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# Training Tesseract for Ancient Greek OCR

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This paper discusses the process of training the Tesseract OCR engine to support Ancient Greek. It covers the general procedures involved in training a new language for Tesseract, both training the script with common printed fonts and adding hints about how the language works to improve recognition. It discusses the particular challenges that arose with Ancient Greek, in the main due to Tesseract's English language heritage. It goes on to describe the various strategies and small programs which were written to overcome these. It concludes with recommendations for changes to Tesseract to make OCR training easier and further improve recognition accuracy.

## 1 Introduction

Optical Character Recognition (OCR) is a difficult task. Put simply, it is the automatic extraction of text from an image, which may be in a variety of fonts, and be distorted in all sorts of ways. Thankfully, it is a problem which is well-understood, and has been worked on by many intelligent people in recent decades. Historically most work on OCR technologies has been focused primarily on English, but happily most of the difficult problems are quite generalisable. General purpose OCR software is now available, making the creation of an OCR solution for other scripts feasible in a reasonable length of time.

We currently worked on a research project funded by the European Research Council, entitled ‘Living Poets: A New Approach to Ancient Poetry.’ The project needs digital copies of a variety of Ancient Greek works. Some of the texts we need have no digital version at all, and others are unfortunately not freely licensed, leaving us unable to use them safely. So we decided to be bold and forge an OCR solution. Even for our small corpus of texts it saved time over manually inputting them, but more importantly the result can be shared and used freely by anybody else.

We hope that this article may be useful to several groups of people. It aims to be broadly useful for those interested in training a similar language for OCR (or improving an existing training), in which case it should be read alongside Tesseract's own training guide. We hope that it will also be interesting to a broader audience as a discussion of the particular challenges involved in the accurate OCR of Ancient Greek.

# 2 OCR options

## 2.1 Requirements

There are several good quality OCR programs which could be taught to recognise Ancient Greek. A key requirement for us was that the program we built on was free and open source software (FOSS), both for pragmatic and ideological reasons.

The ability to study how the program works is a massive advantage in best tailoring it for our needs. Another big plus is that any potential improvements can be discussed with the developers of the software, and potentially added, either by ourselves, the core developers, or other interested parties. It also ensures that the work we have done has a better chance of remaining beneficial after the project, as anybody who finds it useful can build upon it and keep it working should the OCR program it is built upon significantly change.

Working with software which is not FOSS, and thus being unable to fully share the results for others to use and build on, inevitably results in duplication of work. This is particularly harmful given that Ancient Greek scholarship is such a niche and poorly funded field.

More broadly, by contributing to common code, and ensuring the results are themselves freely available for study and improvement, we are able to maximise the utility and good the project does.

## 2.2 Tesseract

One FOSS OCR program shines in comparison to its competitors, namely Tesseract, originally developed by Hewlett-Packard in the 1980s, and now overseen by Google, and very likely seeing heavy use in the Google Books project. Like most OCR programs, it was originally designed for English, but over the last few years there has been heavy emphasis on making it more suitable for other languages and scripts. While its English heritage is still visible in parts (as discussed below), it remains an excellent option for other languages, as evidenced by the large range of languages already available for it.

A large variety of other OCR software now uses Tesseract as a base. This gives the additional advantage that any of these extra programs can automatically then support Ancient Greek, including programs which are entirely web based, and programs written for smartphones.

In summary, it is an excellent quality OCR program, with a large amount of flexibility, a solid codebase, and a large, engaged community of interested people around it.

# 3 Training the machine

Teaching Tesseract to recognise a new language is a process called *training*. Each training consists of several parts, describing the shapes of characters and giving a variety of information on how the language works. Each major part of the training is covered below, as we walk through the steps to training Ancient Greek.

There are several points in training where one can make a trade-off between the speed of Tesseract's recognition versus its accuracy. In most such cases, we erred on the side of accuracy—Tesseract is very efficient and quick (taking a modest desktop PC a few seconds to process a book page), and slowing it down slightly is generally well worth it for improved accuracy.

