ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI FORLÌ

91258 / B0385
Natural Language Processing

Lesson 4. Rule-based Sentiment Analysis (+ Naïve Bayes)

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Previously

- Pre-processing (e.g., tokenisation, stemming, stopwording)
- BoW representation
- Dot product

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Sentiment Analysis (with VADER)

Sentiment Analysis

It does not refer to actual sentiment (e.g., love or hate)[1]
It is about positive and negative perceptions (plus neutral)

a

This monitor is definitely a good value. Does it have superb color and contrast? No. Does it boast the best refresh rate on the market? No. But if you're tight on money, this thing looks and preforms great for the money. It has a Matte screen which does a great job at eliminating glare. The chassis it's enclosed within is absolutely stunning.

POSITIVE

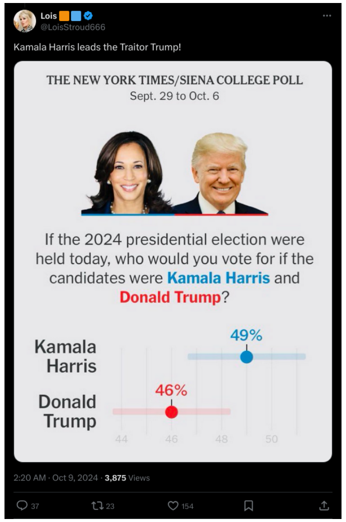
His [ssa] didnt concede until July 12, 2016. Because he was throwing a tantrum. I can't say this enough: [kcuF] Bernie Sanders.

NEGATIVE

From (Lane et al., 2019, p. 62–65)

[1]That's emotion analysis; e.g., Fernicola et al. (2020); Zhang et al. (2022)

Sentiment Analysis



https://x.com/LoisStroud666/status/1843808652802801745

Valence Aware Dictionary for sEntiment Reasoning
(Hutto and Gilbert, 2014)[2]

- It has a lexicon packed with tokens and their associated "sentiment" score
- It counts all tokens belonging to each category: [pos, neu, neg]
  . . . and combine them to determine the sentiment

  </> Let us see it working

[2]http://comp.social.gatech.edu/papers/icwsm14.vader.hutto.pdf
https://github.com/cjhutto/vaderSentiment

Into ML

Machine Learning

"[. . .] an umbrella term for **solving problems** for which development of algorithms by human programmers would be cost-prohibitive"

"[. . .] the problems are solved by helping machines **"discover" their "own" algorithms**, without needing to be explicitly told what to do by any human-developed algorithms."

https://en.wikipedia.org/wiki/Machine_learning

Machine Learning

A change of paradigm

From hand-crafted rules

To training

Diagrams borrowed from L. Moroney's Introduction to TensorFlow for Artificial Intelligence, Machine Learning, and Deep Learning

Supervised vs Unsupervised

Supervised The algorithms build a mathematical model of a set of data including. . .

- the inputs
- desired outputs

Unsupervised The algorithms take a set of data that contains. . .

- only inputs

. . . and find structure in the data

https://en.wikipedia.org/wiki/Machine_learning

Naïve Bayes

Naïve Bayes

1. Introduced in the IR community by Maron (1961)
2. First machine learning approach
3. It is a supervised model
4. It applies Bayes' theorem with strong (naïve) independence assumptions between the features
   - they are independent
   - they contribute "the same"

Naïve Bayes
A conditional probability model

Given an instance represented by a vector

$$\mathbf{x} = (x_1, \ldots, x_n) \tag{1}$$

representing n independent features $x_1, x_2, x_3, \ldots, x_{n-2}, x_{n-1}, x_n$

n could be $|V|$ (the size of the vocabulary)

The model assigns to instance $\mathbf{x}$ the probability

$$p(C_k \mid \mathbf{x}) = p(C_k \mid x_1, \ldots, x_n) \tag{2}$$

for each of the k possible outcomes C_k

where $C_k = \{c_1, \ldots, c_k\}$

From `https://en.wikipedia.org/wiki/Naive_Bayes_classifier`

Naïve Bayes'
Using Bayes' Theorem

The conditional probability $p(C_k \mid x_1, \ldots, x_n)$ can be decomposed as

$$p(C_k \mid \mathbf{x}) = \frac{p(C_k)\ p(\mathbf{x} \mid C_k)}{p(\mathbf{x})} \tag{3}$$

Which can be read as

$$\text{posterior} = \frac{\text{prior} \times \text{likelihood}}{\text{evidence}}$$

But $p(x)$ does not depend on the class (since it is constant):

$$p(C_k \mid \mathbf{x}) \sim p(C_k)\ p(\mathbf{x} \mid C_k) \tag{4}$$

From `https://en.wikipedia.org/wiki/Naive_Bayes_classifier`

Naïve Bayes
Going deeper (assuming a binary classifier)

$$p(C \mid \mathbf{x}) = \frac{p(C)\ p(\mathbf{x} \mid C)}{p(\mathbf{x})} \tag{5}$$

$$\text{posterior probability} = \frac{\text{class prior probability} \times \text{likelihood}}{\text{predictor prior probability}}$$

$p(C \mid \mathbf{x})$ Posterior probability of the class given the input[3]

```
if p > 0.5:
    class = positive
else:
    class = negative
```

Naïve Bayes

Going deeper (assuming a binary classifier)

$$p(C \mid \mathbf{x}) = \frac{p(C)\ p(\mathbf{x} \mid C)}{p(\mathbf{x})} \tag{6}$$

$$\text{posterior probability} = \frac{\text{class prior probability} \times \text{likelihood}}{\text{predictor prior probability}}$$

$p(C)$ Class prior probability
How many positive instances I have seen (during training)?

