

# Day 11: Topic Models

ME314: Introduction to Data Science and Machine Learning

---

Jack Blumenau

6th July 2021

Topic Models

Latent Dirichlet Allocation (LDA)

Beyond Latent Dirichlet Allocation

Correlated and Dynamic Topic Models

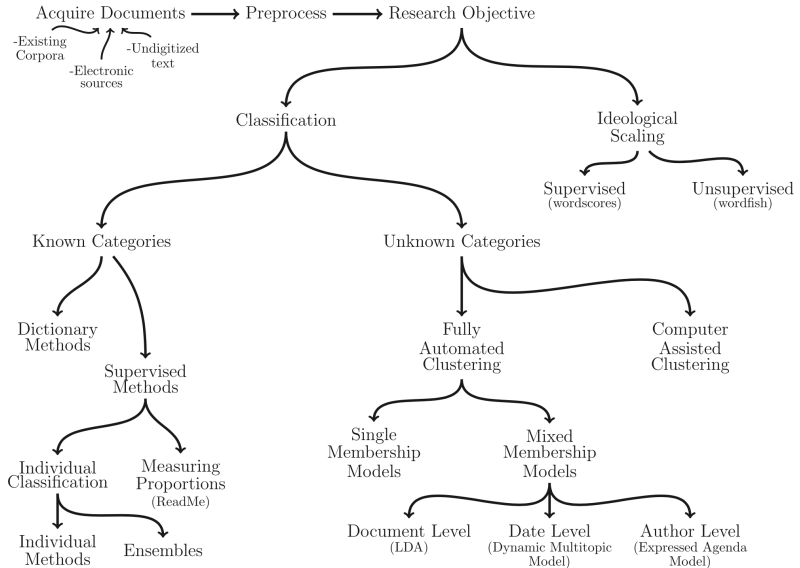
Structural Topic Model

Summary

Quantitative text analysis always requires:

1. Construction of a quantitative matrix from textual features
2. A quantitative or statistical procedure applied to that matrix
3. Summary or interpretation of the results of that procedure

# Where are we?



- For the past two days:
  1. Dictionary approaches
  2. Supervised approaches
  3. Scaling methods
- Today we move on to unsupervised methods
- Note that we will still need to make many of the same feature selection decisions as we did previously...

## Topic Models

---

Topic models allow us to cluster similar documents in a corpus together.

Wait. Don't we already have tools for that?

Topic models allow us to cluster similar documents in a corpus together.

Wait. Don't we already have tools for that? Yes! Dictionaries and supervised learning.



Topic models allow us to cluster similar documents in a corpus together.

Wait. Don't we already have tools for that? Yes! Dictionaries and supervised learning.

So what do topic models add?

## What do topic models add?

		Do you know the categories in which you want to place documents?	
		Yes	No
Do you know the rule for placing documents in categories?	Yes		
	No		

## What do topic models add?

		Do you know the categories in which you want to place documents?
		Yes No
Do you know the rule for placing documents in categories?	Yes	Dictionary methods
	No	

## What do topic models add?

		Do you know the categories in which you want to place documents?
		Yes                      No
Do you know the rule for placing documents in categories?	Yes	Dictionary methods
	No	Supervised learning

## What do topic models add?

		Do you know the categories in which you want to place documents?	
		Yes	No
Do you know the rule for placing documents in categories?	Yes	Dictionary methods	
	No	Supervised learning	Topic Models

## What do topic models add?

		Do you know the categories in which you want to place documents?	
		Yes	No
Do you know the rule for placing documents in categories?	Yes	Dictionary methods	NA
	No	Supervised learning	Topic Models

# Introduction to topic models

- Topic models are algorithms for discovering the main **themes** in an unstructured corpus
- They require no prior information, training set, or labelling of texts before estimation
- They allow us to automatically organise, understand, and summarise large archives of text data.
  1. Uncover hidden themes.
  2. Annotate the documents according to themes.
  3. Organise the collection using annotations.

# What is a “topic”?

- **Google:** “a matter dealt with in a text or conversation; a subject.”
- **Topic models:** probability distribution over a fixed word vocabulary
- Consider a vocabulary: gene, dna, genetic, data, number, computer
- When speaking about **genetics**, you will:
  - frequently use the words “gene”, “dna” & “genetic”
  - infrequently use the words “data”, “number” & “computer”
- When speaking about **computation**, you will:
  - frequently use the words “data”, “number” & “computation”
  - infrequently use the words “gene”, “dna” & “genetic”

Topic	gene	dna	genetic	data	number	computer
Genetics	0.4	0.25	0.3	0.02	0.02	0.01
Computation	0.02	0.01	0.02	0.3	0.4	0.25

Note that no word has probability of exactly 0 under either topic.



# A motivating example

- Data: UK House of Commons' debates (PMQs)
  - $\approx 30000$  parliamentary speeches from 1997 to 2015
  - $\approx 3000$  unique words
  - $\approx 2m$  total words
- Sample/feature selection decisions
  - Sample selection: Only PMQs ( $\approx 3\%$  of total speeches)
  - Feature selection: Removed frequently occurring & very rare words
  - Feature selection: All words have been "stemmed"
- Results of a 30-topic model

## Latent Dirichlet Allocation (LDA)

---

# Latent Dirichlet Allocation (LDA)

## Latent Dirichlet Allocation

**David M. Blei**

*Computer Science Division  
University of California  
Berkeley, CA 94720, USA*

BLEI@CS.BERKELEY.EDU

**Andrew Y. Ng**

*Computer Science Department  
Stanford University  
Stanford, CA 94305, USA*

ANG@CS.STANFORD.EDU

**Michael I. Jordan**

*Computer Science Division and Department of Statistics  
University of California  
Berkeley, CA 94720, USA*

JORDAN@CS.BERKELEY.EDU

**Editor:** John Lafferty

### Abstract

We describe *latent Dirichlet allocation* (LDA), a generative probabilistic model for collections of discrete data such as text corpora. LDA is a three-level hierarchical Bayesian model, in which each item of a collection is modeled as a finite mixture over an underlying set of topics. Each topic is, in turn, modeled as an infinite mixture over an underlying set of topic probabilities. In the context of text modeling, the topic probabilities provide an explicit representation of a document. We present efficient approximate inference techniques based on variational methods and an EM algorithm for empirical Bayes parameter estimation. We report results in document modeling, text classification, and collaborative filtering, comparing to a mixture of unigrams model and the probabilistic LSI model.

[PDF]

**Latent Dirichlet Allocation - Journal of Machine Learning Research**

[www.jmlr.org/papers/volume3/blei03a/blei03a.pdf](http://www.jmlr.org/papers/volume3/blei03a/blei03a.pdf) ▼

by DM Blei - 2003 - **Cited by 27700** - [Related articles](#)

We describe latent Dirichlet allocation (LDA), a generative probabilistic model for collections of ... c 2003 David M. Blei, Andrew Y. Ng and Michael I. Jordan.

# Latent Dirichlet Allocation (LDA)

## Topics

gene 0.04  
dna 0.02  
genetic 0.01  
...

life 0.02  
evolve 0.01  
organism 0.01  
...

brain 0.04  
neuron 0.02  
nerve 0.01  
...

data 0.02  
number 0.02  
computer 0.01  
...

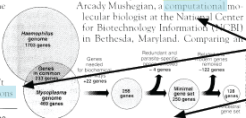
## Documents

### Seeking Life's Bare (Genetic) Necessities

COLD SPRING HARBOR, NEW YORK—How many **genes** does an **organism** need to **survive**? Last week at the genome meeting here,\* two genome researchers with radically different approaches presented complementary views of the basic genes needed for **life**. One research team, using **computer** analyses to compare known **genomes**, concluded that today's **organisms** can be sustained with just 250 genes, and that the earliest life forms required a mere 128 **genes**. The other researcher mapped genes in a simple parasite and estimated that for this organism, 800 genes are plenty to do the job—but that anything short of 100 wouldn't be enough.

Although the numbers don't match precisely, those **predictions**

"are not all that far apart," especially in comparison to the 75,000 **genes** in the human genome, notes Siv Andersson at the University in Sweden, who arrived at the 800 number. But coming up with a consensus answer may be more than just a **genetic numbers** game, particularly as more and more **genomes** are completely mapped and sequenced. "It may be a way of organizing any newly **sequenced genome**," explains Arcady Mushegian, a **computational** molecular biologist at the National Center for Biotechnology Information (NCBI) in Bethesda, Maryland. Comparing an



\* Genome Mapping and Sequencing, Cold Spring Harbor, New York, May 8 to 12.

SCIENCE • VOL. 272 • 24 MAY 1996

**Stripping down.** Computer analysis yields an estimate of the minimum modern and ancient genomes.

## Topic proportions and assignments



# Latent Dirichlet Allocation (LDA)

## Topics

gene 0.04  
dna 0.02  
genetic 0.01  
...

life 0.02  
evolve 0.01  
organism 0.01  
...

brain 0.04  
neuron 0.02  
nerve 0.01  
...

data 0.02  
number 0.02  
computer 0.01  
...

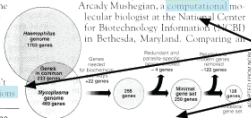
## Documents

### Seeking Life's Bare (Genetic) Necessities

COLD SPRING HARBOR, NEW YORK—How many **genes** does an **organism** need to **survive**? Last week at the genome meeting here,\* two genome researchers with radically different approaches presented complementary views of the basic genes needed for **life**. One research team, using **computer** analyses to compare known **genomes**, concluded that today's **organisms** can be sustained with just 250 genes, and that the earliest life forms required a mere 128 **genes**. The other researcher mapped genes in a simple parasite and estimated that for this organism, 800 genes are plenty to do the job—but that anything short of 100 wouldn't be enough.

Although the numbers don't match precisely, those **predictions**

"are not all that far apart," especially in comparison to the 75,000 **genes** in the human genome, notes Sir Andersson at the University in Sweden, who arrived at the 800 number. But coming up with a consensus answer may be more than just a **genetic numbers** game, particularly as more and more **genomes** are completely mapped and sequenced. "It may be a way of organizing any newly **sequenced genome**," explains Arcady Mushegian, a **computational** molecular biologist at the National Center for Biotechnology Information (NCBI) in Bethesda, Maryland. Comparing an



\* Genome Mapping and Sequencing, Cold Spring Harbor, New York, May 8 to 12.

**Stripping down.** Computer analysis yields an estimate of the minimum modern and ancient genomes.

SCIENCE • VOL. 272 • 24 MAY 1996

## Topic proportions and assignments



- Each **topic** is a distribution over words

# Latent Dirichlet Allocation (LDA)

## Topics

gene 0.04  
dna 0.02  
genetic 0.01  
...

life 0.02  
evolve 0.01  
organism 0.01  
...

brain 0.04  
neuron 0.02  
nerve 0.01  
...

data 0.02  
number 0.02  
computer 0.01  
...

