Introducing Bayesian Language models

Unigram, Bigram, Hidden Markov, & Topic models

Mark Andrews Psychology Department, Nottingham Trent University

> > July 16, 2017

Language data

▶ A *minimal* description of observed language data is as follows:

$$\mathcal{D} = \{w_1, w_2 \dots w_j \dots w_J\},\,$$

with

$$w_{j} = w_{ji}, w_{j2} \dots w_{jn_{j}},$$

and

$$w_{ji} \in \mathcal{V}$$
,

where \mathcal{V} is a finite vocabulary, which can be represented for simplicity by integers

$$\mathcal{V} = \{1, 2 \dots V\}.$$

- In other words, we can describe language data as a set of sequences of symbols.
- ► Each w_{ji} usually represents a word (but could represent e.g. phonemes, instead) and each w_j represents a text or sentence.

Unigram probabilistic language model

- ▶ A *probabilistic language model* is any probabilistic generative model of the language data D.
- ▶ One of the simplest possible probabilistic language models is

$$w_{ji} \sim \operatorname{dcat}(\pi)$$
, for $i \in 1, 2 \dots n_j$, $j \in 1, 2 \dots J$

where dcat() represents a categorical distribution (probability mass function) over $1\dots V$ with

$$Pr(w_{ji} = k) = \pi_k.$$

▶ In other words, we model each word w_{ji} as drawn independently from a single categorical distribution with parameters π .

Bayesian unigram models

- ▶ In any Bayesian model, we provide a full probabilistic account of all variables, including observed variables, parameters, etc.
- ► For the case of a probabilistic unigram model, a common Bayesian unigram model would be

$$\begin{split} \pi &\sim ddirichlet(\alpha),\\ w_{j\,i} &\sim dcat(\pi), \quad \text{for } i \in 1,2\dots n_j, j \in 1,2\dots J. \end{split}$$

- ▶ Here, ddirichlet() denotes a V-dimensional Dirichlet distribution, which is a probability distribution over V-dimensional probability mass functions. It has hyperparameters $\alpha = \alpha_1, \alpha_2 \dots \alpha_V \dots \alpha_V$, where each $\alpha_V > 0.0$.
- ► The Dirichlet distribution is commonly chosen in this context because it is a conjugate prior of the categorical distribution.

Dirichlet Distribution

► The Dirichlet distribution is

$$ddirichlet(\alpha) = \frac{\Gamma(\sum_{\nu} \alpha_{\nu})}{\prod_{\nu} \Gamma(\alpha_{\nu})} \prod_{\nu=1}^{V} \pi_{\nu}^{\alpha_{\nu}-1}$$

where

$$\frac{\Gamma(\sum_{\nu}\alpha_{\nu})}{\prod_{\nu}\Gamma(\alpha_{\nu})}$$

is the normalizing constant, i.e.,

$$\frac{\prod_{\nu} \Gamma(\alpha_{\nu})}{\Gamma(\sum_{\nu} \alpha_{\nu})} = \int \prod_{\nu=1}^{V} \pi_{\nu}^{\alpha_{\nu}-1} d\pi$$

Dirichlet distribution hyperparameters

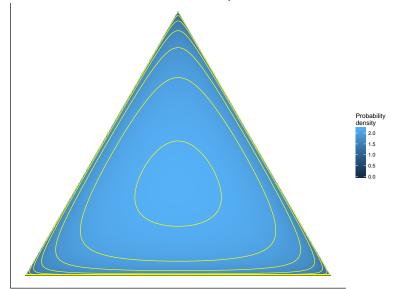
- As mentioned, the hyperparameters of a V-dimensional Dirichlet distribution is a V-dimensional vector α of positive values.
- ▶ It is convenient to sometimes represent α as follows:

$$\alpha = a \cdot m$$

where a > 0 is a scalar and m is V-dimensional probability mass function, i.e $0 \le m_v \le 1$ and $\sum_v m_v = 1$.

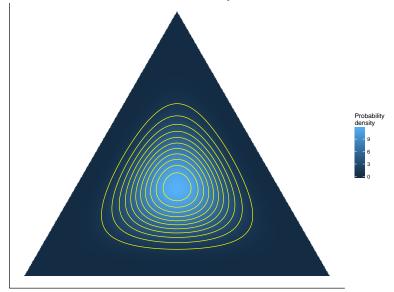
- ▶ In this reparameterization, m is a *location* vector and a is a *scale* vector. In other words, m is the centre of the distribution, and a indicates how spread out around the centre the distribution is. Also, m is exactly the average, or expected value of the distribution.
- ▶ Note $a = \sum_{v} \alpha_{v}$, $m = \alpha/a$.

