

Statistical Analysis of Corpus Data with R

You shall know a word by the company it keeps!

Collocation extraction with statistical association measures

— Part 1 —

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Collocations & Multiword Expressions (MWE)

What are collocations?

Types of cooccurrence

Quantifying the attraction between words

Contingency tables

Contingency tables and hypothesis tests in R

Practice session

What is a collocation?

- ▶ Words tend to appear in typical, recurrent combinations:

day and night

ring and bell

milk and cow

kick and bucket

brush and teeth

☞ such pairs are called **collocations** (Firth 1957)

- ▶ the meaning of a word is in part determined by its characteristic collocations
- ▶ “*You shall know a word by the company it keeps!*”

What is a collocation?

- ▶ Native speakers have strong & widely shared intuitions about such collocations
- ▶ Collocational knowledge is essential for non-native speakers in order to sound natural ⇨ “idiomatic English”

An important distinction ...

... which has been the cause of many misunderstandings.

- ▶ **collocations** are an empirical linguistic phenomenon
 - ▶ can be observed in corpora & quantified
 - ▶ provide a window to lexical meaning and word usage
 - ▶ applications in language description (Firth 1957) and computational lexicography (Sinclair 1966, 1991)
 - ▶ **multiword expressions** = lexicalised word combinations
 - ▶ MWE need to be lexicalised (i.e., stored as units) because of certain idiosyncratic properties
 - ▶ non-compositionality, non-substitutability, non-modifiability (Manning & Schütze 1999)
 - ▶ not observable, defined by linguistic tests (e.g. substitution test) and native speaker intuitions
- ☞ the term "collocations" has been used for both concepts

But what are collocations?

- ▶ Empirically, collocations are words that show an **attraction** towards each other (or a "mutual expectancy")
 - ▶ in other words, a tendency to occur near each other
 - ▶ collocations can also be understood as statistically salient patterns that can be exploited by language learners
- ▶ Linguistically, collocations are an **epiphenomenon** ...
 - ... some might also say a hotchpotch ...
 - ... of many different linguistic causes that lie behind the observed surface attraction.

Collocates of *bucket* (n.)

| noun | f | verb | f | adjective | f |
|------------------|-----|------------------|----|----------------------|----|
| <i>water</i> | 183 | <i>throw</i> | 36 | <i>large</i> | 37 |
| <i>spade</i> | 31 | <i>fill</i> | 29 | <i>single-record</i> | 5 |
| <i>plastic</i> | 36 | <i>randomize</i> | 9 | <i>cold</i> | 13 |
| <i>slop</i> | 14 | <i>empty</i> | 14 | <i>galvanized</i> | 4 |
| <i>size</i> | 41 | <i>tip</i> | 10 | <i>ten-record</i> | 3 |
| <i>mop</i> | 16 | <i>kick</i> | 12 | <i>full</i> | 20 |
| <i>record</i> | 38 | <i>hold</i> | 31 | <i>empty</i> | 9 |
| <i>bucket</i> | 18 | <i>carry</i> | 26 | <i>steaming</i> | 4 |
| <i>ice</i> | 22 | <i>put</i> | 36 | <i>full-track</i> | 2 |
| <i>seat</i> | 20 | <i>chuck</i> | 7 | <i>multi-record</i> | 2 |
| <i>coal</i> | 16 | <i>weep</i> | 7 | <i>small</i> | 21 |
| <i>density</i> | 11 | <i>pour</i> | 9 | <i>leaky</i> | 3 |
| <i>brigade</i> | 10 | <i>douse</i> | 4 | <i>bottomless</i> | 3 |
| <i>algorithm</i> | 9 | <i>fetch</i> | 7 | <i>galvanised</i> | 3 |
| <i>shovel</i> | 7 | <i>store</i> | 7 | <i>iced</i> | 3 |
| <i>container</i> | 10 | <i>drop</i> | 9 | <i>clean</i> | 7 |
| <i>oats</i> | 7 | <i>pick</i> | 11 | <i>wooden</i> | 6 |
| <i>sand</i> | 12 | <i>use</i> | 31 | <i>old</i> | 19 |
| <i>Rhino</i> | 7 | <i>tire</i> | 3 | <i>ice-cold</i> | 2 |
| <i>champagne</i> | 10 | <i>rinse</i> | 3 | <i>anti-sweat</i> | 1 |

Collocates of *bucket* (n.)

