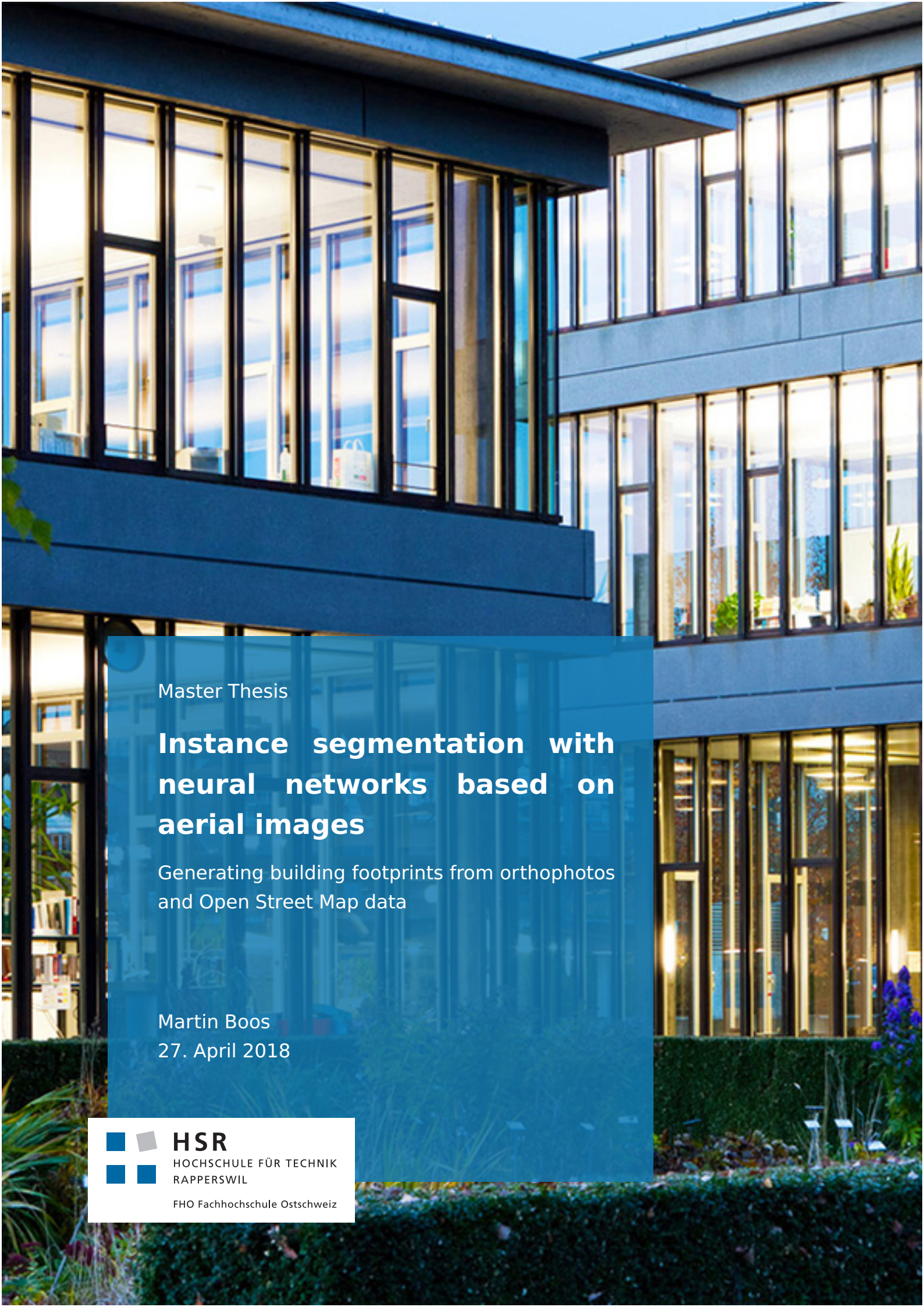

Master Thesis

Instance segmentation with neural networks based on aerial images

Generating building footprints from orthophotos and Open Street Map data

Martin Boos
27. April 2018

HSR
HOCHSCHULE FÜR TECHNIK
RAPPERSWIL

FHO Fachhochschule Ostschweiz

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Abstract

tbd

Acknowledgments

Put your acknowledgments here.

Prof. Stefan Keller tbd

Contents

Examples 1

This chapter is to demonstrate some of the capabilities of this LaTeX template. Please take a good look at this chapter and try to follow the guidelines.

