rest of this document shows off a few features of the template files. Look at the source code to see which macros we used!

The template is divided into TeX files as follows:

1. `thesis.tex` is the main file.

2. `extrapackages.tex` holds extra package includes.

3. `layoutsetup.tex` defines the style used in this document.

4. `theoremsetup.tex` declares the theorem-like environments.

5. `macrosetup.tex` defines extra macros that you may find useful.

6. `introduction.tex` contains this text.

7. `sections.tex` is a quick demo of each sectioning level available.

8. `refs.bib` is an example bibliography file. You can use BibTeX to quote references. For example, read [**?**] if you can get a hold of it.

6.1.1 Extra package includes

The file `extrapackages.tex` lists some packages that usually come in handy. Simply have a look at the source code. We have added the following comments based on our experiences:

REC This package is recommended.

OPT This package is optional. It usually solves a specific problem in a clever way.

ADV This package is for the advanced user, but solves a problem frequent enough that we mention it. Consult the package's documentation.

As a small example, here is a reference to the Section *Features* typeset with the recommended *varioref* package:

See Section 6.1 on the preceding page.

6.1.2 Layout setup

This defines the overall look of the document – for example, it changes the chapter and section heading appearance. We consider this a 'do not touch' area. Take a look at the excellent *Memoir* documentation before changing it.

In fact, take a look at the excellent *Memoir* documentation, full stop.

6.1.3 Theorem setup

This file defines a bunch of theorem-like environments.

Theorem 6.1 *An example theorem.*

Proof Proof text goes here. □

Note that the q.e.d. symbol moves to the correct place automatically if you end the proof with an `enumerate` or `displaymath`. You do not need to use `\qedhere` as with *amsthm*.

Theorem 6.2 (Some Famous Guy) *Another example theorem.*

Proof This proof

1. ends in an enumerate. □

Proposition 6.3 *Note that all theorem-like environments are by default numbered on the same counter.*

Proof This proof ends in a display like so:

$$f(x) = x^2.$$
□

6.1.4 Macro setup

For now the macro setup only shows how to define some basic macros, and how to use a neat feature of the *mathtools* package:

$$|a|, \quad \left|\frac{a}{b}\right|, \quad |\frac{a}{b}|.$$

Chapter 7

Writing scientific texts in English

This chapter was originally a separate document written by Reto Sphel. It is reprinted here so that the template can serve as a quick guide to thesis writing, and to provide some more example material to give you a feeling for good typesetting.

7.1 Basic writing rules

The following rules need little further explanation; they are best understood by looking at the example in the booklet by Knuth et al., 2–3.

Rule 7.1 Write texts, not chains of formulas.

More specifically, write full sentences that are logically interconnected by phrases like 'Therefore', 'However', 'On the other hand', etc. where appropriate.

Rule 7.2 Displayed formulas should be embedded in your text and punctuated with it.

In other words, your writing should not be divided into 'text parts' and 'formula parts'; instead the formulas should be tied together by your prose such that there is a natural flow to your writing.

7.2 Being nice to the reader

Try to write your text in such a way that a reader enjoys reading it. That's of course a lofty goal, but nevertheless one you should aspire to!

Rule 7.3 Be nice to the reader.

Give some intuition or easy example for definitions and theorems which might be hard to digest. Remind the reader of notations you introduced

many pages ago – chances are he has forgotten them. Illustrate your writing with diagrams and pictures where this helps the reader. Etc.

Rule 7.4 Organize your writing.

Think carefully about how you subdivide your thesis into chapters, sections, and possibly subsections. Give overviews at the beginning of your thesis and of each chapter, so the reader knows what to expect. In proofs, outline the main ideas before going into technical details. Give the reader the opportunity to 'catch up with you' by summing up your findings periodically.

Useful phrases: 'So far we have shown that . . . ', 'It remains to show that . . . ', 'Recall that we want to prove inequality (7), as this will allow us to deduce that . . . ', 'Thus we can conclude that . . . . Next, we would like to find out whether . . . ', etc.

Rule 7.5 Don't say the same thing twice without telling the reader that you are saying it twice.

Repetition of key ideas is important and helpful. However, if you present the same idea, definition or observation twice (in the same or different words) without telling the reader, he will be looking for something new where there is nothing new.

