

Text Categorization: Discriminative Classifiers

Overview

- What is text categorization?
- Why text categorization?
- How to do text categorization?
 - Generative probabilistic models
 - **Discriminative approaches**
- How to evaluate categorization results?

Anatomy of Naïve Bayes Classifier

Two categories: θ_1 and θ_2

$$\text{score}(d) = \log \frac{p(\theta_1 | d)}{p(\theta_2 | d)} = \log \frac{p(\theta_1) \prod_{w \in V} p(w | \theta_1)^{c(w,d)}}{p(\theta_2) \prod_{w \in V} p(w | \theta_2)^{c(w,d)}}$$

$$= \underbrace{\log \frac{p(\theta_1)}{p(\theta_2)}}_{\text{Category bias } (\beta_0) \text{ doesn't depend on } d!} + \sum_{w \in V} \underbrace{c(w,d)}_{\text{Sum over all words (features } \{x_i\})} \underbrace{\log \frac{p(w | \theta_1)}{p(w | \theta_2)}}_{\text{Feature value: } x_i = c(w,d) \text{ Weight on each word (feature) } \beta_i}$$



Generalize

$$d = (x_1, x_2, \dots, x_M), \quad x_i \in \mathcal{R}$$

$$\text{score}(d) = \beta_0 + \sum_{i=1}^M x_i \beta_i \quad \beta_i \in \mathcal{R}$$

= Logistic Regression!

Discriminative Classifier 1: Logistic Regression

Binary Response Variable: $Y \in \{0,1\}$

Predictors: $X = (x_1, x_2, \dots, x_M)$, $x_i \in \mathbb{R}$

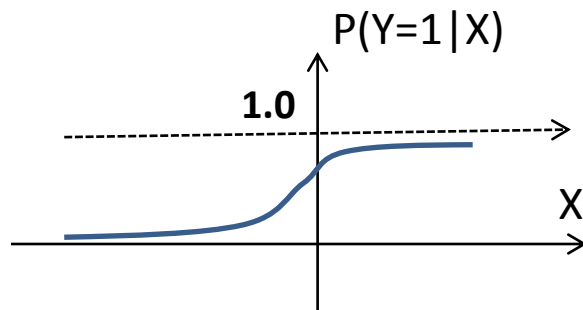
$$Y = \begin{cases} 1 & \text{category}(d) = \theta_1 \\ 0 & \text{category}(d) = \theta_2 \end{cases}$$

Modeling $p(Y|X)$ directly

Allow many other features than words!

$$\log \frac{p(\theta_1 | d)}{p(\theta_2 | d)} = \log \frac{p(Y = 1 | X)}{p(Y = 0 | X)} = \log \frac{p(Y = 1 | X)}{1 - p(Y = 1 | X)} = \beta_0 + \sum_{i=1}^M x_i \beta_i \quad \beta_i \in \mathbb{R}$$

$$p(Y = 1 | X) = \frac{e^{\beta_0 + \sum_{i=1}^M x_i \beta_i}}{e^{\beta_0 + \sum_{i=1}^M x_i \beta_i} + 1}$$



Estimation of Parameters

- Training Data: $T = \{(X_i, Y_i)\}, i=1, 2, \dots, |T|$
- Parameters: $\vec{\beta} = (\beta_0, \beta_1, \dots, \beta_M)$
- Conditional likelihood: $p(T | \vec{\beta}) = \prod_{i=1}^{|T|} p(Y = Y_i | X = X_i, \vec{\beta})$

$Y_i = 1$

$$p(Y = 1 | X) = \frac{e^{\beta_0 + \sum_{i=1}^M x_i \beta_i}}{e^{\beta_0 + \sum_{i=1}^M x_i \beta_i} + 1}$$

$Y_i = 0$

$$p(Y = 0 | X) = \frac{1}{e^{\beta_0 + \sum_{i=1}^M x_i \beta_i} + 1}$$

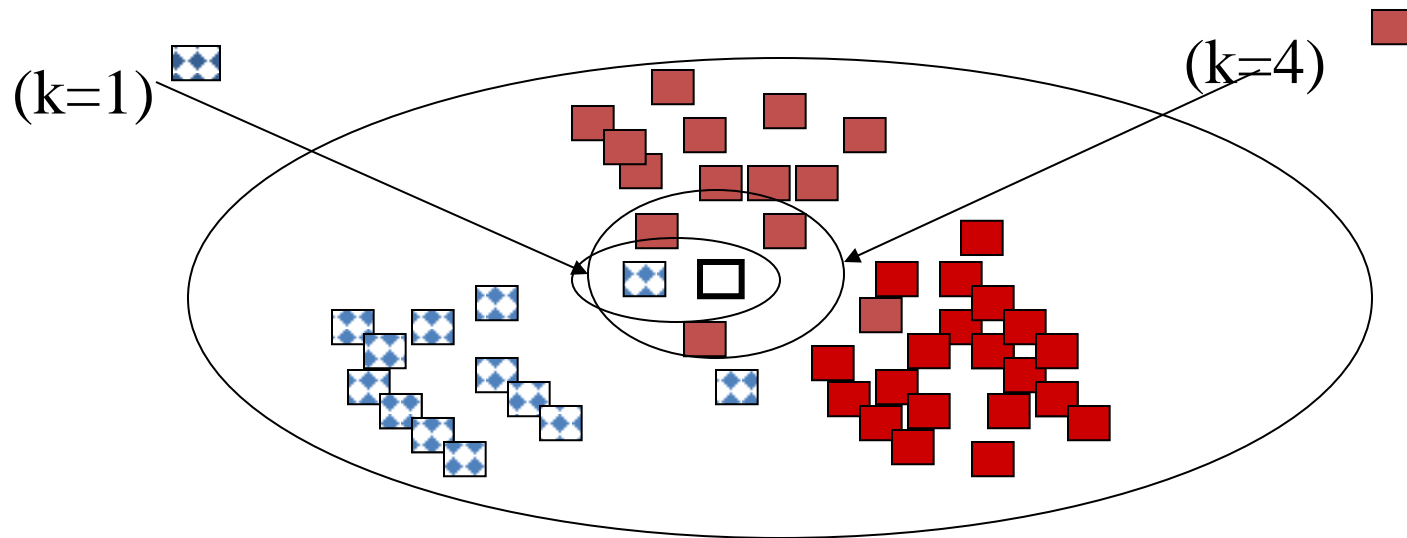
- Maximum Likelihood estimate $\vec{\beta}^* = \arg \max_{\vec{\beta}} p(T | \vec{\beta})$

Can be computed in many ways (e.g., Newton's method)

Discriminative Classifier 2: K-Nearest Neighbors (K-NN)

- Find k examples in the training set that are most similar to the text object to be classified (“neighbor” documents)
- Assign the category that is most common in these neighbor text objects (neighbors vote for the category)
- Can be improved by considering the distance of a neighbor (a closer neighbor has more influence)
- Can be regarded as a way to directly estimate the conditional probability of label given data instance, i.e., $p(Y|X)$
- Need a similarity function to measure similarity of two text objects

Illustration of K-NN Classifier

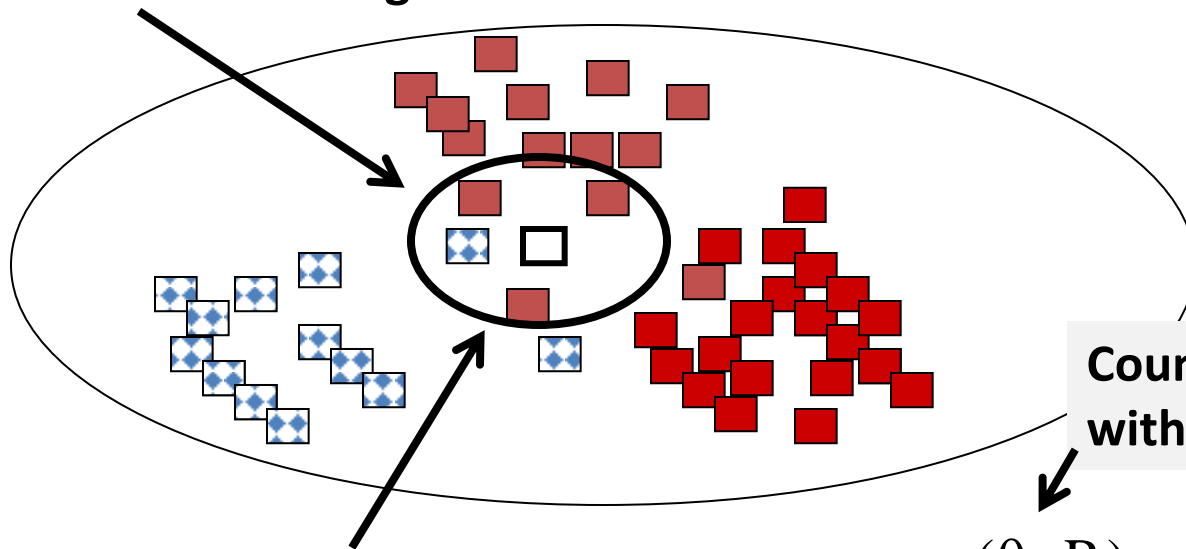


K-NN as an Estimate of $p(Y|X)$

Assume $p(\theta_i | d)$ is locally smooth, i.e.,
the same for all the d 's in this region R



