
Text Categorization using Naïve Bayes

Mausam

(based on slides of Dan Weld, Dan Jurafsky, Prabhakar Raghavan, Hinrich Schutze, Guillaume Obozinski, David D. Lewis, Fei Xia)

Categorization

- Given:
 - A **description of an instance**, $x \in X$, where X is the *instance language* or *instance space*.
 - A **fixed set of categories**:
 $C = \{c_1, c_2, \dots, c_n\}$
- Determine:
 - The **category of x** : $c(x) \in C$, where $c(x)$ is a categorization function whose domain is X and whose range is C .

County vs. Country?

[article](#) [discussion](#) [edit this page](#) [history](#)

King County, Washington

From Wikipedia, the free encyclopedia

Coordinates: 47°47′, −121°84′

"King County" redirects here. For other uses, see [King County \(disambiguation\)](#).

King County is located in the [U.S. state](#) of [Washington](#). The population in the 2000 census was 1,737,034 and in 2006 was an estimated 1,835,300. By population, King is the largest county in Washington, and the 12th largest in the United States. As of 2006, the county had a population comparable to that of the state of [Nebraska](#).

The county seat is [Seattle](#), which is the state's largest city. About two-thirds of the county's population lives in the city's [suburbs](#). King County ranks among the 100 [highest-income counties](#) in the United States.

Contents [\[show\]](#)

History [\[edit\]](#)

The county was formed out of territory within [Thurston County](#) on [December 22, 1852](#), by the [Oregon Territory](#) legislature, and was named after [Alabama](#) resident [William Rufus King](#), vice president under president [Franklin Pierce](#). Seattle was made the county seat on [January 11, 1853](#).^{[[1](#)]}^{[[2](#)]}^{[[3](#)]}

King County originally extended to the [Olympic Peninsula](#). According to historian [Bill Speidel](#),

King County, Washington


King County

Map


Location in the state of [Washington](#)


Washington's location in the [USA](#)

Statistics

Founded	December 22, 1852
Seat	Seattle

[article](#) [discussion](#) [edit this page](#) [history](#)

Kenya

From Wikipedia, the free encyclopedia

This article needs additional [references or sources](#) for [verification](#).
Please help [improve this article](#) by adding [reliable references](#). Unverifiable m
be [challenged](#) and removed.

The **Republic of Kenya** is a country in [Eastern Africa](#). It is bordered by [Ethiopia](#) to the north, [Somalia](#) to the northeast, [Tanzania](#) to the south, [Uganda](#) to the west, and [Sudan](#) to the northwest, with the [Indian Ocean](#) running along the southeast [border](#).

Contents [\[show\]](#)

History [\[edit\]](#)

Main article: [History of Kenya](#)

[Paleontologists](#) have discovered many fossils of [prehistoric](#) animals in Kenya. At one of the rare [dinosaur fossil](#) sites in Africa, two hundred [Cretaceous theropod](#) and [giant crocodile](#) fossils have been discovered in Kenya, dating from the [Mesozoic Era](#), over 200 million years ago. The fossils were found in an excavation conducted by a team from the [University of Utah](#) and the [National Museums of Kenya](#) in July-August 2004 at

**Jamhuri ya
Republic o**


Flag

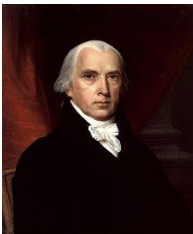
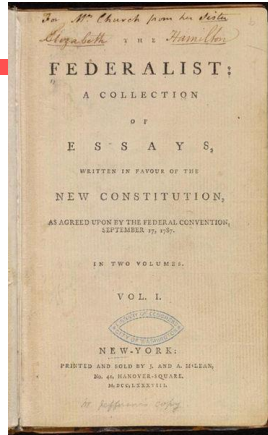
Motto
"Harambee"
"Let us all pull"

Anthem
Ee Mungu Ngu
"Oh God of All"

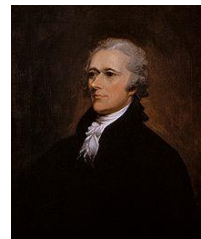


Who wrote which Federalist papers?

- 1787-8: anonymous essays try to convince New York to ratify U.S Constitution: Jay, Madison, Hamilton.
- Authorship of 12 of the letters in dispute
- 1963: solved by Mosteller and Wallace using Bayesian methods



James Madison



Alexander Hamilton

Male or female author?

- The main aim of this article is to propose an exercise in stylistic analysis which can be employed in the teaching of English language. It details the design and results of a workshop activity on narrative carried out with undergraduates in a university department of English. The methods proposed are intended to enable students to obtain insights into aspects of cohesion and narrative structure: insights, it is suggested, which are not as readily obtainable through more traditional methods.
- My aim in this article is to propose an exercise in stylistic analysis which can be employed in the teaching of English language. It details the design and results of a workshop activity on narrative carried out with undergraduates in a university department of English. The methods proposed are intended to enable students to obtain insights into aspects of cohesion and narrative structure: insights, it is suggested, which are not as readily obtainable through more traditional methods.

Female writers use

more first person/second person pronouns

more gender laden third person pronouns

(overall more personalization)

approach to

ending of

what some of these so-called apposition markers indicate. It will be argued

that the decision to put something in other words is essentially a decision





about style, a point which is, perhaps, anticipated by Burton-Roberts when he

describes loose apposition as a rhetorical device. However, he does not justify

this suggestion by giving the criteria for classifying a mode of expression as a

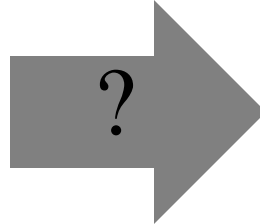
rhetorical device.

Positive or negative movie review?

-  • unbelievably disappointing
-  • Full of zany characters and richly applied satire, and some great plot twists
-  • this is the greatest screwball comedy ever filmed
-  • It was pathetic. The worst part about it was the boxing scenes.

MeSH Subject Category Hierarchy

MEDLINE Article



- Antagonists and Inhibitors
- Blood Supply
- Chemistry
- Drug Therapy
- Embryology
- Epidemiology
- ...

Text Classification

- Assigning documents to a fixed set of categories, *e.g.*
- Web pages
 - Yahoo-like classification
 - Assigning subject categories, topics, or genres
- Email messages
 - Spam filtering
 - Prioritizing
 - Folderizing
- Blogs/Letters/Books
 - Authorship identification
 - Age/gender identification
- Reviews/Social media
 - Language Identification
 - Sentiment analysis
 - ...

Classification Methods:

Hand-coded rules

- Rules based on combinations of words or other features
 - spam: black-list-address OR (“dollars” AND “have been selected”)
- Accuracy can be high
 - If rules carefully refined by expert
- But building and maintaining these rules is expensive

Learning for Text Categorization

- Hard to construct text categorization functions.
- Learning Algorithms:
 - **Bayesian (naïve)**
 - Neural network
 - Logistic Regression
 - Nearest Neighbor (case based)
 - Support Vector Machines (SVM)

Example: County vs. Country?

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King County originally extended to the Olympic Peninsula. According to historian Bill Speidel, when peninsular prohibitionists threatened to shut down Seattle's saloons, Doc Maynard engineered a peninsular independence movement, King

Statistics

Founded	December 22, 1852
Seat	Seattle
Area	
 - Total	5,974 km ² (2,307 mi ²)
 - Land	5,508 km ² (2,126 mi ²)

Kenya

From Wikipedia, the free encyclopedia

This article needs additional references or sources for verification. Please help improve this article by adding reliable references. Unsourced material may be challenged and removed.

The **Republic of Kenya** is a country in Eastern Africa. It is bordered by Ethiopia to the north, Somalia to the northeast, Tanzania to the south, Uganda to the west, and Sudan to the northwest, with the Indian Ocean running along the southeast border.

