Faculty of Computer Science, Dalhousie University *14-Oct-2025*

CSCI 4152/6509 — Natural Language Processing

Lecture 6: Text Similarity and Applications

Location: Studley LSC-Psychology P5260 Instructor: Vlado Keselj
Time: 14:35 – 15:55

Previous Lecture

- Back Reference Examples (continued)
- RegEx: Shortest match, Substitutions
- Text processing examples
  - tokenization
  - counting letters
- Elements of Morphology
  - Lemmatization, Morphological Processes
- Word Counting and Zipf's Law
- N-grams definition
- Extracting and Analyzing n-grams in Perl

In our previous solution the repeated space characters (labelled as '_') were occurring due to our way of reading and tokenizing the input line by line. We did treat a sequence of white-space characters as one space token by using the regular expression `/\s+/`, but still when going from line to line we can get repeated space characters if the next line is empty or starts with some space characters. These repeated space characters do not generally have significance and we would prefer to treat them as one space character. An easy way to solve this problem is to read the whole file as one string, and effectively treat it as one line with a reuse of the same code:

Extracting Character N-grams (attempt 3)

```
#!/usr/bin/perl
# char-ngrams3.pl - third attempt

$n = 3;
$_ = join('',<>); # notice how <> behaves differently
            # in an array context, vs. scalar context

while (/\S|\s+/g) {
  my $token = $&;
  if ($token =~ /^\s+$/) { $token = '_' }
  push @ng, $token;
  shift @ng if scalar(@ng) > $n;
  print "@ng\n" if scalar(@ng) == $n;
}

# Output of: ./char-ngrams3.pl TomSawyer.txt
# _ T h   f _ T   a r k
# T h e   _ T o   r k _
```

```
# h e _   T o m   k _ T
# e _ A   o m _   _ T w
# _ A d   m _ S   T w a
# A d v   _ S a   w a i
# d v e   S a w   a i n
# v e n   a w y   i n _
# e n t   w y e   n _ (
# n t u   y e r   _ ( S
# t u r   e r _   ( S a
# u r e   r _ b   S a m
# r e s   _ b y   a m u
# e s _   b y _   m u e
# s _ o   y _ M   u e l
# _ o f   _ M a   e l _
# o f _   M a r   ...
```

These days computers have very large working memories (RAM, or Random Access Memories), so reading a whole file in memory as in the above example is normally not a problem.

Character N-gram processing in Line-by-line Mode. If we want to avoid reading the whole file into memory and still recognize multi-line whitespace as one space character, it can be done but we will leave it as an exercise. One approach would be to write a function `next_char` that keeps the current line and on each call reads the next character and returns it. When encoutering a whitespace character, it would read as many lines as needed until a non-whitespace character is found, and it would return a space. This approach would be preferred with very large input files and the processing speed is important.

Word N-gram Frequencies

```
#!/usr/bin/perl
# word-ngrams-f.pl

$n = 3;

while (<>) {
  while (/'?[a-zA-Z]+/g) {
     push @ng, lc($&); shift @ng if scalar(@ng) > $n;
     &collect(@ng) if scalar(@ng) == $n;
  }
}

sub collect {
  my $ng = "@_";
  $f{$ng}++; ++$tot;
}

print "Total $n-grams: $tot\n";

for (sort { $f{$b} <=> $f{$a} } keys %f) {
  print sprintf("%5d %lf %s\n",
                $f{$_}, $f{$_}/$tot, $_);
}
```

```
# Output of: ./word-ngrams-f.pl TomSawyer.txt
# Total 3-grams: 73522
#     70 0.000952 i don ’t
#     44 0.000598 there was a
#     35 0.000476 don ’t you
#     32 0.000435 by and by
#     25 0.000340 there was no
#     25 0.000340 don ’t know
#     24 0.000326 it ain ’t
#     22 0.000299 out of the
#     22 0.000299 i won ’t
#     21 0.000286 it ’s a
#     21 0.000286 i didn ’t
#     21 0.000286 i can ’t
#     20 0.000272 it was a
#     19 0.000258 and i ’ll
#     18 0.000245 injun joe ’s
#     18 0.000245 you don ’t
#     17 0.000231 i ain ’t
#     17 0.000231 he did not
#     16 0.000218 he had been
#     15 0.000204 out of his
#     15 0.000204 all the time
#     15 0.000204 it ’s all
#     15 0.000204 to be a
#     15 0.000204 what ’s the
#     14 0.000190 that ’s so
#...
```