- ▶ opaque **idioms** (*kick the bucket*, but often used literally)
- ▶ **proper names** (*Rhino Bucket*, a hard rock band)
- ▶ noun **compounds**, lexicalised or productively formed (*bucket shop*, *bucket seat*, *slop bucket*, *champagne bucket*)
- ▶ **lexical collocations** = semi-compositional combinations (*weep buckets*, *brush one's teeth*, *give a speech*)
- ▶ cultural **stereotypes** (*bucket and spade*)
- ▶ **semantic compatibility** (*full*, *empty*, *leaky bucket*; *throw*, *carry*, *fill*, *empty*, *kick*, *tip*, *take*, *fetch a bucket*)
- ▶ **semantic fields** (*shovel*, *mop*; hypernym *container*)
- ▶ **facts** of life (*wooden bucket*; *bucket of water*, *sand*, *ice*, ...)
- ▶ often sense-specific (*bucket size*, *randomize to a bucket*)

Operationalising collocations

- ▶ Firth introduced collocations as an essential component of his methodology, but without any clear definition

Moreover, these and other technical words are given their 'meaning' by the restricted language of the theory, and by applications of the theory in quoted works. (Firth 1957, 169)

- ▶ Empirical concept needs to be formalised and quantified
 - ▶ intuition: collocates are "attracted" to each other, i.e. they tend to occur near each other in text
 - ▶ definition of "nearness" ⇔ **cooccurrence**
 - ▶ quantify the strength of attraction between collocates based on their recurrence ⇔ cooccurrence **frequency**

☞ We will consider word pairs (w_1, w_2) such as (*brush, teeth*)

Types of cooccurrence: examples

Surface cooccurrence

- ▶ **Surface cooccurrences** of $w_1 = \textit{hat}$ with $w_2 = \textit{roll}$
 - ▶ symmetric window of four words (L4, R4)
 - ▶ limited by sentence boundaries

A vast deal of coolness and a peculiar degree of judgement, are requisite in catching a hat. A man must not be precipitate, or he runs over it; he must not rush into the opposite extreme, or he loses it altogether. [...] There was a fine gentle wind, and Mr. Pickwick's hat rolled sportively before it. The wind puffed, and Mr. Pickwick puffed, and the hat rolled over and over, as merrily as a lively porpoise in a strong tide; and on it might have rolled, far beyond Mr. Pickwick's reach, had not its course been providentially stopped, just as that gentleman was on the point of resigning it to its fate.

- ▶ **cooccurrence frequency** $f = 2$
- ▶ **marginal frequencies** $f_1 = f_2 = 3$

Different types of cooccurrence

1. Surface cooccurrence

- ▶ criterion: surface distance measured in word tokens
- ▶ words in a *collocational span* around the node word, may be symmetric (L5, R5) or asymmetric (L2, R0)
- ▶ traditional approach in lexicography and corpus linguistics

2. Textual cooccurrence

- ▶ words cooccur if they are in the same text segment (sentence, paragraph, document, Web page, ...)
- ▶ often used in Web-based research (⇔ Web as corpus)

3. Syntactic cooccurrence

- ▶ words in a specific syntactic relation, e.g.
 - ▶ adjective modifying noun
 - ▶ subject / object noun of verb
 - ▶ N of N and similar patterns
- ▶ suitable for extraction of MWE (Krenn & Evert 2001)