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Fossils found in East Africa suggest that primates roamed the area more than 20 million years ago. Recent finds near Kenya's Lake Turkana indicate that hominids such as *Homo habilis* (1.8 and 2.5 million years ago)

Jamhuri ya Kenyaa
Republic of Kenya

Flag Coat of arms

Motto
"Harambee" (Swahili)
"Let us all pull together"



Anthem
Ex Nguzi Nguzi Yetu
"Oh Lord of our Creation"

Map of Africa with Kenya highlighted

Capital (and largest city)	Nairobi 1°17′S 36°49′E﻿ / ﻿1.28°S 36.82°E﻿ / -1.28; 36.82
Official languages	Swahili (since 1963), English ^[1]
Demonym	Kenyan
Government	Republic

Learning for Categorization

- A *training example* is an instance $x \in X$, paired with its correct category $c(x)$: $\langle x, c(x) \rangle$ for an unknown categorization function, c .
- Given a set of training examples, D .

$\{ \langle \text{King County, Washington}$
 , county $\rangle, \langle \text{Kenya}$
 , country \rangle, \dots

- Find a hypothesized categorization function, $h(x)$, such that: $\forall \langle x, c(x) \rangle \in D : h(x) = c(x)$

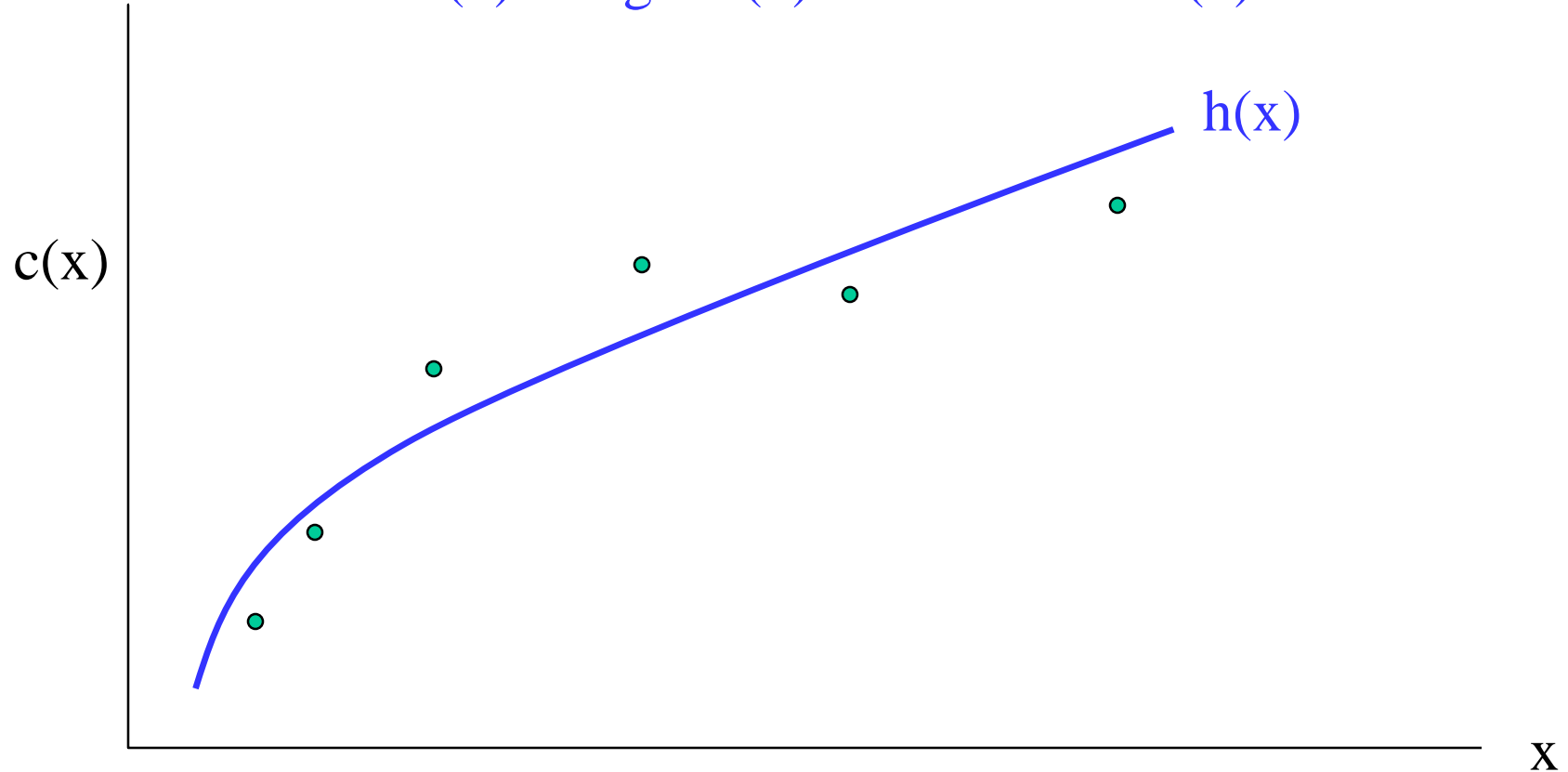
Consistency

Function Approximation

May not be any perfect fit

Classification ~ discrete functions

$$h(x) = \text{nigeria}(x) \wedge \text{wire-transfer}(x)$$



General Learning Issues

- Many hypotheses consistent with the training data.
- **Bias**
 - Any criteria other than consistency with the training data that is used to select a hypothesis.
- Classification accuracy
 - % of instances classified correctly
 - (Measured on independent test data.)
- Training time
 - Efficiency of training algorithm
- Testing time
 - Efficiency of subsequent classification

Generalization

- Hypotheses must *generalize* to correctly classify instances not in the training data.
- Simply memorizing training examples is a consistent hypothesis *that does not generalize*.

Why is Learning Possible?

Experience alone never justifies any conclusion about any unseen instance.

Learning occurs when
PREJUDICE meets **DATA!**

Bias

- The nice word for prejudice is “bias”.
- What kind of hypotheses will you *consider*?
 - What is allowable *range* of functions you use when approximating?
- What kind of hypotheses do you *prefer*?

Bayesian Methods

- Learning and classification methods based on probability theory.
 - Bayes theorem plays a critical role in probabilistic learning and classification.
 - Uses *prior* probability of each category given no information about an item.
- Categorization produces a *posterior* probability distribution over the possible categories given a description of an item.

Bayes' Rule Applied to Documents and Classes

- For a document d and a class c

$$P(c | d) = \frac{P(d | c)P(c)}{P(d)}$$

Naïve Bayes Classifier (I)

$$c_{MAP} = \operatorname{argmax}_{c \in C} P(c | d)$$

MAP is “maximum a posteriori” = most likely class

$$= \operatorname{argmax}_{c \in C} \frac{P(d | c)P(c)}{P(d)}$$

Bayes Rule

$$= \operatorname{argmax}_{c \in C} P(d | c)P(c)$$

Dropping the denominator

Naïve Bayes Classifier (II)

$$c_{MAP} = \operatorname{argmax}_{c \in C} P(d | c)P(c)$$

$$= \operatorname{argmax}_{c \in C} P(x_1, x_2, \dots, x_n | c)P(c)$$

Document d
represented as
features $x_1..x_n$

Naïve Bayes Classifier (IV)

$$c_{MAP} = \operatorname{argmax}_{c \in C} P(x_1, x_2, \dots, x_n | c) P(c)$$

$O(|X|^n \cdot |C|)$ parameters

How often does this class occur?

Could only be estimated if a very, very large number of training examples was available.

We can just count the relative frequencies in a corpus

Multinomial Naïve Bayes Independence Assumptions

$$P(x_1, x_2, \dots, x_n \mid c)$$

- **Bag of Words assumption:** Assume position doesn't matter

The bag of words representation

Y(

I love this movie! It's sweet, but with satirical humor. The dialogue is great and the adventure scenes are fun... It manages to be whimsical and romantic while laughing at the conventions of the fairy tale genre. I would recommend it to just about anyone. I've seen it several times, and I'm always happy to see it again whenever I have a friend who hasn't seen it yet.