3d Dirichlet distribution: Example 1



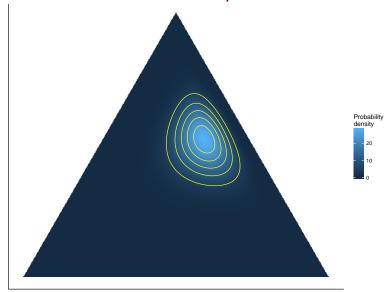
Here, $\alpha = 1.1, 1.1, 1.1$, or $\alpha = 3.3$, $m = [\frac{1}{3}, \frac{1}{3}, \frac{1}{3}]$

3d Dirichlet distribution: Example 2



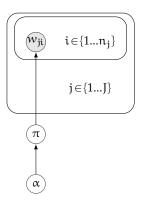
Here, $\alpha = 5, 5, 5$, or $\alpha = 15$, $m = [\frac{1}{3}, \frac{1}{3}, \frac{1}{3}]$

3d Dirichlet distribution: Example 3



Here, $\alpha = 5, 10, 15$, or $\alpha = 30$, $m = [\frac{1}{6}, \frac{1}{3}, \frac{1}{2}]$

Unigram model: Bayesian network



This is a *graphical model* or *Bayesian network*. It shows the conditional independence structure of the variables in the probabilistic model.

Posterior inference

Because the Dirichlet distribution is a conjugate prior to the categorical distribution, calculating the posterior distribution over π is possible algebraically:

$$\begin{split} P(\boldsymbol{\pi}|\boldsymbol{\mathfrak{D}},\boldsymbol{\alpha}) &= \frac{P(\boldsymbol{D}|\boldsymbol{\pi})P(\boldsymbol{\pi}|\boldsymbol{\alpha})}{\int P(\boldsymbol{D}|\boldsymbol{\pi})P(\boldsymbol{\pi}|\boldsymbol{\alpha})d\boldsymbol{\pi}}, \propto \prod_{\{j\mathbf{i}\}} P(w_{j\mathbf{i}}|\boldsymbol{\pi})P(\boldsymbol{\pi}|\boldsymbol{\alpha}), \\ &\propto \prod_{\nu=1}^{V} \pi_{\nu}^{n_{\nu}} \prod_{\nu=1}^{V} \pi_{\nu}^{\alpha_{\nu}-1}, \\ &\propto \prod_{\nu=1}^{V} \pi_{\nu}^{n_{\nu}+\alpha_{\nu}-1}, \\ &\text{ddirichlet}(\boldsymbol{n}+\boldsymbol{\alpha}). \end{split}$$

▶ In other words, given the prior $ddirichlet(\alpha)$ and observed counts of $n = n_1, n_2 ... n_{\nu}$ (i.e., n_{ν} is the number of observations of word ν), the posterior distribution is always $ddirichlet(n + \alpha)$.

Unigram model of Moby Dick

```
data("stop words")
moby_dick <- gutenberg_download(2701)</pre>
word counts <- moby dick %>%
  unnest tokens(word, text, token = 'words') %>%
  anti_join(stop_words) %>%
  count(word, sort=TRUE)
# Make a (named) vector of counts
counts <- word_counts$n
words <- word counts$word
```

Unigram model of Moby Dick

As a starting point, choose uniform prior

```
alpha <- rep(1, length(counts))</pre>
```

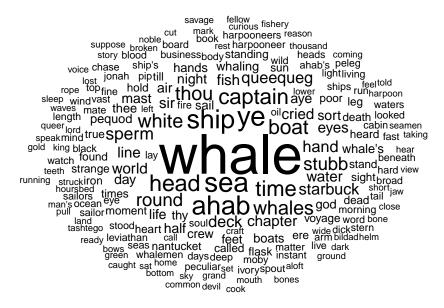
▶ Draw a sample from posterior distribution $P(\pi|\mathcal{D}, \alpha)$:

```
vpi <- sample.dirichlet(counts+alpha)</pre>
```

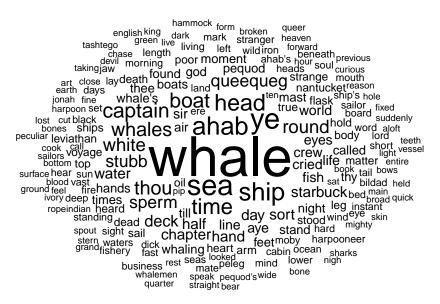
We can graphically represent this sample as follows

```
wordcloud(words = words, freq = vpi, max.words = 200)
```

