ayes Algorithm (with codes in Python and

- **Note: This article was originally published on Sep 13th, 2015 and updated on Sept 11th, 2017**

Introduction

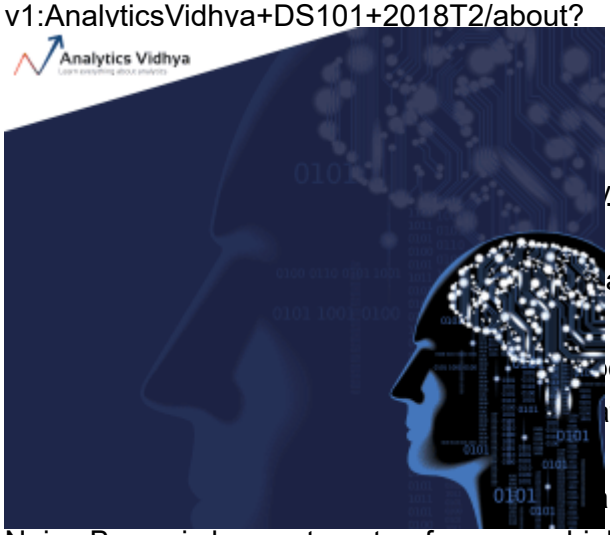
Here's a situation you've got into:

You are working on a classification problem and you have generated your set of hypothesis, created features and discussed the importance of variables. Within an hour, stakeholders want to see the first cut of the model.

What will you do? You have hunderds of thousands of data points and quite a few variables in your training data set. In such situation, if I were at your place, I would have used '**Naive Bayes**', which can be extremely fast relative to other classification algorithms. It works on Bayes theorem of probability to predict the class of unknown data set.

In this article, I'll explain the basics of this algorithm, so that next time when you come across large data sets, you can bring this algorithm to action. In addition, if you are a newbie in Python or R (https://www.analyticsvidhya.com/learning-paths-data-science-business-analytics-business-intelligence-big-data/learning-path-data-science-python/), you should be overwhelmed by the presence of available codes in this article.

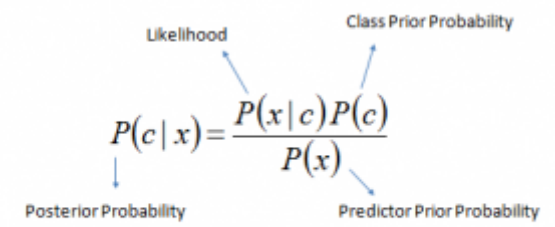
aive Bayes?
n
del in Python
es Model
(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+DS101+2018T2/about?



es' Theorem (https://en.wikipedia.org/wiki/Bayes%27_theorem)
predictors. In simple terms, a Naive Bayes classifier assumes
a class is unrelated to the presence of any other feature. For
apple if it is red, round, and about 3 inches in diameter. Even if
on the existence of the other features, all of these properties
t this fruit is an apple and that is why it is known as 'Naive'.

rticularly useful for very large data sets. Along with simplicity, Naive Bayes is known to outperform even highly sophisticated classification methods.
(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+CVDL101+CVDL101_T1/about?utm_source=CV101AVBlogBanner&utm_medium=Stickybanner2utm_campaign=CV101banner)

Bayes theorem provides a way of calculating posterior probability P(c|x) from P(c), P(x) and P(x|c). Look at the equation below:



$$P(c \mid X) = P(x_1 \mid c) \times P(x_2 \mid c) \times \cdots \times P(x_n \mid c) \times P(c)$$

(https://www.analyticsvidhya.com/wp-content/uploads/2015/09/Bayes_rule-300x172.png)Above,

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- *P*(*c*|*x*) is the posterior probability of *class* (c, *target*) given *predictor* (x, *attributes*).
- *P*(*c*) is the prior probability of *class*.
- *P*(*x*|*c*) is the likelihood which is the probability of *predictor* given *class*.
- *P*(*x*) is the prior probability of *predictor*.

