

TEXT MINING FOR ECONOMICS AND FINANCE

UNSUPERVISED LEARNING

Stephen Hansen

INTRODUCTION

There are two main divisions in machine learning:

1. *Supervised learning* seeks to build models that predict labels associated with observations.
2. *Unsupervised learning* seeks to model hidden structure in unlabeled observations.

We begin with unsupervised learning. This can be seen as an intermediate step in empirical analysis in which we first quantify text on a low-dimensional space before using that representation in econometric work.

Important differences with respect to dictionary methods:

1. Use all dimensions of variation in the document-term matrix to estimate the latent space.
2. Let data reveal which are the most important dimensions for discriminating among observations.

LATENT VARIABLE MODELS

The implicit assumption of dictionary methods is that the set of words in the dictionary map back into an underlying theme of interest.

For example we might have that

$\mathcal{D} = \{\text{school, university, college, teacher, professor}\} \rightarrow \text{education}.$

Latent variable models formalize the idea that documents are formed by hidden variables that generate correlations among observed words.

In a natural language context, these variables can be thought of as topics; other applications will have other interpretations.

Latent variable models generally share the following features:

1. Associate words with latent variables; the same word can be associated to more than one latent variable.
2. Associate documents with (one or more) latent variables.

INFORMATION RETRIEVAL

Latent variable representations can more accurately identify document similarity.

The problem of *synonymy* is that several different words can be associated with the same topic. Cosine similarity between following documents?

school	university	college	teacher	professor
0	5	5	0	2
school	university	college	teacher	professor
10	0	0	4	0

The problem of *polysemy* is that the same word can have multiple meanings. Cosine similarity between following documents?

tank	seal	frog	animal	navy	war
10	10	3	2	0	0
tank	seal	frog	animal	navy	war
10	10	0	0	4	3

If we correctly map words into topics, comparisons become more accurate.

Single-membership models:

1. K-means algorithm
2. Multinomial mixture model and the EM algorithm

Mixed-membership models:

1. Latent semantic indexing and singular value decomposition
2. Probabilistic latent semantic indexing

K-MEANS

Recall we can represent document d as a vector $\vec{x}_d \in \mathbb{R}_+^V$. In the k-means model, every document has a single cluster assignment.

Let D_k be the set of all documents that are in cluster k . The *centroid* of the documents in cluster k is $\vec{u}_k = \frac{1}{|D_k|} \sum_{d \in D_k} \vec{x}_d$.

In k-means we choose cluster assignments $\{D_1, \dots, D_K\}$ to minimize the sum of squares between each document and its cluster centroid:

$$\sum_k \sum_{d \in D_k} \|\vec{x}_d - \vec{u}_k\|^2$$

Solution groups similar documents together, and centroids represent prototype documents within each cluster.

Normalize document lengths to cluster on content, not length.

SOLUTION ALGORITHM

First initialize the centroids \vec{u}_k for $1, \dots, K$.

Repeat the following steps until convergence:

1. Assign each document to its closest centroid, i.e. choose an assignment k for d that minimizes $\|\vec{x}_d - \vec{u}_k\|$.
2. Recompute the cluster centroids as $\vec{u}_k = \frac{1}{|D_k|} \sum_{d \in D_k} \vec{x}_d$ given the updated assignments in previous step.

The objective function is guaranteed to decrease at each step \rightarrow convergence to local minimum.

Proof: for step 1 obvious; for step 2 choose elements of vector $\vec{y} \in \mathbb{R}_+^V$ to minimize $\sum_{d \in D_k} \|\vec{x}_d - \vec{y}\|^2 \equiv \sum_{d \in D_k} \sum_v (x_{d,v} - y_v)^2$. Solution is exactly \vec{u}_k .

PROBABILISTIC MODELING

The k-means model might produce useful groupings, but is ad hoc and has no immediately obvious statistical foundations relevant to text.

