

Using the koRpus Package for Text Analysis

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The R package `koRpus` aims to be a versatile tool for text analysis, with an emphasis on scientific research on that topic. It implements dozens of formulae to measure readability and lexical diversity. On a more basic level `koRpus` can be used as an R wrapper for third party products, like the tokenizer and POS tagger `TreeTagger` or language corpora of the Leipzig Corpora Collection. This vignette takes a brief tour around its core components, shows how they can be used and gives some insight on design decisions.

1 What is koRpus?

Work on `koRpus` started in February 2011, primarily with the goal in mind to examine how similar different texts are. Since then, it quickly grew into an R package which implements dozens of formulae for readability and lexical diversity, and wrappers for language corpus databases and a tokenizer/POS tagger.

2 Recommendations

2.1 TreeTagger

At the very beginning of almost every analysis with this package, the text you want to examine has to be sliced into its components, and the components must be identified and named. That is, it has to be split into its semantic parts (tokens), words, numbers, punctuation marks. After that, each token will be tagged regarding its part-of-speech (POS). For both of these steps, `koRpus` can use the third party software `TreeTagger` (Schmid, 1994).¹ Especially for Windows users installation of `TreeTagger` might be a

¹<http://www.ims.uni-stuttgart.de/projekte/corplex/TreeTagger/DecisionTreeTagger.html>

little more complex – e.g., it depends on Perl², and you need a tool to extract .tar.gz archives³. Detailed installations instructions are beyond the scope of this vignette.

If you don't want to use TreeTagger, `koRpus` provides a simple tokenizer of its own called `tokenize()`. While the tokenizing itself works quite well, `tokenize()` is not as elaborate as is TreeTagger when it comes to POS tagging, as it can merely tell words from numbers, punctuation and abbreviations. Although this is sufficient for most readability formulae, you can't evaluate word classes in detail. If that's what you want, a TreeTagger installation is needed.

2.2 Word lists

Some of the readability formulae depend on special word lists (like Dale & Chall, 1948; Bormuth, 1968; Spache, 1953). For copyright reasons these lists are not included as of now. This means, as long as you don't have copies of these lists, you can't calculate these particular measures, but of course all others. The expected format to use a list with this package is a simple text file with one word per line, preferably in UTF-8 encoding.

2.3 Language corpora

The frequency analysis functions in this package can look up how often each word in a text is used in its language, given that a corpus database is provided. Databases in Celex format are supported, as is the Leipzig Corpora Collection (Quasthoff, Richter, & Biemann, 2006) file format. To use such a database with this package, you simply need to download one of the .zip/.tar files.

2.4 Translated Human Rights Declaration

If you want to estimate the language of a text, reference texts in known languages are needed. In `koRpus`, the Universal Declaration of Human Rights with its more than 350 translations⁴ is used.

3 A sample session

From now on it is assumed that the above requirements are correctly installed and working. If an optional component is used it will be noted. Further, we'll need a sample text to analyze. We'll use the section on defense mechanisms of Phasmatodea from Wikipedia⁵ for this purpose.

²For a free implementation try <http://strawberryperl.com>

³Like <http://7-zip.org>

⁴<http://www.unicode.org/udhr/download.html>

⁵http://en.wikipedia.org/wiki/Phasmatodea#Defense_mechanisms

3.1 Tokenizing and POS tagging

As explained earlier, splitting the text up into its basic components can be done by TreeTagger. To achieve this and have the results available in R, the function `treetag()` is used.