Sample from posterior distribution: Example 1



Sample from posterior distribution: Example 2



Sample from posterior distribution: Example 3

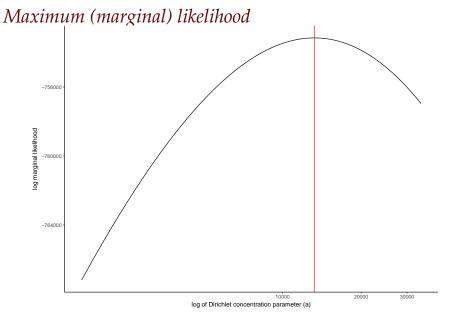
homesuddenly bow ten monster sharks purpose doorground indian voice n coffin beneath savagefeel stranger flukes brain coffin fine deep leviathan wide hundred lay ahab's matter ahab's foot thy significant flux sign oil business harpooneers standing hear length body sailor feet thy sight chapter days mind living lance strange stand cried deck running book dead man's bed times white world seas left grand aye time called voyage means nigh harpoon sir boats heart bone moby cabin god top dark land bottom peleg sort thee ye ship headhand sperm moment pequod's whaling shine entired reason blacktrue night oy waters wild air water captal whales whaling ships entire close morning hard Crewline eyes pequod half heardarm flask wondrous rope ord found whale's famous fishery soul word found whale's common mark lower harpooneer spout vast straight iron fast light short mouth bonesfresh instantwhalemen greenland bildad forward

Marginal likelihood

▶ The marginal likelihood is

$$\begin{split} P(\mathcal{D}|\alpha) &= \int P(D|\pi)P(\pi|\alpha)d\pi, \\ &= \frac{\Gamma(\sum_{\nu}\alpha_{\nu})}{\prod_{\nu}\Gamma(\alpha_{\nu})} \int \prod_{\nu=1}^{V} \pi_{\nu}^{n_{k}+\alpha_{k}-1d}d\pi, \\ &= \frac{\Gamma(\sum_{\nu}\alpha_{\nu})}{\prod_{\nu}\Gamma(\alpha_{\nu})} \frac{\prod_{\nu}\Gamma(n_{\nu}+\alpha_{\nu})}{\Gamma(\sum_{\nu}(\alpha_{\nu}+n_{\nu}))}. \end{split}$$

- ▶ It is the likelihood function of α , and is marginalized (i.e. integrated) over π .
- ▶ We can treat this like any other likelihood function.



We can set the value of a to the value that maximizes the likelihood function. This is a type of *empirical Bayes* inference.

Bigram models

- ▶ A bigram probabilistic language model for our observed language data D is as follows.
- For $1 \le j \le J$, $w_{j1} \sim \operatorname{dcat}(\pi),$ $w_{ji} \sim \operatorname{dcat}(\theta_{[w_{ii-1}]}), \quad \text{for } 2 \le i \le n_j.$

where θ is a V × V matrix, and $\theta_{vu} \triangleq P(w_{ji} = u | w_{ji-1} = v)$

▶ In other words, for each sentence or text, we first sample the initial word for a categorical distribution. For the remaining words, we sample their values from a categorical distribution that is conditioned on the previous word.

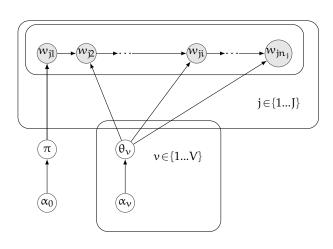
Bayesian Bigram model

- For a Bayesian version of a bigram model, we provide priors on π and θ.
- ► Common choices are Dirichlet distributions

$$\begin{split} \pi &\sim ddirichlet(\alpha_0),\\ \theta_{\nu} &\sim ddirichlet(\alpha_{\nu}), \quad \text{for } 1 \leqslant \nu \leqslant V,\\ w_{j1} &\sim dcat(\pi),\\ w_{ji} &\sim dcat(\theta_{w_{ji-1}}), \quad \text{for } 2 \leqslant i \leqslant n_j. \end{split}$$

Note that here we have a separate α_{ν} prior for each conditional distribution θ_{ν} . Other options are possible.

Bigram model Bayesian network



Posterior inference

► The posterior distribution over θ_{ν} is similar to the case of the posterior inference in Dirichlet distributions in the unigram case, with the difference being that the relevant *counts* are

$$R_{\nu} = R_{\nu 1}, R_{\nu 2} \dots R_{\nu u} \dots R_{\nu V}$$

where $R_{\nu u}$ gives the number of times word u follows word ν in the corpus.