A more satisfactory approach might be to write down a statistical model for documents whose parameters we estimate—allows us to incorporate and make inferences about relevant structure in the corpus.

Akin to structural modeling in econometrics (although no behavioral model), and called *generative* modeling in the machine learning literature.

SIMPLE LANGUAGE MODEL

We can view a document d as an (ordered) list of words $\mathbf{w}_d = (w_{d,1}, \dots, w_{d,N_d})$.

In a unigram model, $\Pr[\mathbf{w}_d] = \Pr[w_{d,1}] \Pr[w_{d,2}] \Pr[w_{d,3}] \dots \Pr[w_{d,N_d}]$.

Let $\Pr[w_{d,n} = v] = \beta_v$ and let $\beta \equiv (\beta_1, \dots, \beta_V) \in \Delta^{V-1}$. This defines a categorical distribution parametrized by β .

The probability of the data given the parameters is

$$\Pr[\mathbf{w}_d | \beta] = \prod_n \sum_v \mathbb{1}(w_{d,n} = v) \beta_v = \prod_v \beta_v^{x_{d,v}}.$$

Note that term counts are all we need to compute this likelihood, which is a consequence of the independence assumption. This provides a statistical foundation for the bag-of-words model. $\Pr[\mathbf{w}_d | \beta] = \Pr[\mathbf{x}_d | \beta]$.

MAXIMUM LIKELIHOOD INFERENCE

We can estimate β with maximum likelihood. The Lagrangian is

$$\mathfrak{L}(\beta, \lambda) = \underbrace{\sum_v x_{d,v} \log(\beta_v)}_{\text{log-likelihood}} + \lambda \underbrace{\left(1 - \sum_v \beta_v\right)}_{\text{Constraint on } \beta}.$$

First order condition is $\frac{x_{d,v}}{\beta_v} - \lambda = 0 \Rightarrow \beta_v = \frac{x_{d,v}}{\lambda}$.

Constraint gives $\frac{\sum_v x_{d,v}}{\lambda} = 1 \Rightarrow \lambda = \sum_v x_{d,v} = N_d$.

So MLE estimate is $\hat{\beta}_v = \frac{x_{d,v}}{N_d}$, the observed frequency of term v in document d .

MULTINOMIAL MIXTURE MODEL


A basic probabilistic model for unsupervised learning with discrete data is the multinomial mixture model.


This builds on the simple language model above, but introduces k separate categorical distributions, each with parameter vector β_k .


Every document belongs to a single category $z_d \in \{1, \dots, K\}$, which is independent across documents and drawn from $\Pr[z_d = k] = \rho_k$.


The probability that documents with category k generate term v is $\beta_{k,v}$.

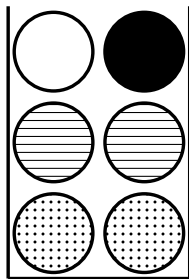
TOPICS AS URNS

 = wage

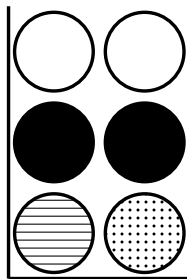
 = price

 = employ

 = increase

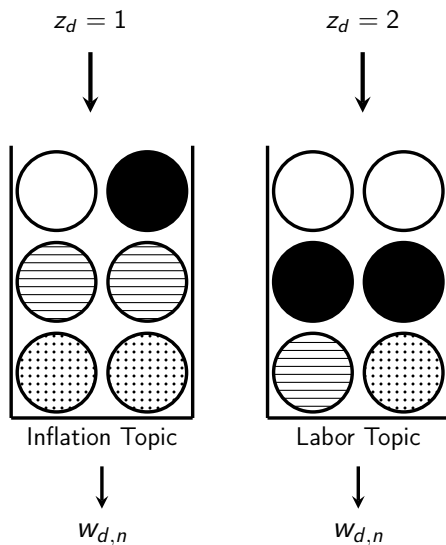


"Inflation" Topic



"Labor" Topic

MIXTURE MODEL FOR DOCUMENT



PROBABILITY OF DOCUMENT

Now we can again write down the probability of observing a document given the vector of mixing probabilities ρ and the matrix of term probabilities \mathbf{B} .