## 3.1 The *tif/box* step: character shape training

The most important part of training is specifying the shapes of every character. This is done by creating image files containing each character, and specifying in a separate text file the coordinates and UTF-8 codepoint of each character. One can then run several programs distributed with Tesseract to extract and store the character shapes. This is generally referred to as the *tif/box* step, as historically the only image format Tesseract supported was TIFF, and the text file specifying character coordinates is called a *box file*.

The official advice is to use scanned images for training, run Tesseract in a special mode to guess at the correct location of each character, and edit the resulting coordinates and UTF-8 characters as appropriate. However, there are several issues that make this difficult for Ancient Greek.

For a reliable training process every character needs to occur at least a few times, which can be difficult with a large character set or if one is interested in including uncommon characters. While Ancient Greek does not have a large alphabet, for the purposes of OCR with Tesseract it does. Ancient Greek has two types of diacritical marks; breathing marks (which can be smooth: ᾿ or rough: ῾), and accents (which can be acute: ΄ grave: ` or circumflex: ῀). These can be applied in a large variety of combinations to all vowels, and are placed either above the character, or to the left for the upper case.

Being designed originally for English, Tesseract has no concept of diacritics, and thus cannot separately recognise a character and a diacritical mark above it, and output the individual UTF-8 codepoints for the character and the combining diacritical mark. Instead it must be trained every possible combination of characters and diacritical marks. Moreover, one cannot just scan character lists, as Tesseract requires the image to be as close to the format of printed text as possible, in order to make informed choices about relative character position and size. Using scans would therefore require many pages, and a great deal of time to create the corresponding box files, to ensure every possible character was accounted for.

A much better choice is to generate an image file and corresponding box file automatically. This makes it easy to include every character several times, and removes the tedious, time-consuming and error-prone step of manually editing box files. As mentioned above, it is important to include the characters in *realistic* text, so that the relative position and size of each character can be correctly determined. The solution we came to was two-fold. First, a text file is created, which is filled with random words from an Ancient Greek wordlist in such a way as to ensure that each required character is accounted for at least a minimum number of times, and sentences start with an uppercase letter. This text file is then fed into another program which outputs an image file using a given font, and a corresponding box file describing the location of each character. We named the text generation program `makegarbage`, and the image and box generation program `lazytrain`. They, and indeed all programs we used in the training, are freely available online (see below for links) in the hope that they may be useful to others, both to improve on the Ancient Greek training, and to help create OCR trainings for new languages (and indeed they have already been used to help train Esperanto). More information on their workings is included below.

Tesseract can be trained for as many different fonts as are needed. The wonderful fonts available from the Greek Font Society were obvious good candidates to use, being high quality and closely based on the most common printed typefaces of Ancient Greek. We initially also included all other fonts installed on a Debian system which had the appropriate characters, but on testing found that they reduced quality significantly. The lesson being to train Tesseract only with the kinds of fonts you are likely to encounter in the works you actually plan to scan.

Another tricky issue is that while Tesseract on the one hand wants text as close as possible to what it will be scanning, training will fail if the characters are too close together. This has become less of a problem with newer releases of Tesseract, but is particularly important to bear in mind if training for Tesseract version 2.

The greater the number of characters that are present in the training set, the greater the chance for Tesseract to misrecognise a character for a similar-looking one. Other than with word lists (described in more detail below), there is no way to inform Tesseract of the rarity of a character. This creates a trade-off between complete coverage of characters, including rare forms, and accuracy of the most common characters. Fortunately recognition was good enough that adding archaic and rare characters did not have a large negative impact on results, but it is something else to be wary of.

### 3.1.1 `makegarbage`: creating a comprehensive—if incomprehensible—Greek text

The `makegarbage` program, when given a list of required characters and a wordlist, will print out random words ensuring that each character is included at least five times. The number 5 was chosen as it should provide enough of a representative sample for Tesseract to be confident of character positioning and shape, without causing the resulting text file to expand to enormous proportions. It is written in `bourne shell`, and works by going through each required character and printing a random word containing it from the wordlist. If the character is punctuation, it is just printed directly after the last word. This is not strictly ideal, as it should follow the conventions of where the punctuation is used, but in practice was easier and still gave good results. The wordlist is all lowercase, so if the character is uppercase it does not match anything in the wordlist, and so is just prepended onto a random word.