► As such,

$$P(\theta_{\nu}|\mathcal{D}) = ddirichlet(R_{\nu} + \alpha_{\nu})$$

▶ For the posterior over π , we can use the marginal count vector \mathbf{r} , where \mathbf{r}_{ν} simply gives the frequency of occurrence of word ν :

$$P(\pi|\mathcal{D}) = ddirichlet(r + \alpha_0)$$

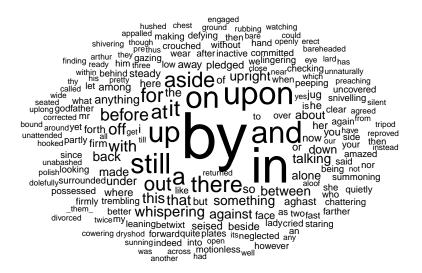
Bigram model of collected works of Charles Dickens

```
dickens_books_id <- gutenberg_works(</pre>
  author == "Dickens, Charles")$gutenberg_id
dickens books <- gutenberg download(
  dickens_books_id, meta_fields = "title")
dickens words <- dickens books %>%
  unnest tokens(word, text, token = 'words') %>%
  count(word, sort=TRUE)
dickens_bigrams <- dickens_books %>%
  unnest tokens(bigram, text, token = 'ngrams', n=2) %>%
  count(bigram, sort=TRUE) %>%
  separate(bigram, c('word1', 'word2'), sep=' ')
```

Sample from posterior distribution of θ_{dear}



Sample from posterior distribution of θ_{stand}



Sample from posterior distribution of θ_{tall}



Simulations from a bigram model

- ▶ We can generate data from a trained bigram model as follows:
- ▶ First, we sample from the posterior distribution $P(\pi|D, \alpha_0)$, and then sample w_1 from $dcat(\pi)$.
- ▶ We then sample from $P(\theta_{[w_1]}|\mathcal{D}, \alpha_{[w_1]})$, and sample w_2 from $dcat(\theta_{[w_1]})$.

Simulations from a bigram model: Examples 1-3

- admirable lady acknowledged supremacy and then i might think that ought to whom she once not your time organist ought to divine who had folded up to mutter among them a level of the next morning three j linton bespeckled prospect the knocker marley's slushed and defarge as mr jaggers
- curtains wherever he took deadly cold arch wore itself but i would have we my own face was quite necessary to wear this couplet about two pair of saying that in his vigorous play with an arm round upon that the real military life may be an eye these walls
- constantinopolitan chamber straight before they looked at enormous hit with me steerforth as they called him with the people live in it to night if he had entered according to do sit thee get'st tobacco post in germany and of characteristics of beasts and slept and no idea good part

Simulations from a bigram model: Examples 4-6

- only ended the duke has lost to this little tavern he has been careful of the door and present seat mr pickwick after making expiation for this three quarters over an angry sultan pomp about the plan of all appearance of yesterday i shut lest he covered with love the
- name as if they came to contribute to his gloved hand would be such a positive intelligence when he had insisted that he did not quite a wry faces clustering pillars strong alliance but she could not that it formed into the other side with me we find yourself to
- ▶ most distant corner of oh cap'en cuttle walked forth against me but whom he opened from view to him what provision to cast off a little cage in every fresh discussion fledgeby you do it the expression of the house where he observed to giving me and with this woman

Simulations from a bigram model: Examples 7-9

- boot cleaning for i would have so i had not set of course though it had come upon her and all very near your heart which i don't you should disparage my dear rogues you to a bar and full sincerity he much tickled in the mother and more money
- ▶ restless too much satisfaction of breath folding up directly in one of the obstinacy reputation and of us for i may derive from the third in all the regular in the park the top of the correction of that the change in reduced and find him and believe i should
- ▶ penalty then drank bitter laughs i need keep up into the confederation observes when i cannot come at the old curiosity out in reference to come to appear asleep what's her rosy cheeked charmers with great that the seat till now don't know that had said she gave some horrible

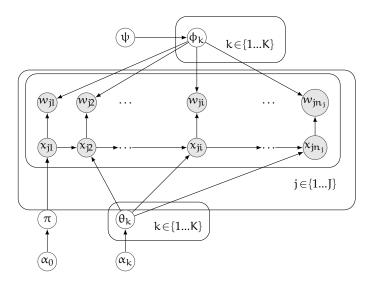
Hidden Markov model

- ▶ A Hidden Markov model is a type of latent variable model.
- ▶ It assumes that observed data are generated by sampling from categorical distributions that are indexed by a latent (hidden) first order Markov chain of state variables.
- ► The cardinality of the state variable, denoted by K here, is a modelling choice.
- ▶ As a probabilistic language model for our \mathcal{D} , a Hidden Markov model is a follows: For $j \in \{1 ... J\}$,

