Analyzing Time Structured Corpora

Corpus Statistics Research Group launch event
Birmingham, 11th Feb 2016

Tony Hennessey (University of Nottingham)

joint work with R. Carrington, Y. van Gennip, M. Mahlberg, S. Preston, K. Severn, V. Wiegand
Overview

How to look at the time dependency in the properties of a corpus.
- Recap terminology and describe the main example used throughout the presentation.
- Binning data and how to think about binning mathematically.
- Using kernels which are better than bins.
Setting the scene (and a bit of a recap)

- some matrix representation of the corpus

\[ \begin{pmatrix} 0 & 2 & 2 & 1 & 0 & \ldots \\ 0 & 0 & 2 & 1 & 1 & \ldots \\ 1 & 0 & 0 & 1 & 1 & \ldots \\ 1 & 1 & 0 & 0 & 1 & \ldots \\ 1 & 1 & 1 & 0 & 0 & \ldots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix} \]
Setting the scene (and a bit of a recap)

X - some matrix representation of the corpus

\[
\begin{pmatrix}
\text{aardvark} & \text{abacus} & \text{badger} & \text{bandicoot} & \text{bonsai} \\
\hline
\text{doc 01} & 0 & 2 & 2 & 1 & 0 & \ldots \\
\text{doc 02} & 0 & 0 & 2 & 1 & 1 & \ldots \\
\text{doc 03} & 1 & 0 & 0 & 1 & 1 & \ldots \\
\text{doc 04} & 1 & 1 & 0 & 0 & 1 & \ldots \\
\text{doc 05} & 1 & 1 & 1 & 0 & 0 & \ldots \\
\end{pmatrix}
\]

document-term matrix
Setting the scene (and a bit of a recap)

$f(X)$ - some function that we apply to the corpus
Setting the scene (and a bit of a recap)

\[ f(\mathbf{X}) \] - some function that we apply to the corpus

The cosine of the angle between words in a vector space which was derived using a matrix factorization.
\( \mathbf{X} = \mathbf{U} \mathbf{S} \mathbf{V}^T \) singular value decomposition

This measure quantifies the degree of association between words i.e. a bigger value implies closer association.
Setting the scene (and a bit of a recap)

X (document-term matrix)

- 11,543,110 documents
- 472,331 terms
Setting the scene (and a bit of a recap)

X (document-term matrix)

- 11,543,110 documents
- 472,331 terms

Meta-data for each document includes a date
How does the corpus change with time?

Let us try binning the data using dates.
Binning by date

\[ X = \begin{pmatrix}
\text{aardvark} & \text{abacus} & \text{badger} \\
\text{doc 01} & 0 & 2 & 2 & \ldots \\
\text{doc 02} & 0 & 0 & 2 & \ldots \\
\text{doc 03} & 1 & 0 & 0 & \ldots \\
\text{doc 04} & 1 & 1 & 0 & \ldots \\
\text{doc 05} & 1 & 1 & 1 & \ldots \\
\text{doc 06} & 4 & 2 & 0 & \ldots \\
\text{doc 07} & 2 & 1 & 1 & \ldots \\
\text{doc 08} & 2 & 0 & 2 & \ldots \\
\text{doc 09} & 1 & 2 & 0 & \ldots \\
\text{doc 10} & 0 & 4 & 0 & \ldots \\
\vdots & \vdots & \vdots & \vdots & \ddots
\end{pmatrix} \]
## Binning by date

<table>
<thead>
<tr>
<th>Date</th>
<th>aardvark</th>
<th>abacus</th>
<th>badger</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Jan 1785</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>doc 01</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>doc 02</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>doc 03</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>doc 04</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2nd Jan 1785</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>doc 05</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>doc 06</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>doc 07</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3rd Jan 1785</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>doc 08</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>doc 09</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>doc 10</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