The resulting text file looks like wonderful Ancient Greek to Tesseract, and garbage to anybody who actually tries to read it.

#### 3.1.2 `lazytrain`: automatically creating use *tif/box* sets

`lazytrain` (named loosely after the Ozzy Osbourne song *Crazy Train*) outputs an image file and box file to train Tesseract character shapes. It is written in `C`, and uses the `ImageMagick` API for both font processing and image writing. It works by going through a UTF-8 text file (created by `makegarbage`) character by character, outputting each character in the chosen font, and recording the position and dimensions of the character drawn into the box file.

Tesseract works best if trained with a similar DPI (dots per inch) to what is being scanned, 600 DPI being the general preference. Whereas Tesseract expects scanned pages for training, there is no harm in using images of different dimensions to a normal page, so long as line breaks still occur as expected. With that in mind, the height of the image is calculated to be as large as is needed to fit all of the text on one image, which was generally pretty huge. (So huge in fact that trying to display the image triggered a bug in our whizzy office PC crashing the graphics driver.) The other key consideration is spacing between characters. As mentioned above, version 2 of Tesseract is particularly fussy about each character having plenty of space around it, or it will often fail in the training with unclear error messages. After some testing, we found that around 10 pixels of space between each letter worked well, which is not actually very significant in a 600 DPI image.

### 3.2 Wordlists: vocabulary training

Tesseract trainings can include two wordlists, a somewhat comprehensive list, and a *most frequent words* list. There are not any guidelines on how many words should be included in each list, but examining other popular trainings the consensus seems to be in the hundreds of thousands for the main list, and in the low hundreds for the frequent words list.

The Perseus project now makes its Ancient Greek texts freely available to download in a bundle, licensed under the Creative Commons Attribution–ShareAlike license, which we could be confident in using freely. So we wrote a program (`wordlistfromperseus`) to scan through the corpus and generate a list of all words and their frequencies, which could be easily parsed into two wordlists of appropriate sizes for Tesseract. We excluded the least common words from the final wordlist, both to reduce the likelihood of including typos and to minimise the chances of common words being substituted for rare words by Tesseract.

### 3.3 `unicharambigs`: teaching some basic rules

A `unicharambigs` file is designed to allow Tesseract to spot and correct common misrecognition errors, where a set of characters which are unlikely to be next to one another are substituted for a more likely combination. A simple example is the rule

```
2   ε ὠ   2   ε ώ   1
2   ε ὡ   2   ε ὼ   1
2   ε ὢ   2   ε ῶ   1
2   ε ὣ   2   ε ῶ   1
2   ε ὤ   2   ε ῶ   1
2   ε ὥ   2   ε ῶ   1
2   ε ὦ   2   ε ῶ   1
2   ε ὧ   2   ε ῶ   1
```

**Figure 1**: Excerpt of `unicharambigs` file showing rules to replace invalid positions of breathing characters with likely alternatives. These rules state that any time epsilon (**ε**) is followed by omega (**ω**) with a breathing mark and any accentuation, they should always be replaced with an **ε** followed by **ω** with similar looking accentuation, but without a breathing mark.

to change two apostrophes into a double quote mark. These rules come in two types, *suggestions* and *demands*. Suggestions are taken into account by Tesseract, but not necessarily acted on (e.g., they are unlikely to change a word in the word list to a word not in it.) The other types of rules are always executed.

A good way to find rules is to create a training with the above parts, and see which types of errors are particularly common. Some obvious examples were pi (**π**) being misrecognised as double tau (**ττ**), and phi (**φ**) being misrecognised as open bracket followed by rho (**(ρ**).