)=C



The bag of words representation

Y(

I **love** this movie! It's **sweet**, but with **satirical** humor. The dialogue is **great** and the adventure scenes are **fun**... It manages to be **whimsical** and **romantic** while **laughing** at the conventions of the fairy tale genre. I would **recommend** it to just about anyone. I've seen it **several** times, and I'm always **happy** to see it **again** whenever I have a friend who hasn't seen it yet.

)=C



The bag of words representation: using a subset of words

Y(

```
x love xxxxxxxxxxxxxxxxxxxx sweet
xxxxxxxx satirical xxxxxxxxxxxx
xxxxxxxxxxxx great xxxxxxxx
xxxxxxxxxxxxxxxxxxxxxxxxxxxx fun xxxx
xxxxxxxxxxxxxxxx whimsical xxxx
romantic xxxx laughing
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
xxxxxxxxxxxxxxxx recommend xxxxxx
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
xx several xxxxxxxxxxxxxxxxxxxx
xxxxx happy xxxxxxxx again
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
xxxxxxxxxxxxxxxxxxxxxxxxxxxx
```

)=C





The bag of words representation

Y(

great	2
love	2
recommend	1
laugh	1
happy	1
...	...

) = **C**

Bag of words for document classification

?

Test
document

parser
language
label
translation
...

Machine
Learning

learning
training
algorithm
shrinkage
network...

NLP

parser
tag
training
translation
language...

Garbage
Collection

garbage
collection
memory
optimization
region...

Planning

planning
temporal
reasoning
plan
language...

GUI

...

Multinomial Naïve Bayes Classifier

$$c_{MAP} = \operatorname{argmax}_{c \in C} P(x_1, x_2, \dots, x_n | c) P(c)$$

$$c_{NB} = \operatorname{argmax}_{c \in C} P(c) \prod_{x \in X} P(x | c)$$

Multinomial Naïve Bayes Independence Assumptions

$$P(x_1, x_2, \dots, x_n \mid c)$$

- **Bag of Words assumption:** Assume position doesn't matter
- **Conditional Independence:** Assume the feature probabilities $P(x_i \mid c_j)$ are independent given the class c .

$$P(x_1, \dots, x_n \mid c) = P(x_1 \mid c) \bullet P(x_2 \mid c) \bullet P(x_3 \mid c) \bullet \dots \bullet P(x_n \mid c)$$

Applying Multinomial Naive Bayes Classifiers to Text Classification

positions \leftarrow all word positions in test document

$$c_{NB} = \underset{c_j \in C}{\operatorname{argmax}} P(c_j) \prod_{i \in \text{positions}} P(x_i | c_j)$$

Learning the Multinomial Naïve Bayes Model

- First attempt: maximum likelihood estimates
 - simply use the frequencies in the data

$$\hat{P}(c_j) = \frac{\text{doccount}(C = c_j)}{N_{doc}}$$

$$\hat{P}(w_i | c_j) = \frac{\text{count}(w_i, c_j)}{\sum_{w \in V} \text{count}(w, c_j)}$$

Parameter estimation

$$\hat{P}(w_i | c_j) = \frac{\text{count}(w_i, c_j)}{\sum_{w \in V} \text{count}(w, c_j)}$$

fraction of times word w_i appears
among all words in documents of topic c_j

- Create mega-document for topic j by concatenating all docs in this topic
 - Use frequency of w in mega-document

Problem with Maximum Likelihood

lec13.3

- What if we have seen no training documents with the word ***fantastic*** and classified in the topic **positive** (***thumbs-up***)?

$$\hat{P}(\text{"fantastic"} \mid \text{positive}) = \frac{\text{count}(\text{"fantastic"}, \text{positive})}{\sum_{w \in V} \text{count}(w, \text{positive})} = 0$$

- Zero probabilities cannot be conditioned away, no matter the other evidence!

$$c_{MAP} = \operatorname{argmax}_c \hat{P}(c) \prod_i \hat{P}(x_i \mid c)$$

Laplace (add-1) smoothing for Naïve Bayes

$$\begin{aligned}\hat{P}(w_i | c) &= \frac{\text{count}(w_i, c) + 1}{\sum_{w \in V} (\text{count}(w, c) + 1)} \\ &= \frac{\text{count}(w_i, c) + 1}{\sum_{w \in V} \text{count}(w, c) + |V|}\end{aligned}$$

Multinomial Naïve Bayes: Learning

- From training corpus, extract *Vocabulary*
- Calculate $P(c_j)$ terms
 - For each c_j in C do
 - $docs_j \leftarrow$ all docs with class = c_j
 - $$P(c_j) \propto \frac{|docs_j|}{|\text{total \# documents}|}$$
- Calculate $P(w_k | c_j)$ terms
 - $Text_j \leftarrow$ single doc containing all $docs_j$
 - For each word w_k in *Vocabulary*
 - $n_k \leftarrow$ # of occurrences of w_k in $Text_j$
 - $$P(w_k | c_j) \propto \frac{n_k + a}{n + a | \text{Vocabulary} |}$$

Naïve Bayes Time Complexity

- **Training Time:** $O(|D|L_d + |C||V|)$
where L_d is the average length of a document in D .
 - Assumes V and all D_i , n_i , and n_{ij} pre-computed in $O(|D|L_d)$ time during one pass through all of the data.
 - Generally just $O(|D|L_d)$ since usually $|C||V| < |D|L_d$
- **Test Time:** $O(|C| L_t)$
where L_t is the average length of a test document.
- Very efficient overall, linearly proportional to the time needed to just read in all the data.

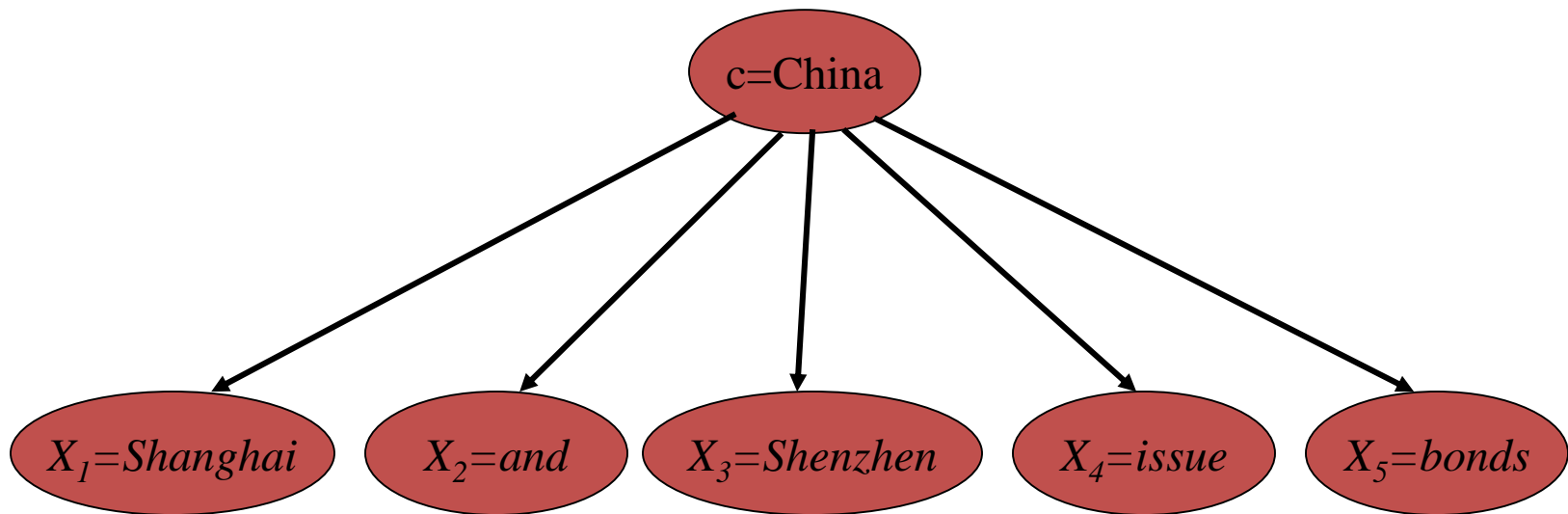
Easy to Implement

- But...
- If you do... it probably won't work...