Character N-gram Frequencies

```
#!/usr/bin/perl
# char-ngrams-f.pl

$n = 3;
$_ = join(’’,<>); # notice how <> behaves differently
            # in an array context, vs. scalar context

while (/\S|\s+/g) {
  my $token = $&;
  if ($token =~ /^\s+$/) { $token = ’_’ }
  push @ng, $token;
  shift @ng if scalar(@ng) > $n;
  &collect(@ng) if scalar(@ng) == $n;
}

sub collect {
  my $ng = "@_";
  $f{$ng}++; ++$tot;
}
```

```
print "Total $n-grams: $tot\n";

for (sort { $f{$b} <=> $f{$a} } keys %f) {
  print sprintf("%5d %lf %s\n",
                $f{$_}, $f{$_}/$tot, $_);
}

# Output of: ./char-ngrams-f.pl TomSawyer.txt
# Total 3-grams: 389942
#  6556 0.016813 _ t h
#  5110 0.013105 t h e
#  4942 0.012674 h e _
#  3619 0.009281 n d _

#  3495 0.008963 _ a n
#  3309 0.008486 a n d
#  2747 0.007045 e d _
#  2209 0.005665 _ t o
#  2169 0.005562 i n g
#  1823 0.004675 t o _
#  1817 0.004660 n g _
#  1738 0.004457 _ a _
#  1682 0.004313 _ w a
#  1673 0.004290 _ h e
#  1672 0.004288 e r _
#  1592 0.004083 d _ t
#  1566 0.004016 _ o f
#  1541 0.003952 a s _
#  1526 0.003913 _ ` `
#  1511 0.003875 ' ' _
#  1485 0.003808 a t _
# ...
```

7.3 Using Ngrams Module

This section is covered in the lab, but you can also read here about the basic use of the Ngrams module.

We will now discuss how different kinds of n-grams can be collected using a Perl module named Text::Ngrams. A program associate with this module is named `ngrams.pl`, and both files, `Ngrams.pm` and `ngrams.pl`, can be found in the directory `~prof6509/public` on bluenose. They can also be found on the course website under the tab 'Misc'. If you use the web-site, for technical reasons the file `ngrams.pl` was renamed to `ngrams-pl.txt` and if you download it, you will need to rename it back to `ngrams.pl`.

The module and the program are open-source code, and can be found in the CPAN archive. The newest version is available on bluenose. The modules are typically installed system-wide and the Perl is configured in such way that it can easily find them. Since you do not have administrative permissions on bluenose, we need to use a way to use the module locally. The Perl modules can be installed on a per-user basis, either in a more systematic way or in more ad-hoc way. We will use here a local ad-hoc installation. You will cover the steps of installing the module in more details in the lab, but for now, we will assume that you are in a convenient sub-directory of your your home directory on bluenose. You would first copy the appropriate files using the commands:

```
cp ~prof6509/public/ngrams.pl .
```

```
cp ~prof6509/public/Ngrams.pm .
```

These files may actually be installed system-wide on bluenose, but to be sure to use the local version, we will do a couple additional operations and checks. First, create a subdirectory `Text` and copy the module there:

```
mkdir Text
cp Ngrams.pm Text
```