Types of cooccurrence: examples

Textual cooccurrence

- ▶ **Textual cooccurrences** of $w_1 = \textit{hat}$ and $w_2 = \textit{over}$
 - ▶ textual units = sentences
 - ▶ multiple occurrences within a sentence ignored

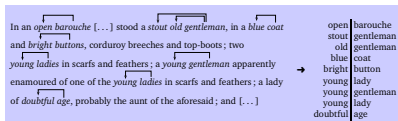
| | | |
|---|-----|------|
| A vast deal of coolness and a peculiar degree of judgement, are requisite in catching a <u>hat</u> . | hat | — |
| A man must not be precipitate, or he runs over it; | — | over |
| he must not rush into the opposite extreme, or he loses it altogether. | — | — |
| There was a fine gentle wind, and Mr. Pickwick's <u>hat</u> rolled sportively before it. | hat | — |
| The wind puffed, and Mr. Pickwick puffed, and the <u>hat</u> rolled over and over as merrily as a lively porpoise in a strong tide; | hat | over |

- ▶ cooccurrence frequency $f = 1$
- ▶ marginal frequencies $f_1 = 3, f_2 = 2$

Types of cooccurrence: examples

Syntactic cooccurrence

- **Syntactic cooccurrences** of adjectives and nouns
 - every instance of the syntactic relation of interest is extracted as a **pair token**



Cooccurrence frequency data for *young gentleman*:

- cooccurrence frequency $f = 1$
- marginal frequencies $f_1 = f_2 = 3$

Quantifying attraction

- Quantitative measure for attraction between words based on their recurrence ⇔ **cooccurrence frequency**
- But cooccurrence frequency is not sufficient
 - bigram *is to* occurs $f = 260$ times in Brown corpus
 - but both components are so frequent ($f_1 \approx 10,000$ and $f_2 \approx 26,000$) that one would also find the bigram 260 times if words in the text were arranged in completely random order
 - ⇨ take **expected frequency** into account as “baseline”
- Statistical model required to bring in notion of “chance cooccurrence” and to adjust for sampling variation
 - ⇨ NB: bigrams can be understood either as syntactic cooccurrences (adjacency relation) or as surface cooccurrences (L1, R0 or L0, R1)

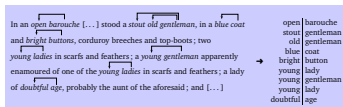
Attraction as statistical association

- Tendency of events to cooccur = **statistical association**
 - statistical measures of association are available for **contingency tables**, resulting from a **cross-classification** of a set of “items” according to two (binary) factors
 - cross-classifying factors represent the two events
- Application to word cooccurrence data
 - most natural for **syntactic cooccurrences**
 - “items” are pair tokens = instances of syntactic relation
 - factor 1: Is first component of pair token an instance of word type w_1 ?
 - factor 2: Is second component of pair token an instance of word type w_2 ?

Contingency table of observed frequencies

For **syntactic** cooccurrences

| | $+ w_2$ | $+ -w_2$ | | $+ gent.$ | $+ -gent.$ | |
|----------|----------|----------|---------|-----------|------------|-------|
| $w_1 +$ | O_{11} | O_{12} | $= f_1$ | 1 | 2 | $= 3$ |
| $-w_1 +$ | O_{21} | O_{22} | | 2 | 4 | |
| | $= f_2$ | $= N$ | | $= 3$ | $= 9$ | |