Tony Hennessey (UoN)
## Binning by date

<table>
<thead>
<tr>
<th>Date</th>
<th>aardvark</th>
<th>abacus</th>
<th>badger</th>
<th>aardvark</th>
<th>abacus</th>
<th>badger</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Jan 1785</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 01</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 02</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 03</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 04</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 05</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 06</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 07</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 08</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>doc 09</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>2nd Jan 1785</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 04</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 05</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 06</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>3rd Jan 1785</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 07</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 08</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>doc 09</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Binning by date

\[
X(t)
\]

<table>
<thead>
<tr>
<th></th>
<th>aardvark</th>
<th>abacus</th>
<th>badger</th>
</tr>
</thead>
<tbody>
<tr>
<td>doc 01</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>doc 02</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>doc 03</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\[
X(t = 1st \ Jan \ 1785) =
\]

<table>
<thead>
<tr>
<th></th>
<th>aardvark</th>
<th>abacus</th>
<th>badger</th>
</tr>
</thead>
<tbody>
<tr>
<td>doc 04</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>doc 05</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>doc 06</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

\[
X(t = 2nd \ Jan \ 1785) =
\]

<table>
<thead>
<tr>
<th></th>
<th>aardvark</th>
<th>abacus</th>
<th>badger</th>
</tr>
</thead>
<tbody>
<tr>
<td>doc 07</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>doc 08</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>doc 09</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
Binning by date

\[ f(X(t)) \]

\[
\begin{align*}
X(t = 1\text{st Jan 1785}) &= \begin{pmatrix} \text{doc 01} \\ \text{doc 02} \\ \text{doc 03} \end{pmatrix} = \begin{pmatrix} 0 & 2 & 2 \ldots \\ 0 & 0 & 2 \ldots \\ 1 & 0 & 0 \ldots \end{pmatrix} \\
X(t = 2\text{nd Jan 1785}) &= \begin{pmatrix} \text{doc 04} \\ \text{doc 05} \\ \text{doc 06} \end{pmatrix} = \begin{pmatrix} 1 & 1 & 0 \ldots \\ 1 & 1 & 1 \ldots \\ 4 & 2 & 0 \ldots \end{pmatrix} \\
X(t = 3\text{rd Jan 1785}) &= \begin{pmatrix} \text{doc 07} \\ \text{doc 08} \\ \text{doc 09} \end{pmatrix} = \begin{pmatrix} 2 & 1 & 1 \ldots \\ 2 & 0 & 2 \ldots \\ 1 & 2 & 0 \ldots \end{pmatrix}
\end{align*}
\]
Binning by date

Identity matrix

\[
X = I \times X
\]

\[
\begin{pmatrix}
0 & 2 & 2 & \ldots \\
0 & 0 & 2 & \ldots \\
1 & 0 & 0 & \ldots \\
1 & 1 & 0 & \ldots \\
1 & 1 & 1 & \ldots \\
4 & 2 & 0 & \ldots \\
2 & 1 & 1 & \ldots \\
2 & 0 & 2 & \ldots \\
1 & 2 & 0 & \ldots \\
0 & 4 & 0 & \ldots \\
\vdots & \vdots & \vdots & \ddots
\end{pmatrix}
= \begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & \ldots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots
\end{pmatrix}
= \begin{pmatrix}
0 & 2 & 2 & \ldots \\
0 & 0 & 2 & \ldots \\
1 & 1 & 0 & \ldots \\
1 & 1 & 1 & \ldots \\
4 & 2 & 0 & \ldots \\
2 & 1 & 1 & \ldots \\
2 & 0 & 2 & \ldots \\
1 & 2 & 0 & \ldots \\
0 & 4 & 0 & \ldots \\
\vdots & \vdots & \vdots & \ddots
\end{pmatrix}
\]
Binning by date

Filter by date

\[
X(t) = b(t) X
\]

where \( t = '1st Jan 1785' \)
Binney by date

Filter by date

\[ \mathbf{X}(t) = \mathbf{b}(t) \mathbf{X} \]

where \( t = '2nd Jan 1785' \)
How wide should the bins be?