Goal of this chapter

1.1 Equations

1.1.1 some equations

Equations can easily be written using the *Equation* environment. Inline equations are inserted with $\sqrt{-1} = i$. Equations can also be labeled, so it is possible to reference them. This should be done for all important equations.

Equations

$$x^2 + y^2 = 1 \tag{1.1}$$

There are several environments for multi line equations. A very useful one is *align*, see equation (1.4).

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0} \tag{1.2}$$

$$\oint \vec{B} \cdot d\vec{A} = 0 \tag{1.3}$$

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \tag{1.4}$$

Images are always inserted inside a *figure* environment. If possible, it is advisable to use `[tb]` as position. Always remember to add a caption and a label, so you can reference the image like this: Fig. 1.1. If possible, images

Figures and Tables

FIGURE 1.1 An example image

some	text	is shown	here
there is more and	text here even	and here more	cool. here.

TABLE 1.1 A sample table

should be inserted as vector graphics, e.g. `eps` or `pdf` - or even drawn manually in TikZ.

Tables can be used quite similarly. They are inserted inside a *table* environment, as shown in Tab. 1.1.

Another useful tool is the *tabularx* environment. It lets the user specify the total width of the table, instead of each column. An example is shown in Tab. 1.2.

Please read the documentation of the *booktabs*[1] package to find information on how to create good tables. Always remember the first two guidelines and try also to stick to the other three:

1. Never, ever use vertical rules.
2. Never use double rules.
3. Put the units in the column heading (not in the body of the table).
4. Always precede a decimal point by a digit; thus 0.1 *not* just .1.
5. Do not use „ditto“ signs to repeate a value. In many circumstances a blank will serve just as well. If it won't, then repeat the value.

PARAGRAPHS Note that each paragraph is ended with an empty line. *Never* use `\\` to end paragraphs – this is a new line, not a new paragraph. Also try to keep your source code clean: about 80 characters per line. Using source control makes your life much easier

QUOTES Quotes can easily be made using the „csquotes“ package. Citing text passages is

[1] `http://www.ctan.org/pkg/booktabs`

some	text	is shown here
there is more and	text here even	and here. more here.

TABLE 1.2 Tabularx example

easily done: „First argument: citation, second argument: terminal punctuation!“ (me) Whole block quotes are also easily possible.

> Formal requirements in academic writing frequently demand that quotations be embedded in the text if they are short but set oV as a distinct and typically indented paragraph, a so-called block quotation, if they are longer than a certain number of lines or words. In the latter case no quotation marks are inserted.

SI UNITS

Any numbers and units should by typed using the siunitx package. Numbers are written as 1234 3.45×10^{-5} 1, 2 and 4 4 to 30 10° 5°3′2″. Units are written with $\mathrm{kg\,m/s^2}$ or $14\,\mathrm{F^4}$. Of course also possible is 10 m, 40 m and 12 m or −40 °C to 125 °C Almost every unit you could possibly think of is implemented!

BIBLIOGRAPHY

The bibliography is created using *Bibtex*. The standard format is set to `ieeetr`, which is the IEEE Standard. There are example entries for different types of in the separate bibliography file **article book booklet conference inbook incollection manual mastersthesis misc phdthesis proceedings techreport unpublished**.

INDEX & GLOSSARY

All glossary entries are made in the separate file `glossary.tex`. They can then be used with Equation. Acronyms are defined as shown there and used similarly. The first time, it will be *support vector machine (SVM)*. The second time: *SVM*. The glossary has to be created manually by invoking `makeindex -s doku.ist -t doku.glg -o doku.gls doku.glo`. The index is simply created by using `index{text}`. It is generated automatically.

1.1.2 Listings

Listings are created by the `lstlistings` package.

This is a simple ToDo note

ToDo

This is a small note [Citation needed]

ToDo

ToDo

2 Neural Networks

2.1 Introduction

tbd

Theoretical and Practical Challenges 3

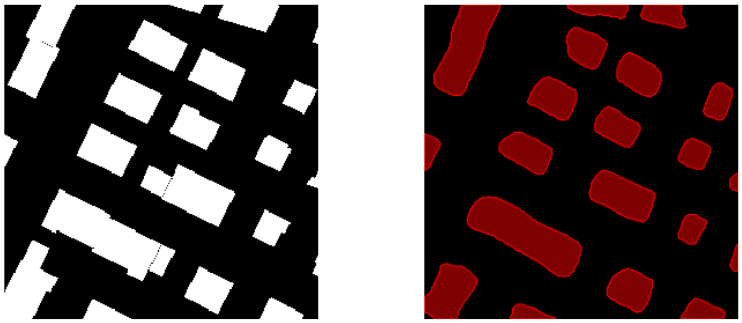
3.1 Training data generation

In order to train the neural network a data set was required, which could then be used for training and validation. Due to this, a tool [1] has been developed which uses publicly available vector data from OpenStreetMap and satellite imagery Microsoft Bing.

tbd

3.2 Building outline regularization

Once the network has been trained, it can be used to make predictions on images, it has never "seen" before. However, there are situations in which the predictions are far from perfect, especially then if the building is partially covered from trees or has unclear outlines. This can be seen in Fig. 3.1.