Contingency table of observed frequencies

For **textual** cooccurrences (sentence windows)

| | $w_2 \in S$ | $w_2 \notin S$ | |
|----------------|-------------|----------------|---------|
| $w_1 \in S$ | O_{11} | O_{12} | $= f_1$ |
| $w_1 \notin S$ | O_{21} | O_{22} | $= f_2$ |
| | | | $= N$ |

| | over $\in S$ | over $\notin S$ | |
|----------------|--------------|-----------------|-------|
| hat $\in S$ | 1 | 2 | $= 3$ |
| hat $\notin S$ | 1 | 1 | $= 2$ |
| | | | $= 5$ |

| | | |
|--|-----|------|
| A vast deal of coolness and a peculiar degree of judgement, are requisite in catching a <u>hat</u> . | hat | — |
| A man must not be precipitate, or he runs over it ; | — | over |
| he must not rush into the opposite extreme, or he loses it altogether. | — | — |
| There was a fine gentle wind, and Mr. Pickwick's <u>hat</u> rolled sportively before it. | hat | — |
| The wind puffed, and Mr. Pickwick puffed, and the <u>hat</u> rolled over and over as merrily as a lively porpoise in a strong tide ; | hat | over |

Contingency table of observed frequencies

For **surface** cooccurrences (L4, R4)

| | w_2 | $\neg w_2$ | |
|------------------|----------|------------|-----------------------|
| $near(w_1)$ | O_{11} | O_{12} | $\approx k \cdot f_1$ |
| $\neg near(w_1)$ | O_{21} | O_{22} | $= f_2$ |
| | | | $= N - f_1$ |

| | roll | $\neg roll$ | |
|------------------|------|-------------|---------|
| $near(hat)$ | 2 | 18 | $= 20$ |
| $\neg near(hat)$ | 1 | 87 | $= 88$ |
| | | | $= 3$ |
| | | | $= 108$ |

A vast deal of coolness and a peculiar degree of judgement, are requisite in catching a hat. A man must not be precipitate, or he runs over it ; he must not rush into the opposite extreme, or he loses it altogether. [...] There was a fine gentle wind, and Mr. Pickwick's hat rolled sportively before it. The wind puffed, and Mr. Pickwick puffed, and the hat rolled over and over, as merrily as a lively porpoise in a strong tide ; and on it might have rolled, far beyond Mr. Pickwick's reach, had not its course been providentially stopped, just as that gentleman was on the point of resigning it to its fate.

More details: Section 5.1 of Evert, S. (2008, in press). *Corpora and collocations*. In A. Lüdeling and M. Kytö (eds.), *Corpus Linguistics. An International Handbook*, article 57. Mouton de Gruyter, Berlin.

Measuring association in contingency tables

A) Measures of **significance**

- ▶ apply statistical hypothesis test with null hypothesis H_0 : independence of rows and columns
- ▶ H_0 implies there is no association between w_1 and w_2
- ▶ **association score** = test statistic or p-value
- ▶ one-sided vs. two-sided tests

☞ amount of evidence for association between w_1 and w_2

B) Measures of **effect-size**

- ▶ compare observed frequencies O_{ij} to **expected frequencies** E_{ij} under H_0 (*: later)
- ▶ or estimate conditional prob. $\Pr(w_2 | w_1)$, $\Pr(w_1 | w_2)$, etc.
- ▶ maximum-likelihood estimates or confidence intervals

☞ strength of the attraction between w_1 and w_2

Contingency tables in R

- ▶ Contingency table is represented as a **matrix** in R, i.e. a rectangular array of numbers
 - ▶ looks like numeric data frame, but different internally
- ▶ E.g. for the following observed frequencies:
 $O_{11} = 9$, $O_{12} = 47$, $O_{21} = 82$, $O_{22} = 956$

```
> A <- matrix(c(10, 47, 82, 956),
             nrow=2, ncol=2, byrow=TRUE)
> A
```

```
# construct matrix from row (or column) vectors
> A <- rbind(c(10, 47), c(82, 956))
```

Independence tests in R

```
# chi-squared test is the standard independence test
> chisq.test(A)

# use test statistic as association score, p-value for interpretation

# Is there significant evidence for a collocation?

# Fisher's exact test works better for small samples and skewed tables
> fisher.test(A)
```