Naïve Bayes

Going deeper (assuming a binary classifier)

$$p(C \mid \mathbf{x}) = \frac{p(C)\ p(\mathbf{x} \mid C)}{p(\mathbf{x})} \tag{7}$$

$$\text{posterior probability} = \frac{\text{class prior probability} \times \text{likelihood}}{\text{predictor prior probability}}$$

$p(\mathbf{x} \mid C)$ Likelihood
The probability of the document given the class

Rough Idea

- The value of a particular feature is independent of the value of any other feature, given the class variable
- All features contribute the same to the classification

- Naïve Bayes' tries to find keywords in a set of documents that are predictive of the target (output) variable
- The internal coefficients will try to map tokens to scores
- Same as VADER, but without manually-created rules
  the machine will *estimate* them!

From (Lane et al., 2019, p. 65–68)

Naïve Bayes

A toy example: Should I ride my bike today?

One single factor: *zone (flag)*


sunny


overcast



rainy


(here come some dense slides)

Naïve Bayes

A toy example: Should I ride my bike today?

Dataset

Flag	🚲
🟡	yes
🟠	yes
🟡	no
🔴	yes
🟡	yes
🟠	yes
🟡	yes
🟠	yes
🔴	yes
🟡	no
🔴	no
🟠	yes
🔴	no
🔴	no

Computing all the probabilities by "counting"

Frequency table

	🚲	
Flag	yes	no
🟡	3	2
🟠	4	0
🔴	2	3

Likelihood table

	🚲	
Flag	yes	no
🟡	3/9	2/5
🟠	4/9	0/5
🔴	2/9	3/5

Adapted from `http://www.saedsayad.com/naive_bayesian.htm`

Naïve Bayes

A toy example: Should I ride my bike today?

Likelihood table

	🚲	
Flag	yes	no
🟡	3/9 [1]	2/5
🟠	4/9	0/5
🔴	2/9	3/5
	9/14 [2]	5/14

[1] $p(x \mid c) = p(🟡 \mid \text{yes}) = 3/9 = 0.33$

[2] $p(c) = p(\text{yes}) = 9/14 = 0.64$

$p(x) = p(🟡) = 5/14 = 0.36$

What is the Naïve Bayes' probability of yes if 🟡?

$$
\begin{aligned}
p(c \mid x) &= p(c)p(x \mid c)/p(x) \\
p(\text{yes} \mid 🟡) &= p(\text{yes})p(🟡 \mid \text{yes})/p(🟡) \\
p(\text{yes} \mid 🟡) &= 0.64 * 0.33/0.36 \\
p(\text{yes} \mid 🟡) &= 0.59
\end{aligned}
$$

Adapted from `http://www.saedsayad.com/naive_bayesian.htm`

Naïve Bayes

A toy example: Should I ride my bike today?

If. . . 🟡 let's ride 🚲!

Naïve Bayes

A toy example: Should I ride my bike today?

Considering more data

Flag	Temp	Humidity	Windy	🚲
🔴	hot	high	false	no
🔴	hot	high	true	no
🟠	hot	high	false	yes
🟠	mild	high	false	yes
🟡	cool	normal	false	yes
🟡	cool	normal	true	no
🟠	cool	normal	true	yes
🔴	mild	high	false	no
🔴	cool	normal	false	yes
🟡	mild	normal	false	yes
🔴	mild	normal	true	yes
🟠	mild	high	true	yes
🟠	hot	normal	false	yes

Adapted from `http://www.saedsayad.com/naive_bayesian.htm`

Naïve Bayes

A toy example: Should I ride my bike today?

Frequency tables

Flag	yes	no
	3	2
	4	0
	2	3

Humidity	yes	no
high	3	4
normal	6	1

Temp	yes	no
hot	2	2
mild	4	2
cool	3	1

Windy	yes	no
false	6	2

Likelihood tables

Flag	yes	no
	3/9	2/5
	4/9	0/5
	2/9	3/5

Humidity	yes	no
high	3/9	4/5
normal	6/9	1/5

Temp	yes	no
hot	2/9	2/5
mild	4/9	2/5
cool	3/9	1/5

Windy	yes	no
false	6/9	2/5

Adapted from `http://www.saedsayad.com/naive_bayesian.htm`

Naïve Bayes

Likelihood tables

Flag	yes	no
	3/9	2/5
	4/9	0/5
	2/9	3/5

Temp	yes	no
hot	2/9	2/5
mild	4/9	2/5
cool	3/9	1/5

Humidity	yes	no
high	3/9	4/5
normal	6/9	1/5

Windy	yes	no
false	6/9	2/5
true	3/9	3/5

flag	temp	humidity	windy	ride
	cool	high	true	?