## Documents

### Seeking Life's Bare (Genetic) Necessities

COLD SPRING HARBOR, NEW YORK—How many **genes** does an **organism** need to **survive**? Last week at the genome meeting here,\* two genome researchers with radically different approaches presented complementary views of the basic genes needed for **life**. One research team, using **computer** analyses to compare known **genomes**, concluded that today's **organisms** can be sustained with just 250 genes, and that the earliest life forms required a mere 128 **genes**. The other researcher mapped genes in a simple parasite and estimated that for this organism, 800 genes are plenty to do the job—but that anything short of 100 wouldn't be enough.

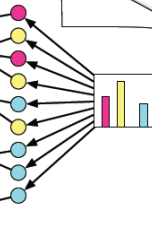
Although the numbers don't match precisely, those **predictions** "are not all that far apart," especially in comparison to the 75,000 **genes** in the human genome, notes Sir Andersson at the University in Sweden, who arrived at the 800 number. But coming up with a consensus answer may be more than just a **genetic numbers** game, particularly as more and more **genomes** are completely mapped and sequenced. "It may be a way of organizing any newly **sequenced genome**," explains Arcady Mushegian, a **computational** molecular biologist at the National Center for Biotechnology Information (NCBI) in Bethesda, Maryland. Comparing an



\* Genome Mapping and Sequencing, Cold Spring Harbor, New York, May 8 to 12.

SCIENCE • VOL. 272 • 24 MAY 1996

## Topic proportions and assignments



- Each **topic** is a distribution over words
- Each **document** is a mixture of corpus-wide topics

# Latent Dirichlet Allocation (LDA)

## Topics

gene 0.04  
dna 0.02  
genetic 0.01  
...

life 0.02  
evolve 0.01  
organism 0.01  
...

brain 0.04  
neuron 0.02  
nerve 0.01  
...

data 0.02  
number 0.02  
computer 0.01  
...

## Documents

### Seeking Life's Bare (Genetic) Necessities

COLD SPRING HARBOR, NEW YORK—How many **genes** does an **organism** need to **survive**? Last week at the genome meeting here,\* two genome researchers with radically different approaches presented complementary views of the basic genes needed for **life**. One research team, using **computer** analyses to compare known **genomes**, concluded that today's **organisms** can be sustained with just 250 genes, and that the earliest life forms required a mere 128 **genes**. The other researcher mapped genes in a simple parasite and estimated that for this organism, 800 genes are plenty to do the job—but that anything short of 100 wouldn't be enough.

Although the numbers don't match precisely, those **productions**

"are not all that far apart," especially in comparison to the 75,000 **genes** in the human genome, notes Sir Andersson at the University in Sweden, who arrived at the 800 number. But coming up with a consensus answer may be more than just a **genetic numbers** game, particularly as more and more **genomes** are completely mapped and sequenced. "It may be a way of organizing any newly **sequenced genome**," explains Arcady Mushegian, a **computational** molecular biologist at the National Center for Biotechnology Information (NCBI) in Bethesda, Maryland. Comparing an



\* Genome Mapping and Sequencing, Cold Spring Harbor, New York, May 8 to 12.

SCIENCE • VOL. 272 • 24 MAY 1996

## Topic proportions and assignments



- Each **topic** is a distribution over words
- Each **document** is a mixture of corpus-wide topics
- Each **word** is drawn from one of those topics

# Latent Dirichlet Allocation (LDA)

Topics



Documents

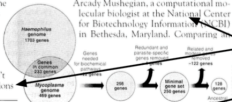
Topic proportions and assignments

## Seeking Life's Bare (Genetic) Necessities

COLD SPRING HARBOR, NEW YORK—How many genes does an organism need to survive? Last week at the genome meeting here,\* two genome researchers with radically different approaches complemented each other. One research team, using computer analyses to compare known genomes, concluded that today's organisms can be sustained with just 250 genes, and that the earliest life forms required a mere 128 genes. The other researcher mapped genes in a simple parasite and estimated that for this organism, 800 genes are plenty to do the job—but that anything short of 100 wouldn't be enough.

Although the numbers don't match precisely, those predictions

"are not all that far apart," especially in comparison to the 75,000 genes in the human genome, reports Siv Andersson, of the University of Sweden, who arrived at the 800 number. But coming up with a consensus answer may be more than just a genetic numbers game. Particularly for more and more genomes are sequenced, stored and sequenced. "It may be a way of organizing any newly sequenced genome," explains Arcady Mushegian, a computational molecular biologist at the National Center for Biotechnology Information (NCBI) in Bethesda, Maryland. Comparing an



\* Genome Mapping and Sequencing, Cold Spring Harbor, New York, May 8 to 12.

**Stripping down.** Computer analysis yields an estimate of the minimum modern and ancient genomes.

SCIENCE • VOL. 272 • 24 MAY 1996



# Latent Dirichlet Allocation (LDA)

Topics



Documents

## Seeking Life's Bare (Genetic) Necessities

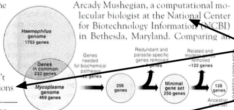
COLD SPRING HARBOR, NEW YORK—How many genes does an organism need to survive? Last week at the genome meeting here, two genome researchers with radically different approaches presented complementary views of the basic genes needed for life. One research team, using computer analyses to compare known genomes, concluded that today's organisms can be sustained with just 250 genes, and that the earliest life forms required a mere 128 genes. The other researcher mapped genes in a simple parasite and estimated that for this organism, 800 genes are plenty to do the job—but that anything short of 100 wouldn't be enough.

Although the numbers don't match precisely, those predictions

\* Genome Mapping and Sequencing, Cold Spring Harbor, New York, May 8 to 12.

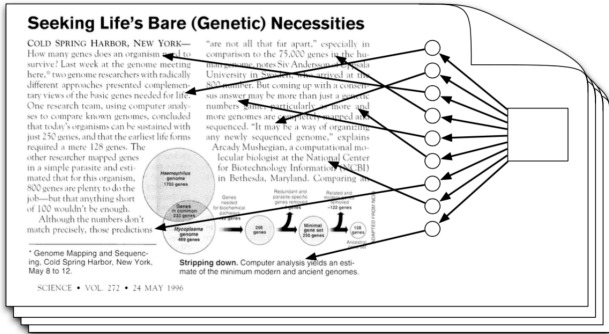
SCIENCE • VOL. 272 • 24 MAY 1996

"are not all that far apart," especially in comparison to the 75,000 genes in the human genome, says Siv Andersson, a biologist at the University of Stockholm, who arrived at the 800 number. But coming up with a consensus answer may be more than just a genetic numbers game. Particularly if more and more genomes are sequenced, stored and sequenced. "It may be a way of organizing any newly sequenced genome," explains Arcady Mushegian, a computational molecular biologist at the National Center for Biotechnology Information (NCBI) in Bethesda, Maryland. Comparing an



**Stripping down.** Computer analysis yields an estimate of the minimum modern and ancient genomes.

Topic proportions and assignments



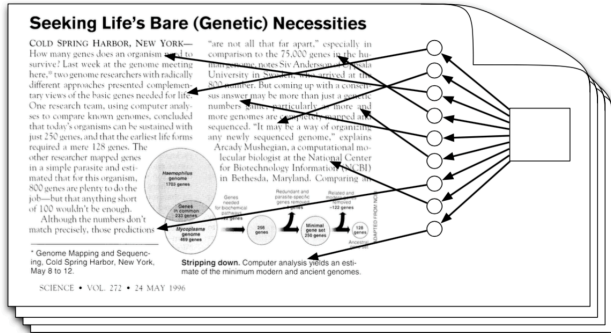
- In reality, we only observe the documents
- The other structure are **hidden variables**

# Latent Dirichlet Allocation (LDA)

Topics



Documents



Topic proportions and assignments

- Our goal is to **infer** the hidden variables
- I.e., compute their distribution conditioned on the documents

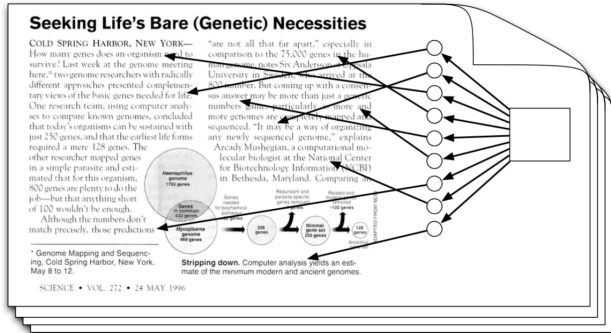
$$p(\text{topics}, \text{proportions}, \text{assignments} | \text{documents})$$

# Latent Dirichlet Allocation (LDA)

Topics



Documents



Topic proportions and assignments

- Topic modelling allows us to extrapolate backwards from a collection of documents to infer the “topics” that could have generated them.

# Latent Dirichlet Allocation (LDA)

- The LDA model is a Bayesian mixture model for discrete data where topics are assumed to be uncorrelated
- LDA provides a generative model that describes how the documents in a dataset were created
- Each of the  $K$  topics is a distribution over a fixed vocabulary
- Each document is a collection of words, generated according to a multinomial distribution, one for each of  $K$  topics
- Inference consists of estimating a posterior distribution over the parameters of the probability model from a combination of what is observed (words in documents) and what is hidden (topic and word parameters)

# Latent Dirichlet Allocation: Details

- For each document, the LDA generative process is:
  1. randomly choose a distribution over topics (multinomial of length  $K$ )
  2. for each word in the document
    - 2.1 Probabilistically draw one of the  $K$  topics from the distribution over topics obtained in step 1, say topic  $k$  (each document contains topics in different proportions)
    - 2.2 Probabilistically draw one of the  $V$  words from  $\beta_k$  (each individual word in the document is drawn from one of the  $K$  topics in proportion to the document's distribution over topics as determined in previous step)
- The goal of inference in LDA is to discover the topics from the collection of documents, and to estimate the relationship of words to these, *assuming this generative process*

1. Term distribution  $\beta$  for each topic is drawn:

$$\beta_k \sim \text{Dirichlet}(\eta)$$

→ probability that each word occurs in a given topic ( $k$ )

1. Term distribution  $\beta$  for each topic is drawn:

$$\beta_k \sim \text{Dirichlet}(\eta)$$

→ probability that each word occurs in a given topic ( $k$ )

2. proportions  $\theta$  of the topic distribution for the document are drawn by

$$\theta_d \sim \text{Dirichlet}(\alpha)$$

→ probability that each topic occurs in a given document ( $d$ )

# LDA generative model

1. Term distribution  $\beta$  for each topic is drawn:

$$\beta_k \sim \text{Dirichlet}(\eta)$$

→ probability that each word occurs in a given topic ( $k$ )