Association scores from hypothesis tests

```
# chi-squared statistic  $X^2$  as association score
> chisq.test(A)$statistic

# p-value of Fisher's test and corresponding association score
> fisher.test(A)$p.value
> -log10(fisher.test(A)$p.value)

# NB: chi-squared and Fisher scores are not on same scale

# log odds ratio and conservative estimate
> log(fisher.test(A)$estimate)
> log(fisher.test(A)$conf.int[1])

> str(fisher.test(A)) # or read help page carefully
```

Interpreting hypothesis tests as association scores

- ▶ Establishing significance
 - ▶ p-value = probability of observed (or more "extreme") contingency table if H_0 is true
 - ▶ theory: H_0 can be rejected if p-value is below accepted **significance level** (commonly .05, .01 or .001)
 - ▶ practice: nearly all word pairs are highly significant
- ▶ Test statistic = significance association score
 - ▶ **convention** for association scores: high scores indicate strong attraction between words
 - ▶ satisfied by **test statistic** X^2 , but not by p-value
 - ▶ Fisher's test: transform p-value, e.g. $-\log_{10} p$
- ▶ Odds ratio as measure of effect size
 - ▶ Fisher's test also provides estimate for **odds ratio** θ , an effect-size measure for association strength
 - ▶ log odds ratio $\log \theta$ as effect-size association score (0 for independence, large values indicate strong attraction)
 - ▶ conservative estimate = lower bound of confidence interval

Association scores from hypothesis tests

```
# define two further (invented) contingency tables
> B1 <- rbind(c(16, 84), c(84, 816))
> B2 <- rbind(c(1, 99), c(99, 801))

# calculate chi-squared and Fisher scores for the two tables,
# as well as estimates for their log odds ratios

# Do the results look plausible to you? What is wrong?
```

One-sided vs. two-sided association scores

- ▶ Chi-squared and Fisher are **two-sided** tests
 - ▶ calculate high association scores (= low p-values) both for strong positive association (**attraction**) and for strong negative association (**repulsion**)
 - ▶ we are usually interested in attraction only (unless we are looking for "anti-collocations")
- ▶ Fisher can be applied as **one-sided** test
 - ▶ we are only interested in the **alternative** to H_0 that there is greater than chance cooccurrence, not in the alternative of less than chance cooccurrence

```
> fisher.test(B1, alternative="greater")
# high scores (significance and log odds ratio)
> fisher.test(B2, alternative="greater")
# low scores (significance and log odds ratio)
```

Practice: bigrams in the Brown corpus

- ▶ Data set of bigrams with $f \geq 5$ in the Brown corpus
 - ▶ available on course homepage as `brown_bigrams.tbl`
- ▶ 24,167 rows (= bigrams) with variables:
 - ▶ **id** = numeric ID of bigram
 - ▶ **word1** = first word (e.g. *long* for *long time*)
 - ▶ **pos1** = part-of-speech code (e.g. `J` for adjective)
 - ▶ **word2** = second word (e.g. *time* for *long time*)
 - ▶ **pos2** = part-of-speech code (e.g. `N` for noun)
 - ▶ **O11** = observed cooccurrence frequency O_{11}
 - ▶ **O12** = observed frequency O_{12}
 - ▶ **O21** = observed frequency O_{21}
 - ▶ **O22** = observed frequency O_{22}

Practice: bigrams in the Brown corpus

```
> Brown <- read.delim("brown_bigrams.tbl")
```

```
# Now select a number of bigrams (e.g. low and high cooccurrence
# frequency, or specific part-of-speech combinations), construct
# the corresponding contingency tables in matrix form,
# and calculate the different association scores you know.
# Can you find a bigram with strong negative association?
```

```
# NB: You can use the same tests for corpus frequency comparisons.
# Assume that a certain expression occurs 50 times in the 100,000
# tokens of corpus A, and twice in the 1,000 tokens of corpus B.
# What is an appropriate contingency table for these data, and what
# results do you obtain from the chi-squared and Fisher test?
```