$$p(\theta_i | d) = p(\theta_i | R)$$



Count of d 's in R
with category θ_i

Estimate $p(\theta_i | R)$ based on
the known categories in the region

$$p(\theta_i | R) = \frac{c(\theta_i, R)}{|R|}$$

Total # of
docs in R

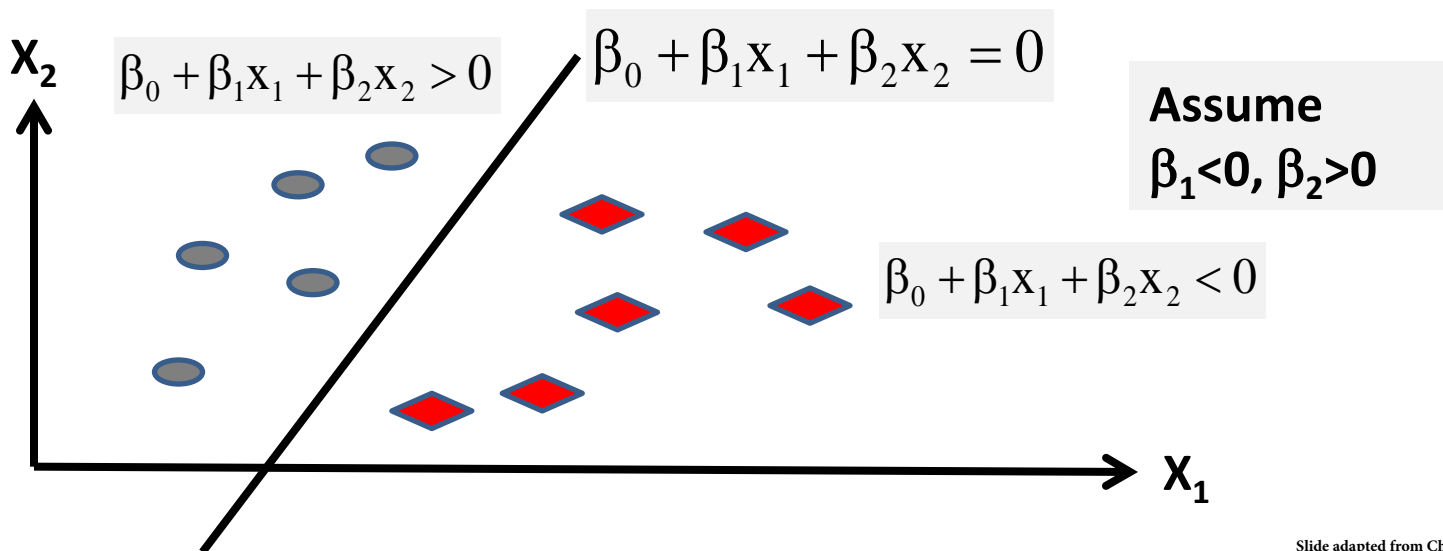
Discriminative Classifier 3: Support Vector Machine (SVM)

- Consider two categories: $\{\theta_1, \theta_2\}$

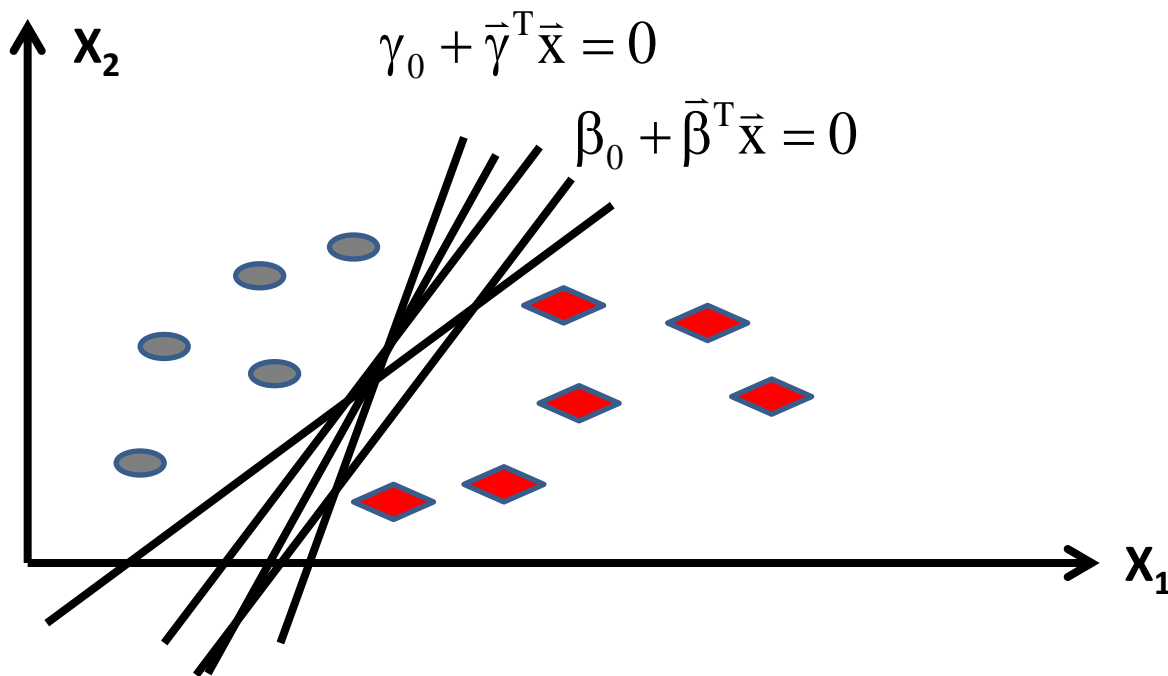
$f(X) \geq 0 \Rightarrow X$ is in category θ_1

$f(X) < 0 \Rightarrow X$ is in category θ_2

- Use a linear separator $f(X) = \beta_0 + \sum_{i=1}^M x_i \beta_i \quad \beta_i \in \mathbb{R}$



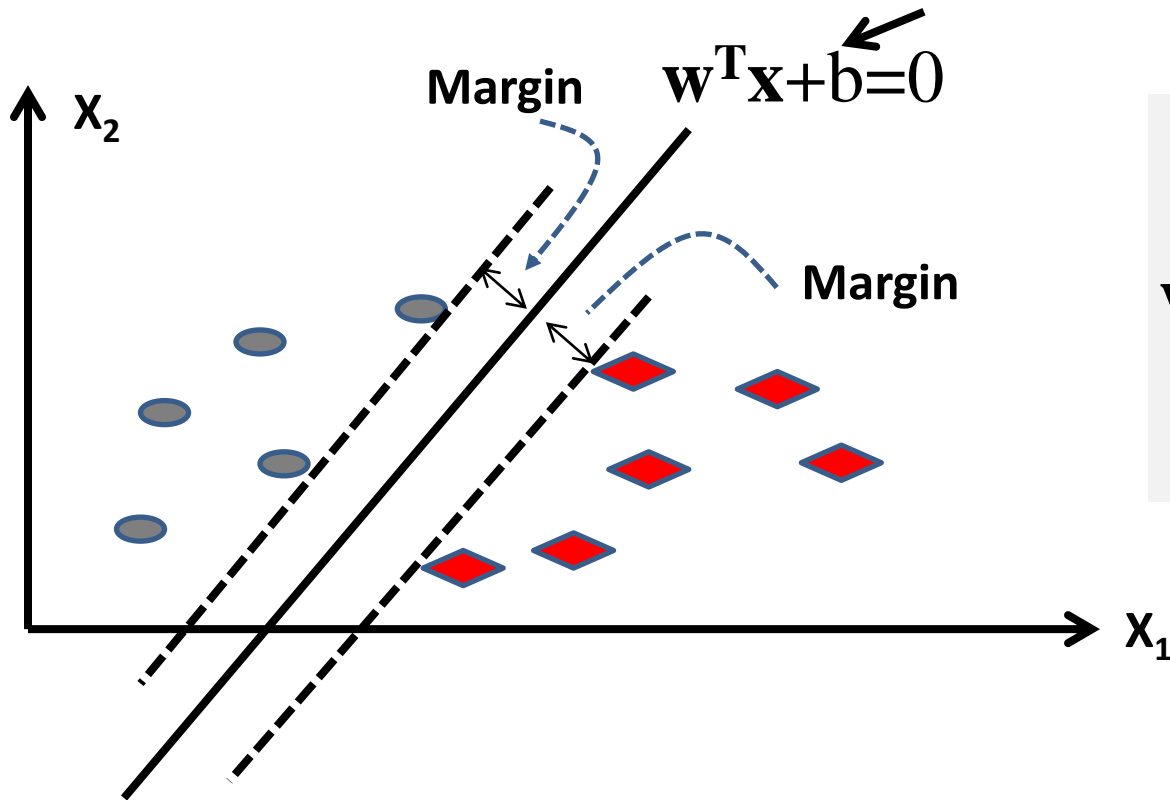
Which Linear Separator Is the Best?