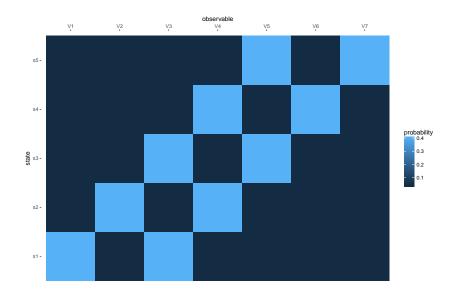
$$\begin{split} &x_{j1} \sim dcat(\pi), \\ &x_{ji} \sim dcat(\theta_{\lfloor x_{ji-1} \rfloor}), \quad \text{for } 2 \leqslant i \leqslant n_{ji}, \\ &w_{ji} \sim dcat(\varphi_{\lfloor x_{ji} \rfloor}), \text{for } 2 \leqslant i \leqslant n_{ji} \end{split}$$

- ► Here, θ is a K × K matrix, with $P(x_{ji} = l | x_{ji-1} = k) = \theta_{kl}$.
- ► The ϕ is a K × V matrix, $P(w_{ji} = v | x_{ji} = k) = \phi_{kv}$.
- ► We put Dirichlet priors on π , θ , ϕ .

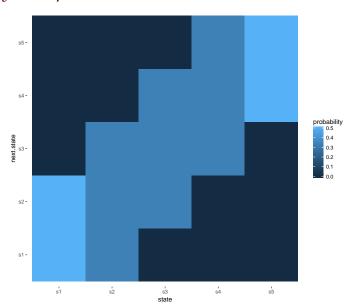
Hidden Markov model Bayesian network



Toy example: ф



Toy example: θ



Posterior inference

- ▶ We usually will use Dirichlet priors on π , ϕ_1 , ϕ_2 ... ϕ_K , and θ_1 , θ_2 ... θ_K .
- ► However, the posterior distribution

$$P(\pi, \phi, \theta | \mathcal{D})$$

is not analytically tractable.

- ▶ In this situation, we use Monte Carlo methods to draw samples from this posterior distribution.
- ▶ For this, we may use a *blocked Gibbs sampler* such where we iteratively draw a sample from the posterior distribution of the latent state space, assuming values for the parameters, and then from the posterior over the parameters, assuming values for the state space:

$$\begin{split} \tilde{x} \sim P(x|w,\tilde{\pi},\tilde{\varphi},\tilde{\theta}),\\ \tilde{\pi},\tilde{\varphi},\tilde{\theta} \sim P(\pi,\varphi,\theta|w,\tilde{x}) \end{split}$$

State space inference

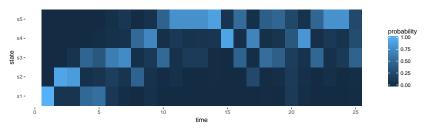
- ▶ Given a sequence of observations $w_1, w_2 ... w_n$, what is the probability distribution over the possible values of $x_1, x_2 ... x_n$?
- Assuming we know π , φ , θ , we can use recursive inference as follows:

$$P(x_{i}|w_{1}...w_{2}) = \frac{P(w_{i}|x_{i})P(x_{i}|w_{1},w_{2}...w_{i-1})}{\sum_{\{x_{i}\}}P(w_{i}|x_{i})P(x_{i}|w_{1},w_{2}...w_{i-1})},$$

$$\propto P(w_{i}|x_{i})\sum_{\{x_{i-1}\}}P(x_{i}|x_{i-1})P(x_{i-1}|w_{1},w_{2}...w_{i-1})$$

State space inference in toy example

► Given the observed values — 4, 2, 4, 3, 3, 5, 5, 4, 6, 5, 7, 5, 5, 7, 6, 5, 4, 5, 5, 1, 6, 5, 7, 5, 3 — the inferred values of the states are:



► The actual values of the state trajectory are: 1, 2, 3, 3, 3, 4, 5, 4, 4, 5, 5, 5, 5, 5, 5, 4, 3, 2, 3, 3, 4, 3, 2, 3, 3.

Latent Dirichlet Allocation

- ► Latent Dirichlet Allocation is a probabilistic bag-of-words language model.
- ▶ It is a type of multilevel/hierarchical probabilistic mixture model.
- ▶ It is defined as follows: For $1 \le j \le J$,

$$\pi_j \sim \text{ddirichlet}(\alpha), \quad \text{for } 1 \leqslant j \leqslant J,$$

and for $1 \leqslant i \leqslant n_{ji}$,

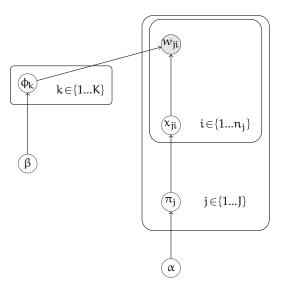
$$x_{ji} \sim dcat(\pi_j),$$

 $w_{ji} \sim dcat(\phi_{[x_{ji}]})$

- ▶ The cardinality of ϕ is a modelling choice.
- ▶ As such, we treat each document j as a sample from a probabilistic mixture model, where the component probabilities are π_j , which are sampled from a Dirichlet distribution.