Suppose that $z_d = k$. Then the probability of \mathbf{w}_d is $\prod_v (\beta_{k,v})^{x_{d,v}}$.

To compute the unconditional probability of document d , we need to marginalize over the latent assignment variable z_d

$$\Pr[\mathbf{x}_d \mid \rho, \mathbf{B}] = \sum_{z_d} \Pr[\mathbf{x}_d \mid z_d; \rho, \mathbf{B}] \Pr[z_d \mid \rho, \mathbf{B}] = \sum_k \rho_k \prod_v (\beta_{k,v})^{x_{d,v}}.$$

PROBABILITY OF CORPUS

By independence of latent variables across documents, the likelihood of entire corpus, which we can summarize with document-term matrix \mathbf{X} is

$$L(\mathbf{X} \mid \boldsymbol{\rho}, \mathbf{B}) = \prod_d \sum_k \rho_k \prod_v (\beta_{k,v})^{x_{d,v}}$$

and log-likelihood is

$$\ell(\mathbf{X} \mid \boldsymbol{\rho}, \mathbf{B}) = \sum_d \log \left(\sum_k \rho_k \prod_v (\beta_{k,v})^{x_{d,v}} \right).$$

INFERENCE

Here the sum over the latent variable assignments lies within the logarithm, which makes MLE intractable.

On the other hand, if we knew the category assignment of each document, MLE would be very easy.

We can therefore use the expectation-maximization (EM) algorithm for parameter inference.

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See Arcidiacono and Jones (ECMA 2003) and Arcidiacono and Miller (ECMA 2011) for applications in economics.

EM ALGORITHM REVIEW

First initialize parameter values ρ^0 and \mathbf{B}^0 . Then, at iteration i :

1. (E-step). Compute the posterior distribution over the latent variables $\mathbf{z}_d = (z_1, \dots, z_D)$ given $\rho^{i-1}, \mathbf{B}^{i-1}$ and data. Use this distribution to form

$$Q(\rho, \mathbf{B}, \rho^{i-1}, \mathbf{B}^{i-1}) \equiv \mathbb{E}_{\mathbf{z}}[\ell_{\text{comp}}(\mathbf{X}, \mathbf{z} \mid \rho, \mathbf{B})].$$

2. (M-step). Update parameter estimates to ρ^i, \mathbf{B}^i by maximizing $Q(\rho, \mathbf{B}, \rho^{i-1}, \mathbf{B}^{i-1})$ with respect to ρ, \mathbf{B} .
3. If convergence criterion met, stop; otherwise proceed to iteration $i = i + 1$.

The log-likelihood $\ell(\mathbf{X} \mid \rho, \mathbf{B})$ is guaranteed to increase at each iteration. We converge to a local maximum.

COMPLETE DATA LOG-LIKELIHOOD

The joint distribution of \mathbf{x}_d and z_d is $\prod_k [\rho_k \prod_v (\beta_{k,v})^{x_{d,v}}] \mathbb{1}(z_d=k)$ and so the joint distribution of \mathbf{X} and $\mathbf{z} = (z_1, \dots, z_D)$ is

$$L_{\text{comp}}(\mathbf{X}, \mathbf{z} \mid \boldsymbol{\rho}, \mathbf{B}) = \prod_d \prod_k \left[\rho_k \prod_v (\beta_{k,v})^{x_{d,v}} \right]^{\mathbb{1}(z_d=k)}$$

The *complete data log-likelihood* is

$$\ell_{\text{comp}}(\mathbf{X}, \mathbf{z} \mid \boldsymbol{\rho}, \mathbf{B}) = \sum_d \sum_k \mathbb{1}(z_d = k) \left[\log(\rho_k) + \sum_v x_{d,v} \log(\beta_{k,v}) \right].$$

Note that this function is much easier to maximize with respect to the parameters than the original log-likelihood function.