3.1.1 `treetag()`

At the very least you must provide it with the text, of course, and name the language it is written in. In addition to that you must specify where you installed TreeTagger. If you look at the package documentation you'll see that `treetag()` understands a number of options to configure TreeTagger, but in most cases using one of the built-in presets should suffice. TreeTagger comes with batch/shell scripts for installed languages, and the presets of `treetag()` are basically just R implementations of these scripts.

```
> tagged.text <- treetag("~/docs/sample_text.txt", treetagger="manual",  
  lang="en", TT.options=c(path=~"/bin/treetagger/", preset="en"))
```

The first argument (file name) and `lang` should explain themselves. The `treetagger` option can either take the full path to one of the original TreeTagger scripts mentioned above, or the keyword "manual", which will cause the interpretation of what is defined by `TT.options`. To use a preset, just put the `path` to your local TreeTagger installation and a valid `preset` name here.⁶

The resulting S4 object is of a class called `kRp.tagged`. For this class of objects, `koRpus` provides some comfortable methods to extract the portions you're interested in. For example, the main results are to be found in the slot `TT.res`. In addition to TreeTagger's original output (token, tag and lemma) `treetag()` also automatically counts letters, assigns tokens to global word classes and explains the rather cryptic POS tags. To get to these results, use the getter method `taggedText()`:

```
> taggedText(tagged.text)
```

	token	tag	lemma	lttr	wclass	desc
[...]						
30	an	DT	an	2	determiner	Determiner
31	attack	NN	attack	6	noun	Noun, singular or mass
32	has	VBZ	have	3	verb	Verb, 3rd person singular present
33	been	VBN	be	4	verb	Verb, past participle
34	initiated	VBN	initiate	9	verb	Verb, past participle
35	(	(	(	1	punctuation	Opening bracket
36	secondary	JJ	secondary	9	adjective	Adjective
37	defense	NN	defense	7	noun	Noun, singular or mass
38	)	)	)	1	punctuation	Closing bracket
[...]						

⁶As of 0.04-38, English, French, Italian, German, Spanish and Russian are implemented, refer to package documentation.

Once you've come this far, i.e., having a valid object of class `kRp.tagged`, all following analyses should run smoothly.

Troubleshooting If `treetag()` should fail, you should first re-run it with the extra option `debug=TRUE`. Most interestingly, that will print the contents of `sys.tt.call`, which is the TreeTagger command given to your operating system for execution. With that it should be possible to examine where exactly the erroneous behavior starts.

3.1.2 Alternative: `tokenize()`

If you don't need detailed word class analysis, you should be fine using `koRpus`' own function `tokenize()`. As you can see, `tokenize()` comes to the same results regarding the tokens, but is rather limited in recognizing word classes:

```
> tagged.text <- tokenize("~/docs/sample_text.txt", lang="en")
> taggedText(tagged.text)
```

	token	tag	lemma	lttr	wclass	desc
[...]						
30	an	word.kRp		2	word	Word (kRp internal)
31	attack	word.kRp		6	word	Word (kRp internal)
32	has	word.kRp		3	word	Word (kRp internal)
33	been	word.kRp		4	word	Word (kRp internal)
34	initiated	word.kRp		9	word	Word (kRp internal)
35	(	(kRp		1	punctuation	Opening bracket (kRp internal)
36	secondary	word.kRp		9	word	Word (kRp internal)
37	defense	word.kRp		7	word	Word (kRp internal)
38	)	)kRp		1	punctuation	Closing bracket (kRp internal)
[...]						

3.1.3 Descriptive statistics

All results of both `treetag()` and `tokenize()` also provide various descriptive statistics calculated from the analyzed text. You can get them by calling `describe()` on the object. If you deal with these for the first time, it's a good idea to first look at its structure:

```
> str(describe(tagged.text))
```

Amongst others, you will find several indices describing the number of characters:

all.chars: Counts each character, including all space characters

normalized.space: Like **all.chars**, but clusters of space characters (incl. line breaks) are counted only as one character

chars.no.space: Counts all characters except any space characters

letters: Counts only letters, excluding(!) digits (which are counted separately as digits)