Latent Dirichlet Allocation Bayesian network

► The Bayesian network diagram of the Latent Dirichlet Allocation model



Topic modelling the AP corpus

```
data("AssociatedPress")
ap_lda <- LDA(AssociatedPress,
              k = 50,
              control = list(seed = 1234))
tidy(ap_lda, matrix = "beta") %>%
  group_by(topic) %>%
  top n(10, beta) %>%
  ungroup() %>%
  arrange(topic, -beta) %>%
```

Example topics from AP corpus

topic_01	topic_05	topic_10	topic_15	topic_20
workers	south	i	party	drug
union	africa	president	governmen	ıt i
labor	african	united	political	cocaine
percent	government states		communist	police
jobs	black	people	soviet	case
strike	mandela	time	opposition	attorney
contract	people	vietnam	gorbachev	fbi
work	national	years	minister	court
job	president	support	elections	told
governme	ntapartheid	government leader		two

```
chiquita
                                                                                                                                                                                                       affected boat
                                                                                                                                                                                                                                                                      annual
                                                                                                                                                                economy
                                                                                                                                                                                                                                                                  security threeyear
                                                                                                                                 support begin information sunday month graduates
                                                                                                                                                                                                     end thousands
                                                                                                                                                                                                                                                    price monday
                                                                                                                                                                                                                                    latest gm come agreements
                                                                    ortega receive strikes survey office day
                                                                                                                                                                                                                                                                                     economic equipment
                                                                                                                                                                                                                                   bargaining
                                                                                                                                                                                                                                                                                                                                residents
                                                                   amnestyagreed increase
                                                                                                                                                                         highersalary american
                                               pickél services just get large pickél services ust get large plants agreement run year unions governmen employers year unions
                                                                                                                                                                                                                                                                                        largest
                                                                                                                                                                                                                                                                                                                           back university
                                                                                                                                                                                                                                                                                       electric today accident major
                                                                                                                                                                                                                            government
                                                                                                                                                                                                                                                                                                                          half
                                                                                                                                                                                                                                                                                                                                                         spokesman
                                                                                                                                                                                                                                                                                                                                training federation
                   assemblywalkout says service jobs top percent safety employment engineering order long autor try public going wage in new jobs to be people told raises benefits
                                                                                                                                                                                                                                                                        job people contracts salaries growing
                                    strikers offer steel agency included a million uaw two big abor
 country
                                                                                                                                                                                                                                                                                                     main chrysler rate making
kolbera
                                                                                                                                                                                                                                                                                                                    number offered career
    fulltime
                                   agency
available industry
  tentative
                                                                                                                                                                                                                                               time members replied to the working city ag firms working apply intertesting
                                                                                                                                                                                                                                                                                                                   time members replacement
   ago money past three Offers
               second fridaydaily lost years dont union sides make pay last average fiveoperations received temporary increases aliens population work received temporary increases aliens population work received temporary received te
                        march corp program saycut Strikecontract president privatelikely goalfiance talks early state issues
                            issue children take news company companies travel united businesses applicants far need management industries wages here industrial total motors
                   minimum '
                                   copies situation administration week worker illegal reached force demanding immigration page 1 page 
                                                                                                                                                                                                                                                                                                                 cost compensation
                                                                                               went association lines negotiations
                                               immigrants
                                                                                                                       leaders hours increased days general striking raise costs accidents minorities deadline newspapers demands tuesday figures midnight council
                                                                                                                                                                                                                                                               national
                                                                                  beainning
                                                                                                                                                                           interview involved
                                                                                                                                                                                                                                                            quality
```

```
pretoria
                                                   stop territory
                                             children yearoldscheduled struggle population granted morocco
                                                                   thursday
                                          weeks
                                  health
                           salinas conflict
                                              mandelas constitution cape agreement
                        pollution farming
                                                                           signed economic
                            restrictions ago mozambique inkatha
                                                                             schools township<sub>foreign</sub>
                                                 official un rule officials
                 churches wednesday
                                                                      statement province
                  december
                                     three
                                              africas meeting
                regiontime
                                                                          groups' elections opposition
                                     political
                                                 john
        peoples
                lesotho mexico
                                                                                  system<sub>mass</sub> known india
           killed front citymiles states island sandsactivists lives recent war years
                                                        president state system mai
                                                                                                 change released
       thousands activists, lives, recent
                                                                              sinhalese world conservative
    economynujoma year paul million sri
         unity southwestleaders