There are also more interesting tasks for which the `unicharambigs` file can be used, with a little imagination. Many languages have rules about places that certain characters cannot be, and Ancient Greek is no exception. A primary example of this is breathing marks, which can only occur above the first character of a word, or the second in the case of a digraph or dipthong. The unicharambigs file syntax is very basic, and can only specify which character combinations should be replaced by others—there is no way of marking the beginning or end of a word, or general rules regarding how different classes of characters can behave.

Accents being misrecognised as breathing marks in the middle of a word was a common enough occurrence that I was keen to find a way to quash it. While it is not possible to directly specify that a character with a breathing that does not come at the start of a word should be replaced with the most similar looking accent character, one can do so in a roundabout way. One can create a series of rules which match each character directly followed by a breathing character, and demand that the breathing character be replaced by a similar accented character (Figure 1). The case of digraphs and dipthongs is similar, in which case no change is made, unless another character preceeds them. When treating every possible accentuation of a letter as a separate character, the number of rules to do this is quite massive. Computers are great rule-followers, though, so we wrote a program (called `breathingambigs`) to output every necessary rule, which ends up being around 35,000 separate rules.

A `unicharambigs` file of that magnitude does slow down OCR processing somewhat. However, it is only on the order of a second or two difference per page, and improves results very significantly. Recognition of diacritics is by far the largest area for mistakes when doing OCR of Ancient Greek, due largely to their small size and distance from the main character. Several other smaller sets of rules also helped to improve things. These ensured that rough breathing characters before uppercase letters were not misrecognised as quote (') or semicolon (*ano teleia*: ·) characters.

The other issue is the rho. This needs to be treated separately from the other vowels in regards to breathings, for two reasons. Firstly, a rho at the start of a word should always have a rough breathing, and secondly, a double rho in the middle of a word is sometimes printed with a smooth followed by a rough breathing (ῤῥ). These issues can be largely dealt with using a couple of types of `unicharambigs` rules, first that a ῥ with anything before it except a ῤ should have its breathing removed, and second that a ῤ without a ῥ following it should have its breathing removed. The rules for this are created using a program called `rhoambigs`.

One casualty of these breathing rules is the crasis; when two words are joined together, a breathing mark can end up in the middle of a word. Diacritic recognition is so improved by the breathing rules that they are still worth having despite sometimes mistakenly removing a valid breathing in the case of a crasis. It should be possible to solve the issue, perhaps by whitelisting crasis words with breathings in the `unicharambigs` rules, but that work still needs to be done.

## 3.4 Configuration

Tesseract has a very large number of configuration options, which can be set in training files. Unfortunately they are not listed anywhere, and generally lack any description as to their use or purpose. The intrepid can however wander through the Tesseract code and get a reasonable idea of extra things to tweak to improve things. A search for the string `_VAR_H` in all `.h` files of the source code produces a list of around 600 options to choose from. In general sticking to the default values makes sense; it gives the best chance of results improving when Tesseract is updated, and over-optimising carries the risk that the recognition may be far worse for certain documents or tasks that have not been anticipated.

One setting that made a massive difference to recognition quality for Ancient Greek involved line detection. There was a persistent problem where Tesseract would often misrecognise diacritics above characters as a separate line of text. This resulted in a line of nonsense, with the diacritics by themselves being incorrectly recognised as whole characters, followed by a line lacking any of the diacritics at all. After a good deal of trial and error, it was found that significantly increasing the option `textord_min_linesize` pretty much solved the issue.

After the initial recognition step, Tesseract applies certain penalties or bonuses to words and characters, to weigh up whether they should be changed according to various rules. This is how the word lists are used, as well as the *suggestion* ambiguity rules. Initially we increased the penalty assigned to words not in a word list, using the `language_model_penalty_non_dict_word` and `language_model_penalty_non_freq_dict_word` options. This increased the chance that a close recognition would be switched to a word from the word list. This seemed to improve results in our testing, but we eventually realised that this was due to the fact that the text with which we were doing most of our testing happened to be used for the wordlist production. Given the large diversity of word forms in Ancient Greek, treating the wordlist as relatively complete and definitive is actually a particularly bad idea, and newer versions of the training no longer have the increased word list penalties. We did however successfully increase the penalty for *unexpected* punctuation, e.g., punctuation in the middle of a word, with the `language_model_penalty_punc` option. This was important as diacritics were sometimes recognised separately from their parent characters, oftentimes resulting in an erroneous quote (') or semicolon (*ano teleia*: ·) in the middle of a word.