2. proportions  $\theta$  of the topic distribution for the document are drawn by

$$\theta_d \sim \text{Dirichlet}(\alpha)$$

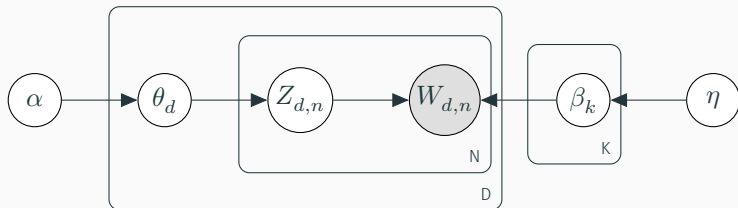
→ probability that each topic occurs in a given document ( $d$ )

3. For each of the  $N$  words in each document

- choose a topic  $z_i \sim \text{Multinomial}(\theta)$
- choose a word  $w_i \sim \text{Multinomial}(p(w_i|z_i, \beta))$

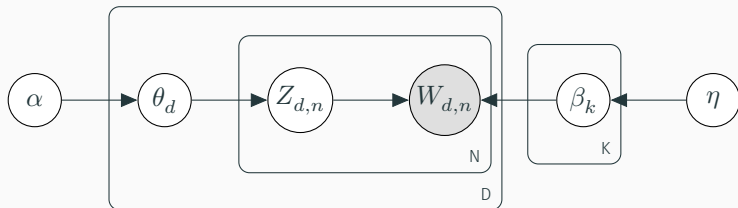


## LDA as a graphical model



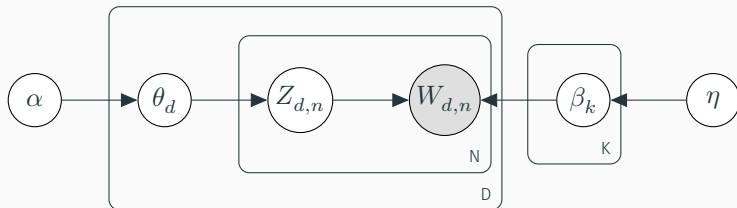
- Encodes assumptions
- Connects to algorithms for computing with data

## LDA as a graphical model



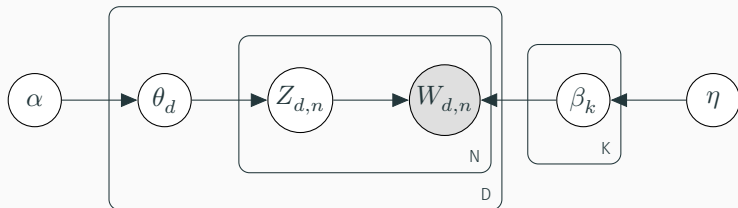
- Nodes are random variables; edges indicate dependence.
- Shaded nodes are observed; unshaded nodes are hidden.
- Plates indicate replicated variables.

## LDA as a graphical model



- $W_{d,n}$  observed word (word level)
- $Z_{d,n}$  topic assignment (word level)
- $\theta_d$  topic proportions (document level)
- $\beta_k$  probability distribution over words (topic level)
- $\alpha$  proportions parameter (corpus level)
- $\eta$  topic parameter (corpus level)

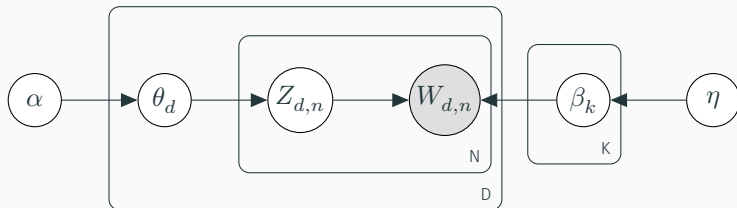
## LDA as a graphical model



- $\beta_k \sim \text{Dirichlet}(\eta)$
- $\theta_d \sim \text{Dirichlet}(\alpha)$
- $Z_{d,n} \sim \text{Multinomial}(\theta_d)$
- $W_{d,n} \sim \text{Multinomial}(p(w_i|z_i, \beta_k))$

Note:  $\eta$  and  $\alpha$  govern the *sparsity* of the draws from the dirichlet. As they  $\rightarrow 0$ , the multinomials become more sparse.

## LDA as a graphical model

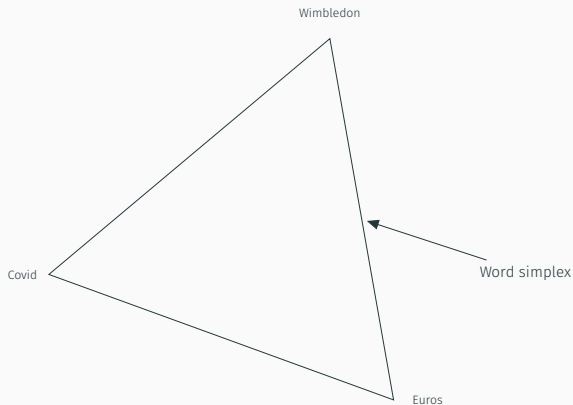


- This joint defines a posterior,  $p(\theta, z, \beta|w)$ .
- From a collection of documents, infer
  - Per-word topic assignment  $z_{d,n}$
  - Per-document topic proportions  $\theta_d$
  - Per-corpus topic distributions  $\beta_k$
- Then use posterior distribution over these parameters to perform the task at hand  $\rightarrow$  information retrieval, document similarity, exploration, and others.

# The Dirichlet distribution

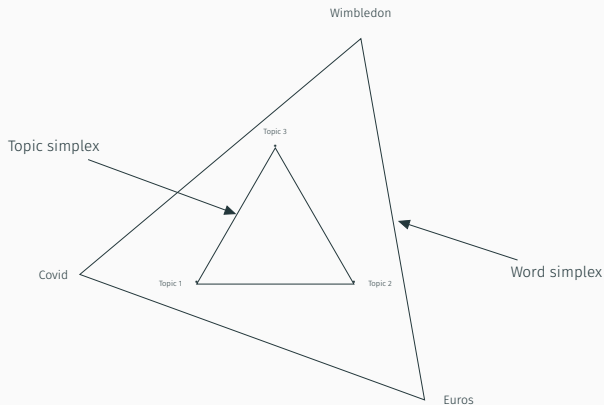
- The Dirichlet distribution is an exponential family distribution over the simplex, i.e., positive vectors that sum to one
- The parameter  $\alpha$  controls the mean shape and sparsity of  $\theta$ .
- The Dirichlet is used twice in LDA:
  - The topic proportions ( $\theta$ ) are a  $K$  dimensional Dirichlet
  - The topics ( $\beta$ ) are a  $V$  dimensional Dirichlet.
- Estimation is performed using collapsed Gibbs sampling and/or Variational Expectation-Maximization (VEM)
- Fortunately, for us these are easily implemented in R

# Latent Dirichlet allocation (LDA)



- Imagine a corpus consisting of only three words
- The word simplex describes the possible probabilities of the multinomial distribution over these three words

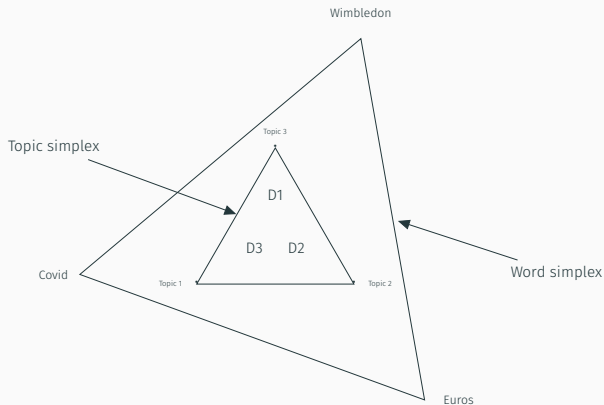
# Latent Dirichlet allocation (LDA)



- We can locate **topics** within the **word-simplex**
- Each topic represents a different distribution over words
- Smaller  $\eta \rightarrow$  sparser topics  $\rightarrow$  topics will be closer to the word-simplex lines



# Latent Dirichlet allocation (LDA)

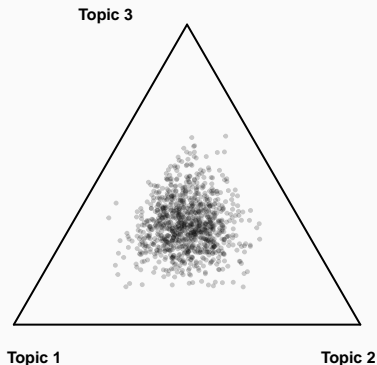


- We can locate **documents** within the **topic-simplex**
- Each document is a mixture of topics
- Smaller  $\alpha \rightarrow$  sparser documents  $\rightarrow$  documents will be closer to topic-simplex lines

## Dirichlet distribution

Recall that  $\theta_d \sim \text{Dirichlet}(\alpha)$ : the topic proportions of each document are governed by a dirichlet distribution with paramter  $\alpha$ .

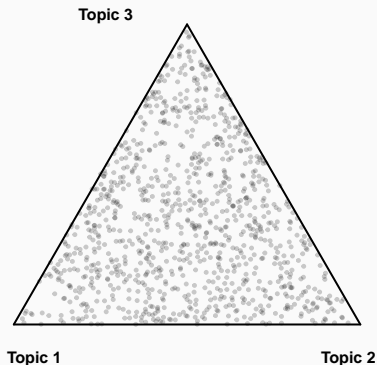
When  $\alpha = 10$



## Dirichlet distribution

Recall that  $\theta_d \sim \text{Dirichlet}(\alpha)$ : the topic proportions of each document are governed by a dirichlet distribution with paramter  $\alpha$ .

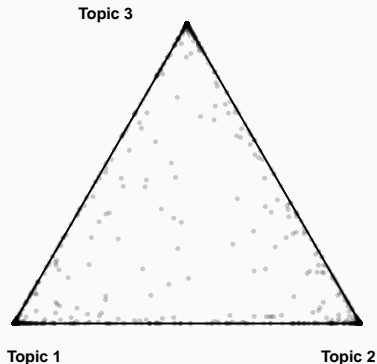
When  $\alpha = 1$



## Dirichlet distribution

Recall that  $\theta_d \sim \text{Dirichlet}(\alpha)$ : the topic proportions of each document are governed by a dirichlet distribution with paramter  $\alpha$ .

When  $\alpha = .1$



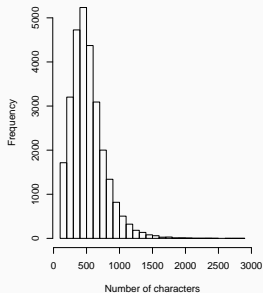
## Why does LDA “work”?

- LDA trades off two goals.
  1. For each document, allocate its words to as few topics as possible. ( $\alpha$ )
  2. For each topic, assign high probability to as few terms as possible. ( $\eta$ )
- These goals are at odds.
  1. Putting a document in a single topic makes (2) hard: All of its words must have probability under that topic.
  2. Putting very few words in each topic makes (1) hard: To cover a document's words, it must assign many topics to it.
- Trading off these goals finds groups of tightly co-occurring words.