I have a training data set of weather and corresponding target
ying). Now, we need to classify whether players will play or not
elow steps to perform it.

table

probabilities like Overcast probability = 0.29 and probability of
laying is 0.64

(https://trainings.analytics vidhya.com/courses/course-v1:AnalyticsVidhya+DS101+2018T2/about?utm_source=CV101AVBlogBanner&utm_medium=Stickybanner2utm_campaign=CV101banner)

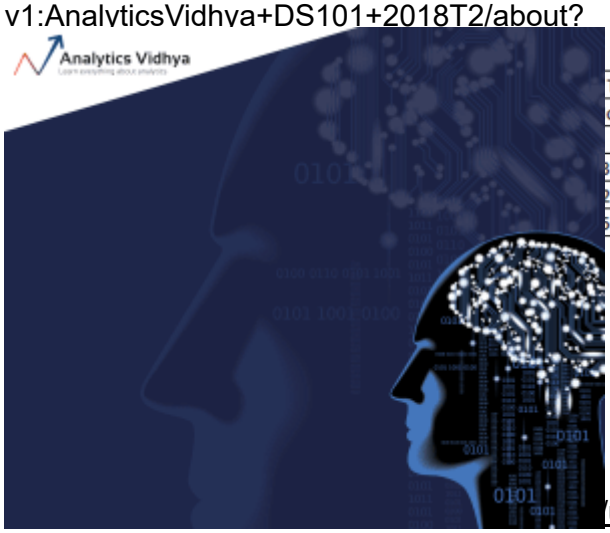

Table	
o	Yes
	4
3	2
2	3
5	9

Likelihood table				
Weather	No	Yes		
Overcast		4	=4/14	0.29
Rainy	3	2	=5/14	0.36
Sunny	2	3	=5/14	0.36
All	5	9		
	=5/14	=9/14		
	0.36	0.64		

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Step 3: Now, use Naive Bayesian equation to calculate the posterior probability for each class. The class with the highest posterior probability is the outcome of prediction.

Problem: Players will play if weather is sunny. Is this statement is correct?

We can solve it using above discussed method of posterior probability.

P(Yes | Sunny) = P(Sunny | Yes) * P(Yes) / P (Sunny)

Here we have P (Sunny |Yes) = 3/9 = 0.33, P(Sunny) = 5/14 = 0.36, P(Yes)= 9/14 = 0.64

Now, P (Yes | Sunny) = 0.33 * 0.64 / 0.36 = 0.60, which has higher probability.

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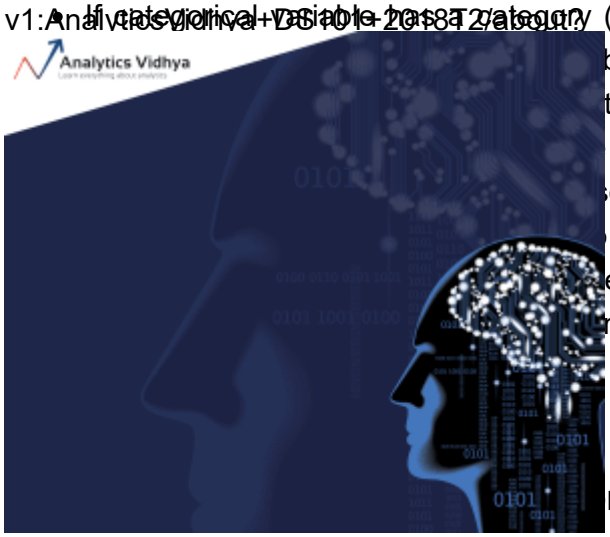
Naive Bayes uses a similar method to predict the probability of different class based on various attributes. This algorithm is mostly used in text classification and with problems having multiple classes.

ve Bayes?

t data set. It also perform well in multi class prediction
holds, a Naive Bayes classifier performs better compare to
d you need less training data.
nput variables compared to numerical variable(s). For numerical
d (bell curve, which is a strong assumption).