You'll also find the number of **words** and **sentences**, as well as average word and sentence lengths, and tables describing how the word length is distributed throughout the text:

```
> describe(tagged.text)[["lttr.distrib"]]

      1      2      3      4      5      6
num    19.000000  92.00000  74.00000  80.00000  51.000000  49.00000
cum.sum 19.000000 111.00000 185.00000 265.00000 316.000000 365.00000
cum.inv 537.000000 445.00000 371.00000 291.00000 240.000000 191.00000 [...]
pct      3.417266 16.54676 13.30935 14.38849  9.172662  8.81295
cum.pct  3.417266 19.96403 33.27338 47.66187 56.834532 65.64748
pct.inv  96.582734 80.03597 66.72662 52.33813 43.165468 34.35252
```

For instance, we can learn that the text has 74 words with three letters, 185 with three or less, and 371 with more than three. The last three lines show the percentages, respectively.

3.2 Lexical diversity (type token ratios)

To analyze the lexical diversity of our text we can now simply hand over the tagged text object to the `lex.div()` function:⁷

```
> lex.div(tagged.text)

Language: "en"
TTR.char: Calculate TTR values
  reached token 1 to 50...
  reached token 1 to 100...
  reached token 1 to 150...
  reached token 1 to 200...
[...]
Total number of tokens: 556
Total number of types: 294

Type-Token Ratio
  TTR: 0.53

TTR characteristics:
  Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

⁷Please note that as of version 0.04-18, the correctness of some of these calculations has not been extensively validated yet. The package was released nonetheless, also to find outstanding bugs in the implemented measures. Any information on the validity of its results is very welcome!

```

0.5297  0.5443  0.5895  0.6139  0.6429  1.0000

Mean Segmental Type-Token Ratio
      MSTTR: 0.72
      Segment size: 100
      Tokens dropped: 56

Hint: A segment size of 92 would reduce the drop rate to 4.
      Maybe try ?segment.optimizer()
[...]
HD-D
      HD-D: 0.85

HD-D characteristics:
      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
0.7677  0.8436  0.8463  0.8426  0.8504  0.8574  8.0000

Measure of Textual Lexical Diversity
      MTLD: 97.18
      Number of factors: 5.72
      Factor size: 0.72
      SD tokens/factor: 36.67 (all factors)
                        29.27 (complete factors only)

MTLD characteristics:
      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
14.00   76.14   86.00   81.96   93.21  103.60   1.00

```

The above output is only a small sample and really much longer. Let's look at some particular parts: At first we are informed of the language, which is read from the tagged object. Following that is a growing feedback stream, letting you know how far calculations of a measures' characteristics⁸ have progressed. This was added because if all possible measures are being calculated and the text is rather long, this can take quite some time, and it might be uplifting to see that R didn't just freeze. After that the actual results are being printed, using the package's `show()` method for this particular kind of object. As you can see, it prints the actual value of each measure before a summary of the characteristics⁹.

Some measures return more information than only their actual index value. For instance, when the Mean Segmental Type-Token Ratio is calculated, you'll be informed

⁸Characteristics can be looked at to examine each measure's dependency on text length. They are calculated by computing each measure repeatedly, beginning with only the first token, then adding the next, progressing until the full text was analyzed.

⁹For information on the measures shown see Tweedie and Baayen (1998); McCarthy and Jarvis (2007, 2010).

how much of your text was dropped and hence not examined. A small feature tool of `koRpus`, `segment.optimizer()`, automatically recommends you with a different segment size if this could decrease the number of lost tokens.

By default, `lex.div()` calculates every measure of lexical diversity that was implemented. Of course this is fully configurable, e.g. to completely skip the calculation of characteristics just add the option `char=NULL`. If you're only interested in one particular measure, it might be more convenient to call the according wrapper function instead of `lex.div()`. For example, to calculate the measures proposed by Maas (1972):