### 3.5 Scripts: automating everything

When creating an OCR training it is important to be able to try different approaches and quickly get feedback. There are quite a number of Tesseract commands to process the different parts into a usable training, however, and some of these take a long time to complete. As such automating different parts of the training process was important for quick and reliable testing, as well as to codify how it all fit together. The core of these scripts is called `combinetraining`, which takes the different components of a Tesseract training and runs the appropriate commands to output a usable training file. The *tif/box* step is particularly time-consuming, however, in the order of hours, so that was done separately with a script called `masstrain`, which was used only when the *tif/box* files changed in some way. We ordered the scripts with a `Makefile`, which tracked dependencies to ensure that only the minimum necessary was rebuilt when something was changed. Creating a new version of the training was then just a case of running `make` and toddling off to make a cup of tea.

## 4 New features that could improve training

With the above work, OCR using the Ancient Greek training is pretty accurate. We think it is more or less as good a training as is possible with the current version of Tesseract. However, there are quite a few features that could be added to Tesseract so as to make both the training process easier, and the resulting training files more effective.

### 4.1 More sophisticated rules

While `unicharambigs` can be abused to add certain types of rules to Tesseract (see above), it is a slow, difficult and limited way of doing so, as it was never intended to be used for that purpose.

One way of applying complicated rules is just to *post-process* the output from Tesseract with another program. However this is not ideal, as it cannot make use of the internal information Tesseract uses to weigh up how sensible a change is, based for example on the confidence of recognition of a specific character. Another possibility would be to create a program which uses the Tesseract API to *hook in* to the OCR process, and fiddle around as appropriate there. That would probably work, but would be a quite large amount of effort, and (more importantly) it would not be generally available for all of the different platforms and uses that Tesseract is. By keeping specific language rules within a training, all improvements are immediately usable by any project that uses Tesseract, from smartphone-based OCR *apps* to large book scanning operations like those operated by the Internet Archive.

A better method to define grammatical rules would be to add a new filetype to the training, which worked similarly to `unicharambigs`, but allowed a limited syntax (not dissimilar to simple regular expressions) to select and act upon groups of letters. The unicharset file, which currently lists each character in the training with basic metadata, could then be extended to *tag* characters. These taken together could make for a quite powerful, simple structure with which to create complex rules. One could extend the idea further by replacing the binary *suggestion* versus *demand* format used by the current `unicharambigs` file with a number indicating how strong of a recommendation the rule is.

This idea was met with some enthusiasm on the Tesseract mailing list, and has now been made into a feature request on the project's issue tracker.

One could also imagine other more advanced rules systems which could take a greater variety of grammatical rules into account. For example checking iota subscript (ͺ) consistency, tracking accent usage in relation to neighbouring words, or even going so far as to compare with an expected metre. Going down this path risks privileging recognition of texts which are closest to what is more formally defined as 'correct' by grammarians, which does not tend to map perfectly onto a textual corpus. *Weighting* systems would therefore be critical to such attempts, to ensure that unusual grammar was not ignored, but just noted as less likely by Tesseract, and the choice of whether to accept it would rely on other factors such as character recognition confidence and wordlist prominence.

## 4.2 A weighted wordlist

Currently there are two wordlists, which are assigned different weightings of importance. However in many cases it is easy to get a far more nuanced view of the popularity of words, beyond either frequent or not, by interrogating a reasonably sized corpus of texts. Feeding this information into a training wordlist would allow for more accurate OCR recognition, giving Tesseract a much more accurate view of how likely a particular word is to appear. It also has the advantage of being a quite simple change to make in the code of Tesseract, though each training file would probably need to be adjusted to accomodate it.

This idea went down well with other participants on the Tesseract mailing list, and is now also in the project's issue tracker.