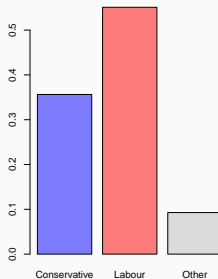
- Data: UK House of Commons' debates (PMQs)
  - $\approx 30000$  parliamentary speeches from 1997 to 2015
  - $\approx 3000$  unique words
  - $\approx 2m$  total words
- Note that I have already made a number of sample selection decisions
  - Only PMQs ( $\approx 3\%$  of total speeches)
  - Removed frequently occurring & very rare words
  - All words have been **stemmed**
- Estimate a range of topic models ( $K \in \{20, 30, \dots, 100\}$ ) using the `topicmodels` package

# LDA example

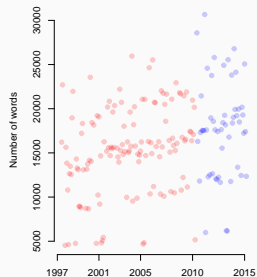
Speech length



Speeches by party



# words by month



# Implementation in R (via quanteda)

```
library(quanteda)

## Create corpus
speechCorpus <- corpus(pmq, text_field = "Speech")

## Create tokens
speechTokens <- tokens(speechCorpus)

## Create and trim DFM
speechDFM <- dfm(speechTokens, remove = stopwords("en"))
speechDFM <- dfm_wordstem(speechDFM)
speechDFM <- dfm_trim(speechDFM, min_termfreq = 5)

## Convert for usage in 'topicmodels' package
tmDFM <- convert(speechDFM, to = 'topicmodels')

## Estimate LDA
ldaOut <- LDA(tmDFM, k = 60)

save(ldaOut, file = "ldaOut_60.Rdata")
```



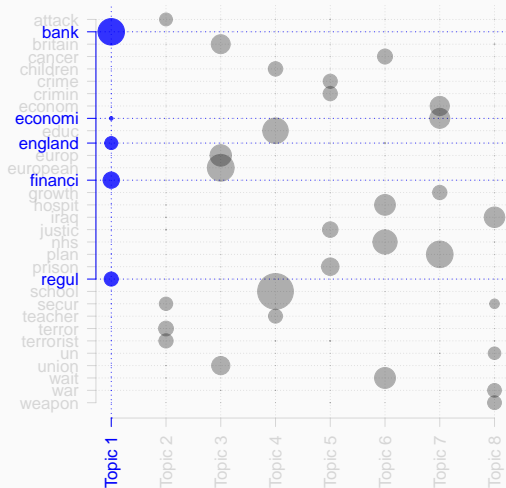
We will make use of the following score to visualise the posterior topics:

$$\text{term-score}_{k,v} = \hat{\beta}_{k,v} \log \left( \frac{\hat{\beta}_{k,v}}{(\prod_{j=1}^K \hat{\beta}_{j,v})^{\frac{1}{K}}} \right)$$

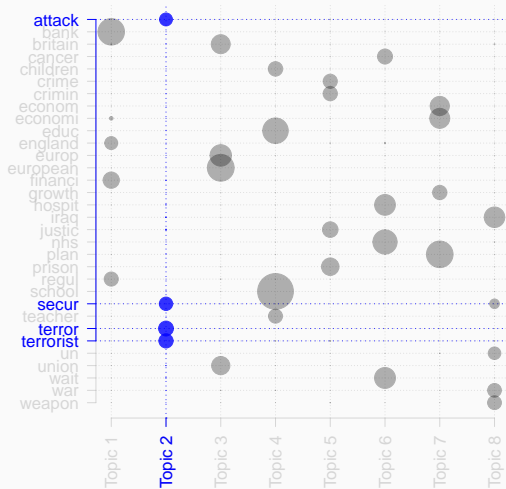
This formulation is similar to the TFIDF term score, where

- the first term,  $\hat{\beta}_{k,v}$ , is the probability of term  $v$  in topic  $k$  and is akin to the term frequency
- the second term is akin to the document frequency (i.e. it down-weights terms that have high probability under all topics)

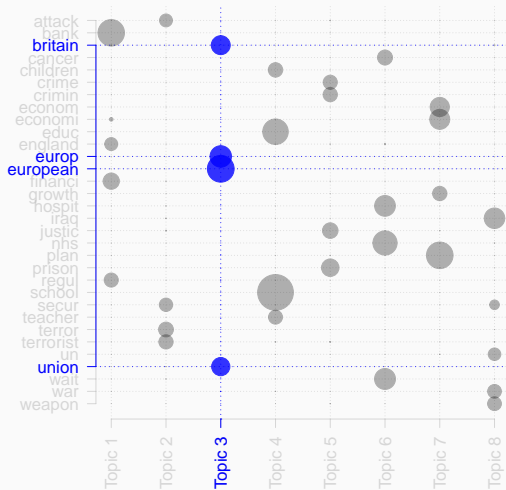
# LDA example



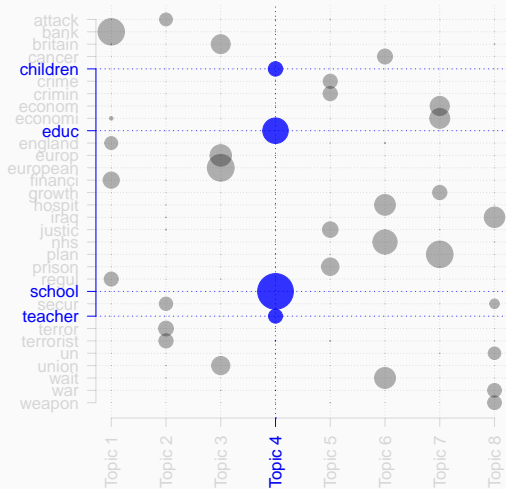
# LDA example



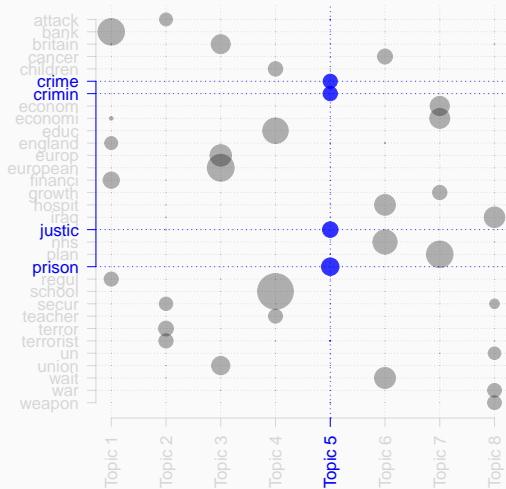
# LDA example



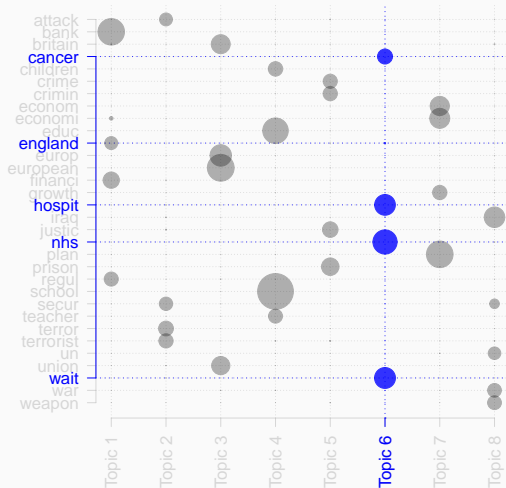
# LDA example



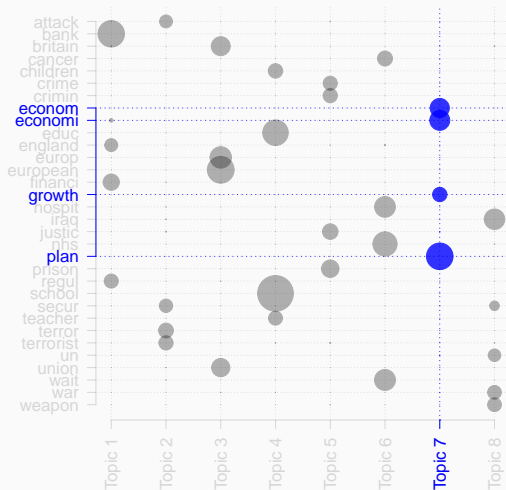
# LDA example



# LDA example

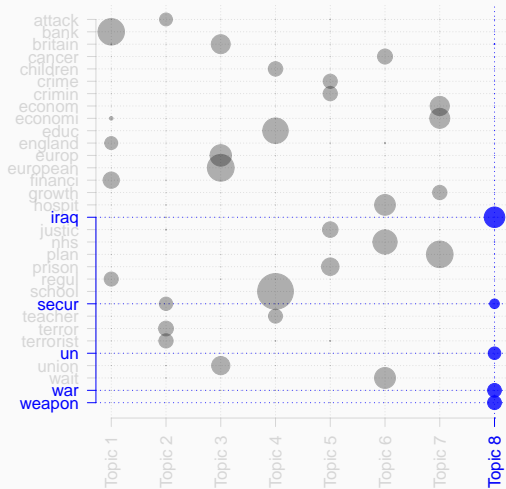


# LDA example





# LDA example



# LDA example

## Topic 1

bank  
financi  
regul  
england  
crisi  
fiscal  
market

## Topic 2

terror  
terrorist  
secur  
attack  
protect  
agre  
act

## Topic 3

european  
europ  
britain  
union  
british  
referendum  
constitut

## Topic 4

school  
educ  
children  
teacher  
pupil  
class  
parent

## Topic 5

prison  
justic  
crimin  
crime  
releas  
court  
sentenc

## Topic 6

nhs  
wait  
hospit  
cancer  
patient  
list  
health

## Topic 7

plan  
economi  
econom  
growth  
grow  
longterm  
deliv

## Topic 8

iraq  
weapon  
war  
un  
resolut  
iraqi  
saddam

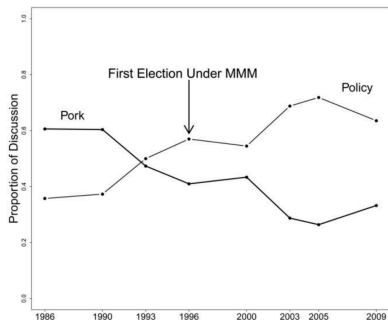
**Research question:** Do different electoral systems create incentives for politicians to focus on different aspects of policy?

Catalinac argues that the electoral reform in 1994 in Japan should increase the amount of attention that politicians devote to “policy” rather than “pork”.

## LDA in research (Catalinac, 2014)

**Research question:** Do different electoral systems create incentives for politicians to focus on different aspects of policy?

Catalinac argues that the electoral reform in 1994 in Japan should increase the amount of attention that politicians devote to “policy” rather than “pork”.



“Applying probabilistic topic modeling... shows that candidates for office change tried-and-true electoral strategies when confronted with an electoral reform.”