- If categorical variable has a category (in test data set), which was not observed in training data set, bability and will be unable to make a prediction. This is often this, we can use the smoothing technique. One of the simplest estimation.
- so known as a bad estimator, so the probability outputs from seriously.
- e assumption of independent predictors. In real life, it is almost rs which are completely independent.



rithms

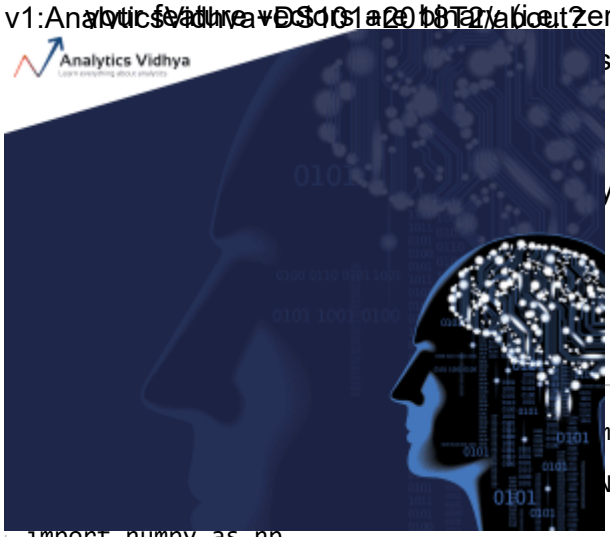
- **Real time Prediction:** Naive Bayes is an eager learning classifier and it is sure fast. Thus, it could be used for making predictions in real time.
- **Multi class Prediction:** This algorithm is also well known for multi class prediction feature. Here we can predict the probability of multiple classes of target variable.
- **Text classification/ Spam Filtering/ Sentiment Analysis:** Naive Bayes classifiers mostly used in text classification (due to better result in multi class problems and independence rule) have higher success rate as compared to other algorithms. As a result, it is widely used in Spam filtering (identify spam e-mail) and Sentiment Analysis (in social media analysis, to identify positive and negative customer sentiments)
- **Recommendation System:** Naive Bayes Classifier and Collaborative Filtering (https://en.wikipedia.org/wiki/Collaborative_filtering) together builds a Recommendation System that uses machine learning and data mining techniques to filter unseen information and predict whether a user would like a given resource or not

How to build a basic model using Naive Bayes in Python?

Again, scikit learn (python library) will help here to build a Naive Bayes model in Python. There are three ... library:

- **Gaussian (http://scikit-learn.org/stable/modules/naive_bayes.html)** It is used in classification and ... l distribution.
- **Multinomial (http://scikit-learn.org/stable/modules/naive_bayes.html):** It is used for discrete ... ve a text classification problem. Here we can consider bernoulli ... stead of "word occurring in the document", we have "count how ... ou can think of it as "number of times outcome number x_i is ...
- **Bernoulli (http://scikit-learn.org/stable/modules/naive_bayes.html):** The binomial model is useful if ... your feature vectors are binary (i.e. zeros and ones). One application would be text classification with ... s are "word occurs in the document" and "word does not occur in ...