Useful phrases: 'Recall that [we have seen in Chapter 5 that] . . . ', 'As argued before / in the proof of Lemma 3, . . . ', 'As mentioned in the introduction, . . . ', 'In other words, . . . ', etc.

Rule 7.6 Don't make statements that you will justify later without telling the reader that you will justify them later.

This rule also applies when the justification is coming right in the next sentence! The reasoning should be clear: if you violate it, the reader will lose valuable time trying to figure out on his own what you were going to explain to him anyway.

Useful phrases: 'Next we argue that . . . ', 'As we shall see, . . . ', 'We will see in the next section that . . . , etc.

7.3 A few important grammar rules

Rule 7.7 There is (almost) *never* a comma before 'that'.

It's really that simple. Examples:

> We assume that . . .
> *Wir nehmen an, dass . . .*

It follows that . . .
Daraus folgt, dass . . .

'thrice' is a word that is seldom used.
'thrice' ist ein Wort, das selten verwendet wird.

Exceptions to this rule are rare and usually pretty obvious. For example, you may end up with a comma before 'that' because 'i.e.' is spelled out as 'that is':

For $p(n) = \log n/n$ we have . . . However, if we choose p a little bit higher, that is $p(n) = (1 + \varepsilon) \log n/n$ for some $\varepsilon > 0$, we obtain that. . .

Or you may get a comma before 'that' because there is some additional information inserted in the middle of your sentence:

Thus we found a number, namely n_0, that satisfies equation (13).

If the additional information is left out, the sentence has no comma:

Thus we found a number that satisfies equation (13).

(For 'that' as a relative pronoun, see also Rules 7.9 and 7.10 below.)

Rule 7.8 There is usually no comma before 'if'.

Example:

A graph is not 3-colorable if it contains a 4-clique.
Ein Graph ist nicht 3-frbbar, wenn er eine 4-Clique enthlt.

However, if the 'if' clause comes first, it is usually separated from the main clause by a comma:

If a graph contains a 4-clique, it is not 3-colorable .
Wenn ein Graph eine 4-Clique enthlt, ist er nicht 3-frbbar.

There are more exceptions to these rules than to Rule 7.7, which is why we are not discussing them here. Just keep in mind: don't put a comma before 'if' without good reason.

Rule 7.9 Non-defining relative clauses have commas.

Rule 7.10 Defining relative clauses have no commas.

In English, it is very important to distinguish between two types of relative clauses: defining and non-defining ones. This is a distinction you absolutely need to understand to write scientific texts, because mistakes in this area actually distort the meaning of your text!

It's probably easier to explain first what a *non-defining* relative clause is. A non-defining relative clauses simply gives additional information *that could also be left out* (or given in a separate sentence). For example, the sentence

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> The WeirdSort algorithm, which was found by the famous mathematician John Doe, is theoretically best possible but difficult to implement in practice.

would be fully understandable if the relative clause were left out completely. It could also be rephrased as two separate sentences:

> The WeirdSort algorithm is theoretically best possible but difficult to implement in practice. [By the way,] WeirdSort was found by the famous mathematician John Doe.

This is what a non-defining relative clause is. *Non-defining relative clauses are always written with commas.* As a corollary we obtain that you cannot use 'that' in non-defining relative clauses (see Rule 7.7!). It would be wrong to write

> ~~The WeirdSort algorithm, that was found by the famous mathematician John Doe, is theoretically best possible but difficult to implement in practice.~~

A special case that warrants its own example is when 'which' is referring to the entire preceding sentence:

> Thus inequality (7) is true, which implies that the Riemann hypothesis holds.

As before, this is a non-defining relative sentence (it could be left out) and therefore needs a comma.

So let's discuss *defining* relative clauses next. A defining relative clause tells the reader *which specific item the main clause is talking about.* Leaving it out either changes the meaning of the sentence or renders it incomprehensible altogether. Consider the following example:

> The WeirdSort algorithm is difficult to implement in practice. In contrast, the algorithm that we suggest is very simple.

Here the relative clause 'that we suggest' cannot be left out – the remaining sentence would make no sense since the reader would not know which algorithm it is talking about. This is what a defining relative clause is. *Defining relative clauses are never written with commas.* Usually, you can use both 'that' and 'which' in defining relative clauses, although in many cases 'that' sounds better.