Check Local `ngrams.pl`

- Use command: `more ngrams.pl`

Let us take a look at the version of `ngrams.pl` that we use here. (This version is slightly different from the version in the CPAN archive.) We can use the command '`more ngrams.pl` and the beginning of the file should look as follows:

```
#!/usr/bin/perl -w

use strict;
use vars qw($VERSION);
$VERSION = 2.005;
# $Revision: 1.26 $

use lib '.';

use Text::Ngrams;
use Getopt::Long;
...
```

The line '`use lib '.';`' is important, since it directs Perl to give priority in finding the module in the current directory, rather than some other versions that may be available in the system. You can test the program `ngrams.pl` but typing:

```
./ngrams.pl
```

then typing some input, and pressing '`C-d`'; i.e., Control-D combination of keyboard keys. For example, if you type input:

```
natural language processing
```

you should get the output:

```
BEGIN OUTPUT BY Text::Ngrams version 2.005

1-GRAMS (total count: 28)
FIRST N-GRAM: N
 LAST N-GRAM: _
-------------------------
_ 3
A 4
```

```
C 1
E 2
G 3
I 1
L 2
N 3
O 1
P 1
R 2
S 2
T 1
U 2

2-GRAMS (total count: 27)
FIRST N-GRAM: N A
 LAST N-GRAM: G _
-------------------------
_ L 1
_ P 1
A G 1
A L 1
A N 1
A T 1
C E 1
E _ 1
E S 1
G _ 1
G E 1
G U 1
I N 1
L _ 1
L A 1
N A 1
N G 2
O C 1
P R 1
R A 1
R O 1
S I 1
S S 1
T U 1
U A 1
U R 1

3-GRAMS (total count: 26)
FIRST N-GRAM: N A T
 LAST N-GRAM: N G _
-------------------------
_ L A 1
_ P R 1
A G E 1
A L _ 1
```

```
A N G 1
A T U 1
C E S 1
E _ P 1
E S S 1
G E _ 1
G U A 1
I N G 1
L _ L 1
L A N 1
N A T 1
N G _ 1
N G U 1
O C E 1
P R O 1
R A L 1
R O C 1
S I N 1
S S I 1
T U R 1
U A G 1
U R A 1

END OUTPUT BY Text::Ngrams
```

This are the character n-grams of up to the size 3 of the given text, with their counts.

Verifying Version of Ngrams.pm

To test that the program is using the correct version of the module `Ngrams.pm` we can edit the file `Text/Ngrams.pm` and temporarily insert a 'die' command at the beginning of the module. The beginning of the module should look as follows:

```
# (c) 2003-2014 Vlado Keselj http://web.cs.dal.ca/~vlado
#
# Text::Ngrams - A Perl module for N-grams processing

die;

package Text::Ngrams;

use strict;
require Exporter;
use Carp;
...
```

- If we run `ngrams.pl` it should report error
- Delete '`die;`' command from the Ngrams.pm file

It is important to note that this is the copy of the module in the subdirectory `Text`. After this small test, do not forget to remove again the line '`die;`'.

8 Elements of Information Retrieval and Text Mining

In the previous sections, we looked at some methods for processing text in a stream mode. Many language processing tasks can be solved in this way, by using mainly regular expressions, extracting some pieces of text, and collecting basic statistics. We will now look at some techniques for working with the documents as whole units withing large collections. First we will look at the task of Information Retrieval, and then the area of Text Mining, with a particular emphasis on Text Classification and brief mentioning of Text Clustering.

The term *Text Mining* was coined at about the same time as *Data Mining*, and it consists of methods for a coarse-grained management of text documents, such as classification and clustering; but also some finer-grained mining of information, such as in information extraction.