(A) Actual ground truth (B) Predicted building masks

FIGURE 3.1 Predicted masks and actual ground truth

As a result of the inaccuracies in the predicted building masks the contours of these predictions can not directly be used to create the vectorized outlines. Instead, the predictions have to be regularized. The approach used is similar to [2] and described in Fig. 3.2.

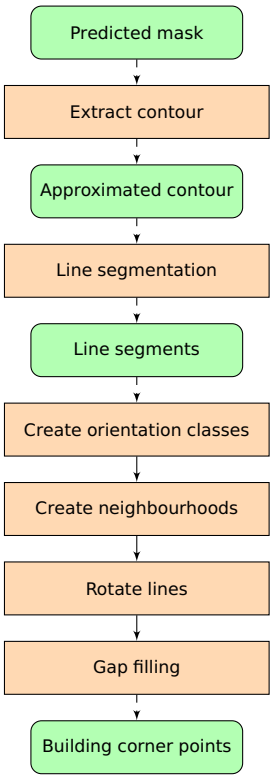


FIGURE 3.2 Rectangularization procedure

The single steps are described in detail in the following sections.

3.2.1 Contour extraction

The first step of the building outline regularization procedure consists of getting the contour from the predicted mask, which covers the whole building. The extraction is done using the marching squares algorithm [3]. In this algorithm, a square consisting of four cells is moved (marched) along the contour in such a way, that at least one cell always covers the object to be contoured. Additionally, the square always has a state, which is derived from the content of its cells, according to (3.1). The cells are traversed in counter clockwise order.

$$\begin{aligned} s &= \sum_{i=0}^{3} 2^i f(c_i) \\ &= 2^0 * f(c_0) + 2^1 * f(c_1) + 2^2 * f(c_2) + 2^3 * f(c_3) \\ &= f(c_{bottomLeft}) + 2 * f(c_{bottomRight}) + 4 * f(c_{topRight}) + 8 * f(c_{topLeft}) \end{aligned} \tag{3.1}$$

where:

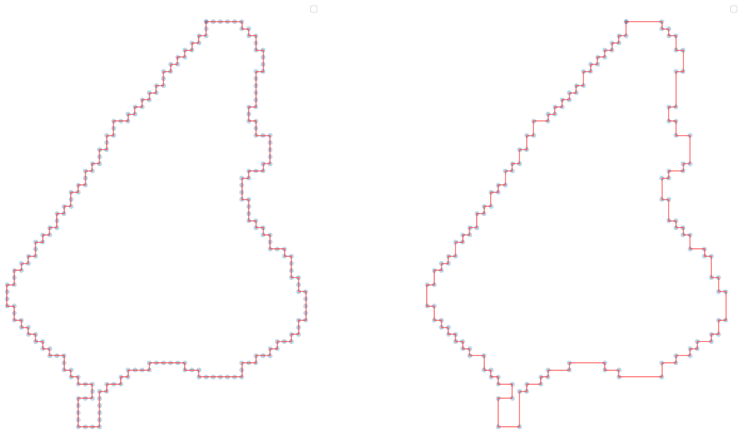
c_i: The value of the cell i

c_0: The bottom left cell

and

$$f(c_i) = \begin{cases} 0 & \text{if } c_i \leq 0 \\ 1 & \text{if } c_i > 0 \end{cases}$$

As soon as the contour has been extracted, its number of points will be reduced using a Douglas-Peucker algorithm [4]. The reason for this is, that the contour has pixel accuracy. That means, there may be several points on the same horizontal or vertical line, even though, the startpoint and endpoint of each such line would be enough, to represent the line. Additionally, the lower the number of points per contour is, the faster the following processing will be.



(A) Original contour (B) Approximated contour

FIGURE 3.3 Contour before and after approximation

3.2.2 Line segmentation

Once the contour has been extracted, it is split into multiple line segments. For this, the main direction of the building is determined using the Hough lines algorithm. The result of this is the line which hits the greatest number of points. The angle between this line and a horizontal line gives the main building orientation.