### Questions:

- LDA on 8000 manifestos
  - Are entire manifestos the appropriate unit of analysis? Would sections, or paragraphs, be more appropriate?
- $K = 69$ 
  - “We fit the model with 69 topics because this was one of the lowest specifications that produced topics that were fine-grained enough to resemble our quantities of interest.”
  - Seems a little arbitrary! Are 69 topics the appropriate number?
- Is this a good case for topic models? We know the categories of interest ex ante
  - Why not use a dictionary approach here? Or supervised learning?

We will discuss strategies for addressing some of these after the break.

- LDA is a probabilistic model of text. It casts the problem of discovering themes in large document collections as a posterior inference problem.
- It lets us visualize the hidden thematic structure in large collections, and generalize new data to fit into that structure.
- LDA is a simple building block that enables many applications.
- It is popular because organizing and finding patterns in data has become important in the sciences, humanities, industry, and culture.
- We can easily fit these models to massive data.

Break

# Evaluating LDA performance

How can we tell how well a given topic model is performing?

## Statistical approaches:

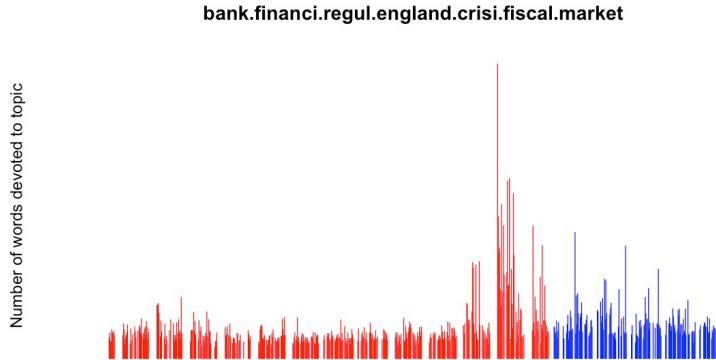
- How well does the model predict held-out data?
- Ask which words the model believes will be in a given document and comparing this to the document's actual word composition
- Splitting texts in half, train a topic model on one half, calculate the held-out likelihood for the other half
- Issues:
  - Prediction is not always important in exploratory or descriptive tasks. We may want models that capture other aspects of the data.
  - There tends to be a negative correlation between quantitative diagnostics such as these and human judgements of topic coherence!

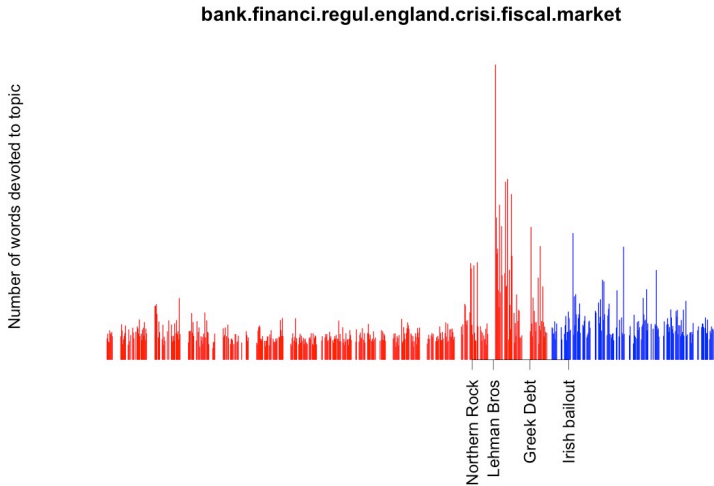


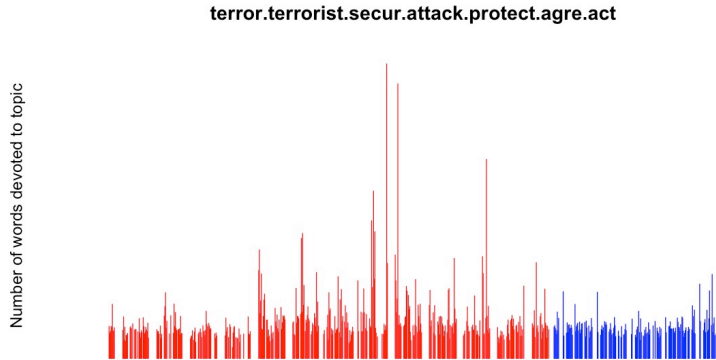
## Substantive approaches:

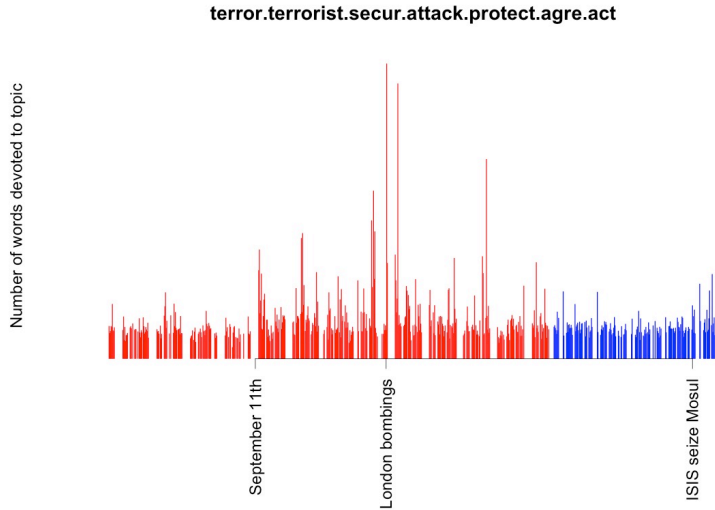
- *Semantic validity*
  1. Do a topic contain coherent groups of words?
  2. Does a topic identify a coherent groups of texts that are internally homogenous but distinctive from other topics?
- *Predictive validity*
  1. How well does variation in topic usage correspond to known events?
- *Construct validity*
  1. How well does our measure correlate with other measures?

Here, we will focus on semantic and predictive validity. (Why?)









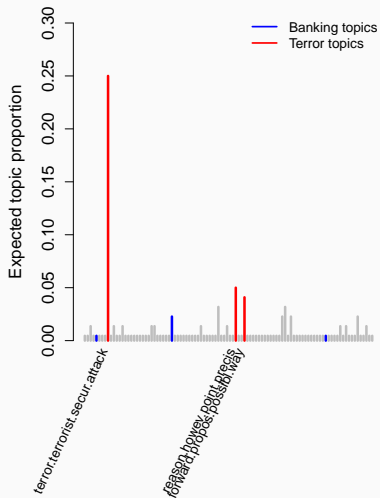
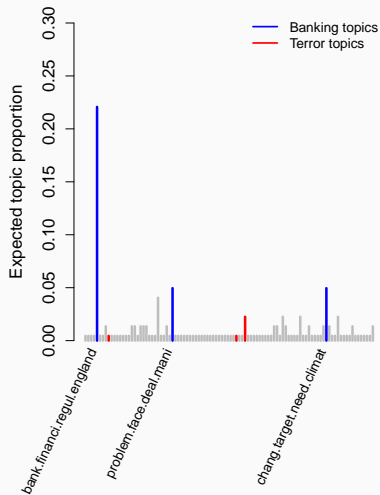
Consider the following texts:

The reforms that we are bringing into the banking system will include greater competition in banking. We will have a judgment from the European Commission soon, which we are supporting, that will allow more competition in British banking. As for the restructuring of the banking system and whether there should be investment banks on one side and retail-only banks on the other, the right hon. Gentleman must remember that Northern Rock was effectively a retail bank and it collapsed. Lehman Brothers was effectively an investment bank without a retail bank and it collapsed. The difference between retail and investment banks is not the cause of the problem. The cause of the problem is that banks have been insufficiently regulated at a global level and we have to set the standards for that for the future. We will be doing that at the G20 Finance Ministers summit in a few weeks' time.

The purpose of this coming before the House is for the Home Secretary to advise us that, in her view, there is an exceptional terrorist threat a grave terrorist threat that either has occurred or is occurring and that the need for action is urgent, but that it has not been possible to assemble the necessary evidence to lay charges within the 28 days. It will then be for the House to vote on the commencement order and agree that an exceptional terrorist incident has occurred. It is not the business of the House to interfere in the individual case, but it should be able to vote simply on whether an exceptional and grave terrorist threat has occurred. Given that the right hon. Gentleman and others have referred to the Civil Contingencies Act 2004 in discussing this issue, I would hope that he understands that this is exactly the same problem that has to be faced in respect of that Act.

We will call these the banking and terrorism texts.

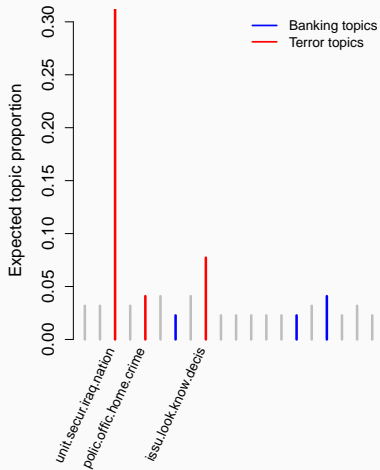
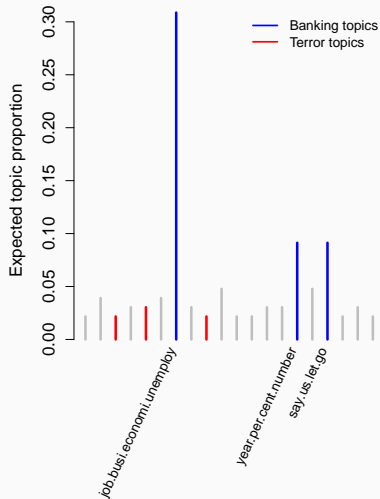
# Semantic validity



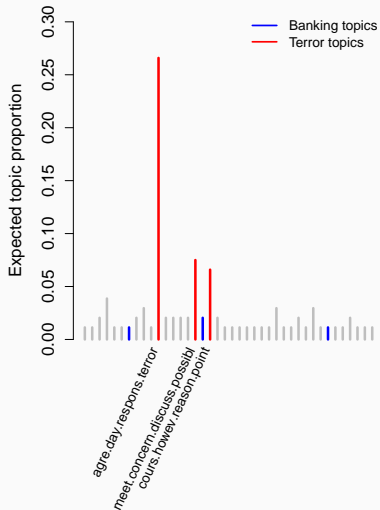
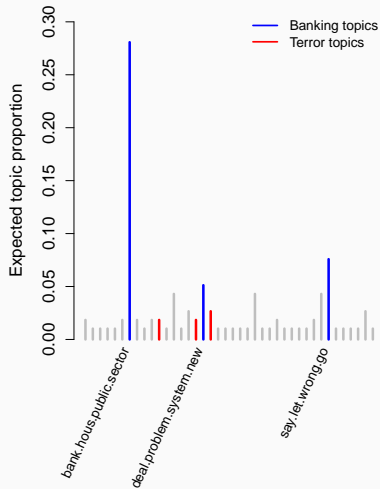
- These plots suggest that our model is picking up at least some properties that we would intuitively expect to see in this particular corpus
- However, they do not help us to choose between the different models that we have estimated
- In other words, how should we pick  $K$ ?