Probabilities: Important Detail!

- We are multiplying lots of small numbers
Danger of underflow!
 - $0.5^{57} = 7 \text{ E } -18$
- Solution? Use logs and add!
 - $p_1 * p_2 = e^{\log(p1)+\log(p2)}$
 - Always keep in log form

Generative Model for Multinomial Naïve Bayes



Naïve Bayes and Language Modeling

- Naïve bayes classifiers can use any sort of feature
 - URL, email address, dictionaries, network features
- But if, as in the previous slides
 - We use **only** word features
 - we use **all** of the words in the text (not a subset)
- Then
 - Naïve bayes has an important similarity to language modeling.

Each class = a unigram language model

lec13.2.1

- Assigning each word: $P(\text{word} \mid c)$
- Assigning each sentence: $P(s \mid c) = \prod P(\text{word} \mid c)$

Class <i>pos</i>						
0.1	I	<u>I</u>	<u>love</u>	<u>this</u>	<u>fun</u>	<u>film</u>
0.1	love	0.1	0.1	.05	0.01	0.1
0.01	this					
0.05	fun					
0.1	film					
...						

$P(s \mid \text{pos}) = 0.00000005$

Naïve Bayes as a Language Model

Sec.13.2.1

- Which class assigns the higher probability to s?

Model pos	
0.1	I
0.1	love
0.01	this
0.05	fun
0.1	film

Model neg	
0.2	I
0.001	love
0.01	this
0.005	fun
0.1	film

<u>I</u>	<u>love</u>	<u>this</u>	<u>fun</u>	<u>film</u>
0.1	0.1	0.01	0.05	0.1
0.2	0.001	0.01	0.005	0.1

$$P(s|\text{pos}) > P(s|\text{neg})$$

Example: Naïve Bayes in Spam Filtering

- SpamAssassin Features:
 - Mentions Generic Viagra
 - Online Pharmacy
 - Mentions millions of (dollar) ((dollar) NN,NNN,NNN.NN)
 - Phrase: impress ... girl
 - From: starts with many numbers
 - Subject is all capitals
 - HTML has a low ratio of text to image area
 - One hundred percent guaranteed
 - Claims you can be removed from the list
 - 'Prestigious Non-Accredited Universities'
 - http://spamassassin.apache.org/tests_3_3_x.html

Advantages

- Simple to implement
 - No numerical optimization, matrix algebra, etc
- Efficient to train and use
 - Easy to update with new data
 - Fast to apply
- Binary/multi-class
- Good in domains with many equally important features
 - Decision Trees suffer from fragmentation in such cases – especially if little data
- Comparatively good effectiveness with small training sets
- A good dependable baseline for text classification
 - But we will see other classifiers that give better accuracy

Disadvantages

- Independence assumption wrong
 - Absurd estimates of class probabilities
 - Output probabilities close to 0 or 1
 - Thresholds must be tuned; not set analytically
- Generative model
 - Generally lower effectiveness than discriminative techniques

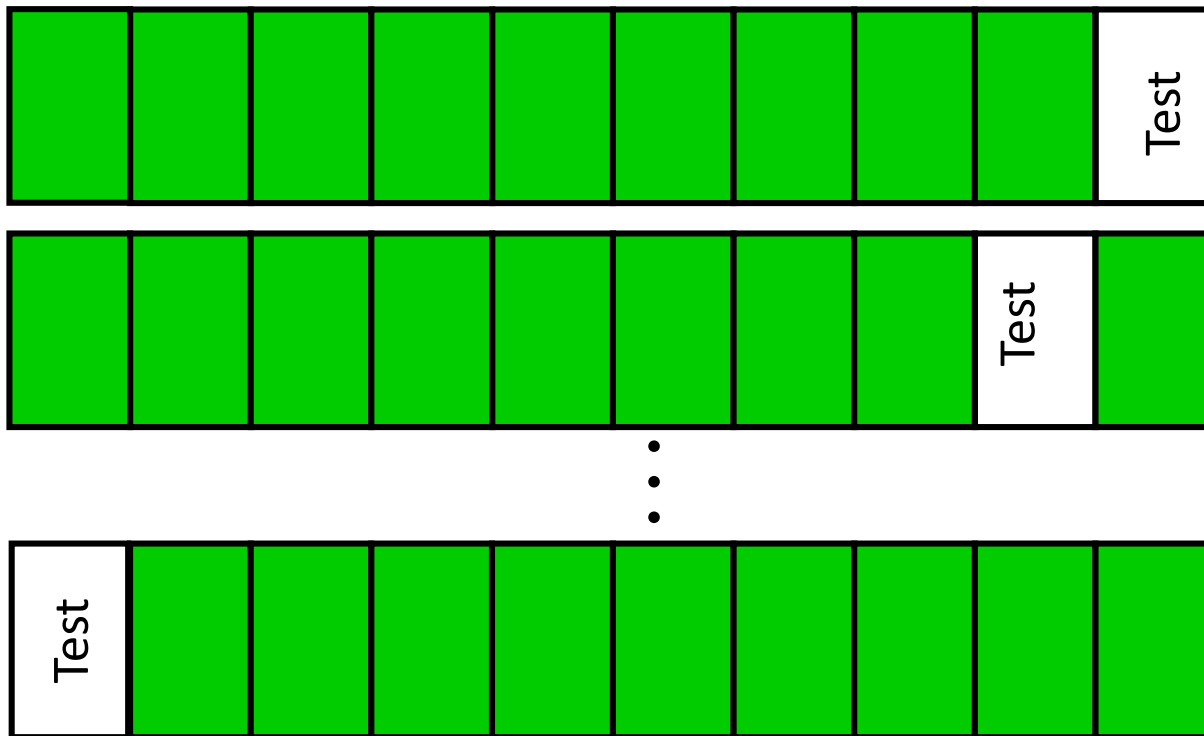
Experimental Evaluation

Question: How do we estimate the performance of classifier on unseen data?

- Can't just at accuracy on training data – this will yield an over optimistic estimate of performance
- Solution: **Cross-validation**
- Note: this is sometimes called estimating how well the classifier will generalize

Evaluation: Cross Validation

- Partition examples into k disjoint sets
- Now create k training sets
 - Each set is union of all equiv classes *except one*
 - So each set has $(k-1)/k$ of the original training data



Cross-Validation (2)

- Leave-one-out
 - Use if < 100 examples (rough estimate)
 - Hold out one example, train on remaining examples
- 10-fold
 - If have 100-1000's of examples
- M of N fold
 - Repeat M times
 - Divide data into N folds, do N fold cross-validation

Evaluation Metrics

- **Accuracy**: no. of questions correctly answered
- **Precision** (for one label): accuracy when classification = label
- **Recall** (for one label): measures how many instances of a label were missed.
- **F-measure** (for one label): harmonic mean of precision & recall.
- **Area under Precision-recall curve** (for one label): vary parameter to show different points on p-r curve; take the area