As a final example, consider the following sentence:

> For the elements in $\mathcal{B}$ which satisfy property (A), we know that equation (37) holds.

Table 7.1: Things you (usually) don't say

~~It holds (that) ...~~	We have ...	*Es gilt ...*
('Equation (5) holds.' is fine, though.)		
~~x fulfills property $\mathcal{P}$.~~	x satisfies property $\mathcal{P}$.	*x erfllt Eigenschaft $\mathcal{P}$.*
~~in average~~	on average	*im Durchschnitt*
~~estimation~~	estimate	*Abschtzung*
~~composed number~~	composite number	*zusammengesetzte Zahl*
~~with the help of~~	using	*mit Hilfe von*
~~surely~~	clearly	*sicher, bestimmt*
~~monotonously increasing~~	monotonically incr.	*monoton steigend*
(Actually, in most cases 'increasing' is just fine.)		

This sentence does not make a statement about all elements in $\mathcal{B}$, only about those satisfying property (A). The relative clause is *defining*. (Thus we could also use 'that' in place of 'which'.)

In contrast, if we add a comma the sentence reads

> For the elements in $\mathcal{B}$, which satisfy property (A), we know that equation (37) holds.

Now the relative clause is *non-defining* – it just mentions in passing that all elements in $\mathcal{B}$ satisfy property (A). The main clause states that equation (37) holds for *all* elements in $\mathcal{B}$. See the difference?

7.4   Things you (usually) don't say in English – and what to say instead

Table 7.1 lists some common mistakes and alternatives. The entries should not be taken as gospel – they don't necessarily mean that a given word or formulation is wrong under all circumstances (obviously, this depends a lot on the context). However, in nine out of ten instances the suggested alternative is the better word to use.

Chapter 8

Typography

8.1 Punctuation

Rule 8.1 Use opening (') and closing (') quotation marks correctly.

In LaTeX, the closing quotation mark is typed like a normal apostrophe, while the opening quotation mark is typed using the French *accent grave* on your keyboard (the *accent grave* is the one going down, as in *frre*).

Note that any punctuation that *semantically* follows quoted speech goes inside the quotes in American English, but outside in Britain. Also, Americans use double quotes first. Oppose

> "Using 'lasers,' we punch a hole in . . . the Ozone Layer," Dr. Evil said.

to

> 'Using "lasers", we punch a hole in . . . the Ozone Layer', Dr. Evil said.

Rule 8.2 Use hyphens (-), en-dashes (–) and em-dashes (—) correctly.

A hyphen is only used in words like 'well-known', '3-colorable' etc., or to separate words that continue in the next line (which is known as hyphenation). It is entered as a single ASCII hyphen character (-).

To denote ranges of numbers, chapters, etc., use an en-dash (entered as two ASCII hyphens --) with no spaces on either side. For example, using Equations (1)–(3), we see. . .

As the equivalent of the German *Gedankenstrich*, use an en-dash with spaces on both sides – in the title of Section 7.4, it would be wrong to use a hyphen instead of the dash. (Some English authors use the even longer emdash (—)

instead, which is typed as three subsequent hyphens in LaTeX. This emdash is used without spaces around it—like so.)

8.2 Spacing

Rule 8.3 Do not add spacing manually.

You should never use the commands \\ (except within tabulars and arrays), \␣ (except to prevent a sentence-ending space after Dr. and such), \vspace, \hspace, etc. The choices programmed into LaTeX and this style should cover almost all cases. Doing it manually quickly leads to inconsistent spacing, which looks terrible. Note that this list of commands is by no means conclusive.

Rule 8.4 Judiciously insert spacing in maths where it helps.

This directly contradicts Rule 8.3, but in some cases TeX fails to correctly decide how much spacing is required. For example, consider

$$f(a, b) = f(a + b, a - b).$$

In such cases, inserting a thin math space \, greatly increases readability:

$$f(a, b) = f(a + b, \, a - b).$$

Along similar lines, there are variations of some symbols with different spacing. For example, Lagrange's Theorem states that $|G| = [G : H]|H|$, but the proof uses a bijection $f : aH \rightarrow bH$. (Note how the first colon is symmetrically spaced, but the second is not.)

Rule 8.5 Learn when to use \␣ and \@.

Unless you use 'french spacing', the space at the end of a sentence is slightly larger than the normal interword space.