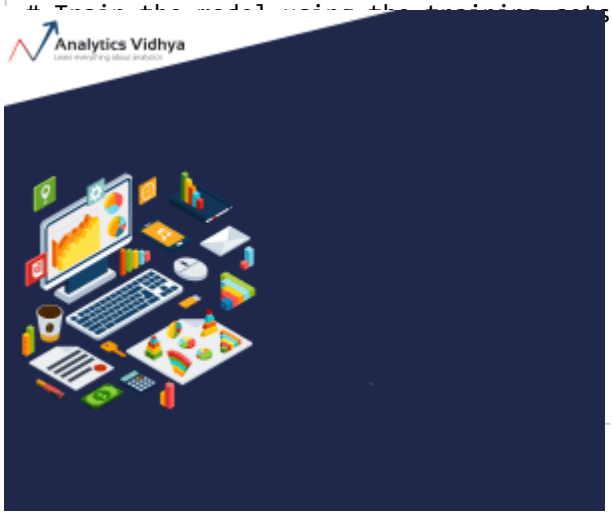
... of above discussed model. Below is the example of Gaussian ...




```
... model
... NB
import numpy as np
x= np.array([[-3,7],[1,5], [1,2], [-2,0], [2,3], [-4,0], [-1,1], [1,1], [-2,2], [2,7], [-4,1], [-2,7]])
Y = np.array([3, 3, 3, 3, 4, 3, 3, 4, 3, 4, 4, 4])
```

```
#Create a Gaussian Classifier
model = GaussianNB()

# Train the model using the training sets
```

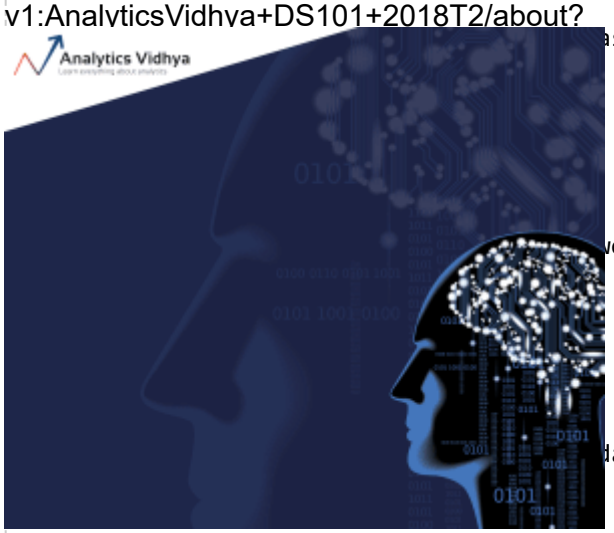


(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+DS101+2018T2/about?

```
assifier

o-class classification problem only

data = Train)
pred <- predict(model1,Test)
table(pred)
```



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Above, we looked at the basic Naive Bayes model, you can improve the power of this basic model by tuning parameters and handle assumption intelligently. Let's look at the methods to improve the performance of Naive Bayes Model. I'd recommend you to go through this document (http://www.inf.ed.ac.uk/teaching/courses/inf2b/learnnotes/inf2b-learn-note07-2up.pdf) for more details on Text classification using Naive Bayes.

Tips to improve the power of Naive Bayes Model

Here are some tips for improving power of Naive Bayes Model:

- If continuous features do not have normal distribution, we should use transformation or different methods to convert it in normal distribution.
- If test data set has zero frequency issue, apply smoothing techniques “Laplace Correction” to predict the class of test data set.
- Remove correlated features, as the highly correlated features are voted twice in the model and it can

tions for parameter tuning like alpha=1 for smoothing, fit_prior= abilities or not and some other options (look at detail here

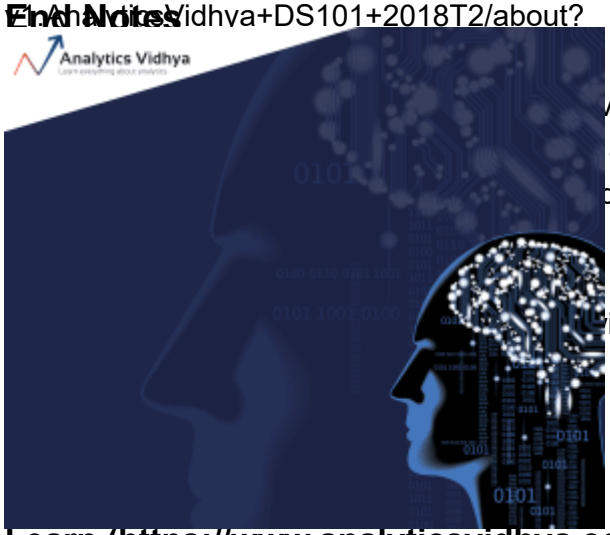
earn.naive_bayes.MultinomialNB.html#sklearn.naive_bayes.Multino

re-processing of data and the feature selection.