Once the main building direction is known, the line segmentation starts at the point which has the smallest distance to this line. The whole procedure is depicted in algorithm 1.

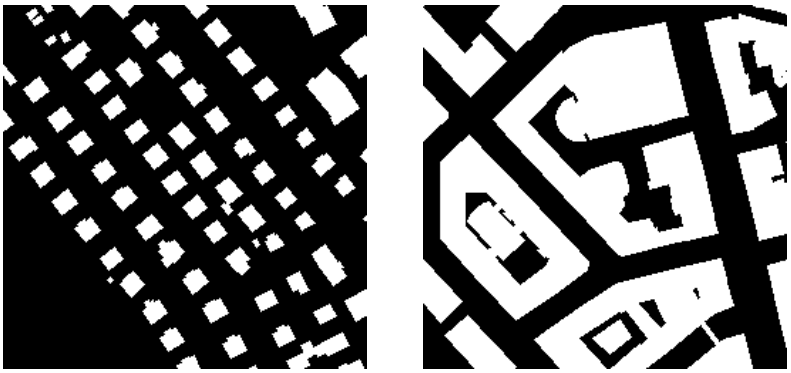
```
Data: Contour points, startpoint
Result: Lines
rearrange points so that startpoint == points[0]
lines = []
while any points left do
    segment = remove first 3 elements from points
    while points is not empty do
        p = points.first()
        err = root mean square error of distance between segment.last() and
         p
        if err > threshold then
            break
        end
        segment.append(p)
        points.remove(p)
    end
    if segment.length() >= 3 then
        line = fit line to points of segment
        lines.append(line)
    end
end
```

Algorithm 1: Line segmentation

3.2.3 Create orientation classes

After the line segmentation, an orientation will be assigned to each line. Generally, most of the buildings consist of mainly right angles. However, there are still buildings, for which this assumption is not true. Due to this, orthogonality

will be preferred, but other angles will still be possible. Algorithm 2 shows the procedure, which assigns a main orientation class to each line and defines the lines parallelity / orthogonality to the longest line of the same orientation class.



(A) Regular buildings (B) Non-orthogonal buildings

FIGURE 3.4 Different kinds of buildings with regard to their corner angles

```
Data: Lines, angleThreshold
while any line without orientation do
    line = longest of unprocessed lines
    line.orientation = angle between line and horizontal-line
    foreach line li without orientation do
        a = angle between line and li
        if a ≤ angleThreshold then
            li.orientation = line.orientation li.orthogonal =
              line.orthogonalTo(line)
        end
    end
end
```

Algorithm 2: Orientation assignment

3.2.4 Create neighbourhoods

At this point, each line segment belongs to a orientation class and the parallelity / orthogonality of each line to the orientation classes main line is known. However, the spatial location of each line has not been taken into account yet, which is done in this step. Clusters of neighbouring lines are created within each orientation class. As a result of this, it is now possible to find

lines, which may be better placed in an other orientation class. This is based in the assumption, that it is unprobable, that a line k of the orientation class x is surrounded by lines of the orientation class y. In this case, the line k will be assigned to the orientation class y.

3.2.5 Update line orientation

Finally, the lines will be adjusted to their orientation class with respect to each lines parallelity / orthogonality. The result of such an adjustment, can be seen in Fig. 3.5, which shows a single orientation class and lines, which have been adjusted either parallel or orthogonal to the orientation class.

FIGURE 3.5 Adjusted lines

3.2.6 Gap filling

In order to create the final building outline, the only thing left to do is to fill the gaps between the line segments.

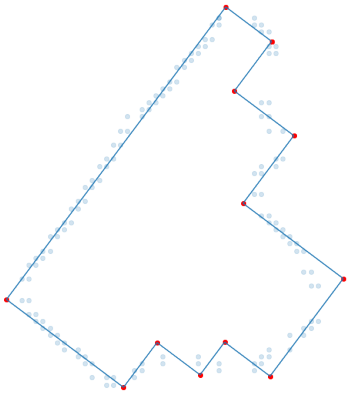


FIGURE 3.6 Final building outline

Appendices

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[4] D. H. DOUGLAS and T. K. PEUCKER, „Algorithms for the reduction of the number of points required to represent a digitized line or its caricature“, *Cartographica: The International Journal for Geographic Information and Geovisualization*, vol. 10, no. 2, pp. 112–122, 1973, ISSN: 0317-7173. DOI: `\url{10.3138/FM57-6770-U75U-7727}`.

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