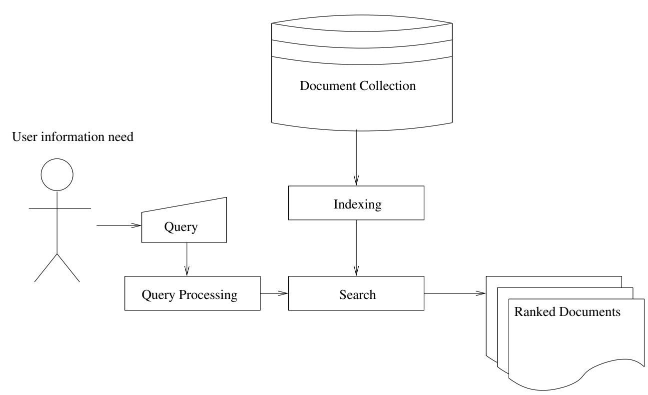
8.1 Elements of Information Retrieval

– Reading: [JM] Sec 23.1, ([MS] Ch.15)

Information Retrieval is an area of Computer Science mainly concerned with the task of finding a set of relevant documents from a document collection given a user query. A search engine, such as Google, is a information retrieval system.

Basic Information Retrieval problem definition: The basic definition of the problem or task of Information Retrieval is also called *ad hoc retrieval* and is given as follows: We are given a set of documents called a *document collection*, where each document is a natural language text. A user has an *information need* which she or he will need to express as a *query*, which is a short text, possibly in natural language or some more specialized format. The task of an Information Retrieval system is to return a subset of documents from the document collection that are *relevant* to the user query. The relevant documents should also be sorted by relevancy, starting from the most relevant document; i.e., a *ranked list of documents*.

Typical IR System Architecture



Steps in Document and Query Processing

– a “bag-of-words” model
– stop-word removal
– rare word removal (optional)
– stemming
– optional query expansion
– document indexing
– document and query representation;
  e.g. sets (Boolean model), vectors

The document semantics is reduced to the set of stems of content-bearing words.

8.2 Vector Space Model

Vector Space Model in IR

- We choose a global set of terms $\{t_1, t_2, \ldots, t_m\}$
- Documents and queries are represented as vectors of weights:

$$\vec{d} = (w_{1,d}, w_{2,d}, \ldots, w_{m,d}) \quad \vec{q} = (w_{1,q}, w_{2,q}, \ldots, w_{m,q})$$

  where weights correspond to respective terms
- What are weights? Could be binary (1 or 0), term frequency, etc.
- A standard choice is: *tfidf* — term frequency inverse document frequency weights

$$\mathit{tfidf} = \mathit{tf} \cdot \log\left(\frac{N}{\mathit{df}}\right)$$

- *tf* is frequency (count) of a term in document, which is sometimes log-ed as well
- *df* is document frequency, i.e., number of documents in the collection containing the term

After preprocessing steps, such as stop-word removal, rare words removal, and stemming, we have a global set of terms $\{t_1, t_2, \ldots, t_m\}$, which are used to represent documents and queries.

In a vector space model, document and queries are represented by vectors of weights, such as

$$\vec{d} = (w_{1,d}, w_{2,d}, \ldots, w_{m,d}), \text{ and } \vec{q} = (w_{1,q}, w_{2,q}, \ldots, w_{m,q})$$

where the weights $w_{i,x}$ correspond to the term t_i, of the document or query x. There are different ways how weights can be determined. One simple way is to use *binary* weights: 1 if the document contains the term, or 0 if it does not. Another option is to use term counts, or frequency within the document or query. The most widely adopted standard choice is to use *term frequency inverse document frequency* weights (*tfidf*), which are calculated using the following formula:

$$\mathit{tfidf} = \mathit{tf} \cdot \log\left(\frac{N}{\mathit{df}}\right)$$

where *tf* is frequency (count) of a term in document, which is sometimes log-ed as well; *df* is document frequency, i.e., number of documents in the collection containing the term; and N is the total number of documents in the collection. The document frequency df is the number of documents that contain the term t. We could also calculate it as the portion of the document collection that contain the term; i.e., the fraction of documents that contain the term, which would be df/N. A term should be more important and have a higher weight if it is more rare, so that is the reason why we use the inverse document frequency, or N/df. For very rare terms this number could be very large, for example the terms with $\mathit{df} = 1$ and $N = 1\,000\,000$ it would be $1\,000\,000$, so to "curb" this growth we apply the slow-growing logarithm function and finally obtain $\mathit{tfidf} = \mathit{tf} \cdot \log(N/\mathit{df})$. In some references, the logarithm is applied to tf as well.