The rule used by TeX is that any space following a period, exclamation mark or question mark is sentence-ending, except for periods preceded by an upper-case letter. Inserting \ before a space turns it into an interword space, and inserting \@ before a period makes it sentence-ending. This means you should write

```
Prof.\ Dr.\ A. Steger is a member of CADMO\@.
If you want to write a thesis with her, you
should use this template.
```

which turns into

Prof. Dr. A. Steger is a member of CADMO. If you want to write a thesis with her, you should use this template.

The effect becomes more dramatic in lines that are stretched slightly during justification:

Prof. Dr. A. Steger is a member of CADMO. If you

Rule 8.6 Place a non-breaking space (~) right before references.

This is actually a slight simplification of the real rule, which should invoke common sense. Place non-breaking spaces where a line break would look 'funny' because it occurs right in the middle of a construction, especially between a reference type (Chapter) and its number.

8.3 Choice of 'fonts'

Professional typography distinguishes many font attributes, such as family, size, shape, and weight. The choice for sectional divisions and layout elements has been made, but you will still occasionally want to switch to something else to get the reader's attention. The most important rule is very simple.

Rule 8.7 When emphasising a short bit of text, use \emph.

In particular, *never* use bold text (\textbf). Italics (or Roman type if used within italics) avoids distracting the eye with the huge blobs of ink in the middle of the text that bold text so quickly introduces.

Occasionally you will need more notation, for example, a consistent typeface used to identify algorithms.

Rule 8.8 Vary one attribute at a time.

For example, for WEIRDSORT we only changed the shape to small caps. Changing two attributes, say, to bold small caps would be excessive (LaTeX does not even have this particular variation). The same holds for mathematical notation: the reader can easily distinguish g_n, $G(x)$, $\mathcal{G}$ and G.

Rule 8.9 Never underline or uppercase.

No exceptions to this one, unless you are writing your thesis on a typewriter. Manually. Uphill both ways. In a blizzard.

8.4 Displayed equations

Rule 8.10 Insert paragraph breaks *after* displays only where they belong. Never insert paragraph breaks *before* displays.

LATEX translates sequences of more than one linebreak (i.e., what looks like an empty line in the source code) into a paragraph break in almost all contexts. This also happens before and after displays, where extra spacing is inserted to give a visual indication of the structure. Adding a blank line in these places may look nice in the sources, but compare the resulting display

$$a = b$$

to the following:

$$a = b$$

The first display is surrounded by blank lines, but the second is not. It is bad style to start a paragraph with a display (you should always tell the reader what the display means first), so the rule follows.

Rule 8.11 Never use `eqnarray`.

It is at the root of most ill-spaced multiline displays. The *amsmath* package provides better alternatives, such as the `align` family

$$f(x) = \sin x,$$
$$g(x) = \cos x,$$

and `multline` which copes with excessively long equations:

$$P\big[X_{t_0} \in (z_0, z_0 + dz_0], \ldots, X_{t_n} \in (z_n, z_n + dz_n]\big]$$
$$= \nu(dz_0)K_{t_1}(z_0, dz_1)K_{t_2-t_1}(z_1, dz_2) \cdots K_{t_n-t_{n-1}}(z_{n-1}, dz_n).$$

8.5 Floats

By default this style provides floating environments for tables and figures. The general structure should be as follows:

```
\begin{figure}
  \centering
  % content goes here
  \caption{A short caption}
  \label{some-short-label}
\end{figure}
```

Note that the label must follow the caption, otherwise the label will refer to the surrounding section instead. Also note that figures should be captioned at the bottom, and tables at the top.

The whole point of floats is that they, well, *float* to a place where they fit without interrupting the text body. This is a frequent source of confusion and changes; please leave it as is.

Rule 8.12 Do not restrict float movement to only 'here' (h).

If you are still tempted, you should avoid the float altogether and just show the figure or table inline, similar to a displayed equation.

Appendix

A.1   Example URL of Google Static Maps API

```
https://maps.googleapis.com/maps/api/staticmap?maptype=satellite&center=41

&style=feature:all|element:labels|visibility:off&style=feature:landscape.n
```

A.2   OpenStreetMap

According to the Google Maps JavaScript API [1],

A.3   Projection

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[1]https://developers.google.com/maps/documentation/javascript/coordinates

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