EXPECTATION STEP

Compute expected value of the complete data log-likelihood with respect to the latent variables given the current value of the parameters ρ^j and \mathbf{B}^j and data.

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Clearly $\mathbb{E}[\mathbb{1}(z_d = k) \mid \rho^i, \mathbf{B}^i, \mathbf{X}] = \Pr[z_d = k \mid \rho^i, \mathbf{B}^i, \mathbf{X}] \equiv \hat{z}_{d,k}$.

By Bayes' Rule we have that

$$\begin{aligned}\hat{z}_{d,k} &= \Pr[z_d = k \mid \rho^i, \mathbf{B}^i, \mathbf{x}_d] \propto \\ &\Pr[\mathbf{x}_d \mid \rho^i, \mathbf{B}^i, z_d = k] \Pr[z_d = k \mid \rho^i, \mathbf{B}^i] = \rho_k \prod_v (\beta_{k,v})^{x_{d,v}}.\end{aligned}$$

So the expected complete log-likelihood becomes

$$Q(\rho, \mathbf{B}, \rho^i, \mathbf{B}^i) = \sum_d \sum_k \hat{z}_{d,k} \left[\log(\rho_k) + \sum_v x_{d,v} \log(\beta_{k,v}) \right]$$

MAXIMIZATION STEP

Maximize the expected complete log-likelihood with respect to ρ and \mathbf{B} .

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The Lagrangian for this problem is

$$Q(\rho, \mathbf{B}, \rho^i, \mathbf{B}^i) + \nu \left(1 - \sum_k \rho_k \right) + \sum_k \lambda_k \left(1 - \sum_v \beta_{k,v} \right).$$

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Standard maximization gives

$$\rho_k^{i+1} = \frac{\sum_d \hat{z}_{d,k}}{\sum_k \sum_d \hat{z}_{d,k}},$$

or the average probability that documents have topic k and

$$\beta_{k,v}^{i+1} = \frac{\sum_d \hat{z}_{d,k} x_{d,v}}{\sum_d \hat{z}_{d,k} \sum_v x_{d,v}},$$

or the expected number of times documents of type k generate term v over the expected number of words generated by type k documents.

EXAMPLE

Let $K = 2$ and consider the corpus of 1,232 paragraphs of State-of-the-Union Addresses since 1900.

Topic	Top Terms
0	tax.job.help.must.congress.need.health.care.busi.let.school.time
1	world.countri.secur.must.terrorist.iraq.state.energi.help.unit

$$(\rho_0, \rho_1) = (0.42, 0.58).$$

No *ex ante* labels on clusters, so any interpretation is *ex post*, and potentially subjective, judgment on the part of the researcher.

K-MEANS AS EM

The k-means algorithm can be viewed as the EM algorithm under a special case of a Gaussian mixture model in which the distribution of data in cluster k is $\mathcal{N}(\mu_k, \Sigma_k)$ where $\Sigma_k = \sigma^2 \mathbf{I}_V$ and σ^2 is small.

The probability that document d is generated by the cluster with the closest mean is then close to 1, so the assignment of documents to the closest centroid in the k-means algorithm is the E-step.

Given the spherical covariance matrix, the probability of observing documents within cluster k is proportional to the sum of squared distances between documents and the mean. So recomputing the cluster centroids is the M-step.

Good news is that k-means has statistical foundations; bad news is that the appropriateness of these for count data is doubtful.

MIXED-MEMBERSHIP MODELS

In both k-means and the multinomial mixture model, documents are associated with a single topic.

NB: the EM algorithm provides a probability distribution over topic assignments.

In practice, we might imagine that documents cover more than one topic.

Examples: State-of-the-Union Addresses discuss domestic and foreign policy; monetary policy speeches discuss inflation and growth.