Precision & Recall

Two class situation

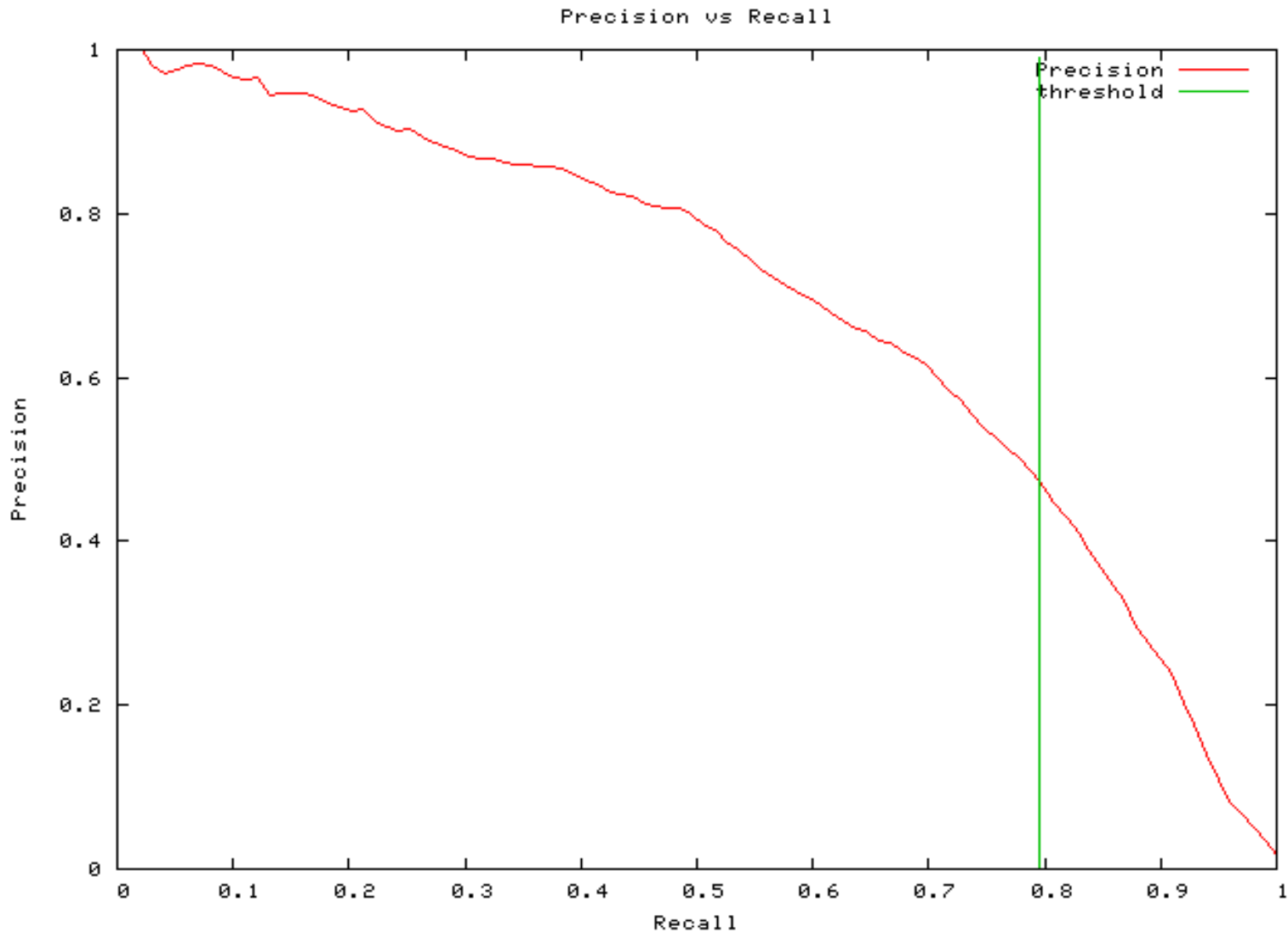
	Predicted		
Actual		“P”	“N”
	P	TP	FN
	N	FP	TN

$$\text{Precision} = \text{TP}/(\text{TP}+\text{FP})$$

$$\text{Recall} = \text{TP}/(\text{TP}+\text{FN})$$

$$\text{F-measure} = 2pr/(p+r)$$

A typical precision-recall curve



Construct Better Features

- Key to machine learning is having good features
- In industrial data mining, large effort devoted to constructing appropriate features
- Ideas??

Issues in document representation

Cooper's concordance of Wordsworth was published in 1911. The applications of full-text retrieval are legion: they include résumé scanning, litigation support and searching published journals on-line.

- *Cooper's vs. Cooper vs. Coopers.*
- *Full-text vs. full text vs. {full, text} vs. fulltext.*
- *résumé vs. resume.*

Punctuation

- *Ne'er*: use language-specific, handcrafted “locale” to normalize.
- *State-of-the-art*: break up hyphenated sequence.
- *U.S.A.* vs. *USA*
- *a.out*

Numbers

- 3/12/91
- Mar. 12, 1991
- 55 B.C.
- B-52
- 100.2.86.144
 - Generally, don't represent as text
 - Creation dates for docs

Possible Feature Ideas

- Look at capitalization (may indicated a proper noun)
- Look for commonly occurring sequences
 - E.g. New York, New York City
 - Limit to 2-3 consecutive words
 - Keep all that meet minimum threshold (e.g. occur at least 5 or 10 times in corpus)

Case folding

- Reduce all letters to lower case
- Exception: upper case in mid-sentence
 - *e.g., General Motors*
 - *Fed* vs. *fed*
 - *SAIL* vs. *sail*

Thesauri and Soundex

- Handle synonyms and homographs and polysemes
 - Hand-constructed equivalence classes
 - e.g., *car* = *automobile*
 - *bark, bank, minute...*
- Homophones

Spell Correction

- Look for all words within (say) edit distance 3 (Insert/Delete/Replace) at query time
 - *e.g., Alanis Morissette*
- Spell correction is expensive and slows the processing significantly
 - Invoke only when index returns zero matches?

Lemmatization

- Reduce inflectional/variant forms to base form
 - *am, are, is* → *be*
 - *car, cars, car's, cars'* → *car*

the boy's cars are different colors

→

the boy car be different color

Stemming

- Are there different index terms?
 - retrieve, retrieving, retrieval, retrieved, retrieves...
- Stemming algorithm:
 - (retrieve, retrieving, retrieval, retrieved, retrieves) \Rightarrow **retriev**
 - Strips prefixes of suffixes (-s, -ed, -ly, -ness)
 - Morphological stemming
- Problems: sand / sander & wand / wander

Stemming Continued

- Can reduce vocabulary by $\sim 1/3$
- C, Java, Perl versions, python, c#
www.tartarus.org/~martin/PorterStemmer
- Criterion for removing a suffix
 - Does "a document is about w_1 " mean the same as
 - a "a document about w_2 "
- Problems: sand / sander & wand / wander
- Commercial SEs use giant in-memory tables