Best Separator = Maximize the Margin

Notation Change: $\beta \rightarrow w$; $\beta_0 \rightarrow b$

Bias constant



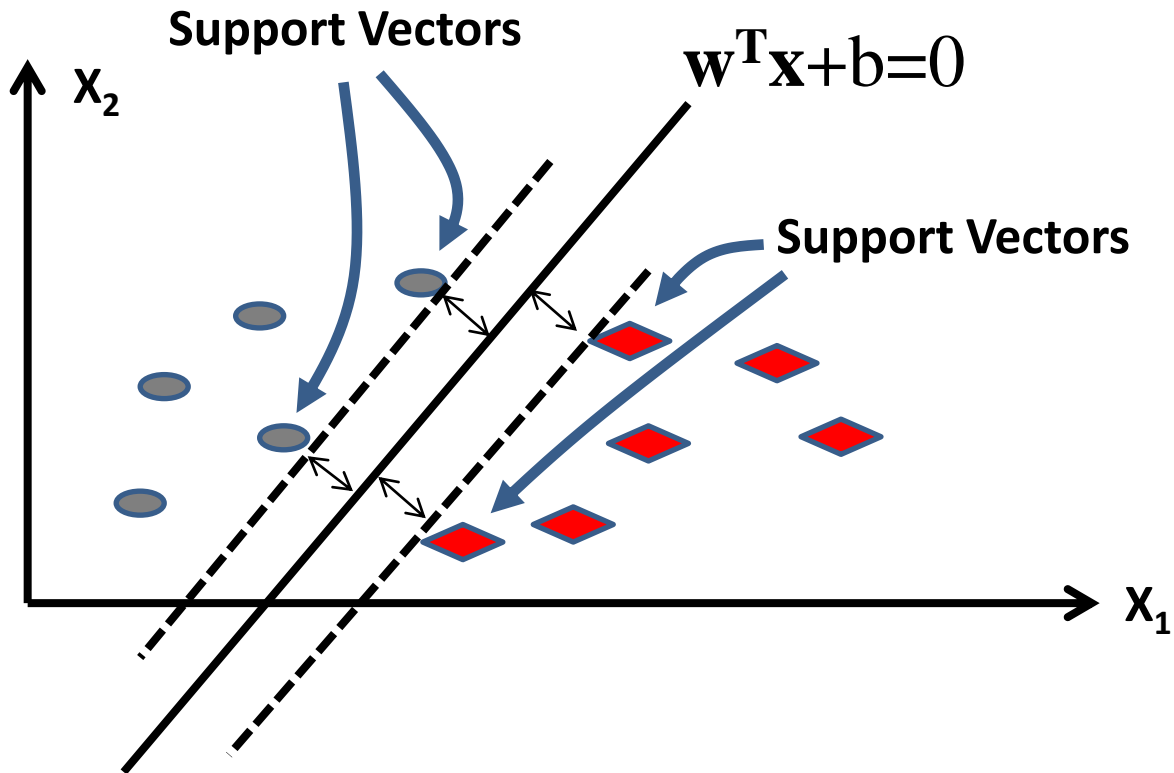
Feature
Weights

$$\mathbf{w} = \begin{pmatrix} w_1 \\ w_2 \\ \dots \\ w_M \end{pmatrix}$$

Feature Vector
(e.g., word counts)

$$\mathbf{x} = \begin{pmatrix} x_1 \\ x_2 \\ \dots \\ x_M \end{pmatrix}$$

Only the Support Vectors Matter



Linear SVM

Classifier: $f(\mathbf{x}) = \mathbf{w}^T \mathbf{x} + b$

Parameters: \mathbf{w} , b

Training Data: $T = \{(\mathbf{x}_i, \mathbf{y}_i)\}$, $i=1, \dots, |T|$. \mathbf{x}_i is a feature vector; $\mathbf{y}_i \in \{-1, 1\}$

$f(X) \geq 0 \Rightarrow X$ is in category θ_1

$f(X) < 0 \Rightarrow X$ is in category θ_2

Goal 1: Correct labeling on training data:

If $\mathbf{y}_i = 1 \rightarrow \mathbf{w}^T \mathbf{x}_i + b \geq 1$

If $\mathbf{y}_i = -1 \rightarrow \mathbf{w}^T \mathbf{x}_i + b \leq -1$



Constraint

$$\forall i, \mathbf{y}_i (\mathbf{w}^T \mathbf{x}_i + b) \geq 1$$

Objective

$$\text{Minimize } \Phi(\mathbf{w}) = \mathbf{w}^T \mathbf{w}$$

Goal 2: Maximize margin

Large margin \Leftrightarrow Small $\mathbf{w}^T \mathbf{w}$

The optimization problem is quadratic programming with linear constraints

Linear SVM with Soft Margin

Classifier: $f(\mathbf{x}) = \mathbf{w}^T \mathbf{x} + b > 0$?

Parameters: \mathbf{w} , b

Training Data: $T = \{(\mathbf{x}_i, y_i)\}, i=1, \dots, |T|$.

Find \mathbf{w} , b , and ξ_i to minimize $\Phi(\mathbf{w}) = \mathbf{w}^T \mathbf{w} + C \sum_{i \in [1, |T|]} \xi_i$

Added to allow training errors

Subject to $\forall i \in [1, |T|], y_i(\mathbf{w}^T \mathbf{x}_i + b) \geq 1 - \xi_i, \quad \xi_i \geq 0$

$C > 0$ is a parameter to control the trade-off between minimizing the errors and maximizing the margin

The optimization problem is still quadratic programming with linear constraints

Summary of Text Categorization Methods

- Many methods are available, but no clear winner
 - All require effective feature representation (need domain knowledge)
 - It is useful to compare/combine multiple methods for a particular problem
- Most techniques rely on supervised machine learning and thus can be applied to **any** text categorization problem!
 - Humans annotate training data and design features
 - Computer optimizes the combination of features
 - Good performance requires 1) effective features and 2) plenty of training data
 - Performance is generally (much) more affected by the effectiveness of features than by the choice of a specific classifier

Summary of Text Categorization Methods (cont.)

- How to design effective features? (application-specific)
 - Analyze the categorization problem and exploit domain knowledge
 - Perform error analysis to obtain insights
 - Leverage machine learning techniques (e.g., feature selection, dimension reduction, deep learning)
- How to obtain “enough” training examples?
 - Low-quality (“pseudo”) training examples may be leveraged
 - Exploit unlabeled data (using semi-supervised learning techniques)
 - Domain adaptation/transfer learning (“borrow” training examples from a related domain/problem)

Suggested Reading

Manning, Chris D., Prabhakar Raghavan, and Hinrich Schütze. *Introduction to Information Retrieval*. Cambridge: Cambridge University Press, 2007. (Chapters 13-15)

Text Categorization: Evaluation

Overview

- What is text categorization?
- Why text categorization?
- How to do text categorization?
 - Generative probabilistic models
 - Discriminative approaches
- **How to evaluate categorization results?**

General Evaluation Methodology

- Have humans to create a test collection where every document is tagged with the desired categories (“ground truth”)
- Generate categorization results using a system on the test collection
- Compare the system categorization decisions with the human-made categorization decisions and quantify their similarity (or equivalently difference)
 - The higher the similarity is, the better the results are
 - Similarity can be measured from different perspectives to understand the quality of results in detail (e.g., which category performs better?)
 - In general, different categorization mistakes may have a different cost that inevitably depends on specific applications, but it is okay not to consider such a cost variation for **relative comparison of methods**

Classification Accuracy (Percentage of Correct Decisions)

	$\mathbf{c_1}$	$\mathbf{c_2}$	$\mathbf{c_3}$	$\mathbf{\dots}$	$\mathbf{c_k}$	
$\mathbf{d_1}$	y(+)	y(-)	n(+)		n(+)	+/- human answer
$\mathbf{d_2}$	y(-)	n(+)	y(+)		n(+)	(+= correct; - =incorrect)
$\mathbf{d_3}$	n(+)	n(+)	y(+)		n(+)	y/n system result
$\mathbf{\dots}$						(y=yes; n=no)
$\mathbf{d_N}$	$\mathbf{\dots}$	$\mathbf{\dots}$				

$$\begin{aligned}
 \text{Classification Accuracy} &= \frac{\text{Total number of correct decisions}}{\text{Total number of decisions made}} \\
 &= \frac{\text{count}(y(+)) + \text{count}(n(-))}{kN}
 \end{aligned}$$

Problems with Classification Accuracy

- Some decision errors are more serious than others
 - It may be more important to get the decisions right on some documents than others
 - It may be more important to get the decisions right on some categories than others
 - E.g., spam filtering: missing a legitimate email costs more than letting a spam go
- Problem with imbalanced test set
 - Skewed test set: 98% in category 1; 2% in category 2
 - Strong baseline: put all instances in category 1 → 98% accuracy!