$$p(\text{yes} \mid x) = \frac{p(\text{yes})p(\quad \mid \text{yes})p(\text{cool} \mid \text{yes})p(\text{high} \mid \text{yes})p(\text{true} \mid \text{yes})}{p(\quad)p(\text{cool})p(\text{high})p(\text{true})}$$
$$= \frac{9/14 \times 2/9 \times 3/9 \times 3/9 \times 3/9}{5/14 \times 4/14 \times 7/14 \times 6/14}$$

Adapted from `http://www.saedsayad.com/naive_bayesian.htm`

Naïve Bayes

Back to the definition...

$$p(C \mid \mathbf{x}) = \frac{p(C)\ p(\mathbf{x} \mid C)}{p(\mathbf{x})} \tag{8}$$

The probability $p(\mathbf{x})$ is constant for any given input

$$p(C \mid \mathbf{x}) = \frac{p(C)\ p(\mathbf{x} \mid C)}{\cancel{p(\mathbf{x})}} \tag{9}$$

$$p(c \mid \mathbf{x}) \propto p(c)p(\mathbf{x} \mid c) \tag{10}$$

Naïve Bayes

Back to the definition...

$$p(c \mid \mathbf{x}) \propto p(c)p(\mathbf{x} \mid c) \tag{11}$$

Remember that $\mathbf{x}$ is a vector

$$p(c \mid x_1 \dots x_n) \propto p(c)p(x_1 \mid c) \times p(x_2 \mid c) \times \dots \times p(x_n \mid c) \tag{12}$$

Eq. (12) can be rewritten as

$$p(c \mid x_1 \dots x_n) \propto p(c) \prod_{i=1}^{n} p(x_i \mid c) \tag{13}$$

Naïve Bayes
The classification process

Back to the toy example

$p(\text{yes} \mid x) \propto p(\text{yes})p($$\mid \text{yes})p(\text{cool} \mid \text{yes})p(\text{high} \mid \text{yes})p(\text{true} \mid \text{yes})$

$\propto 9/14 \times 2/9 \times 3/9 \times 3/9 \times 3/9$

$\propto 0.00529$, which is not a probability

Classification: the maximum for all the classes

$$c \propto \arg\max_{c} p(c) \prod_{i=1}^{n} p(x_i \mid c) \tag{14}$$

```
compute p(yes|x)
compute p(no|x)
if p(yes|x) > p(no|x):
    yes
else:
    no
```


Naïve Bayes
Classification process

$$p(C \mid \mathbf{x}) = \frac{p(C)\ p(\mathbf{x} \mid C)}{p(\mathbf{x})} \tag{15}$$

The probability $p(\mathbf{x})$ is constant for any given input!

$$p(C \mid \mathbf{x}) = \frac{p(C)\ p(\mathbf{x} \mid C)}{\cancel{p(\mathbf{x})}} \tag{16}$$

Back to the toy example, using Eq. (16)...

$$\begin{aligned} p(\text{yes} \mid x) &= p(\text{yes})p(\text{rainy} \mid \text{yes})p(\text{cool} \mid \text{yes})p(\text{high} \mid \text{yes})p(\text{true} \mid \text{yes}) \\ &= 9/14 \times 2/9 \times 3/9 \times 3/9 \times 3/9 \\ &= 0.00529 \text{ not a probability!} \end{aligned}$$

Training a Machine Learning Model

The dataset

We need a bunch of items (documents) with their associated class

kind	**examples**
binary	{positive, negative}
	{0, 1}
	{-1, 1}
multiclass	{positive, neutral, negative}
	{0,1,2}

In our case, we need the sentiment:

d_1	pos	d_5	neg	d_9	neu
d_2	neu	d_6	neg	d_{10}	pos
d_3	pos	d_7	neg	d_{11}	neu
d_4	pos	d_8	pos	d_{12}	neg

The dataset

Option 1 Use a corpus created by somebody else

Option 2 Build your own corpus[4]

(a) You have/hire experts to do it
(b) You engage non-experts through gamification
(c) You hire non-experts through explicit crowdsourcing
(d) There are many other ways to get annotated data

[4] A lesson about this is going on now.

Let us go and build a classifier with a corpus built by Hutto and Gilbert (2014)[5]

If you are following NLP in Action, they instruct you to download and install their software companion:

`https://github.com/totalgood/nlpia`

[5] http://comp.social.gatech.edu/papers/icwsm14.vader.hutto.pdf

What I did on OsX and GNU Linux

I use pipenv[6]

```
$ pipenv install --skip-lock nlpia
```

On Github they explain how to install it with conda or pip if you plan to contribute to the project

</> Let us see it working

[6] `https://pipenv.readthedocs.io/en/latest/`

References

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