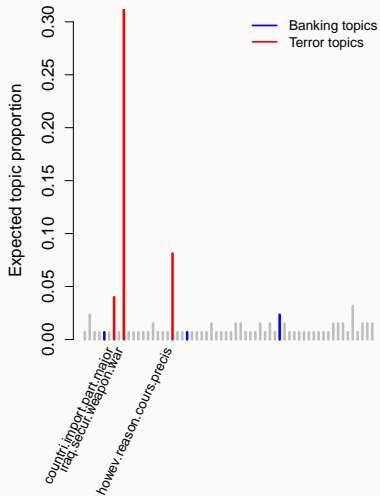
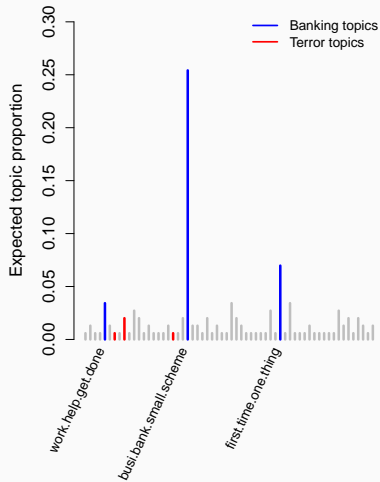
# Which K?



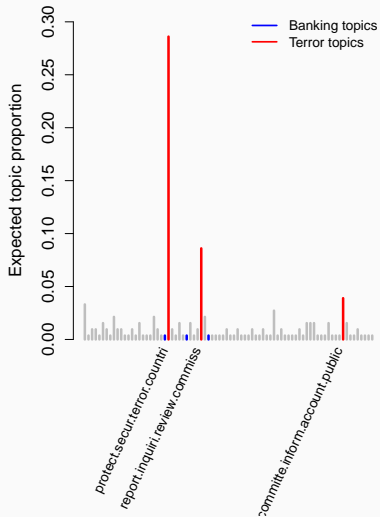
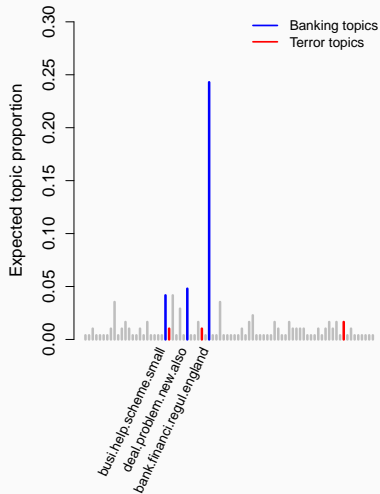
# Which K?



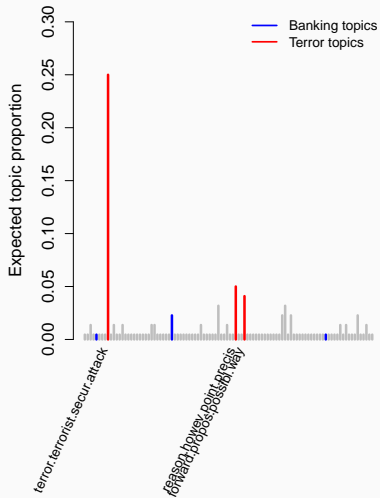
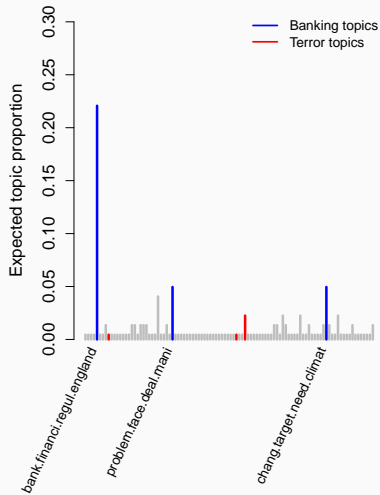
# Which K?



# Which K?



# Which K?



*Word intrusion:* Test if topics have semantic coherence by asking humans identify a spurious word inserted into a topic.

Topic	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6
1	bank	financ	terror	england	fiscal	market
2	europe	union	eu	referendum	vote	school
3	act	deliv	nhs	prison	mr	right

**Assumption:** When humans find it easy to locate the “intruding” word, the topics are more coherent.

## Semantic validity ([Chang et al. 2009](#))

*Word intrusion:* Test if topics have semantic coherence by asking humans identify a spurious word inserted into a topic.

Topic	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6
1	bank	financ	terror	england	fiscal	market
2	europe	union	eu	referendum	vote	school
3	act	deliv	nhs	prison	mr	right

**Assumption:** When humans find it easy to locate the “intruding” word, the topics are more coherent.

## Semantic validity ([Chang et al. 2009](#))

*Topic intrusion:* Test if the association between topics and documents makes sense by asking humans to identify a topic that was not associated with a document.

*Reforms to the banking system are an essential part of dealing with the crisis, and delivering lasting and sustainable growth to the economy. Without these changes, we will be weaker, we will be less well respected abroad, and we will be poorer.*

Topic	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6
1	bank	financ	regul	england	fiscal	market
2	plan	econom	growth	longterm	deliv	sector
3	school	educ	children	teacher	pupil	class

**Assumption:** When humans find it easy to locate the “intruding” topic, the mappings are more sensible.



## Semantic validity ([Chang et al. 2009](#))

*Topic intrusion:* Test if the association between topics and documents makes sense by asking humans to identify a topic that was not associated with a document.

*Reforms to the banking system are an essential part of dealing with the crisis, and delivering lasting and sustainable growth to the economy. Without these changes, we will be weaker, we will be less well respected abroad, and we will be poorer.*

Topic	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6
1	bank	financ	regul	england	fiscal	market
2	plan	econom	growth	longterm	deliv	sector
3	school	educ	children	teacher	pupil	class

**Assumption:** When humans find it easy to locate the “intruding” topic, the mappings are more sensible.

### Conclusion:

*“Topic models which perform better on held-out likelihood may infer less semantically meaningful topics.” (Chang et al. 2009.)*

## Semantic validity (2)

- Semantic validity requires that topics are coherent and meaningful.
  - We hope that texts assigned to a given topic are homogenous
  - We hope that texts from different topics are distinctive
- We can assess the quality of the topics by asking humans whether pairs of documents with high probability under the same topic are related to one another
- One option would be to crowdsource validation using online workers
  - Benoit et. al (2015) *Crowd-Sourced Text Analysis: Reproducible and Agile Production of Political Data*
- Another option is to mercilessly exploit a class of students (not you, don't worry)

# Semantic validity (revisited)

Your task is simply to read these short texts, and use the answer box to tell me whether the pair of speeches you are looking at are 'unrelated', 'loosely related' or 'closely related' in terms of the topics under consideration.

Related?

Unrelated ▼

**NEXT COMPARISON.**

Comparisons completed: 0

**Text one:**

That is total complacency about one month's figures when the Prime Minister has had five years of failure under this Government. Under this Prime Minister we are a country of food banks and bank bonuses; a country of tax cuts for millionaires while millions are paying more. Is not his biggest broken promise of all that we are all in it together?

**Text two:**

This is totally desperate stuff because the Prime Minister has nothing to say about the cost of living crisis. That is the reality, and his reshuffle had nothing to do with the country and everything to do with his party. After four years of this Government, we have a recovery that people cannot feel, a cost of living crisis that people cannot deny, and a Prime Minister whom people cannot believe.

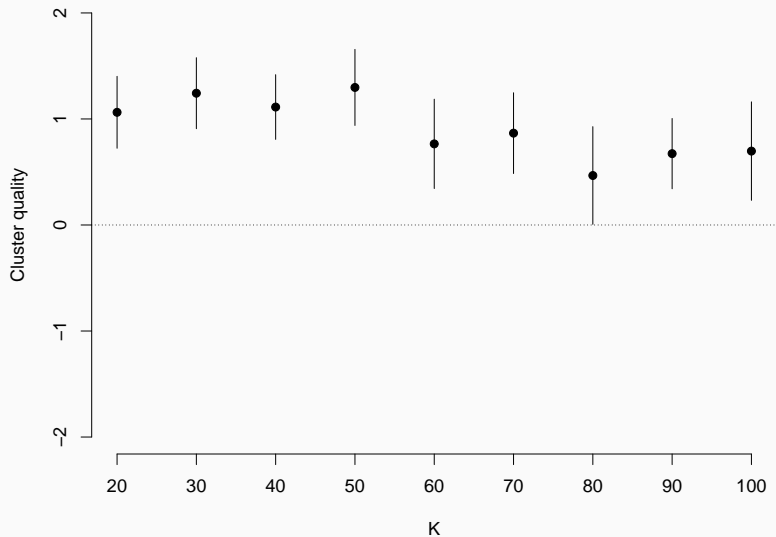
## Semantic validity (revisited)

- Sample pairs of speeches from the posterior distribution
  - 5 pairs from the same topic, for each topic
  - 5 pairs from different topics, for each topic
- Randomly present to human coders, asking whether they are:
  - closely related (3); loosely related (2); unrelated (1)
- Calculate the **Cluster Quality** for the topic by regressing

$$Related_{ik} = \alpha + \beta_k * SameTopic_{ik}$$

- $\beta_k$  is an estimate of the cluster quality of topic model  $k$ 
  - i.e. the difference between relatedness of same-topic and different-topic pairs
- Repeat for each value of  $K$

## Semantic validity (revisited)



## An application

- Once we are happy with the topic model we have estimated, we can use the posterior distribution in various ways
  - Visualisation
  - Information retrieval
  - Corpus exploration
  - Similarity
  - Dimensionality reduction
- In this example, we can use the posterior distribution of document-topic proportions to ask: Which MPs are most active at asking questions in each topic?

$$MPAttention_{i,k} = \frac{MPWords_{i,k}}{\sum_1^K MPWords_{i,k}}$$

# An application

## bank.financi.regul

Christopher Gill  
Malcolm Wicks  
Tom Greatrex  
Alasdair Morgan  
Nick Herbert  
Karl McCartney  
Donald Gorrie  
Justin Tomlinson  
John Townend  
Howard Flight  
Derek Foster  
Lindsay Roy

## prison.justic.crimin

Jack Lopresti  
Kevin McNamara  
Alan Clark  
Chris Skidmore  
Charles Walker  
Jeremy Wright  
Tess Kingham  
Sarah Champion  
Philip Davies  
Kali Mountford  
Mike Wood  
Lynda Waltho

## terror.terrorist.secur

Shahid Malik  
Parmjit Gill  
George Mudie  
Jonathan Djanogly  
James Brokenshire  
Tobias Ellwood  
Brian Wilson  
John Maples  
Seamus Mallon  
Ann Keen  
Stephen Barclay  
Pat McFadden