Per-Document Evaluation

	c_1	c_2	c_3	\dots	c_k
d_1	y(+)	y(-)	n(+)		n(+)
d_2	y(-)	n(+)	y(+)		n(+)
d_3	n(+)	n(+)	y(+)		n(+)

How good are the decisions on d_i ?

When the system says “yes,”
how many are correct?

↓

Precision = $\frac{TP}{TP + FP}$

↗

Recall = $\frac{TP}{TP + FN}$

Does the doc have all the categories
it should have?

	System (“y”)	System (“n”)
Human (+)	True Positives TP	False Negatives FN
Human (-)	False Positives FP	True Negatives TN

Per-Category Evaluation

	c_1	c_2	c_3	...	c_k
d_1	y(+)	y(-)	n(+)		n(+)
d_2	y(-)	n(+)	y(+)		n(+)
d_3	n(+)	n(+)	y(+)		n(-)

How good are the decisions on c_i ?

When the system says “yes,”
how many are correct?

↓

Precision = $\frac{TP}{TP + FP}$

↗

Recall = $\frac{TP}{TP + FN}$

Has the category been assigned to
all the docs of this category?

	System (“y”)	System (“n”)
Human (+)	True Positives TP	False Negatives FN
Human (-)	False Positives FP	True Negatives TN

Combine Precision and Recall: F-Measure

$$F_{\beta} = \frac{1}{\frac{\beta^2}{\beta^2+1} \frac{1}{R} + \frac{1}{\beta^2+1} \frac{1}{P}} = \frac{(\beta^2 + 1)P * R}{\beta^2 P + R}$$

$$F_1 = \frac{2PR}{P + R}$$

P: precision

R: recall

β: parameter (often set to 1)

Why not $0.5 * P + 0.5 * R$?

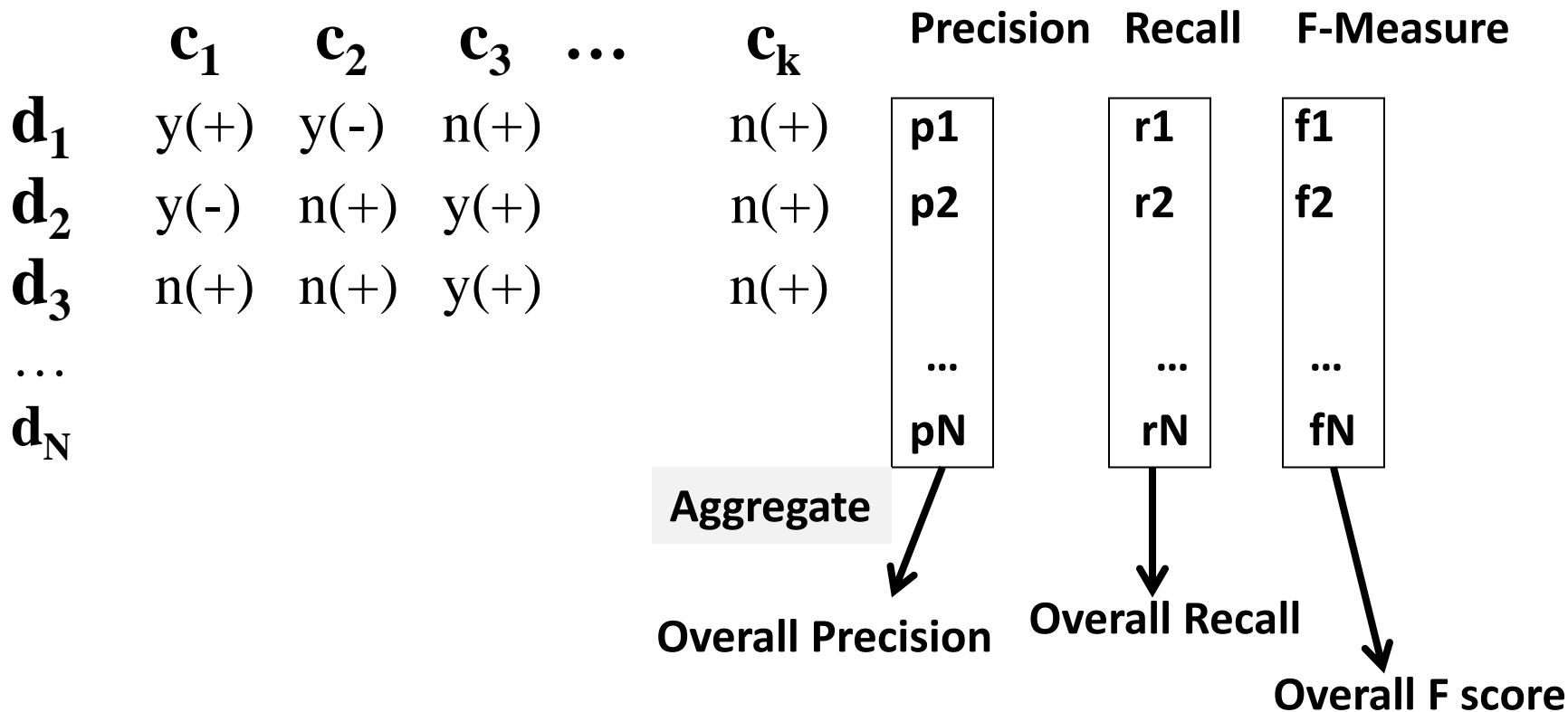
What is R if the system says “y” for all category-doc pairs?

(Macro) Average Over All the Categories

	c_1	c_2	c_3	\dots	c_k
d_1	$y(+)$	$y(-)$	$n(+)$		$n(+)$
d_2	$y(-)$	$n(+)$	$y(+)$		$n(+)$
d_3	$n(+)$	$n(+)$	$y(+)$		$n(+)$
\dots					
d_N	\dots	\dots			

						Aggregate	
Precision	p1	p2	p3	...	pk	→	Overall Precision
Recall	r1	r2	r3	...	rk	→	Overall Recall
F-Measure	f1	f2	f3	...	fk	→	Overall F score

(Macro) Average Over All the Documents



Micro-Averaging of Precision and Recall

	c_1	c_2	c_3	\dots	c_k
d_1	y(+)	y(-)	n(+)		n(+)
d_2	y(-)	n(+)	y(+)		n(+)
d_3	n(+)	n(+)	y(+)		n(+)
\dots					
d_N			

First pool all decisions,
then compute precision and recall



$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{Recall} = \frac{TP}{TP + FN}$$

	System ("y")	System ("n")
Human (+)	True Positives (TP)	False Negatives (FN)
Human (-)	False Positives(FP)	True Negatives(TN)

Sometimes Ranking Is More Appropriate

- The categorization results are often passed to a human for
 - further editing (e.g., correcting system mistakes on news categories)
 - prioritizing a task (e.g., routing an email to the right person for processing)
- In such cases, we can evaluate the results as a ranked list if the system can give scores for the decisions
 - E.g., discovery of spam emails (➔ rank emails for the “spam” category)
 - Often more appropriate to frame the problem as a ranking problem instead of a categorization problem (e.g., ranking documents in a search engine)