Models that associated observations with more than one latent variable are called *mixed-membership* models. Also relevant outside of text mining: in models of group formation, agents can be associated with different latent communities (sports team, workplace, church, etc).

LATENT SEMANTIC ANALYSIS

One of the first mixed-membership models in text mining was the Latent Semantic Analysis/Indexing model of Deerwester et. al. (1990).

A linear algebra rather than probabilistic approach that applies a singular value decomposition to document-term matrix.

Closely related to classical principal components analysis.

Examples in economics: Boukus and Rosenberg (2006); Hendry and Madeley (2010); Acosta (2014).

REVIEW

Let \mathbf{X} be an $N \times N$ symmetric matrix with N linearly independent eigenvectors.

Then there exists a decomposition $\mathbf{X} = \mathbf{Q}\mathbf{\Lambda}\mathbf{Q}^T$, where \mathbf{Q} is an orthogonal matrix whose columns are eigenvectors of \mathbf{X} and $\mathbf{\Lambda}$ is a diagonal matrix whose entries are eigenvalues of \mathbf{X} .

When we apply this decomposition to the variance-covariance matrix of a dataset, we can perform principal components analysis.

The eigenvalues in $\mathbf{\Lambda}$ give a ranking of the columns in \mathbf{Q} according to the variance they explain in the data.

SINGULAR VALUE DECOMPOSITION

The document-term matrix \mathbf{X} is not square, but we can decompose it using a generalization of the eigenvector decomposition called the *singular value decomposition*.

PROPOSITION

The document-term matrix can be written $\mathbf{X} = \mathbf{A}\mathbf{\Sigma}\mathbf{B}^T$ where \mathbf{A} is a $D \times D$ orthogonal matrix, \mathbf{B} is a $V \times V$ orthogonal matrix, and $\mathbf{\Sigma}$ is a $D \times V$ matrix where $\Sigma_{ii} = \sigma_i$ with $\sigma_i \geq \sigma_{i+1}$ and $\Sigma_{ij} = 0$ for all $i \neq j$.

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Some terminology:

- Columns of \mathbf{A} are called left singular vectors.
- Columns of \mathbf{B} are called right singular vectors.
- The diagonal terms of $\mathbf{\Sigma}$ are called singular values.

INTERPRETATION OF LEFT SINGULAR VECTORS

Note that $\mathbf{XX}^T = \mathbf{A}\mathbf{\Sigma}\mathbf{B}^T\mathbf{B}\mathbf{\Sigma}^T\mathbf{A}^T = \mathbf{A}\mathbf{\Sigma}\mathbf{\Sigma}^T\mathbf{A}^T$.

This is the eigenvector decomposition of the matrix \mathbf{XX}^T , whose (i,j) th element measures the overlap between documents i and j .

Left singular vectors are eigenvectors of \mathbf{XX}^T and σ_i^2 are associated eigenvalues.

INTERPRETATION OF RIGHT SINGULAR VECTORS

Note that $\mathbf{X}^T \mathbf{X} = \mathbf{B} \boldsymbol{\Sigma}^T \mathbf{A}^T \mathbf{A} \boldsymbol{\Sigma} \mathbf{B}^T = \mathbf{B} \boldsymbol{\Sigma}^T \boldsymbol{\Sigma} \mathbf{B}^T$.

This is the eigenvector decomposition of the matrix $\mathbf{X}^T \mathbf{X}$, whose (i, j) th element measures the overlap between terms i and j .

Right singular vectors are eigenvectors of $\mathbf{X}^T \mathbf{X}$ and σ_i^2 are associated eigenvalues.

APPROXIMATING THE DOCUMENT-TERM MATRIX

We can obtain a rank k approximation of the document-term matrix \mathbf{X}_k by constructing $\mathbf{X}_k = \mathbf{A}\mathbf{\Sigma}_k\mathbf{B}^T$, where $\mathbf{\Sigma}_k$ is the diagonal matrix formed by replacing $\Sigma_{ii} = 0$ for $i > k$.