r combination technique like ensembling, bagging and boosting ctually, “ensembling, boosting, bagging” won’t help since their ayes has no variance to minimize.

(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+DS101+2018T2/about?

End Notes



vised machine learning algorithm “Naive Bayes” mainly used for & understood this article, you’ve already taken you first step to d is practice.

on data pre-processing and feature selection prior to applying ill discuss about text and document classification using naive

your opinions / thoughts in the comments section below.

TAGS : MACHINE LEARNING (HTTPS://WWW.ANALYTICSVIDHYA.COM/BLOG/TAG/MACHINE-LEARNING/), NAIVE BAYES

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ray/)

Sunil Ray (Https://Www.Analyticsvidhya.Com/Blog/Author/Sunil-Ray/)

I am a Business Analytics and Intelligence professional with deep experience in the Indian Insurance industry. I have worked for various multi-national Insurance companies in last 7 years.

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(https://www.analyticsvidhya.com/algorithm-easy-steps/)

How to use XGBoost algorithm in R in easy steps (https://www.analyticsvidhya.com/blog/2016/01/xgboost-algorithm-easy-steps/)

41 COMMENTS

ARUN CR Reply

September 14, 2015 at 5:36 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-94915)

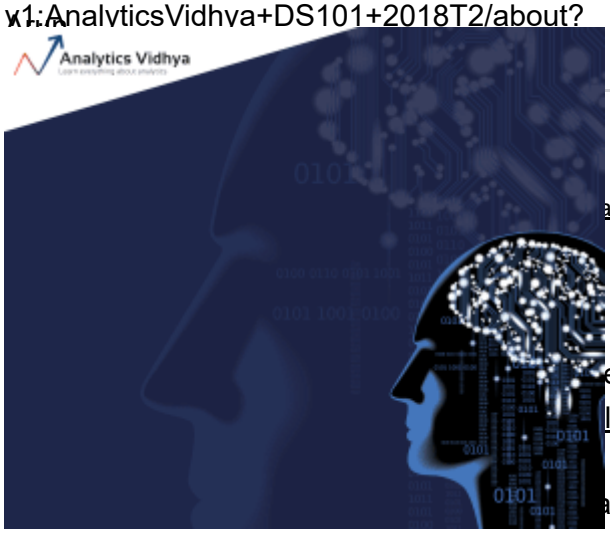
e [1] we know that

ve this?

ng conditional probability. can you suggest such examples.

Thanks,

v1:AnalytcsVidhva+DS101+2018T2/about?



Reply

analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-104496)

e of conditional probability is the Monty Hall problem.

lem (https://en.wikipedia.org/wiki/Monty_Hall_problem)

rticular problem because the solution depends on Bayes'

Theorem, which was described earlier in the article.

(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+CVDL101+CVDL101_T1/about?utm_source=CV101AVBlogBanner&utm_medium=Stickybanner2utm_campaign=CV101banner)

ERDEM KARAKOYLU Reply

March 17, 2016 at 2:26 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-107604)

It's a trivial example for illustration. The "Likelihood table" (a confusing misnomer, I think) is in fact a probability table that has the JOINT weather and play outcome probabilities in the center, and the MARGINAL probabilities of one variable (from integrating out the other variable from the joint) on the side and bottom.