```
> maas(tagged.text)
```

```
Language: "en"
```

```
Total number of tokens: 556
```

```
Total number of types: 294
```

```
Maas' Indices
```

```
  a: 0.19
```

```
lgV0: 5.64
```

```
lgeV0: 12.99
```

```
Relative vocabulary growth (first half to full text)
```

```
  a: 0.79
```

```
lgV0: 6.93
```

```
  V': 0.43 (43 new types every 100 tokens)
```

All wrapper functions have characteristics turned off by default. The following example demonstrates how to calculate the classic type-token ratio with characteristics:

```
> ttr.res <- TTR(tagged.text, char=TRUE)
```

```
> plot(ttr.res@TTR.char, type="l", main="TTR degradation over text length")
```

The plot then shows the typical degradation of TTR values with increasing text length:

TTR degradation over text length



Since this package is intended for research, it should be possible to directly influence all relevant values of each measure and examine the effects. For example, as mentioned before `segment.optimizer()` recommended a change of segment size for MSTTR to drop less words, which is easily done:

```
> MSTTR(tagged.text, segment=92)
```

Language: "en"

Total number of tokens: 556

Total number of types: 294

Mean Segmental Type-Token Ratio


```

MSTTR: 0.75
Segment size: 92
Tokens dropped: 4

```

Please see to the documentation for more detailed information on the available measures and their references.

3.3 Frequency analysis

3.3.1 Importing language corpora data

This package has rudimentary support to import corpus databases.¹⁰ That is, it can read frequency data for words into an R object and use this object for further analysis. Next to the Celex¹¹ database format (`read.corp.celex()`), it can read the LCC flatfile format footnoteActually, it understands two different LCC formats, both the older .zip and the newer .tar archive format. (`read.corp.LCC()`). The latter might be of special interest, because the needed database archives can be freely downloaded.¹² Once you've downloaded one of these archives, it can be comfortably imported:

```
> LCC.en <- read.corp.LCC("~/downloads/corpora/eng_news_2010_1M-text.tar")
```

`read.corp.LCC()` will automatically extract the files it needs from the archive. Alternatively, you can specify the path to the unpacked archive as well. To work with the imported data directly, the tool `query()` was added to the package. It helps you to comfortably look up certain words, or ranges of interesting values:

```
> query(LCC.en, "word", "what")
```

```

      num word  freq      pct pmio  log10 rank.avg rank.min rank.rel.avg
160 210 what 16396 0.000780145  780 2.892095  260759  260759    99.95362
      rank.rel.min
160    99.95362

```

```
> query(LCC.en, "pmio", c(780, 790))
```

```

      num word  freq      pct pmio  log10 rank.avg rank.min rank.rel.avg
156 206  many 16588 0.0007892806  789 2.897077  260763  260763    99.95515
157 207   per 16492 0.0007847128  784 2.894316  260762  260762    99.95477
158 208  down 16468 0.0007835708  783 2.893762  260761  260761    99.95439

```

¹⁰The package also has a function called `read.corp.custom()` which can be used to process language corpora yourself, and store the results in an object of class `kRp.corp.freq`, which is the class returned by `read.corp.LCC()` and `read.corp.celex()` as well. That is, if you can't get any already analyzed corpus database but have a huge language corpus at hand, you can create your own frequency database. But be warned that depending on corpus size and your hardware, this might take ages. On the other hand, `read.corp.custom()` will provide inverse document frequency (idf) values for all types, which is necessary to compute tf-idf with `freq.analysis()`

¹¹<http://celex.mpi.nl>

¹²<http://corpora.informatik.uni-leipzig.de/download.html>

```

159 209 since 16431 0.0007818103 781 2.892651 260760 260760 99.95400
160 210 what 16396 0.0007801450 780 2.892095 260759 260759 99.95362
      rank.rel.min
156      99.95515
157      99.95477
158      99.95439
159      99.95400
160      99.95362

```

3.3.2 Conduct a frequency analysis

We can now conduct a full frequency analysis of our text:

```
> freq.analysis.res <- freq.analysis(tagged.text, corp.freq=LCC.en)
```

The resulting object holds a lot of information, even if no corpus data was used (i. e., `corp.freq=NULL`). To begin with, it contains the two slots `TT.res` and `lang`, which are copied from the analyzed tagged text object. In this way analysis results can always be converted back into `kRp.tagged` objects.¹³ However, if corpus data was provided, the tagging results gained three new columns:

```
> taggedText(freq.analysis.res)
```

	token	tag	lemma	lttr	[...]	pmio	rank.avg	rank.min
[...]								
30	an	DT	an	2	3817	99.98735	99.98735	
31	attack	NN	attack	6	163	99.70370	99.70370	
32	has	VBZ	have	3	4318	99.98888	99.98888	
33	been	VBN	be	4	2488	99.98313	99.98313	
34	initiated	VBN	initiate	9	11	97.32617	97.32137	
35	(	(	(	1	854	99.96013	99.96013
36	secondary	JJ	secondary	9	21	98.23846	98.23674	
37	defense	NN	defense	7	210	99.77499	99.77499	
38	)	)	)	1	856	99.96052	99.96052
[...]								

Perhaps most informatively, `pmio` shows how often the respective token appears in a million tokens, according to the corpus data. Adding to this, the previously introduced slot `desc` now contains some more descriptive statistics on our text, and if we provided a corpus database, the slot `freq.analysis` lists summaries of various frequency information that was calculated.

If the corpus object also provided inverse document frequency (i. e., values in column `idf`) data, `freq.analysis()` will automatically compute `tf-idf` statistics and put them in a column called `tfidf`.

¹³This can easily be done by calling `as(freq.analysis.res, "kRp.tagged")`.

3.3.3 New to the desc slot

Amongst others, the descriptives now also give easy access to character vectors with all words (`$all.words`) and all lemmata (`$all.lemmata`), all tokens sorted into word classes (e.g., all verbs in `$classes$verb`)¹⁴, or the number of words in each sentence:

```
> describe(freq.analysis.res)[["sentc.length"]]
[1] 34 10 37 16 44 31 14 31 34 23 17 43 40 47 22 19 65 29
```

As a practical example, the list `$classes` has proven to be very helpful to debug the results of TreeTagger, which is remarkably accurate, but of course not free from making a mistake now and then. By looking through `$classes`, where all tokens are grouped regarding to the global word class TreeTagger attributed to it, at least obvious errors (like names mistakenly taken for a pronoun) are easily found:¹⁵

```
> describe(freq.analysis.res)$classes

$conjunction
[1] "both" "and"  "and"  "and"  "and"  "or"   "or"   "and"  "and"  "or"
[11] "and"  "or"   "and"  "or"   "and"  "and"  "and"  "and"

$number
[1] "20"  "one"

$determiner
[1] "an"      "the"     "an"      "The"     "the"     "the"     "some"
[8] "that"    "Some"    "the"     "a"       "a"       "a"       "the"
[15] "that"    "the"     "the"     "Another" "which"    "the"     "a"
[22] "that"    "a"       "The"     "a"       "the"     "that"    "a"
[...]
```

3.4 Readability

The package comes with implementations of several readability formulae. Some of them depend on the number of syllables in the text.¹⁶ To achieve this, the function `hyphen()` takes objects of class `kRp.tagged` and applies an hyphenation algorithm (Liang, 1983) to each word. This algorithm was originally developed for automatic word hyphenation in L^AT_EX, and is gracefully misused here to fulfill a slightly different service.