The idea is to keep the “content” dimensions that explain common variation across terms and documents and drop “noise” dimensions that represent idiosyncratic variation.

Often k is selected to explain a fixed portion p of variance in the data. In this case k is the smallest value that satisfies $\sum_{i=1}^k \sigma_i^2 / \sum_i \sigma_i^2 \geq p$.

We can then perform the same operations on \mathbf{X}_k as on \mathbf{X} , e.g. cosine similarity.

EXAMPLE

Suppose the document-term matrix is given by

$$\mathbf{X} = \begin{array}{ccccc} & \text{car} & \text{automobile} & \text{ship} & \text{boat} \\ \begin{array}{l} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \end{array} & \left[\begin{array}{cccc} 10 & 0 & 1 & 0 \\ 5 & 5 & 1 & 1 \\ 0 & 14 & 0 & 0 \\ 0 & 2 & 10 & 5 \\ 1 & 0 & 20 & 21 \\ 0 & 0 & 2 & 7 \end{array} \right] \end{array}$$

MATRIX OF COSINE SIMILARITIES

	d_1	d_2	d_3	d_4	d_5	d_6
d_1	1	.	.	.	.	.
d_2	0.70	1	.	.	.	.
d_3	0.00	0.69	1	.	.	.
d_4	0.08	0.30	0.17	1	.	.
d_5	0.10	0.21	0.00	0.92	1	.
d_6	0.02	0.17	0.00	0.66	0.88	1

SVD

The singular values are (31.61, 15.14, 10.90, 5.03).

$$\mathbf{A} = \begin{bmatrix} 0.0381 & 0.1435 & -0.8931 & -0.02301 & 0.3765 & 0.1947 \\ 0.0586 & 0.3888 & -0.3392 & 0.0856 & -0.7868 & -0.3222 \\ 0.0168 & 0.9000 & 0.2848 & 0.0808 & 0.3173 & 0.0359 \\ 0.3367 & 0.1047 & 0.0631 & -0.7069 & -0.2542 & 0.5542 \\ 0.9169 & -0.0792 & 0.0215 & 0.1021 & 0.1688 & -0.3368 \\ 0.2014 & -0.0298 & 0.0404 & 0.6894 & -0.2126 & 0.6605 \end{bmatrix}$$

$$\mathbf{B} = \begin{bmatrix} 0.0503 & 0.2178 & -0.9728 & 0.0595 \\ 0.0380 & 0.9739 & 0.2218 & 0.0291 \\ 0.7024 & -0.0043 & -0.0081 & -0.7116 \\ 0.7088 & -0.0634 & 0.0653 & 0.6994 \end{bmatrix}$$

RANK-2 APPROXIMATION

$$\mathbf{x}_2 = \begin{matrix} & \text{car} & \text{automobile} & \text{ship} & \text{boat} \\ \begin{matrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \end{matrix} & \left[\begin{array}{cccc} 0.5343 & 2.1632 & 0.8378 & 0.7169 \\ 1.3765 & 5.8077 & 1.2765 & 0.9399 \\ 2.9969 & 13.2992 & 0.3153 & 0.4877 \\ 0.8817 & 1.9509 & 7.4715 & 7.4456 \\ 1.1978 & 0.0670 & 20.3682 & 20.6246 \\ 0.2219 & 0.1988 & 4.4748 & 4.5423 \end{array} \right] \end{matrix}$$

MATRIX OF COSINE SIMILARITIES

	d_1	d_2	d_3	d_4	d_5	d_6
d_1	1	.	.	.	.	.
d_2	0.97	1	.	.	.	.
d_3	0.91	0.97	1	.	.	.
d_4	0.60	0.43	0.23	1	.	.
d_5	0.45	0.26	0.05	0.98	1	.
d_6	0.47	0.29	0.07	0.98	0.99	1

APPLICATION: TRANSPARENCY

How transparent should a public organization be?