- depends on your research question
  - e.g. over what time scale are you interested in examining change?
- depends on your data
  - e.g. how sparsely distributed are the traits you are looking at likely to be?
An example of binning using the TDA
just showing $f(X(t))$ for ‘smoking’ and ‘cancer’
Binning by date

An example of binning using the TDA
just showing $f(\mathbf{X}(t))$ for ‘smoking’ and ‘cancer’

We used 5 year bins because
- the number of articles about smoking are quite sparsely distributed
- we are mainly interested in long term trends
Binning by date
Binning by date

Sliding the bins
Binning by date

Sliding the bins
Binning by date

Sliding the bins for the TDA example

revisit $f(\mathbf{X}(t))$ for ‘smoking’ and ‘cancer’
Binning by date

Sliding the bins for the TDA example

revisit $f( \mathbf{X}(t) )$ for ‘smoking’ and ‘cancer’
Using a kernel

Can we do better?

Yes. Use a kernel.
Using a kernel

Why use a kernel? Why not just bin?

- A kernel takes account of the width of your data collection window i.e. if you bin, as your bins get wider your effect will get bigger; with a kernel it will not.
Using a kernel

Why use a kernel? Why not just bin?

- A kernel takes account of the width of your data collection window i.e. if you bin, as your bins get wider your effect will get bigger; with a kernel it will not.

\[ k(t) = \frac{1}{w} b(t) \]

\[
\begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & \frac{1}{w} & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & \frac{1}{w} & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & \frac{1}{w} & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{w} & \ldots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots
\end{pmatrix}
= \frac{1}{w} \begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots
\end{pmatrix}
\]
Using a kernel

Why use a kernel? Why not just bin?

- A kernel takes account of the width of your data collection window i.e. if you bin, as your bins get wider your effect will get bigger; with a kernel it will not.
- With a kernel we can control smoothing.
Using a kernel

Why use a kernel? Why not just bin?

- A kernel takes account of the width of your data collection window i.e. if you bin, as your bins get wider your effect will get bigger; with a kernel it will not.
- With a kernel we can control smoothing.
Using a kernel

Why use a kernel? Why not just bin?

- A kernel takes account of the width of your data collection window i.e. if you bin, as your bins get wider your effect will get bigger; with a kernel it will not.
- With a kernel we can control smoothing.
Using a kernel

Some examples of kernels

![Graph of various kernels](image by Brian Amberg (wikicommons))
Using a kernel

Sliding the kernel

\[ f(X(t)) \]
Using a kernel

Sliding the kernel

\[ f(X(t)) \]
Using a kernel

Sliding the kernel

\[ f(X(t)) \]
Using a kernel

Sliding the kernel

\[ f(X(t)) \]
Using a kernel

Sliding the kernel

\[ f(X(t)) \]

\[ t \]

Tony Hennessey (UoN) 16 / 18
Using a kernel

Sliding the kernel

\[ f(X(t)) \]
Using a kernel

Triweight kernel for the TDA example
revisit \( f( X(t) ) \) for ‘smoking’ and ‘cancer’
Using a kernel

Triweight kernel for the TDA example

revisit $f(X(t))$ for ‘smoking’ and ‘cancer’
Using a kernel

Triweight kernel for the TDA example

revisit $f(\mathbf{X}(t))$ for ‘smoking’ and ‘cancer’

1951: Dr Richard Doll and Prof Austin Bradford Hill conduct first large-scale study of link between smoking and lung cancer.

1954: Dr Doll and his team publish a paper confirming the link.
Using a kernel

Triweight kernel for the TDA example

revisit $f( X(t) )$ for ‘smoking’ and ‘cancer’

1962: Royal College of Physicians report concludes that smoking is a cause of lung cancer and bronchitis, and probably contributes to coronary heart disease.
Using a kernel

Triweight kernel for the TDA example

revisit $f(\mathbf{X}(t))$ for ‘smoking’ and ‘cancer’

1971: Government health warnings to be carried on all cigarette packets sold in the UK.

Information from BBC News article online - Timeline: Smoking and disease
Using a kernel

Triweight kernel for the TDA example
revisit $f(X(t))$ for ‘smoking’ and ‘cancer’

1983: Latest Royal College of Physicians report features passive smoking for the first time.


Information from BBC News article online - Timeline: Smoking and disease
The End.