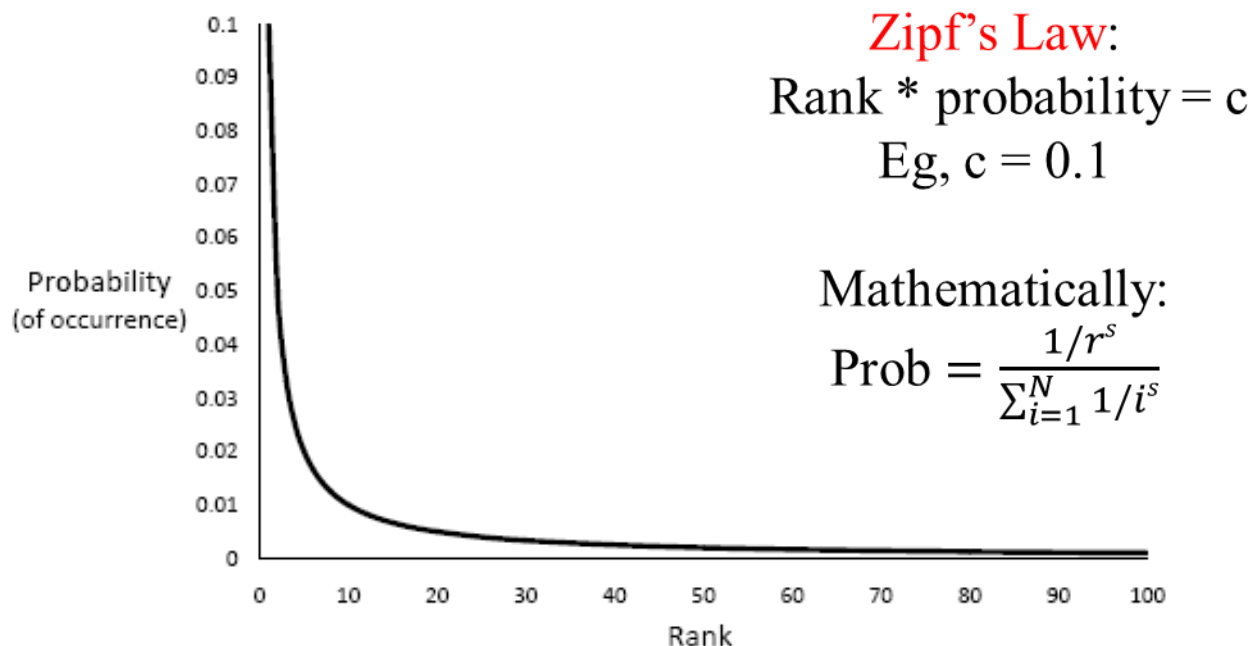
Features

Sec. 15.3.2

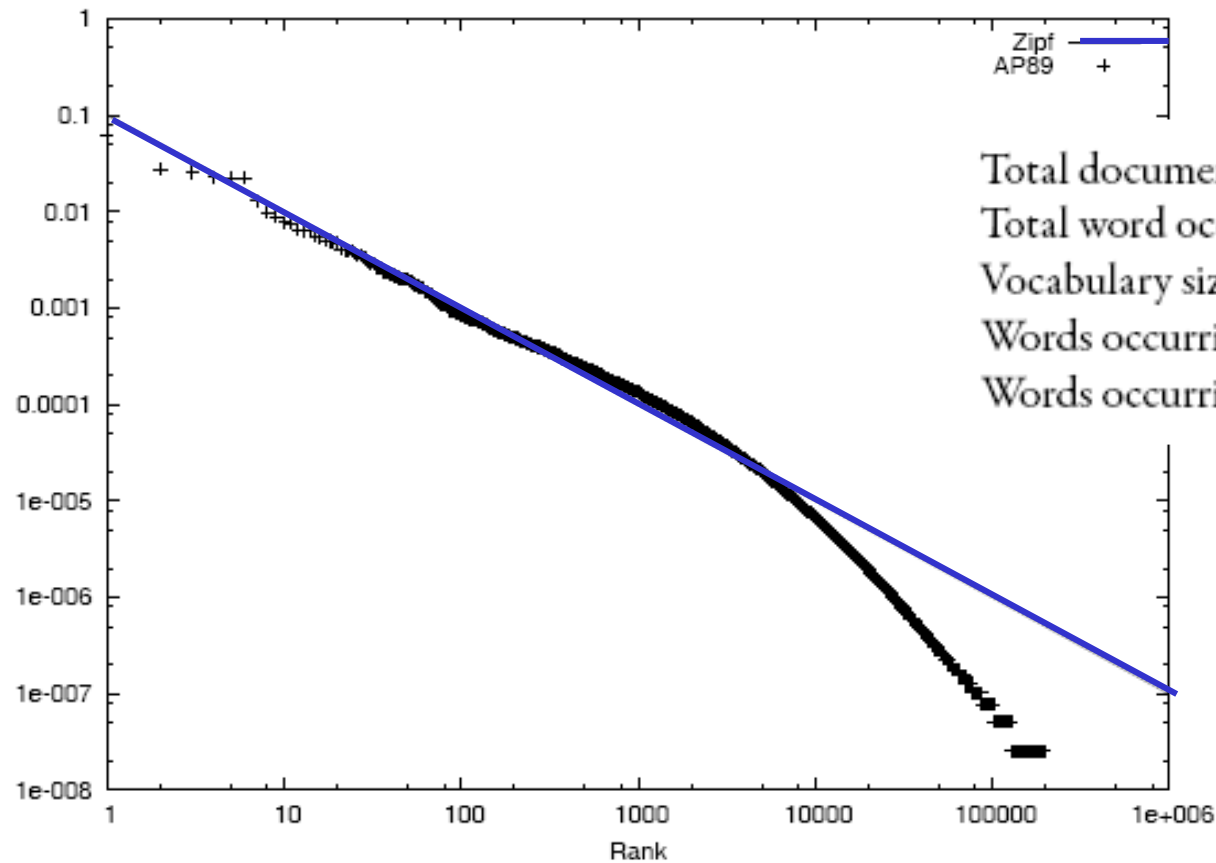
-
- Domain-specific features and weights: *very* important in real performance
 - Upweighting: Counting a word as if it occurred twice:
 - title words (Cohen & Singer 1996)
 - first sentence of each paragraph (Murata, 1999)
 - In sentences that contain title words (Ko *et al*, 2002)

Properties of Text

- Word frequencies - skewed distribution
- 'The' and 'of' account for 10% of all words
- Six most common words account for 40%



Associate Press Corpus 'AP89'



Total documents	84,678
Total word occurrences	39,749,179
Vocabulary size	198,763
Words occurring > 1000 times	4,169
Words occurring once	70,064

Middle Ground

- Very common words → bad features

- Language-based stop list:

words that bear little meaning

20-500 words

http://www.dcs.gla.ac.uk/ir_resources/linguistic_utils/stop_words

- Subject-dependent stop lists

- Very rare words *also* bad features

Drop words appearing less than k times / corpus

Word Frequency

- Which word is more indicative of document similarity?
 - ‘book,’ or ‘Rumplestiltskin’?
 - Need to consider “**document frequency**”--- how frequently the word appears in doc collection.
- Which doc is a better match for the query “Kangaroo”?
 - One with a single mention of Kangaroos... or a doc that mentions it 10 times?
 - Need to consider “**term frequency**”--- how many times the word appears in the current document.

TF x IDF

$$w_{ik} = tf_{ik} * \log(N / n_k)$$

T_k = term k in document D_i

tf_{ik} = frequency of term T_k in document D_i

idf_k = inverse document frequency of term T_k in C

$$idf_k = \log\left(\frac{N}{n_k}\right)$$

N = total number of documents in the collection C

n_k = the number of documents in C that contain T_k

Inverse Document Frequency

- IDF provides high values for rare words and low values for common words

$$\log\left(\frac{10000}{10000}\right) = 0$$

$$\log\left(\frac{10000}{5000}\right) = 0.301$$

$$\log\left(\frac{10000}{20}\right) = 2.698$$

$$\log\left(\frac{10000}{1}\right) = 4$$

- Add 1 to avoid 0.

TF-IDF normalization

- Normalize the term weights
 - so longer docs not given more weight (fairness)
 - force all values to fall within a certain range: $[0, 1]$

$$w_{ik} = \frac{tf_{ik} (1 + \log(N / n_k))}{\sqrt{\sum_{k=1}^t (tf_{ik})^2 [1 + \log(N / n_k)]^2}}$$

The Real World

Sec. 15.3.1

-
- I'm building a text classifier for real, now!
 - What should I do?

No training data?

Manually written rules

Sec. 15.3.1

If (wheat or grain) and not (whole or bread) then
Categorize as grain

- Need careful crafting
 - Human tuning on development data
 - Time-consuming: 2 days per class

Very little data?

Sec. 15.3.1

- Use Naïve Bayes
 - Naïve Bayes is a “high-bias” algorithm (Ng and Jordan 2002 NIPS)
- Get more labeled data
 - Find clever ways to get humans to label data for you
- Try semi-supervised training methods:
 - Bootstrapping, EM over unlabeled documents, ... (later)

A reasonable amount of data?

Sec. 15.3.1

- Perfect for all the clever classifiers (later)
 - SVM
 - Regularized Logistic Regression
- You can even use user-interpretable decision trees
 - Users like to hack
 - Management likes quick fixes

A huge amount of data?