Benefit of transparency: accountability.

Costs of transparency:

1. Direct costs
2. Privacy
3. Security
4. Worse behavior → “chilling effect”

TRANSPARENCY AND MONETARY POLICY

Mario Draghi (2013): “It would be wise to have a richer communication about the rationale behind the decisions that the governing council takes.”

TABLE: Disclosure Policies as of 2014

	Fed	BoE	ECB
Minutes?	✓	✓	X
Transcripts?	✓	X	X

NATURAL EXPERIMENT

FOMC meetings were recorded and transcribed from at least the mid-1970's in order to assist with the preparation of the minutes.

Committee members unaware that transcripts were stored prior to October 1993.

Greenspan then acknowledged the transcripts' existence to the Senate Banking Committee, and the Fed agreed:

1. To begin publishing them with a five-year lag.
2. To publish the back data.

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Fed Misread Fiscal Crisis, Records Show

***After Caution in 2008,
Series of Bold Steps***

By BINYAMIN APPELBAUM

WASHINGTON — On the morning after Lehman Brothers filed for bankruptcy in 2008, most Federal Reserve officials still believed that the American economy would keep growing despite the metastasizing financial crisis.

The Fed's policy-making committee voted unanimously against bolstering the economy by cutting interest rates, and several officials praised what they described as the decision to let Lehman fail, saying it would help to restore a sense of accountability on Wall Street.

James Bullard, president of the Federal Reserve Bank of St. Louis, urged his colleagues "to wait for some time to assess the impact of the Lehman bankruptcy filing, if any, on the national economy," according to transcripts of the Fed's 2008 meetings that it published on Friday.

DETROIT OUTLINES MAP TO SOLVENCY, STRESSING REPAIR

WAY OUT OF BANKRUPTCY

**Balancing Act Worries
Banks and Angers
Retirees in City**

By MONICA DAVEY
and MARY WILLIAMS WALSH

DETROIT — Seven months after this city entered bankruptcy, its leaders on Friday presented a federal judge with the first official road map to Detroit's future — documents designed to show how it aims to settle its \$18 billion debt to creditors and make itself livable again.

But the proposal is less a vision for a brand-new city than a repair estimate for the old one. It is a document designed by lawyers and bankruptcy experts to find ways to pay off more than 100,000 creditors and then budget money over a period of years to create a

Deal Signed in Ukraine, but Shows Str



GREENSPAN'S VIEW ON TRANSPARENCY

“A considerable amount of free discussion and probing questioning by the participants of each other and of key FOMC staff members takes place. In the wide-ranging debate, new ideas are often tested, many of which are rejected ... The prevailing views of many participants change as evidence and insights emerge. This process has proven to be a very effective procedure for gaining a consensus ... It could not function effectively if participants had to be concerned that their half-thought-through, but nonetheless potentially valuable, notions would soon be made public. I fear in such a situation the public record would be a sterile set of bland pronouncements scarcely capturing the necessary debates which are required of monetary policymaking.”

MEASURING DISAGREEMENT

Acosta (2014) uses LSA to measure disagreement before and after transparency.

For each member i in each meeting t , let \vec{d}_{it} be member i 's words.

Let $\vec{d}_{-i,t} = \sum_i \vec{d}_{it} - \vec{d}_{it}$ be all other members' words.

Quantity of interest is the similarity between \vec{d}_{it} and $\vec{d}_{-i,t}$.

Total set of documents— \vec{d}_{it} and $\vec{d}_{-i,t}$ for all meetings and speakers—is 6,152.