```
> hyph.txt.en <- hyphen(tagged.text)
```

¹⁴This sorting depends on proper POS-tagging, so this will only contain useful data if you used `treetag()` instead of `tokenize()`.

¹⁵And can then be corrected by using the function `correct.tag()`

¹⁶Whether this is the case can be looked up in the documentation.

This separate hyphenation step can actually be skipped, as `readability()` will do it automatically if needed. But similar to TreeTagger, `hyphen()` will most likely not produce perfect results. As a rule of thumb, if in doubt it seems to behave rather conservative, that is, it underestimates the real number of syllables in a text. This, however, would of course affect the results of several readability formulae.

So, the more accurate the end results should be, the less you should rely on the automatic hyphenation alone. But it sure is a good starting point, for there is a function called `correct.hyph()` to help you clean these results of errors later on. Probably the most comfortable way to do this is to open the slot `hyph.txt.en@hyphen`, which is a data frame with two columns, `word` (the hyphenated words) and `syll` (the number of syllables), in a spreadsheet editor:¹⁷

```
> hyph.txt.en@hyphen
```

```
      syll      word
[...]
```

20	1	first
21	1	place
22	1	primary
23	2	de-fense
24	1	and

```
[...]
```

You can then manually correct wrong hyphenations by removing or inserting “-” as hyphenation indicators, and call the function without further arguments, which will cause it to recount all syllables:

```
> hyph.txt.en <- correct.hyph(hyph.txt.en)
```

Of course the function can also be used to alter entries on its own:

```
> hyph.txt.en <- correct.hyph(hyph.txt.en, word="primary", hyphen="pri-ma-ry")
```

Changed

```
      syll      word
22      1 primary

into

      syll      word
22      3 pri-ma-ry
```

The hyphenated text object can now be given to `readability()`, to calculate the measures of interest:¹⁸

¹⁷For example, this can be comfortably done with RKWard: <http://rkward.sourceforge.net>

¹⁸Please note that as of version 0.04-18, the correctness of some of these calculations has not been extensively validated yet. The package was released nonetheless, also to find outstanding bugs in the implemented measures. Any information on the validity of its results is very welcome!

```
> readbl.txt <- readability(tagged.text, hyphen=hyph.txt.en, index="all")
```

Similar to `lex.div()`, by default `readability()` calculates almost¹⁹ all available measures:

```
> readbl.txt
```

Flesch Reading Ease

Parameters: en (Flesch)

RE: 39.76

Grade: >= 13 (college)

Flesch.PSK Reading Ease

Parameters: Powers-Sumner-Kearl

Grade: 7.5

Age: 12.5

[...]

Gunning Frequency of Gobbledygook (FOG)

Parameters: Powers-Sumner-Kearl

Score: 7.39

[...]

Coleman Formulas

Parameters: default

Pronouns: 1.62 (per 100 words)

Prepos.: 13.31 (per 100 words)

Formula 1: 39% cloze completions

Formula 2: 37% cloze completions

Formula 3: 35% cloze completions

Formula 4: 36% cloze completions

[...]

To get a more condensed overview of the results try the `summary()` method:

```
> summary(readbl.txt)
```

Text language: en

	index	flavour	raw	grade	age
1	Flesch	en (Flesch)	39.76	>= 13 (college)	
2	Flesch	Powers-Sumner-Kearl		7.5	12.5
3	Flesch	de (Amstad)	55.26	>= 10 (high school)	
4	Flesch	es (Fernandez-Huerta)	79.07	7	
5	Flesch	fr (Kandel-Moles)	64.38	8-9	
6	Flesch	nl (Douma)	73.11	7	
7	Flesch-Kincaid			15.39	

¹⁹Measures which rely on word lists will be skipped if no list is provided.