Sec. 15.3.1

-
- Can achieve high accuracy!
 - At a cost:
 - SVMs (train time) or kNN (test time) can be too slow
 - Regularized logistic regression can be somewhat better
 - Ng and Jordan 2002
 - Generative (NB) approaches asymptotic error faster
 - Discriminative (LR) has lower asymptotic error

Real-world systems generally combine

- Automatic classification
- Manual review of uncertain/difficult/"new" cases

Multi-class Problems

Evaluation:

Classic Reuters-21578 Data Set

Sec 15.2.4

- Most (over)used data set, 21,578 docs (each 90 types, 200 tokens)
- 9603 training, 3299 test articles (ModApte/Lewis split)
- 118 categories
 - An article can be in more than one category
 - Learn 118 binary category distinctions
- Average document (with at least one category) has 1.24 classes
- Only about 10 out of 118 categories are large

Common categories
(#train, #test)

- | | |
|----------------------------|-----------------------|
| • Earn (2877, 1087) | • Trade (369, 119) |
| • Acquisitions (1650, 179) | • Interest (347, 131) |
| • Money-fx (538, 179) | • Ship (197, 89) |
| • Grain (433, 149) | • Wheat (212, 71) |
| • Crude (389, 189) | • Corn (182, 56) |

Reuters Text Categorization data set (Reuters-21578) document

Sec 15.2.4

<REUTERS TOPICS="YES" LEWISSPLIT="TRAIN" CGISPLIT="TRAINING-SET" OLDID="12981"
NEWID="798">

<DATE> 2-MAR-1987 16:51:43.42</DATE>

<TOPICS><D>livestock</D><D>hog</D></TOPICS>

<TITLE>AMERICAN PORK CONGRESS KICKS OFF TOMORROW</TITLE>

<DATELINE> CHICAGO, March 2 - </DATELINE><BODY>The American Pork Congress kicks off tomorrow, March 3, in Indianapolis with 160 of the nations pork producers from 44 member states determining industry positions on a number of issues, according to the National Pork Producers Council, NPPC.

Delegates to the three day Congress will be considering 26 resolutions concerning various issues, including the future direction of farm policy and the tax law as it applies to the agriculture sector. The delegates will also debate whether to endorse concepts of a national PRV (pseudorabies virus) control and eradication program, the NPPC said.

A large trade show, in conjunction with the congress, will feature the latest in technology in all areas of the industry, the NPPC added. Reuter

</BODY></TEXT></REUTERS>

Precision & Recall

Two class situation

Actual \ Predicted			
		“P”	“N”
	P	TP	FN
	N	FP	TN

Multi-class situation:

Classname	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
alt.atheism	1	251	6	1	3	32	1	1	2	1	2	0	0	0	0	0	0	0	0	0
soc.religion.christian	2	9	277	0	1	6	0	0	1	0	0	0	0	1	2	2	0	0	0	1
sci.space	3	3	1	273	1	0	1	2	0	1	1	9	0	1	2	3	0	0	1	1
talk.politics.misc	4	2	0	3	213	24	3	0	17	3	0	0	0	0	0	1	0	1	33	0
talk.religion.misc	5	88	36	2	23	132	0	1	0	0	0	0	0	0	0	2	0	1	15	0
rec.autos	6	0	0	0	3	1	272	0	0	7	1	2	1	6	4	1	0	0	2	0
comp.windows.x	7	1	1	2	1	0	1	246	0	2	2	30	5	3	1	1	1	0	0	0
talk.politics.mideast	8	0	3	1	18	0	0	0	275	0	1	0	0	0	0	0	0	1	1	0
sci.crypt	9	1	0	1	2	1	0	3	0	284	0	3	0	1	0	0	1	0	0	3
rec.motorcycles	10	0	0	0	1	0	4	1	0	1	2	0	2	0	1	2	1	0	0	1
comp.graphics	11	0	1	2	1	1	0	10	1	0	5	243	23	7	3	3	3	0	0	0
comp.sys.ibm.pc.hardware	12	0	0	0	0	0	2	7	0	1	0	5	243	23	12	3	1	3	0	0
comp.sys.mac.hardware	13	0	0	1	1	0	2	1	0	0	7	10	260	8	9	1	0	0	0	0
sci.electronics	14	1	0	1	0	0	0	2	0	7	13	13	245	6	3	0	1	0	0	0
misc.forsale	15	0	1	4	2	0	12	1	0	0	4	1	19	10	8	233	1	0	1	1
sci.med	16	0	1	5	0	1	1	0	0	1	2	0	2	7	2	275	0	1	1	1
comp.os.mswindows.misc	17	1	0	2	0	1	1	58	1	3	0	38	71	17	3	6	0	97	1	0
rec.sport.baseball	18	2	1	1	0	0	0	0	0	0	4	0	0	0	1	1	0	282	1	7
talk.politics.guns	19	0	0	0	9	5	1	0	0	1	0	0	0	1	0	0	1	1	281	0
rec.sport.hockey	20	0	1	0	0	0	1	0	0	0	2	0	0	1	1	0	0	3	0	291

$$\text{Precision} = \text{TP}/(\text{TP}+\text{FP})$$

$$\text{Recall} = \text{TP}/(\text{TP}+\text{FN})$$

$$\text{F-measure} = 2pr/(p+r)$$

Micro-- vs. Macro--Averaging

- If we have more than one class, how do we combine multiple performance measures into one quantity?
- Macroaveraging
 - Compute performance for each class, then average.
- Microaveraging
 - Collect decisions for all classes, compute contingency table, evaluate

Precision & Recall

Multi-class situation:

Missed predictions

Aggregate

$$\text{Average Macro Precision} = \Sigma p_i / N$$

$$\text{Average Macro Recall} = \Sigma r_i / N$$

$$\text{Average Macro F-measure} = 2p_M r_M / (p_M + r_M)$$

$$\text{Average Micro Precision} = \Sigma TP_i / \Sigma_i Col_i$$

$$\text{Average Micro Recall} = \Sigma TP_i / \Sigma_i Row_i$$

$$\text{Average Micro F-measure} = 2p_\mu r_\mu / (p_\mu + r_\mu)$$

Aren't μ prec and μ recall the same?

Classifier hallucinations

Classname	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
alt.atheism	1	251	6	1	3	32	1	1	2	1	2	0	0	0	0	0	0	0	0	0
soc.religion.christian	2	9	277	0	1	6	0	0	1	0	0	0	0	1	2	2	0	0	0	1
sci.space	3	3	1	273	1	0	1	2	0	1	1	9	0	0	1	2	3	0	0	1
talk.politics.misc	4	2	0	3	213	24	3	0	17	3	0	0	0	0	0	1	0	1	33	0
talk.religion.misc	5	88	36	2	23	137	0	1	0	0	0	0	0	0	0	2	0	1	15	0
rec.autos	6	0	0	0	3	1	277	0	0	0	7	1	2	1	6	4	1	0	0	2
comp.windows.x	7	1	1	2	1	0	1	246	0	2	2	30	5	3	1	1	2	1	1	0
talk.politics.mideast	8	0	3	1	18	0	0	0	275	0	1	0	0	0	0	0	0	1	1	0
sci.crypt	9	1	0	1	2	1	0	3	0	284	0	3	0	1	0	0	1	0	0	3
rec.motorcycles	10	0	0	0	1	0	4	1	0	0	286	1	2	0	1	2	1	0	0	1
comp.graphics	11	0	1	2	1	1	0	10	1	2	0	243	23	7	3	3	3	0	0	0
comp.sys.ibm.pc.hardware	12	0	0	0	0	0	2	7	0	1	0	5	243	23	12	3	1	3	0	0
comp.sys.mac.hardware	13	0	0	1	1	0	2	1	0	0	0	7	10	260	8	9	1	0	0	0
sci.electronics	14	1	0	1	0	1	5	2	0	2	0	7	13	13	245	6	3	0	1	0
misc.forsale	15	0	1	4	2	0	12	1	0	0	4	1	19	10	8	233	1	0	1	2
sci.med	16	0	1	5	0	1	1	0	0	0	1	2	0	2	7	2	275	0	1	1
comp.os.mswindows.misc	17	1	0	2	0	1	1	58	1	3	0	38	71	17	3	6	0	97	1	0
rec.sport.baseball	18	2	1	1	0	0	0	0	0	0	4	0	0	0	1	1	0	282	1	7
talk.politics.guns	19	0	0	0	9	5	1	0	0	1	0	0	0	0	1	0	0	1	281	0
rec.sport.hockey	20	0	1	0	0	0	1	0	0	0	2	0	0	1	1	0	0	0	3	281