Summary of Categorization Evaluation

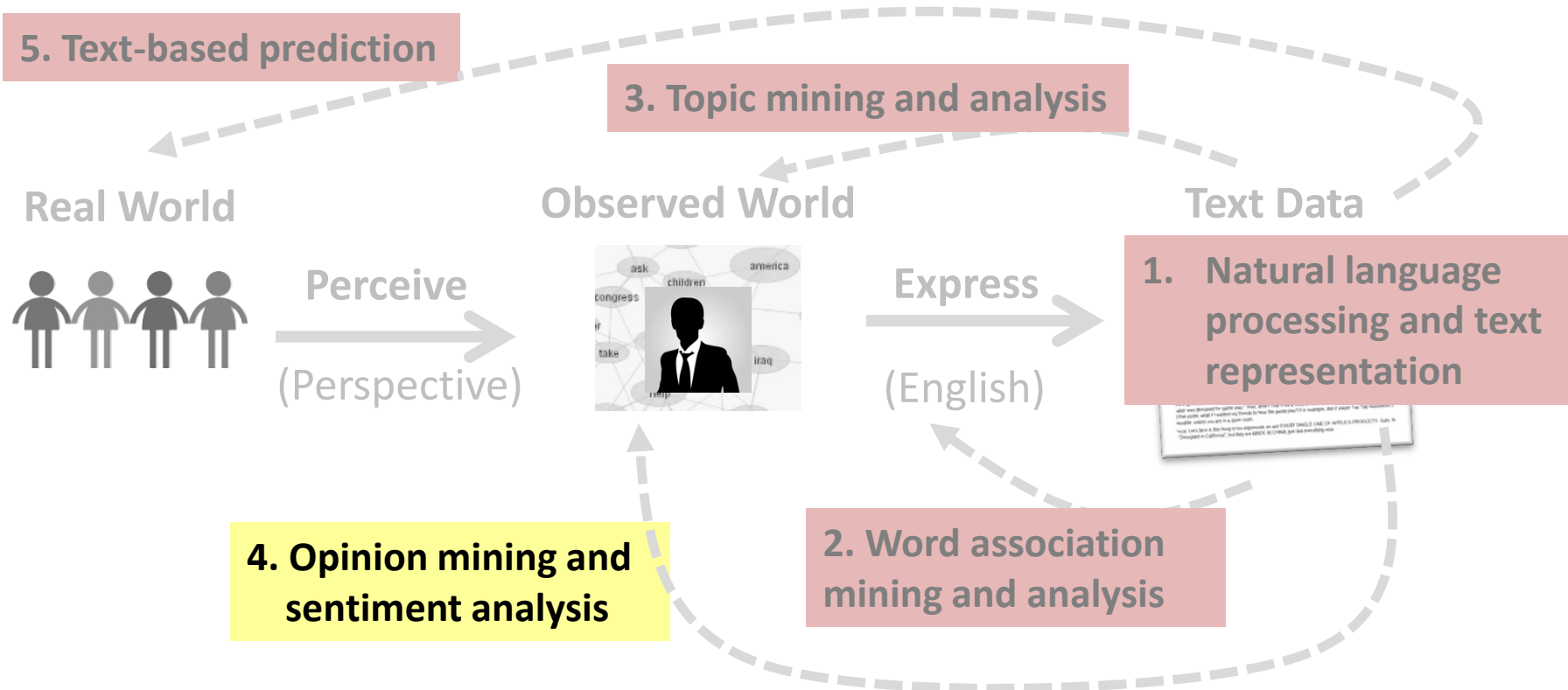
- Evaluation is always very important, so get it right!
- Measures must reflect the **intended use** of the results for a particular application (e.g., spam filtering vs. news categorization)
 - Consider: How will the results be further processed (by a user)?
 - Ideally associate a different cost with each different decision error
- Commonly used measures for **relative** comparison of different methods:
 - Accuracy, precision, recall, F score
 - Variations: per-document, per-category, micro vs. macro averaging
- Sometimes **ranking** may be more appropriate

Suggested Reading

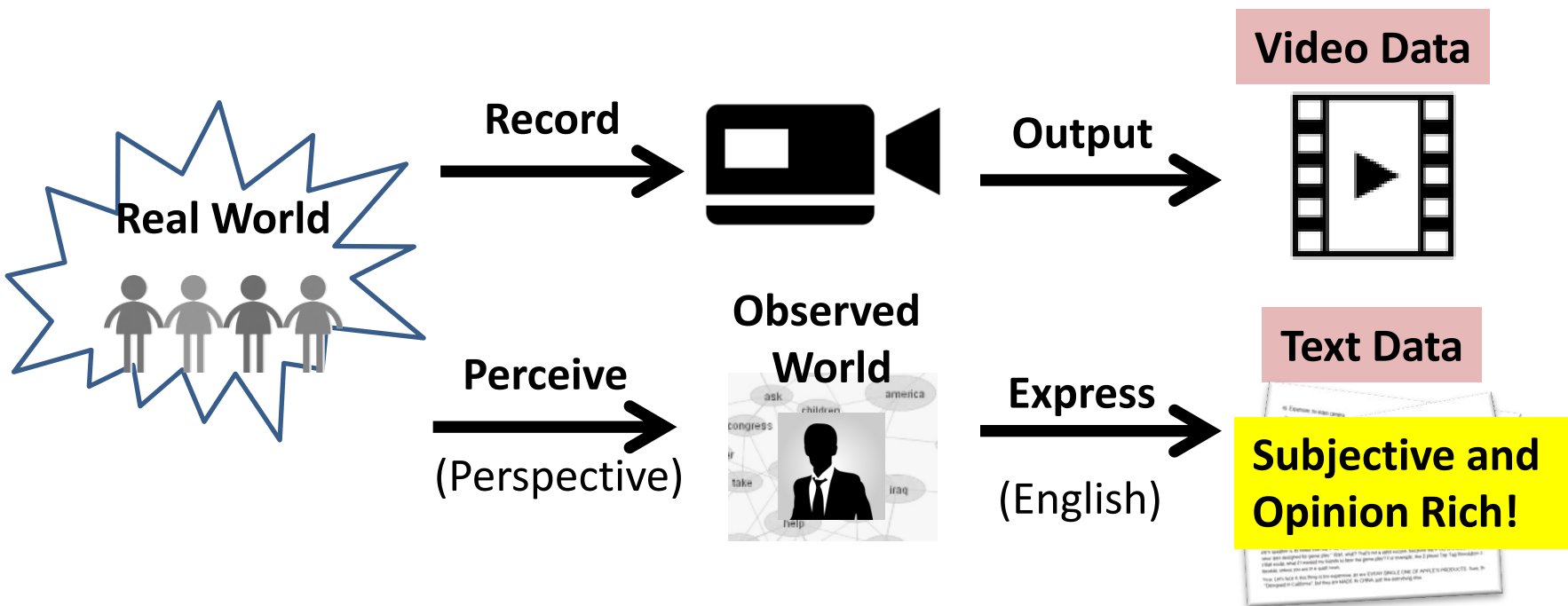
- Manning, Chris D., Prabhakar Raghavan, and Hinrich Schütze. *Introduction to Information Retrieval*. Cambridge: Cambridge University Press, 2007. (Chapters 13-15)
- Yang, Yiming. 1999. An Evaluation of Statistical Approaches to Text Categorization. *Inf. Retr.* 1, 1-2 (May 1999), 69-90. DOI=10.1023/A:1009982220290

Opinion Mining and Sentiment Analysis: Motivation

Opinion Mining and Sentiment Analysis: Motivation



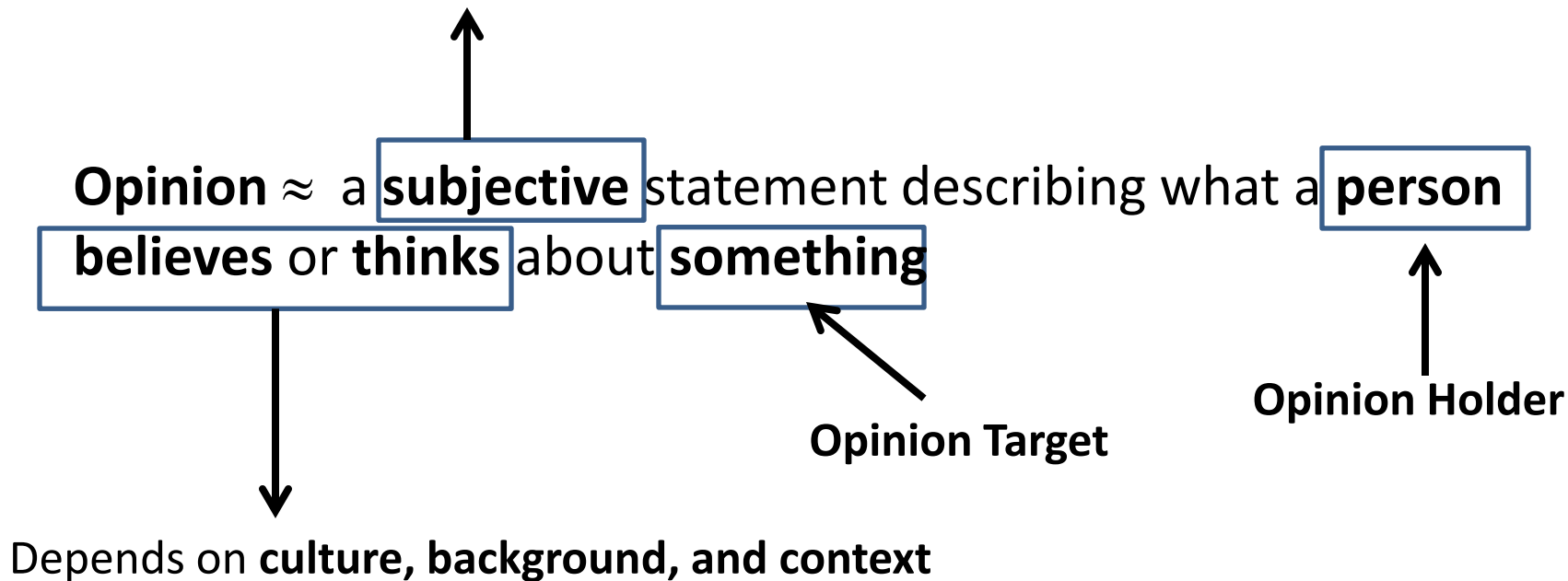
Objective vs. Subjective Sensors



How can we mine and analyze opinion buried in text?

What Is an Opinion?

Objective statement or **Factual** statement (can be proved right/wrong)



Opinion Representation

- Basic Opinion Representation
 - Opinion **holder**: Whose opinion is this?
 - Opinion **target**: What is this opinion about?
 - Opinion **content**: What exactly is the opinion?
- Enriched Opinion Representation
 - Opinion **context**: Under what situation (e.g., time, location) was the opinion expressed?
 - Opinion **sentiment**: What does the opinion tell us about the opinion holder's feeling (e.g., positive vs. negative)?