## 4.3 Extracting character shapes from font files

While there are some advantages to training character shapes using scanned images, namely recognition of common scanning issues for particular characters, it is not a feasible way to train Tesseract for scripts with large character sets, or several diacritics (see above). The method we used, of creating appropriate image and box files using a program, does work, but is time consuming to set up, and a rather inelegant solution to the problem.

A better solution would be to use the appropriate font files directly to get all the necessary character shapes. This would significantly reduce the time and difficulty to produce an OCR training, and lessen the chance of mistakes. It would however require a significant effort to implement.

### 4.4 Explicit support for diacritics

One area in which Tesseract's English-language heritage is particularly apparent is its complete ignorance of diacritics. Characters with the same letter but different diacritical marks are likely to be of a similar overall shape, leading character-level OCR to have a difficult time accurately differentiating between them.

An OCR program could optimise diacritic searching by separating the process of recognising the base letter from checking for any diacritics, and in so doing achieve significantly higher accuracy. Training may be more complex with such a system, however, as diacritical marks would need to be separately marked, and their expected position in relation to each base letter would need to be recorded. It would also be a large task to add this functionality into Tesseract.

### 4.5 Availability of training source files

Given that many scripts share letters it would often make sense to base a new language training on a training for a similar language. Unfortunately, however, at present most training files do not make the *tif/box* files which they used available, so extending or modifying them is not possible. This was done in the past, but as the trainings have been updated over time the tif/box sources have not been updated, and are no longer particularly useful as a basis to build upon. This is a great pity, and we have made a point of making the source files for our Ancient Greek training available, as well as the tools necessary to improve them. We hope that this soon becomes standard practice for OCR trainings.

### 4.6 Documentation of configuration options

Tesseract has many useful knobs to twiddle to adjust the way it works to make it more appropriate for a particular language. While it performs admirably without any tweaks, fiddling with configuration options can yield significant accuracy improvements for certain languages. However, they remain almost entirely undocumented, and are only discoverable by searching through the source code.

Thankfully, it looks like configuration documentation is on the way, and a webpage has recently been created on the Tesseract website for that purpose, to which we have contributed. This will be a great aid to people who seek to improve a training but who are not too comfortable digging through source code.

# 5 Conclusion

Tesseract is a very high-quality and flexible OCR tool, and with some effort Ancient Greek can be trained to a high level of accuracy. Recognition of diacritics is the weakest part of Tesseract for the purposes of Ancient Greek, which is unsuprising given their relatively small size, similar shape, and identical base letters. While more work could be done in the core of Tesseract to improve this, smart (ab)use of the basic rules system within a training file proved very effective in alleviating the issue.

One of the biggest advantages of Tesseract is its open code and development, which allows anybody with the interest and skill to study how it works, and improve it. It is a pity that the source files for most Tesseract trainings are not similarly available, and it is our hope that by ensuring that the source to the Ancient Greek training is, others may learn from and further improve it, to the benefit of all. The same is true of the tools we wrote to aid in the creation of this training, and they have happily proved useful to others already.

The Tesseract project have now accepted the Ancient Greek training file, and it is available directly from their website. To try it out, follow the install instructions on their `ReadMe` webpage (which we recently rewrote for clarity), and let us know how you get on.

# Useful links

More information and downloads of Ancient Greek training, including sources. URL: `http://www.dur.ac.uk/nick.white/grctraining`

Training tools developed for Ancient Greek. URL: `http://www.dur.ac.uk/nick.white/tools`

Tesseract OCR homepage. URL: `http://code.google.com/p/tesseract-ocr`

Tesseract’s training guide. URL: `http://code.google.com/p/tesseract-ocr/wiki/TrainingTesseract3`

Living Poets project. URL: `http://www.dur.ac.uk/classics/livingpoetsproject`

Greek Font Society. URL: `http://www.greekfontsociety.gr/pages/en_typefaces1.html`

Perseus’ “open source” corpus. URL: `http://www.perseus.tufts.edu/hopper/opensource/download`