$$\text{Precision(class } i) = TP_i / (TP_i + FP_i)$$

$$\text{Recall(class } i) = TP_i / (TP_i + FN_i)$$

$$\text{F-measure(class } i) = 2p_i r_i / (p_i + r_i)$$

$$\text{Precision(class 1)} = 251 / (\text{Column}_1)$$

$$\text{Recall(class 1)} = 251 / (\text{Row}_1)$$

$$\text{F-measure(class 1)} = 2p_1 r_1 / (p_1 + r_1)$$

Highlights

- What?
 - Converting a k-class problem to a binary problem.
- Why?
 - For some ML algorithms, a direct extension to the multiclass case may be problematic.
- How?
 - Many methods

Methods

- One-vs-all
- All-pairs
- Error-correcting Output Codes (ECOC)
- ...

One-vs-all

- Idea:
- Create many 1 vs other classifiers
 - Classes = City, County, Country
 - Classifier 1 = {City} {County, Country}
 - Classifier 2 = {County} {City, Country}
 - Classifier 3 = {Country} {City, County}
- Training time:
 - For each class c_m , train a classifier $cl_m(x)$
 - replace (x,y) with
 - $(x, 1)$ if $y = c_m$
 - $(x, -1)$ if $y \neq c_m$

An example: training

- $x_1 \ c_1 \ \dots$
- $x_2 \ c_2 \ \dots$
- $x_3 \ c_1 \ \dots$
- $x_4 \ c_3 \ \dots$

for c_1 -vs-all:

$x_1 \quad 1 \ \dots$
 $x_2 \quad -1 \ \dots$
 $x_3 \quad 1 \ \dots$
 $x_4 \quad -1 \ \dots$

for c_2 -vs-all:

$x_1 \quad -1$
 $x_2 \quad 1 \ \dots$
 $x_3 \quad -1 \ \dots$
 $x_4 \quad -1 \ \dots$

for c_3 -vs-all:

$x_1 \quad -1 \dots$
 $x_2 \quad -1 \dots$
 $x_3 \quad -1 \ \dots$
 $x_4 \quad 1 \ \dots$

One-vs-all (cont)

- Testing time: given a new example x
 - Run each of the k classifiers on x
 - Choose the class c_m with the highest confidence score $cl_m(x)$:
$$c^* = \arg \max_m cl_m(x)$$

An example: testing

- x1 c1 ...
- x2 c2 ...
- x3 c1 ...
- x4 c3 ...

→ three classifiers

for c1-vs-all:

x ?? 1 0.7 -1 0.3

for c2-vs-all

x ?? 1 0.2 -1 0.8

for c3-vs-all

x ?? 1 0.6 -1 0.4

Test data:

x ?? f1 v1 ...

=> what's the system prediction for x?

All-pairs (All-vs-All (AVA))

- Idea:
 - For each pair of classes build a classifier
 - {City vs. County}, {City vs Country}, {County vs. Country}
 - C_k^2 classifiers: one classifier for each class pair.
- Training:
 - For each pair (c_m, c_n) of classes, train a classifier cl_{mn}
 - replace a training instance (x,y) with
 - $(x, 1)$ if $y = c_m$
 - $(x, -1)$ if $y = c_n$
 - otherwise ignore the instance

An example: training

- $x_1 \ c_1 \ \dots$
- $x_2 \ c_2 \ \dots$
- $x_3 \ c_1 \ \dots$
- $x_4 \ c_3 \ \dots$

for c_1 -vs- c_2 :

$x_1 \quad 1 \ \dots$

$x_2 \quad -1 \ \dots$

$x_3 \quad 1 \ \dots$

for c_2 -vs- c_3 :

$x_2 \quad 1 \ \dots$

$x_4 \quad -1 \ \dots$

for c_1 -vs- c_3 :

$x_1 \quad 1 \ \dots$

$x_3 \quad 1 \ \dots$

$x_4 \quad -1 \ \dots$

All-pairs (cont)

- Testing time: given a new example x
 - Run each of the C_k^2 classifiers on x
 - Max-win strategy: Choose the class c_m that wins the most pairwise comparisons:
 - Other coupling models have been proposed: e.g., (Hastie and Tibshirani, 1998)

An example: testing

- x1 c1 ...
- x2 c2 ...
- x3 c1 ...
- x4 c3 ...

→ three classifiers

for c1-vs-c2:

x ?? 1 0.7 -1 0.3

for c2-vs-c3

x ?? 1 0.2 -1 0.8

for c1-vs-c3

x ?? 1 0.6 -1 0.4

Test data:

x ?? f1 v1 ...

=> what's the system prediction for x?

Error-correcting output codes (ECOC)

- Proposed by (Dietterich and Bakiri, 1995)
- Idea:
 - Each class is assigned a unique binary string of length n .
 - Train n classifiers, one for each bit.
 - Testing time: run n classifiers on x to get a n -bit string s , and choose the class which is closest to s .

An example: Digit Recognition

Class	Code Word					
	vl	hl	dl	cc	ol	or
0	0	0	0	1	0	0
1	1	0	0	0	0	0
2	0	1	1	0	1	0
3	0	0	0	0	1	0
4	1	1	0	0	0	0
5	1	1	0	0	1	0
6	0	0	1	1	0	1
7	0	0	1	0	0	0
8	0	0	0	1	0	0
9	0	0	1	1	0	0

Meaning of each column

Column position	Abbreviation	Meaning
1	vl	contains vertical line
2	hl	contains horizontal line
3	dl	contains diagonal line
4	cc	contains closed curve
5	ol	contains curve open to left
6	or	contains curve open to right

Another example: 15-bit code for a 10-class problem

Class	Code Word														
	f_0	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}
0	1	1	0	0	0	0	1	0	1	0	0	1	1	0	1
1	0	0	1	1	1	1	0	1	0	1	1	0	0	1	0
2	1	0	0	1	0	0	0	1	1	1	1	0	1	0	1
3	0	0	1	1	0	1	1	1	0	0	0	0	1	0	1
4	1	1	1	0	1	0	1	1	0	0	1	0	0	0	1
5	0	1	0	0	1	1	0	1	1	1	0	0	0	0	1
6	1	0	1	1	1	0	0	0	0	1	0	1	0	0	1
7	0	0	0	1	1	1	1	0	1	0	1	1	0	0	1
8	1	1	0	1	0	1	1	0	0	1	0	0	0	1	1
9	0	1	1	1	0	0	0	0	1	0	1	0	0	1	1

Hamming distance

- Definition: the **Hamming distance** between two strings of equal length is the number of positions for which the corresponding symbols are different.
- Ex:
 - 10111 and 10010
 - 2143 and 2233
 - Toned and roses

How to choose a good error-correcting code?

- Choose the one with large minimum Hamming distance between any pair of code words.
- If the min Hamming distance is d , then the code can correct at least $(d-1)/2$ single bit errors.

Two properties of a good ECOC

- Row separations: Each codeword should be well-separated in Hamming distance from each of the other codewords
- Column separation: Each bit-position function f_i should be uncorrelated with each of the other f_j .

Summary

- Different methods:
 - Direct multiclass, if possible
 - One-vs-all (a.k.a. one-per-class): k -classifiers
 - All-pairs: C_k^2 classifiers
 - ECOC: n classifiers (n is the num of columns)
- Some studies report that All-pairs and ECOC work better than one-vs-all.