A Product Review (Explicit Holder and Target)

- Basic Opinion Representation

- Opinion **holder**: Whose opinion is this?

Reviewer X

- Opinion **target**: What is this opinion about?

Product: iPhone 6

- Opinion **content**: What exactly is the opinion?

Review Text

- Enriched Opinion Representation

- Opinion **context**: Under what situation (e.g., time, location) was the opinion expressed?

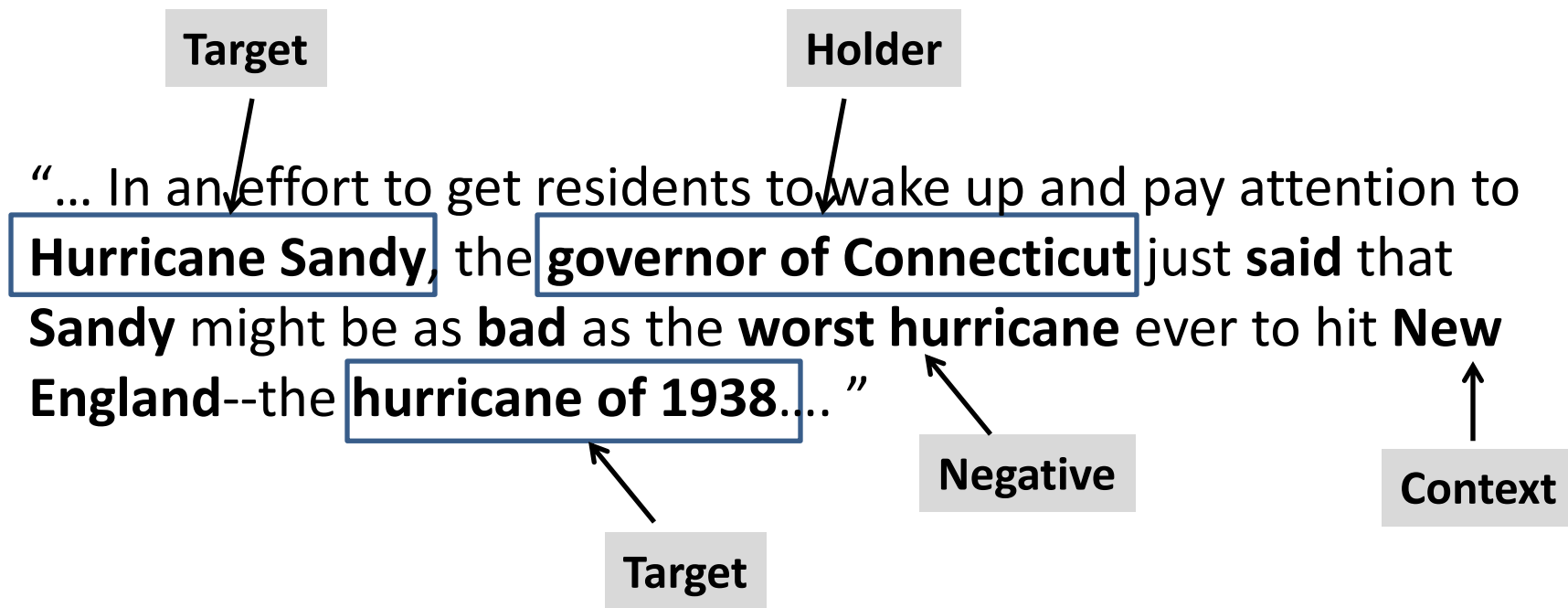
Year = 2015

- Opinion **sentiment**: What does the opinion tell us about the opinion holder's feeling (e.g., positive vs. negative)?

Positive

Relatively Easy to Mine and Analyze

A Sentence in News (Implicit Holder and Target)



Harder to Mine and Analyze: Need deeper NLP

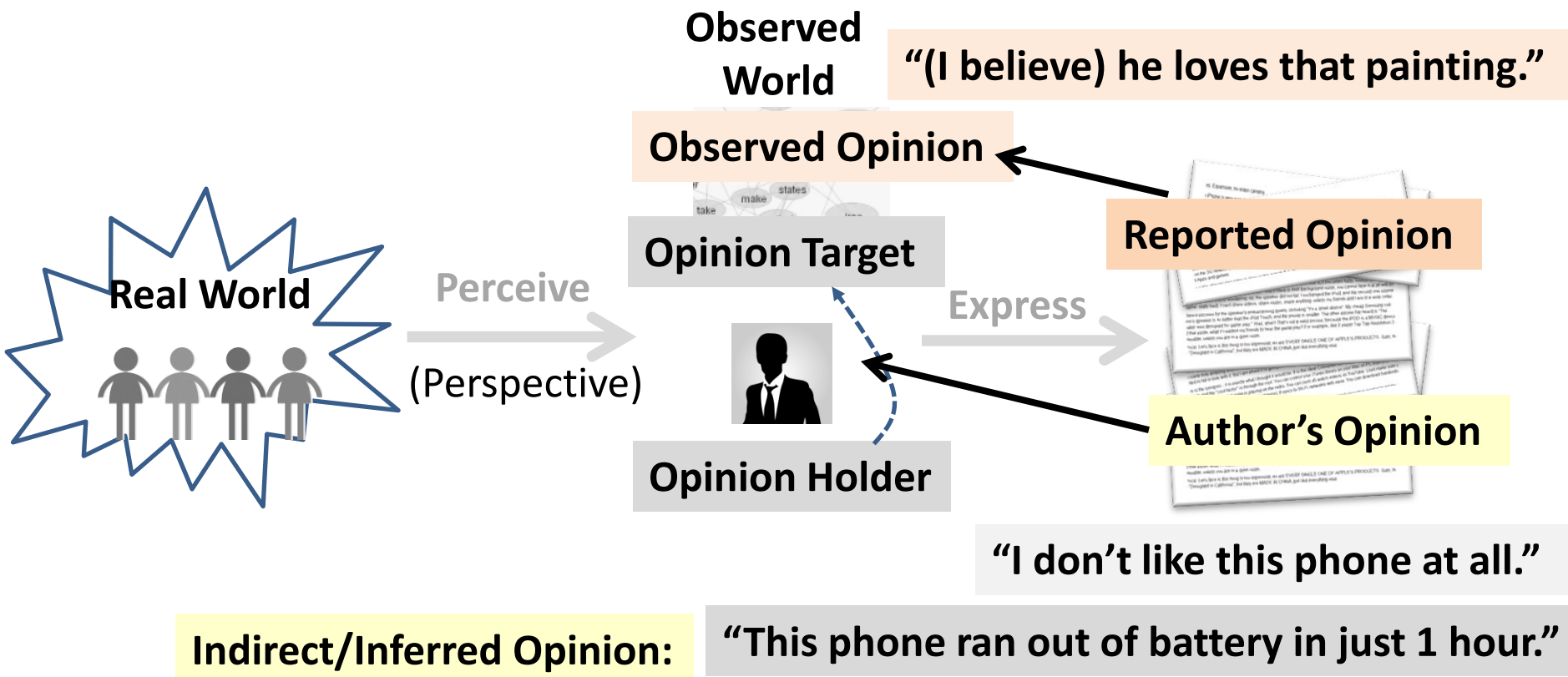
Source: Blodget, H. (2012, October 28). Hurricane Sandy is being compared to the worst hurricane ever to hit New England. *Business Insider*. *Business Insider*. Retrieved from <http://www.businessinsider.com/hurricane-sandy-vs-hurricane-of-1938-2012-10>.

Slide adapted from ChengXiang Zhai's presentation

Variations of Opinions

- **Opinion holder:** Individual vs. group
- **Opinion target:** One entity, a group of entities, one attribute of an entity, someone else's opinion, etc.
- **Opinion content:**
 - Surface variation: one sentence/phrase, a paragraph, a whole article
 - Sentiment/emotion variation: positive vs. negative, happy vs. sad, etc.
- **Opinion context**
 - Simple context: Different time, location, etc.
 - Complex context: Potentially includes the entire discourse context of an opinion

Different Kinds of Opinions in Text Data



The Task of Opinion Mining

A Set of Opinion Representations

Text Data



Opinion Holder

Opinion Target

Opinion Content

Opinion Context

Opinion
Sentiment

Often some elements of the representation are already known

Simplest Opinion Mining task(s)?