SINGULAR VALUES

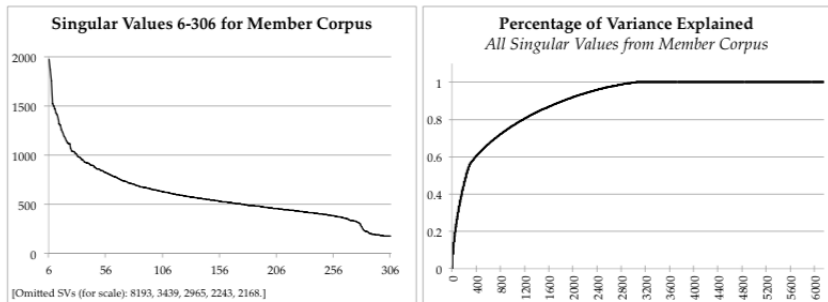
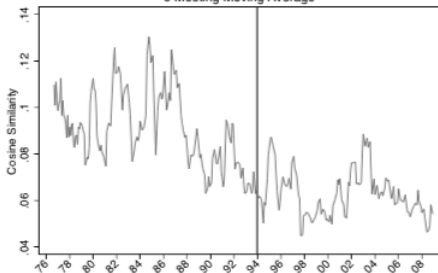


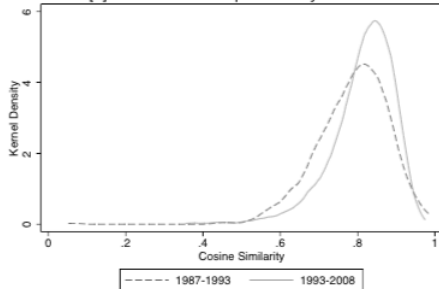
Figure 11: The left hand side shows the 6th through 306th singular values (the elements $\sigma_i \in \Sigma$ from the SVD) from the member corpus. The right hand side graph show percentage of the variance explained by all 6152 singular values for the member corpus.

RESULTS

[3] Std. Dev. of Member-Transcript Similarities
6 Meeting Moving Average



[4] Member-Transcript Similarity Densities



PROBABILISTIC MIXED-MEMBERSHIP MODEL

As with k-means, LSA provides a useful tool for data exploration, but its statistical foundations are unclear.

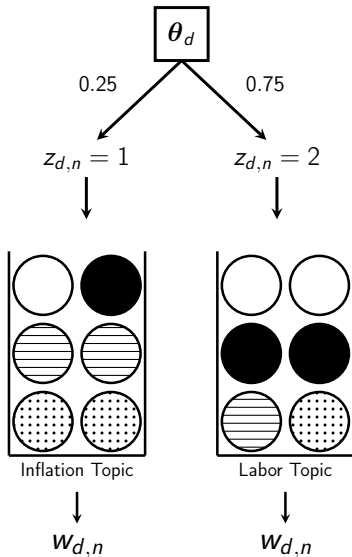
We now turn to exploring probabilistic mixed-membership models. An initial contribution is the probabilistic LSI model of Hofmann (1999).

Instead of assigning each document to a topic, we can assign each word in each document to a topic.

Let $z_{d,n}$ be the topic assignment of the n th word in document d . Suppose it is drawn from a document-specific vector of mixing weights $\theta_d \in \mathbb{R}^K$.

As before, words in a document are conditionally independent.

MIXED-MEMBERSHIP MODEL FOR DOCUMENT



The likelihood function for this model is

$$\prod_d \prod_n \sum_{z_{d,n}} \Pr \left[w_{d,n} \mid \beta_{z_{d,n}} \right] \Pr [z_{d,n} \mid \theta_d].$$

We can fit the parameters by EM, but:

1. Large number of parameters $KV + DK$, prone to over-fitting.
2. No generative model for θ_d .

We will come back to these issues in the next lecture.

CONCLUSION

Key ideas from this lecture:

1. The goal of unsupervised learning is to estimate latent structure in observations. Useful for dimensionality reduction.
2. Ad hoc data exploration tools are a good starting point, but probabilistic models are more flexible and statistically well-founded.
3. EM algorithm for likelihood functions with latent variables.
4. Mixture versus mixed-membership models.