## nhs.wait.hospit

Julia Goldsworthy  
Seema Malhotra  
Michael Penning  
Nick Hurd  
Virendra Sharma  
Tim Farron  
Bill Esterson  
John Penrose  
Malcolm Chisholm  
Grant Shapps  
Marion Roe  
Mike Thornton

## european.europ.britain

David Lock  
William Cash  
Alistair Darling  
Denzil Davies  
David Heathcoat-Amory  
David Wilshire  
David Davis  
Giles Radice  
Ann Winterton  
Jenny Jones  
Dale Campbell-Savours  
Jacob Rees-Mogg

## plan.economi.econom

Chloe Smith  
Conor Burns  
Donald Gorrie  
Guy Opperman  
Karen Bradley  
Neil Carmichael  
Wayne David  
Michael Colvin  
Michael Ellis  
Anne Milton  
John Stevenson  
Sarah Newton

## school.educ.children

Christine Butler  
Melanie Johnson  
Julie Kirkbride  
Sam Gyimah  
Malcolm Moss  
Paul Clark  
Ian Liddell-Grainger  
Michael Heseltine  
Stephen Hammond  
Chris Pond  
Ivan Henderson  
Derek Conway

## iraq.weapon.war

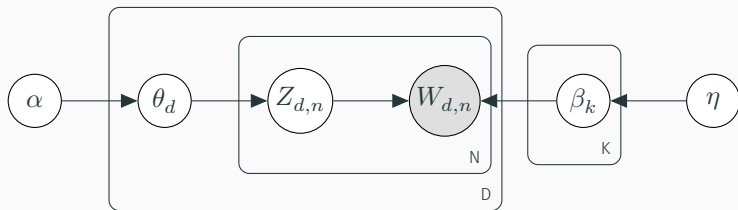
Alan Howarth  
Chris Smith  
Tony Worthington  
Terry Davies  
George Foulkes  
Jonathan Sayeed  
Melanie Johnson  
Denzil Davies  
Paul Stinchcombe  
Adam Price  
Kevin Hughes  
Tony Benn



## Beyond Latent Dirichlet Allocation

---

## LDA summary



- LDA is a simple topic model.
- It can be used to find topics that describe a corpus.
- Each document exhibits multiple topics.
- There are several ways to extend this model.

- LDA can be **embedded in more complicated models**, embodying further intuitions about the structure of the texts.
  - E.g., it can be used in models that account for syntax, authorship, word sense, dynamics, correlation, hierarchies, and other structure.
- The **data generating distribution** can be changed. We can apply mixed-membership assumptions to many kinds of data.
  - E.g., we can build models of images, social networks, music, purchase histories, computer code, genetic data, and other types.
- The **posterior** can be used in creative ways.
  - E.g., we can use inferences in information retrieval, recommendation, similarity, visualization, summarization, and other applications.

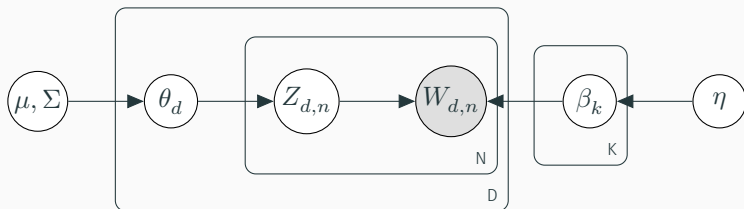
- These different kinds of extensions can be combined.
- To give a sense of how LDA can be extended, we'll look at several examples of major extensions.
- We will discuss
  - Correlated topic models
  - Dynamic topic models
  - Structural topic models

## Correlated and Dynamic Topic Models

---

- The Dirichlet is a distribution on the simplex, positive vectors that sum to 1.
- It assumes that components are nearly independent.
- In real data, an article about fossil fuels is more likely to also be about geology than about genetics.
- The logistic normal is a distribution on the simplex that can model dependence between components (Aitchison, 1980).
- Re-parameterise so that the (log of the) parameters of the topic-proportions multinomial are drawn from a multivariate Gaussian distribution

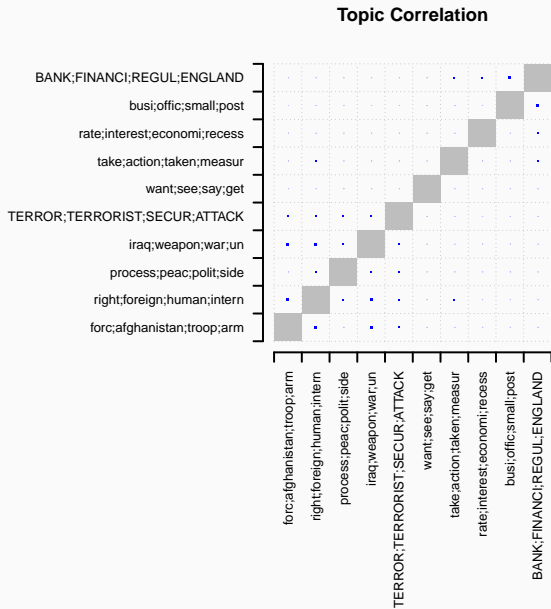
## Correlated topic model



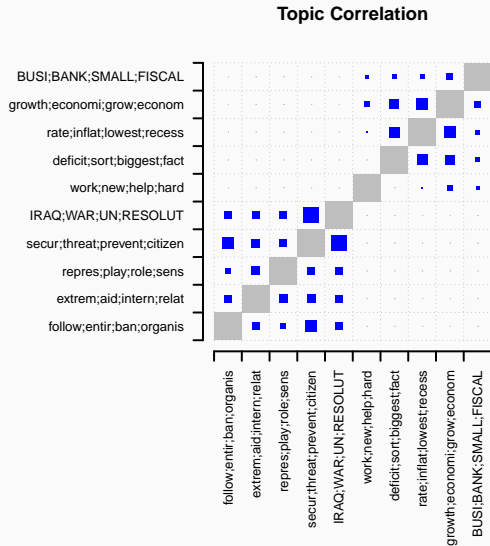
where the first node is logistic normal prior.

- Draw topic proportions from a logistic normal.
- This allows topic occurrences to exhibit correlation.
- Provides a “map” of topics and how they are related
- Provides a better fit to text data, but computation is more complex

# LDA topic correlation







## Advantages:

1. Probably a more reasonable approximation of the “true” data generating process of documents
2. Possible that correlations between topics might be a quantity of interest
3. CTM tends to have better statistical fit to data than LDA

## Disadvantages:

1. CTM is considerably more computationally demanding than LDA
2. CTM tends to have lower topic interpretability than LDA

- LDA assumes that the order of documents does not matter.
- Not appropriate for sequential corpora (e.g., that span hundreds of years)
- We may want to track how language changes over time.

- LDA assumes that the order of documents does not matter.
- Not appropriate for sequential corpora (e.g., that span hundreds of years)
- We may want to track how language changes over time.
  - How has the language used to describe neuroscience developed from “The Brain of Professor Laborde” (1903) to “Reshaping the Cortical Motor Map by Unmasking Latent Intracortical Connections” (1991)

- LDA assumes that the order of documents does not matter.
- Not appropriate for sequential corpora (e.g., that span hundreds of years)
- We may want to track how language changes over time.
  - How has the language used to describe neuroscience developed from “The Brain of Professor Laborde” (1903) to “Reshaping the Cortical Motor Map by Unmasking Latent Intracortical Connections” (1991)
  - How has the language used to describe love developed from “Pride and Prejudice” (1813) to “Eat, Pray, Love” (2006)

- LDA assumes that the order of documents does not matter.
- Not appropriate for sequential corpora (e.g., that span hundreds of years)
- We may want to track how language changes over time.
  - How has the language used to describe neuroscience developed from “The Brain of Professor Laborde” (1903) to “Reshaping the Cortical Motor Map by Unmasking Latent Intracortical Connections” (1991)
  - How has the language used to describe love developed from “Pride and Prejudice” (1813) to “Eat, Pray, Love” (2006)
- Dynamic topic models let the topics drift in a sequence.

# Dynamic topic model

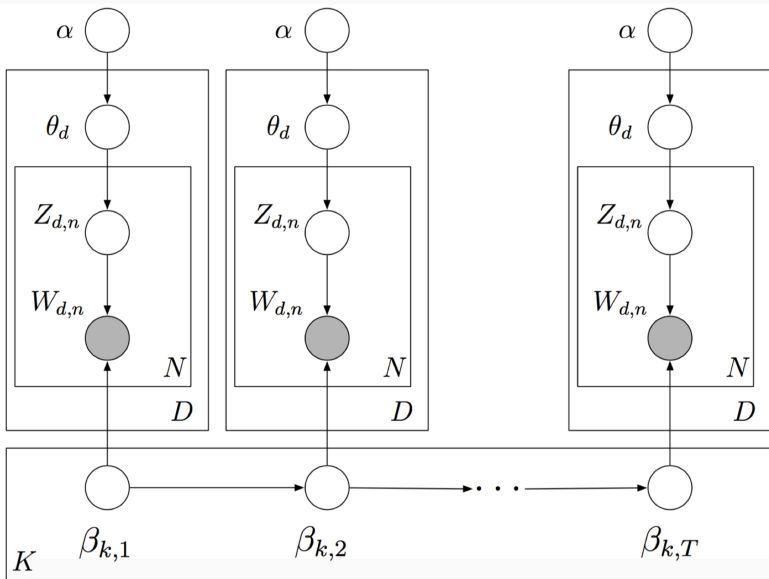


Plate (K) allows topics to “drift” through time.

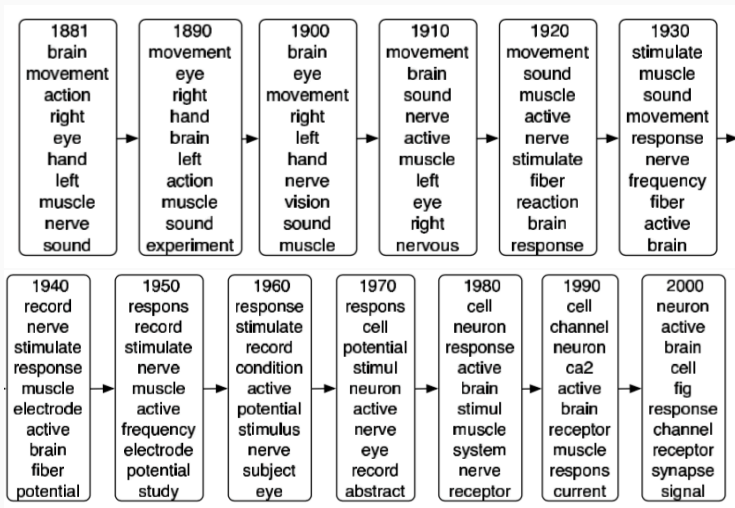


- Use a logistic normal distribution to model topics evolving over time.
  - The  $k$ th topic at time 2 has evolved smoothly from the  $k$ th topic at time 1
- As for CTMs, this makes computation more complex. But it lets us make inferences about sequences of documents.