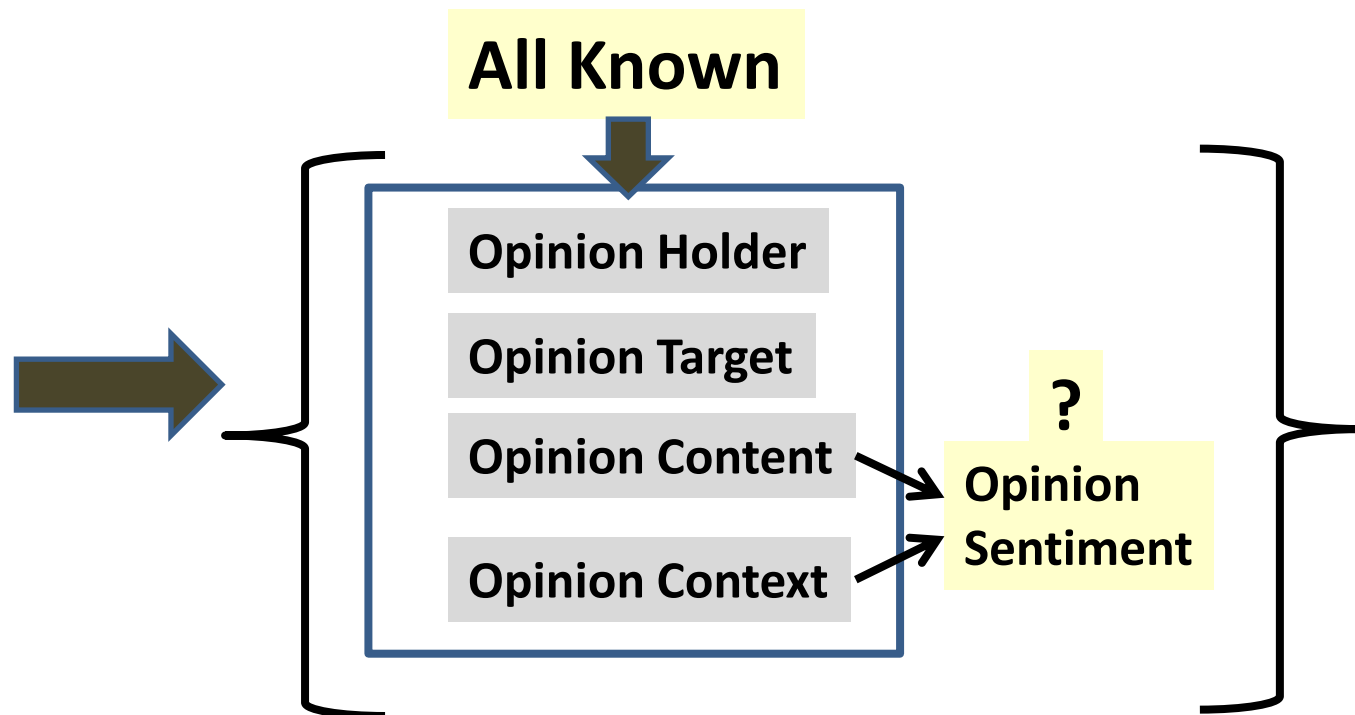
Why Opinion Mining?

- **Decision Support**
 - Help consumers choose a product or service
 - Help voters decide whom to vote for
 - Help policy makers design new policy
- **Understand People**
 - Help understand people's preferences to better serve them (e.g., optimize a product search engine; optimize recommender systems)
 - Help with advertising (targeted advertising)
- **“Voluntary Survey” (humans as sensors; aggregated opinions)**
 - Business intelligence
 - Market research
 - Data-driven social science research
 - Gain advantage in **any** prediction (text-based prediction)

Opinion Mining and Sentiment Analysis: Sentiment Classification

Sentiment Classification

Text Data



Sentiment Classification: Task Definition

- Input: An opinionated text object
- Output: A sentiment tag/label
 - Polarity analysis: e.g., categories = {positive, negative, neutral}, or categories = {5, 4, 3, 2, 1}
 - Emotion analysis (beyond polarity): e.g., categories = {happy, sad, fearful, angry, surprised, disgusted}
- A special case of text categorization! ➔ Any text categorization method can be used to do sentiment classification
- Further improvement comes from
 - More sophisticated features appropriate for sentiment tagging
 - Consideration of the order of the categories (e.g., ordinal regression)

Commonly Used Text Features

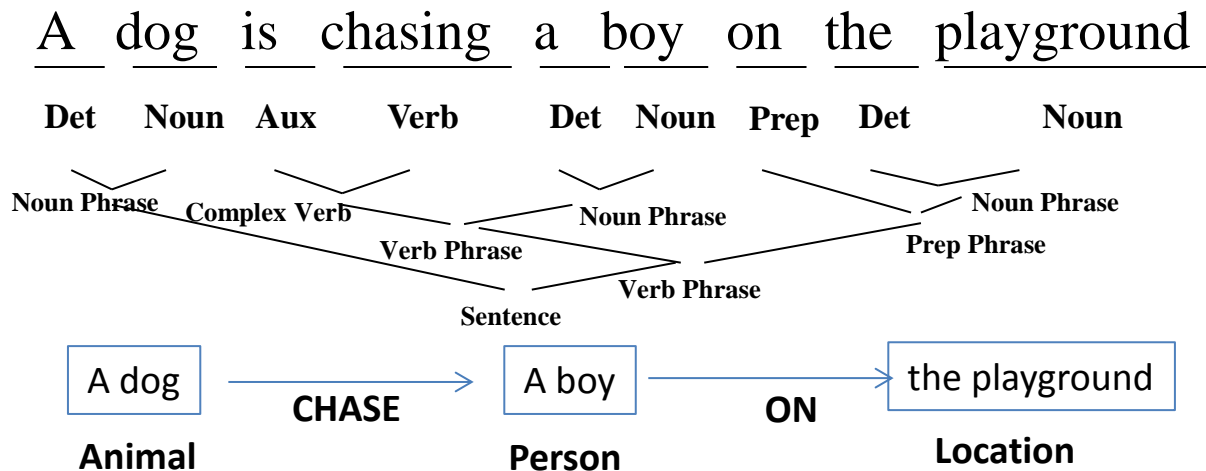
- Character n-grams: can be mixed with different n's
 - General and robust to spelling/recognition errors, but less discriminative than words
- Word n-grams: can be mixed with different n's
 - Unigrams are often very effective, but not for sentiment analysis (e.g. , “it’s not good” or “it’s not as good as”)
 - Long n-grams are discriminative, but may cause overfitting
- POS tag n-grams: mixed n-gram with words and POS tags
 - E.g., “ADJECTIVE NOUN” or “great NOUN”

Commonly Used Text Features (cont.)

- Word classes
 - Syntactic (= POS tags)
 - Semantic Concept: e.g., thesaurus/ontology, recognized entities
 - Empirical word clusters (e.g., cluster of paradigmatically or syntagmatically related words)
- Frequent patterns in text (e.g., frequent word set; collocations)
 - More specific/discriminative than words
 - May generalize better than pure n-grams
- Parse tree-based (e.g., frequent subtrees, paths)
 - Even more discriminative, but need to avoid overfitting
- Pattern discovery algorithms are very useful for feature construction

NLP Enriches Text Representation with Complex Features

A dog is chasing a boy on the playground

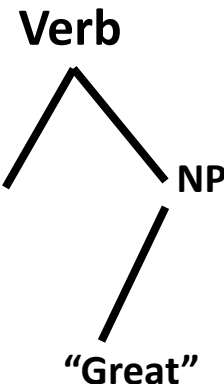


Dog(d1). Boy(b1). Playground(p1). Chasing(d1,b1,p1).

Speech Act = REQUEST

“great NOUN”
“Verb Adv Adj”

...



Feature Construction for Text Categorization

- Feature design affects categorization accuracy significantly
- A combination of machine learning, error analysis, and domain knowledge is most effective
 - Domain knowledge → seed features, feature space
 - Machine learning → feature selection, feature learning
 - Error analysis → feature validation
- NLP enriches text representation → enriches feature space (more likely overfitting!)
- Optimizing the tradeoff between **exhaustivity** and **specificity** is a major goal

high coverage (frequent)

discriminative (infrequent)

Sentiment Analysis: Ordinal Logistic Regression

Motivation: Rating Prediction

- Input: An opinionated text document \mathbf{d}
- Output: Discrete rating $\mathbf{r} \in \{1, 2, \dots, k\}$
- Using regular text categorization techniques
 - Doesn't consider the order and dependency of the categories
 - The features distinguishing $r=2$ from $r=1$ may be the same as those distinguishing $r=k$ from $r=k-1$ (e.g., positive words generally suggest a higher rating)
- Solution: Add order to a classifier (e.g., ordinal logistic regression)

Logistic Regression for Binary Sentiment Classification

Binary Response Variable: $Y \in \{0,1\}$

Predictors: $X = (x_1, x_2, \dots, x_M)$, $x_i \in \mathbb{R}$

$$Y = \begin{cases} 1 & X \text{ is POSITIVE} \\ 0 & X \text{ is NEGATIVE} \end{cases}$$

$$\log \frac{p(Y = 1 | X)}{p(Y = 0 | X)} = \log \frac{p(Y = 1 | X)}{1 - p(Y = 1 | X)} = \beta_0 + \sum_{i=1}^M x_i \beta_i \quad \beta_i \in \mathbb{R}$$