8.3 Cosine Similarity Measure

A natural measure to measure similarity between a document and a query is the *cosine similarity measure.* It is known that the cosine of the angle between two vectors can be easily computed using the following formula:

$$\mathit{sim}(q,d) = \frac{\sum_{i=1}^{m} w_{i,q} w_{i,d}}{\sqrt{\sum_{i=1}^{m} w_{i,q}^2} \cdot \sqrt{\sum_{i=1}^{m} w_{i,d}^2}} = \frac{\vec{q} \cdot \vec{d}}{|\vec{q}| \cdot |\vec{d}|}$$

The formula gives the cosine of the angle between vectors in 2-dimensional and 3-dimensional space, and although we cannot exactly image the angle in spaces in more dimensions it still preserve some nice properties that match our intuition about similarity between documents, or between a document and a query. For example, if a document and query have exactly the same terms and in exactly the same proportion of their frequencies, the angle will be 0, and the cosine will be 1. On the other hand, if and only if the query and the document have no terms in common, the angle will be $90°$, and the cosine will be 0.

The angle between a query and a document vector in the 3-dimensional space is shown in the Figure 1.

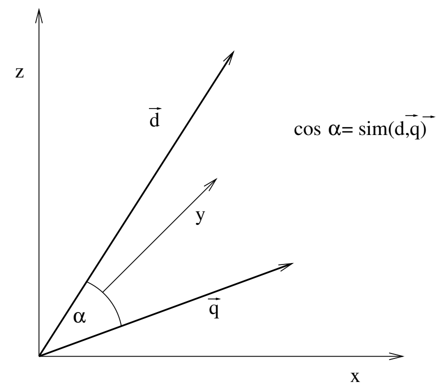


Figure 1: Cosine Similarity in the 3-dimensional Space

If the vectors representing documents ($\vec{d}$) and queries ($\vec{q}$) are normalized in advance, i.e., if they are divided with their length, then the cosine similarity computation becomes simpler and more efficient. Namely, if the normalized vectors are precomputed

$$\vec{d}_0 = \frac{\vec{d}}{|\vec{d}|} = \left(\frac{w_{1,d}}{\sqrt{\sum_{i=1}^m w_{i,d}^2}}, \frac{w_{2,d}}{\sqrt{\sum_{i=1}^m w_{i,d}^2}}, \ldots \frac{w_{m,d}}{\sqrt{\sum_{i=1}^m w_{i,d}^2}} \right)$$

and

$$\vec{q}_0 = \frac{\vec{q}}{|\vec{q}|} = \left(\frac{w_{1,q}}{\sqrt{\sum_{i=1}^m w_{i,q}^2}}, \frac{w_{2,q}}{\sqrt{\sum_{i=1}^m w_{i,q}^2}}, \ldots \frac{w_{m,q}}{\sqrt{\sum_{i=1}^m w_{i,q}^2}} \right)$$

then the similarity value is simply computed as

$$sim(q, d) = \vec{q}_0 \cdot \vec{d}_0 = \sum_{i=1}^m w_{iq_0} w_{id_0}$$

Side Note: An interesting open-source search engine:

- Lucene search engine
- `http://lucene.apache.org`
- Open-source, written in Java
- Uses the vector space model
- Another interesting link: Introduction to IR on-line book covers well text classification: `http://nlp.stanford.edu/IR-book/html/htmledition/irbook.html`