## Dynamic topic model example (Mimno and Lafferty, 2006)]

“Neuroscience” topic based on DTM of 30,000 articles from *Science*



## Summary: Correlated and dynamic topic models

- The Dirichlet assumption on topics and topic proportions makes strong conditional independence assumptions about the data.
- The **correlated topic model** uses a logistic normal on the topic proportions to find patterns in how topics tend to co-occur.
- The **dynamic topic model** uses a logistic normal in a linear dynamic model to capture how topics change over time.
- What's the catch? These models are harder to compute.

## Structural Topic Model

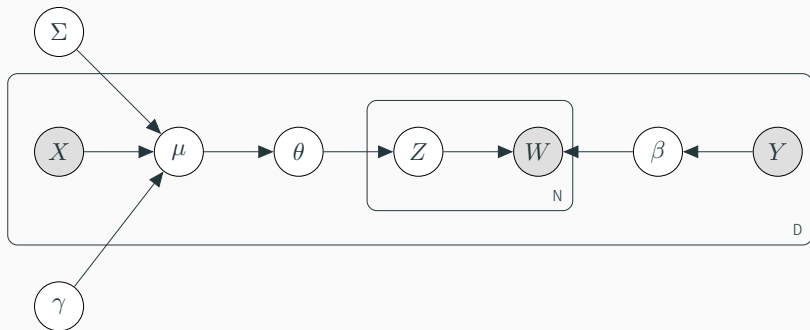
---

- Typically, when estimating topic models we are interested in how some covariate is associated with the prevalence of topic usage (Gender, date, political party, etc)
- The Structural Topic Model (STM) allows for the inclusion of arbitrary covariates of interest into the generative model
- The addition of covariates provides structure to the prior distributions
  1. Benefit 1: improves the estimation of the topics by allowing documents to share information according to the covariates (known as 'partial pooling' of parameters)
  2. Benefit 2: the relationship between covariates and latent topics is most frequently the estimand of interest, so we should include this in the estimation procedure

How does it differ from LDA?

- As with the CTM, topics within the STM can be **correlated**
- **Topic prevalence** is allowed to vary according to the covariates  $X$ 
  - Each document has its own prior distribution over topics, which is defined by its covariates, rather than sharing a global mean
- **Topical content** can also vary according to the covariates  $Y$ 
  - Word use *within* a topic can differ for different groups of speakers/writers

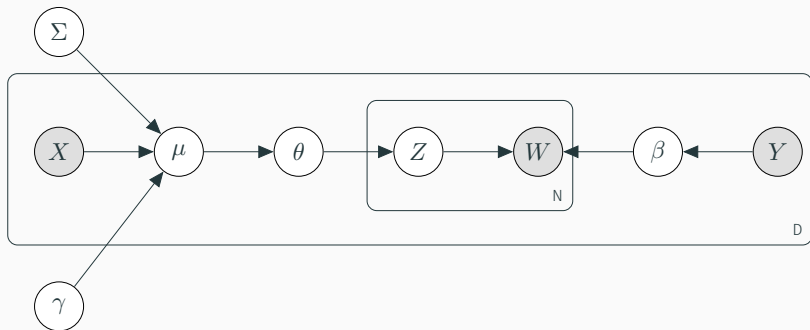
## Structural topic model



Topic prevalence model:

- Draw topic proportions from a logistic normal generalised linear model based on covariates  $X$
- This allows the expected document-topic proportions to vary by covariates, rather than from a single shared prior

## Structural topic model



Topical content model:

- The  $\beta$  coefficients, which indicate the distribution over words for a given topic, are allowed to vary according to the covariates  $Y$
- This allows us to estimate how different covariates affect the words used *within a given topic*

## Structural Topic Model (example)

- In the legislative domain, we might be interested in the degree to which MPs from different parties represent distinct interests in their parliamentary questions
- We can use the STM to analyse how topic prevalence varies by party

```
## Set topic count and estimate STM
```

```
K <- 60
```

```
stmOut <- stm(  
  documents = speechDFM,  
  data= docvars(speechDFM),  
  prevalence = ~party,  
  content = ~party,  
  K = K,  
  seed = 123)
```



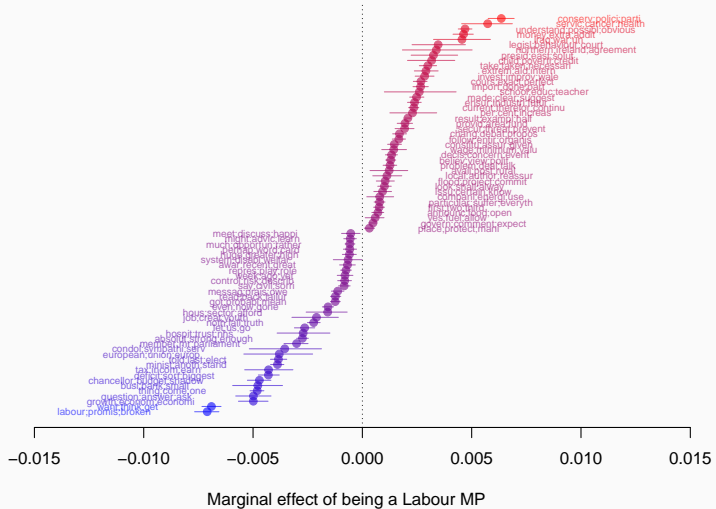
## Structural Topic Model (example)

- Specify a linear model with:
  - the topic proportions of speech  $d$ , by legislator  $i$  as the outcome
  - the party of legislator  $i$  as the predictor

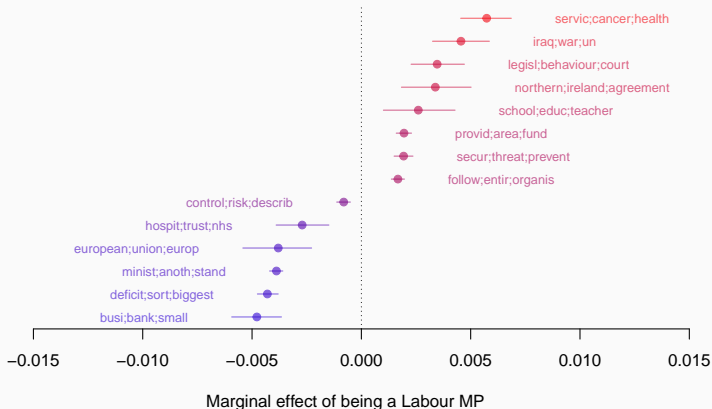
$$\theta_{dk} = \alpha + \gamma_{1k} * \text{labour}_{d(i)}$$

- The  $\gamma_k$  coefficients give the estimated difference in topic proportions for Labour and Conservative legislators for each topic

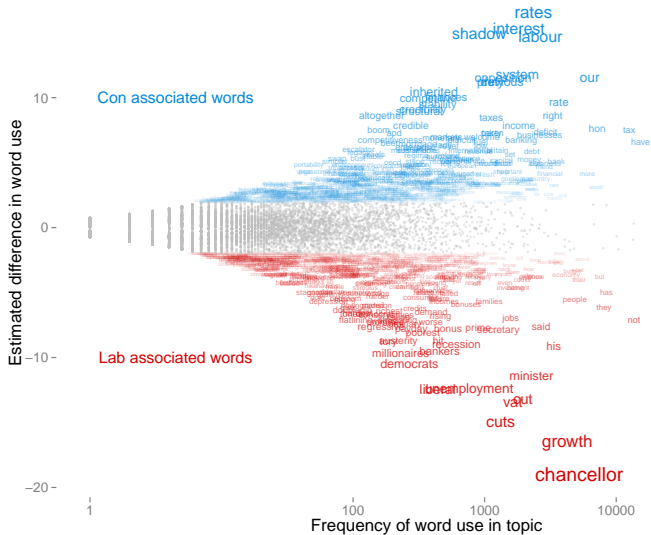
## Labour vs Conservative topic differences

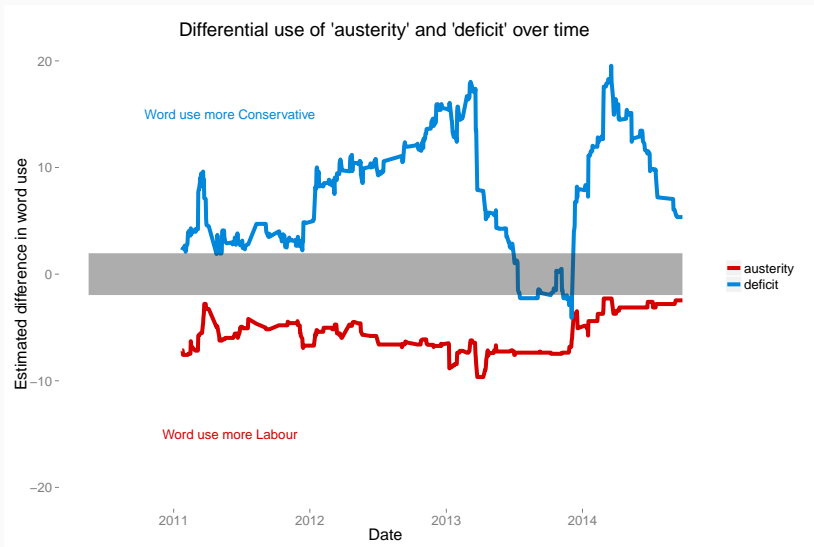


## Labour vs Conservative topic differences



## Topic content





Although developed for text data, topic models are more generally just a form of a Bayesian mixed-membership model.

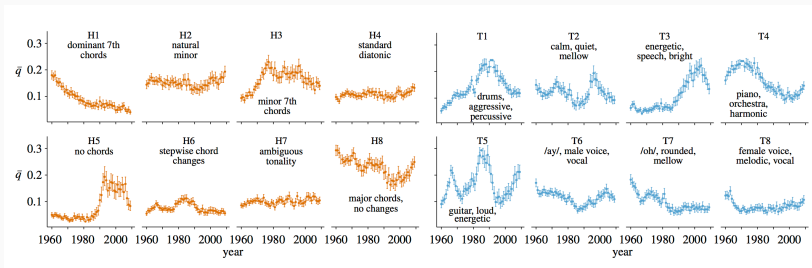
Industrious researchers have applied this machinery to many other types of data.

All that is required is constructing a feature matrix using the appropriate data.

## Other “Topic” Models (Mauch et al, 2015)

**Appliation:** Topic model of 17,000 *recordings* from the US Billboard Hot 100 from 1960 to 2010

**Features:** timbre; harmony; chord progressions; etc



## Summary

---



Topic models assume:

- That there are  $K$  topics shared by a corpus collection.
- That each document exhibits the topics with different proportions.
- That each word is drawn from one topic.
- That we can *discover* the structure that best explain a corpus.

Topic models can be adapted to many settings

- Relax assumptions
- Combine models
- Model more complex data

Incomplete list:

- `topicmodels`
- `lda`
- `stm`
- `stm`
- `mallet`