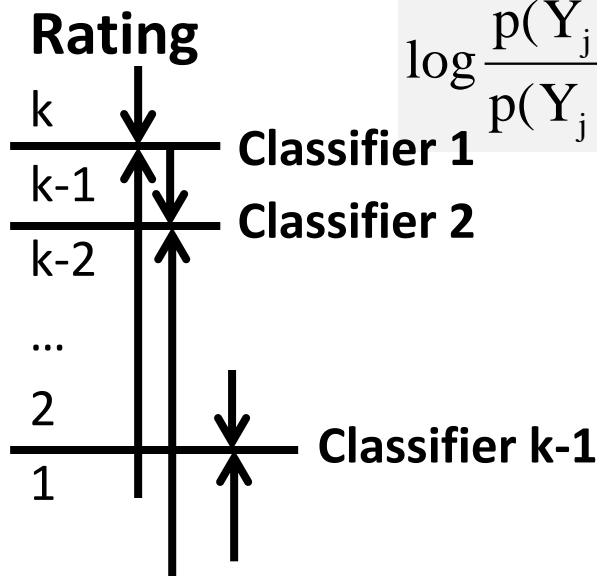
$$p(Y = 1 | X) = \frac{e^{\beta_0 + \sum_{i=1}^M x_i \beta_i}}{e^{\beta_0 + \sum_{i=1}^M x_i \beta_i} + 1}$$

Logistic Regression for Multi-Level Ratings

$$Y_j = \begin{cases} 1 & \text{rating is } j \text{ or above} \\ 0 & \text{rating is lower than } j \end{cases}$$

Predictors: $X = (x_1, x_2, \dots, x_M)$, $x_i \in \mathbb{R}$

Rating: $r \in \{1, 2, \dots, k\}$



$$\log \frac{p(Y_j = 1 | X)}{p(Y_j = 0 | X)} = \log \frac{p(r \geq j | X)}{1 - p(r \geq j | X)} = \alpha_j + \sum_{i=1}^M x_i \beta_{ji} \quad \beta_{ji} \in \mathbb{R}$$

$$p(r \geq j | X) = \frac{e^{\alpha_j + \sum_{i=1}^M x_i \beta_{ji}}}{e^{\alpha_j + \sum_{i=1}^M x_i \beta_{ji}} + 1}$$

Rating Prediction with Multiple Logistic Regression Classifiers

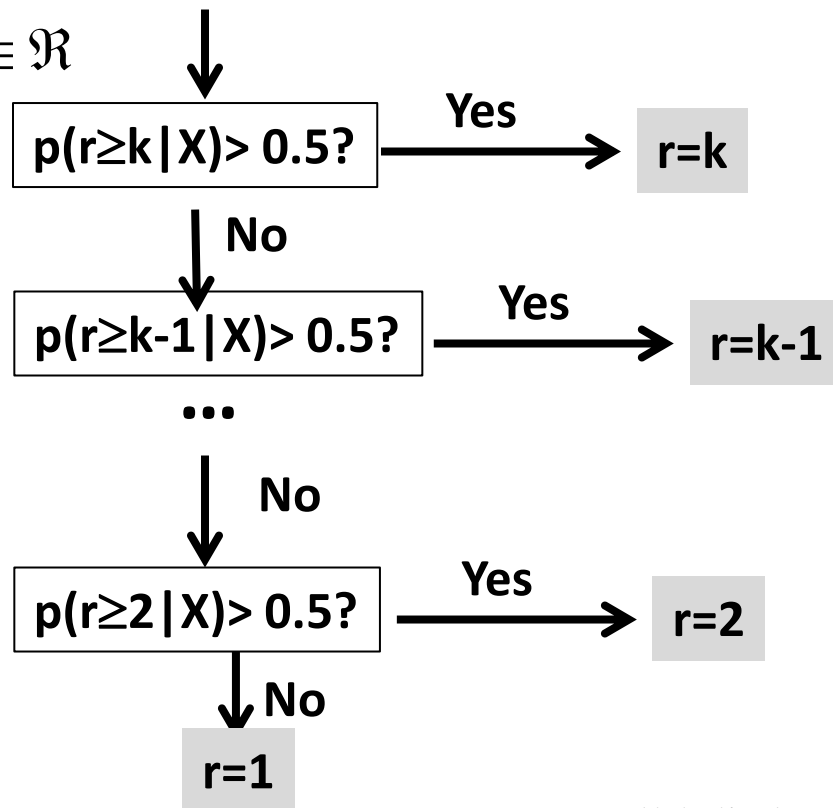
Text Object: $X = (x_1, x_2, \dots, x_M)$, $x_i \in \mathcal{R}$

Rating: $r \in \{1, 2, \dots, k\}$

After training $k-1$
Logistic Regression Classifiers

$$p(r \geq j | X) = \frac{e^{\alpha_j + \sum_{i=1}^M x_i \beta_{ji}}}{e^{\alpha_j + \sum_{i=1}^M x_i \beta_{ji}} + 1}$$

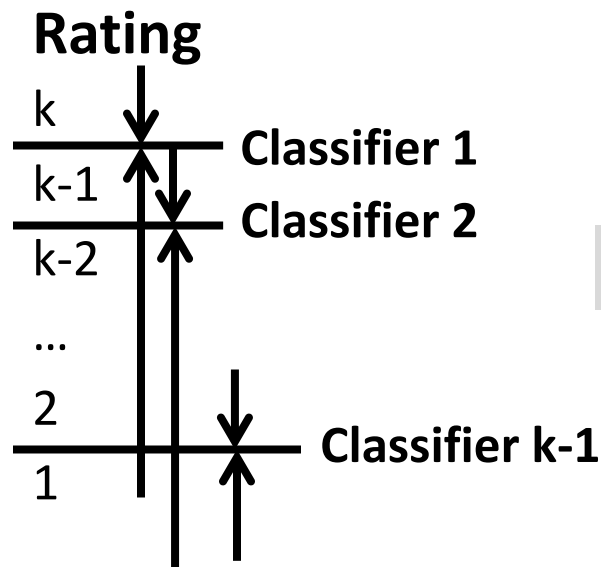
$j = k, k-1, \dots, 2$



Problems with k-1 Independent Classifiers?

$$\log \frac{p(Y_j = 1 | X)}{p(Y_j = 0 | X)} = \log \frac{p(r \geq j | X)}{1 - p(r \geq j | X)} = \alpha_j + \sum_{i=1}^M x_i \beta_{ji} \quad \beta_{ji} \in \Re$$

$$p(r \geq j | X) = \frac{e^{\alpha_j + \sum_{i=1}^M x_i \beta_{ji}}}{e^{\alpha_j + \sum_{i=1}^M x_i \beta_{ji}} + 1}$$



How many parameters are there in total? **$(k-1) \cdot (M+1)$**

The k-1 classification problems are dependent.
The positive/negative features tend to be similar!

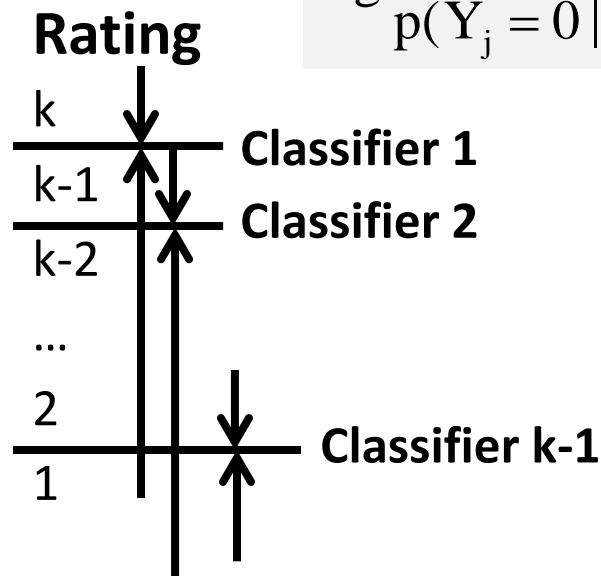
Ordinal Logistic Regression

Key Idea: $\forall i = 1, \dots, M, \forall j = 3, \dots, k, \beta_{ji} = \beta_{j-1i}$

➔ Share training data

➔ Reduce # of parameters

$$\log \frac{p(Y_j = 1 | X)}{p(Y_j = 0 | X)} = \log \frac{p(r \geq j | X)}{1 - p(r \geq j | X)} = \alpha_j + \sum_{i=1}^M x_i \beta_i \quad \beta_i \in \mathcal{R}$$



$$p(r \geq j | X) = \frac{e^{\alpha_j + \sum_{i=1}^M x_i \beta_i}}{e^{\alpha_j + \sum_{i=1}^M x_i \beta_i} + 1}$$

How many parameters are there in total?

M+k-1

Ordinal Logistic Regression: Rating Prediction

$$p(r \geq j | X) \geq 0.5 \Leftrightarrow \frac{e^{\alpha_j + \text{score}(X)}}{e^{\alpha_j + \text{score}(X)} + 1} \geq 0.5 \Leftrightarrow \text{score}(X) \geq -\alpha_j$$