Say, weather type = w and play outcome = p.
P(w,p) is the joint probabilities and P(p) and P(w) are the marginals. Bayes rule described above by Sunil stems from:
P(w,p) = P(w|p) * P(p) = P(p|w) * P(w).
From the center cells we have P(w,p) and from the side/bottom we get P(p) and P(w).

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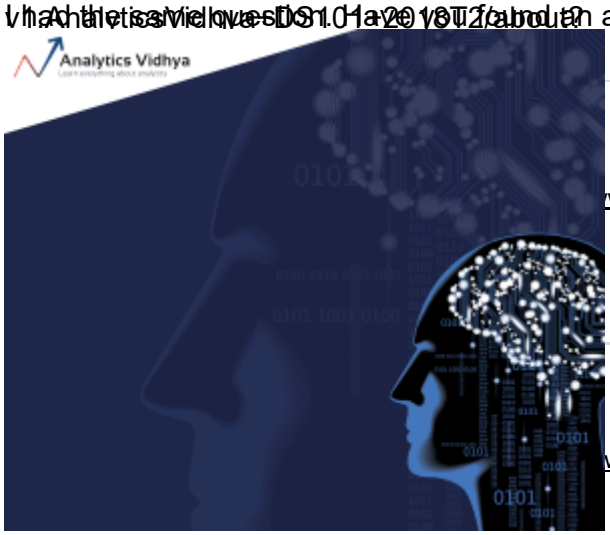
Depending on what you need to calculate, it follows that:
(1): P(w|p) = P(w,p) / P(p) and
(2:)P(p|w) = P(w,p) / P(w), which is what you did with P(sunny,yes) = 3/14 and P(w) = 5/14, yielding (3/14) (14/5), with the 14's cancelling out.

of the two quantities above, P(w|p) or P(p|w) is much harder to
r you'll come to see this as one of two mathematical miracles
cability of Markov Chain Monte Carlo in circumventing some
I digress.

Reply

yticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-113751)

(https://trainings.analyticsvidhya.com/courses/course-
v1:AnalyticsVidhya+DS101+2018_T2/about?
I had the same question. Is there an answer? Thanks!



Reply

w.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-94918)

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ww.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-

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v1:Analyticsvidhya+CVDL101+CVDL101_T1/about?
Amazing content and useful information
utm_source=CV101AVBlogBanner&utm_medium=Stickybanner2utm_campaign=CV101banner)

LEENA **Reply**

February 8, 2016 at 5:59 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-105356)

I'm new to machine learning and Python.Could you please help to read data from CSV and to separate the same data set to training and test data

ISMAEL EZEQUIEL (HTTPS://GITHUB.COM/ISMAELEZEQUIEL) **Reply**

October 15, 2016 at 12:12 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-117171)