```

8  Farr-Jenkins-Paterson                      33.76
9  Farr-Jenkins-Paterson      Powers-Sumner-Kearl          7.37
10                      FOG                                18.9
11                      FOG      Powers-Sumner-Kearl          7.39
12                      FOG              New FOG (NRI)          19
13      Coleman-Liau                      32                14.26
14                      SMOG                                15.97
15                      SMOG de ("Qu", Bamberger-Vanecek)    10.32
16                      LIX                                65.24
17                      RIX                                10.61      > 12 (college)
[...]
```

If you're interested in a particular formula, again a wrapper function might be more convenient:

```

> flesch.res <- flesch(tagged.text, hyphen=hyph.txt.en)
> lix.res <- LIX(tagged.text) # LIX doesn't need syllable count
> lix.res
```

```

Läsbarhetsindex (LIX)
  Parameters: default
    Index: 65.24
```

Text language: en

3.4.1 Readability from numeric data

It is possible to calculate the readability measures from the relevant key values directly, rather than analyze an actual text, by using `readability.num()` instead of `readability()`. If you need to reanalyze a particular text, this can be considerably faster. Therefore, all objects returned by `readability()` can directly be fed to `readability.num()`, since all relevant data is present in the `desc` slot.

3.5 Language detection

Another feature of this package is the detection of the language a text was (most probably) written in. This is done by gzipping reference texts in known languages, gzipping them again with addition of a small sample of the text in unknown language, and determining the case where the additional sample causes the smallest increase in file size (as described in Benedetto, Caglioti, & Loreto, 2002). By default, the compressed objects will be created in memory only.

To use the function `guess.lang()`, you first need to download the reference material. In this implementation, the Universal Declaration of Human Rights in unicode formatting is used, because the document holds the world record of being the text translated into the most languages, and is publicly available²⁰. Please get the zipped

²⁰<http://www.unicode.org/udhr/download.html>

archive with all translations in .txt format. You can, but don't have to unzip the archive. The text to find the language of must also be in a unicode .txt file:

```
> guess.lang("~/docs/sample_text.txt", udhr.path=~"/downloads/udhr_txt.zip")
```

```
Estimated language: English
Identifier: en
Country: UK (Europe)
```

377 different languages were checked.

4 Extending koRpus

The language support in this package was designed almost modular, so with a little effort you should be able to add new languages yourself. You need the package sources for this, then basically you will have to add a new file to it and rebuild/reinstall the package. More details on this topic can be found in `inst/README.languages`. Once you got a new language to work with `koRpus`, I'd be happy to include your module in the official distribution.

References

- Benedetto, D., Caglioti, E., & Loreto, V. (2002). Language trees and zipping. *Physical Review Letters*, 88(4), 048702.
- Bormuth, J. R. (1968). Cloze test readability: Criterion reference scores. *Journal of Educational Measurement*, 5(3), 189–196.
- Dale, E., & Chall, J. S. (1948). A formula for predicting readability. *Educational research bulletin*, 11–28.
- Liang, F. M. (1983). *Word hy-phen-a-tion by com-put-er* (Unpublished doctoral dissertation). Stanford University, Dept. Computer Science, Stanford.
- Maas, H. D. (1972). Über den Zusammenhang zwischen Wortschatzumfang und Länge eines Textes. *Zeitschrift für Literaturwissenschaft und Linguistik*, 2(8), 73–79.
- McCarthy, P. M., & Jarvis, S. (2007). vocd – a theoretical and empirical evaluation. *Language Testing*, 24(4), 459–488.
- McCarthy, P. M., & Jarvis, S. (2010). MTL-D, vocd-D, and HD-D: a validation study of sophisticated approaches to lexical diversity assessment. *Behavior research methods*, 42(2), 381–392.
- Quasthoff, U., Richter, M., & Biemann, C. (2006). Corpus portal for search in monolingual corpora. In *Proceedings of the fifth international conference on language resources and evaluation* (pp. 1799–1802). Genoa.
- Schmid, H. (1994). Probabilistic part-of-speech tagging using decision trees. In *International conference on new methods in language processing* (pp. 44–49). Manchester, UK.

- Spache, G. (1953). A new readability formula for primary-grade reading materials. *The Elementary School Journal*, 53(7), 410–413.
- Tweedie, F. J., & Baayen, R. H. (1998). How variable may a constant be? measures of lexical richness in perspective. *Computers and the Humanities*, 32(5), 323–352.