                                                                                              young supporters
                                                                              groupracial
                                                                             white creek nation residents outside future guerrillas
      saying crowd prison twopeople
                                                                              leadercountry swapo
             sanctions told peace
                                                                                  bush
                                                                            de
                                                                                              life
                                                                                  namibia talks military human
   monday minister whites
   joseph early release step united
                                                                           national council cuban possible botha botswana storks
        week southern blacks end
                                                       i anc klerk pope made Waccused policy black apartheid rebels freed colony nations segregated
namibian plan antiapartheid
  activities johannesburg visited (
                                                      ment visit independence freedom ended accord five tannery
    maintain separate
                        church
         townships yellow
              recently role support control fighting angola oau violence partyunita civil roops largest
                rights percent angolan
                                            organization last today members king polisario liberation free buthelezi
                    negotiationsmember affairs nelson guerrilla minority homehundreds
                                                    ethnic tuesday
                                                                        natal segregation
                                     prisoners organizationswife
                            major
                                                                         powertaken
                                                                africans tamils
                               pressure movement racially africar western
                                                                        despite
                                              services zimbabwe largely
```

```
saying conduct citizenship private reporters
                        deportations chairman press
                            chargesseen countrys emergency inauguration
                                                                                    fundamentalists
                                 ratification talks congress
                                                                  rights
                                                                            eclipses attempt
             committees good positive asked little know relations fact work arrested taken young told positive asked little know relations fact work arrested regovernment, bendjedid intelligence power feedbacknorths pressure agonomic reforms meeting
           forces<sub>bread</sub> official algerian cousin return pact notebooks.
    system cousin return pact notebooks
       days situation army question Support national made longerabm july
                                                                             law leader torture missing
                   man war first letter just vietnam long like clear mandate
  fighting saturday friday rowan last timesta
                                                                          state niklus liberation carl
                                                                QC jail
  black men coalition get Say
                                                                        twosenate islamic
entry algerians chinese bush language regime full end bush
                                                                        ⊸junethink
                                                                                          resolution<sub>east</sub>
                                                          United mr costatown see ask
       george rin foreign
                                                                 government spent give constitutional
                                                                                          rica officials
        forman move day policy years bella un china jantreaty released border added houseben day policy years country goceausescil beliage
                                                            country goceausescu believe
         pell cambodianalgeriaworld aug
                                              kephartrouge political algiers cooperation
                                                                            tired, democracy conference
                     reagan yearkhmer
              met
           mitchell
             contras dont stability military prisoners dictator party ambassador sent countries home algerias mandela
                                               committeeinflife groupel signed got marked
                                                                                        panama
                     diaries million putadministration remains returned past soviet
                                        pang assembly important
                              control
                                                                       wellstone
                                    chadli received living thousands france indicated nations negotiation
                                           indicated
                                               resistance
```

```
conservatives major demands
                                                                                                                                                                                                                                                                     million
                                                                                                                wednesday votes body session criticism program radical
                                                                                                                                                                                                                                                                        spokesman
                                                                              latvia tuesday military reforms secretary foreign saying present yearold warunions polish democracy constitution leading
                                                                                                                                                                                                                                                                             strona
                                                                                                                                                                                                                           constitution leading multiparty
                                      died candidates state conference democrats independent speech member
                                                                                                                                                                                                             presidential timemikhail revolution
                                                                                                                                                                                                          solidarity countrys seats
                                   message parliamentary three economic democratic interiors unday friday
                                                                                                                                                                                                                                                               independence '
                                                                                                                                                                                                                                                                                                                                          proposed
                                                                                                                                                                                  ministerpeople control led saturday opinion
                                                         coup meét public two reform
              role lithuania police public two relorm from today country told leader co
                                                                                                                                                                                                                                                                                           politburo delegates
                                                                                                                                                                                                                                                                                      won
                                                                                                                                                                                                                                                                                                                      elected demanded
                                                                                                                                                                                                                                                                                       labor meeting decree deputies
                    poland workers plan congress SOVIET first POLITICAL
                                                                                                                                                                                                                                                                                          vote supreme deputy rights
                                         am partys election new crisis
                                                                                                                                                                                                                                                                                                                    end
                                                                                                                                                                                                                                                                      held radio .
                                                                                                                                                                                                                                                                                 parties reported resign
                                  majority
dominated form ruling gorbachev
                                                                                                                                                                                                                                                                                                                             yeltsin socialist legislative
                                                                                                                                                                                                                                                                  president conservative head
                     changes coalition
                                                             groups national job |
                                                                                                                                                                                                                                                                                baltic five th group monday appeared