import pandas as pd

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```
person = pd.read_csv('example.csv')
mask = np.random.rand(len(sales)) < 0.8
train = sales[mask]
test = sales[~mask]
```

Reply

lyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-106807)

Reply

alyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-107493)

ase give me that code in JAVA
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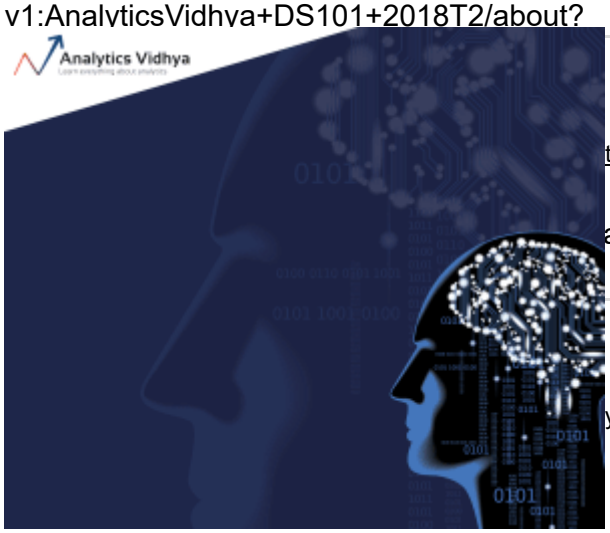

Reply

ticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-108955)

ata mining tool??

Reply

yticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-109291)

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DEVENIR PICHE AU MAROC (HTTP://WWW.COACHOUTLET-FACTORYSTORE3.COM/2015/10/25/JEUX-DARGENT-VS-TRADING/) **Reply**

April 14, 2016 at 5:13 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-109474)

I am really impressed together with your writing skills as wwell as with the format to your weblog.
Is that this a paid theme or did you customiz it yourself?
Anyway stay up the excellent quality writing, it's uncommon tto see a great weblog like this one these days..

รับซื้อ PATEK PHILIPPE (HTTPS://WWW.FACEBOOK.COM/SHINBRANDNAME) **Reply**

April 22, 2016 at 3:52 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-109828)

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You should be a part of a contest for one of the most useful websites online.
I will highly recommend this blog!

TINGTING Reply

July 13, 2016 at 6:57 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-109857)

f models, that ‘s really precious experience.

Reply

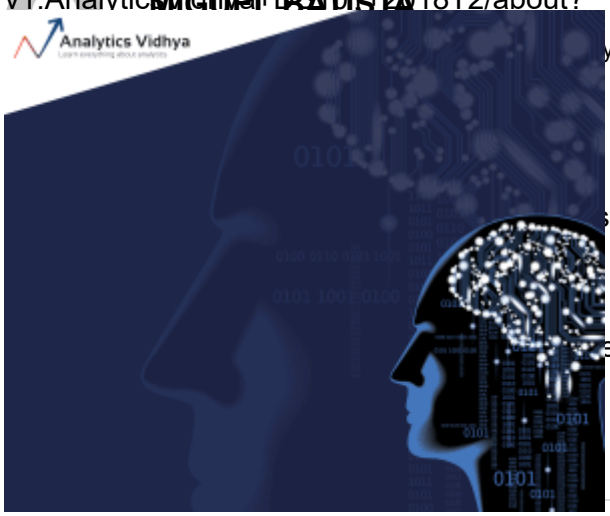
yticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-110810)

e require a CA OCF-1 , We used a sample document here

(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+DS101+2018T2/about?

Mithun PATISTA Reply

yticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-110816)



stribution, we should use transformation or different methods to

echniques?

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BD TV (HTTP://WWW.BANGLADESHILIVETV.COM/) Reply

June 21, 2016 at 2:45 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-111907)

Can I simply just say what a comfort too find someone
who actualy knows what they’re talking about over the
internet. You certainly know how to bring an issue to light and make it important.

A lot more people ought to read this and understand this side of your story.
I can’t believe you aren’t more popular because you certainly have the gift.

NIR Reply

July 13, 2016 at 6:57 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-113416)

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Great article! Thanks. Are there any similar articles for other classification algorithms specially target towards textual features and mix of textual/numeric features?

NICK Reply

nalyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-114946)

Reply

nalyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-115295)

t. Thank you!

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PANGAVHANE NITIN Reply

September 1, 2016 at 6:54 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-115354)

Reply

nalyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-115357)

ned! Loved this article.