                                                                                                                                                                               rernment republics year law republic yea
                            assembly agency leaders
                                                    peoples members 90
                               peoples years asked thursday earlier prime opposition tass power official voters victory weeks results society percent elections central gorbachevs sajudis policies and the people strikes asked thursday earlier prime opposition tass power official voters victory weeks results society percent charge council social newspaper movement parliament elections central gorbachevs sajudis policies and the people strikes are society percent council to the people strikes asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks results asked thursday earlier prime opposition tass power official voters victory weeks asked thursday earlier prime opposition tass power official voters victory weeks asked thursday earlier prime opposition tass power official voters victory weeks asked thursday earlier prime opposition tass power official voters victory weeks asked thursday earlier prime opposition tass power official voters victory were prime of the prime opposition tass power official voters victory were prime of the prime opposition tass power official voters victory were prime official voters victory with the prime of the prime of the prime official voters victory were prime of the prime of the prime of the prime of 
     suggested
                                                                                                                                                                           committeenewsgive republic long greater balloting
                                                                             future liberal supportleadership communists campaign trade challenge confailists talkstop economymarch communists campaign trade challenge confailists talkstop economymarch communists campaign trade challenge
                                                        supporters popular
                                                                                                                                                                                                 moscow governing authorities main
                                                                                                                premier
                                                                                                                                                        resignation
                                                                                         governments made reporters russianlegislature hold candidate
                                                                                                                                                                                                 general late
                                                                                                                                                          possible politics proposals considered constitutional
                                                                                                                                                                                                                                                         ethnic ministers
                                                                                                                                                  television
```

```
narcotics manning
                                                                                                                                                                                                                                     hoppe
                                                                                                                         reactors verdict herrington manslaughter
                                                                                        confiscated poeyosemite criminal
                                                                                                                                                                                                                                     made
                                                                                                                                                                                                                                                                               issued sentence
                                                                                                        lewis
                                                                                                                                                                                                                         wednesday
                                                                                                                                                                                                                                                                                                   divorce documents
                                                                             safety offenders taken grammer
                                                                                                                                                                                                                                                                        family house
                                                                                                                                                                                                             department
                                                                                                                       robbery charged
                                                                                                                                                                                                                                                                       month days ms christian
                                                                                                                                                                                                                                                                                            h days ms husband bond barahona rifle
                                                                                                                                                                    million Judge fernandez
                                                   roberson conrail colombia
                                                                                                                                                                                                         stolen
                                                                                                                                                                                                                                                        united note
                                                                        away make
                                                                                                                            say arrested
                                                   cant
                                                                             local, ring
                                                                                                                                                                                                           enforcement months four evidence
                                                                                                                                                            witness
                                   discovered went
                                                                                                                                                                                                      national defound possession
                                      service driving day trial states
                                  saturday officers users attorney ray Case
                                                                                                                                                                                                                                                                                                                                                        colombian
                                                                                                                                                                                                                                                            owen man<sub>suspects suitcase</sub>
                                                                                                                                                                                                                                                                       e state says
                     bought cash hours year
                    corrections worth crime federal
                                                                                                                                                                                                                                                       car medellin county officer buy teresa two program thieves weeks plea warrant
university marisa know three new 1D
           train alcohol son died
                       investigators spain get court | killed guns toldtestified deal sent read obrien came extradition law prison agents little | police | year old jury street suspect people statement mother families defense time 1/0000 deals and obrien people statement mother families defense time 1/0000 deals and obrien people statement mother families defense time 1/0000 deals and obrien people statement people s
                                        statementinioniei amilies defense time years drugs six room guilty public office jersey asian assaultake authorities work last york Charges oil first murder refused antidrug smuggling charge the sound of the sound
                                                                                                                                                                                                                         arrest spanishlife undercover witnesses
                                        antidrug smuggling charge tuesday
                                                                                                                                                                                      just theft tesumon, just customs home april breeze residents money knew trying hale canning children district
                                                                                                                                                                                                                                               testimony bus traffickers director
                                                       community apartment hearing
                                                                          indictment think
                                                                                                             inn conspiracy south daughter agent convicted south daughter agent trafficking small attention
                                                                                                    auinn
                                                                                                         conviction felony entrapment "
                                                                                                                                   innocent heroin
                                                                                                                                                                                         boy
```