Reply

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September 1, 2016 at 7:02 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-115421)

The 'y' should be capitalized in your code – great article though.

AKASH SWAMY Reply

September 6, 2016 at 7:24 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-115661)

This is the best explanation of NB so far simple and short 🙂

JOHN (HTTPS://FLOOFYDUGONG.GITHUB.IO/) Reply

September 9, 2016 at 5:20 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-115863)

Great article! Really enjoyed it. Just wanted to point out a small error in the Python code.

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Should be a capital “Y” in the predict like so : model.fit(x, Y)

Thanks!

Reply

w.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-116232)

sed as a newbie. Can you please guide?

Reply

analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-117314)

ncept

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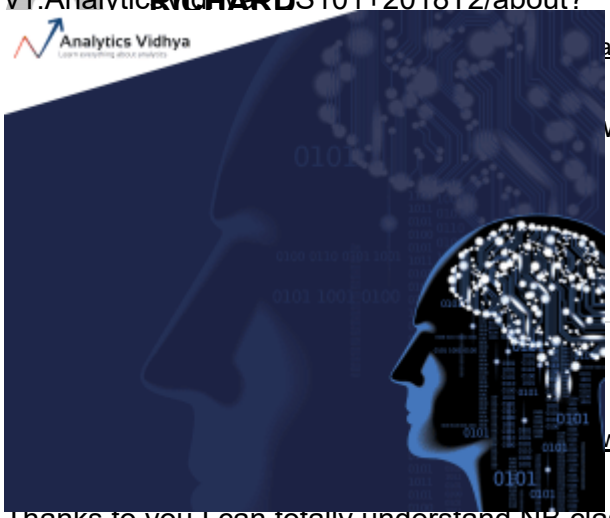
RICHARD **Reply**



analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-117495)

vas handy to me in understanding naive bayes especially the

Reply

w.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-118208)

Thanks to you I can totally understand NB classifier.

(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+CVDL101+CVDL101_T1/about?utm_source=CV101AVBlogBanner&utm_medium=Stickybanner2utm_campaign=CV101banner)

T B **Reply**

July 3, 2017 at 12:17 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-131449)

Really nice article, very use-full for concept building.

AKSHAY **Reply**

July 4, 2017 at 8:40 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-131533)

I didn’t understand the 3rd step. Highest probability out of which probability values?

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>> Now, P (Yes | Sunny) = 0.33 * 0.64 / 0.36 = 0.60, which has higher probability.
Higher than what?

RN Reply

April 12, 2018 at 10:19 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-133229)

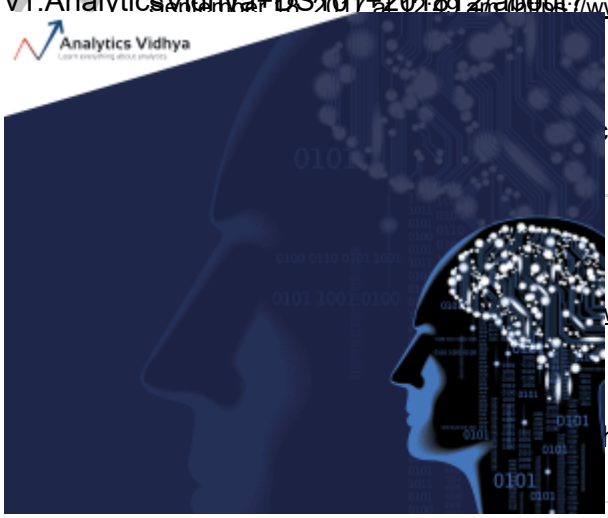
Reply

nalyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-135803)

l this concept

AMIT KUMAR YADAV Reply

April 17, 2018 at 11:21 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-



cuments classification using naive base algorithm.

Reply

ww.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-

he simplicity.Thanks for the effort.

AISHWARYA Reply

November 20, 2017 at 10:12 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-144881)

Good start point for beginners

ABDUL SAMAD Reply

April 12, 2018 at 10:19 am (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-152525)

Weldone sanil
I have a question regarding naive bayes,currently i am working on a project that is detect depression through naive bayes algorithm so plz suggest few links regarding my projects.i shall be gratefull to you.
Thanku so much

AISHWARYA SINGH **Reply**

April 16, 2018 at 4:37 pm (https://www.analyticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-152600)

ed=0ahUKEwix5veO077aAhWCrY8KHeWeBj8QFghkMAQ&url=
w0RSlYviBCcjh9efgoKhKMz) link.

Reply

ticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-153048)

les. Can someone help me

(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+DS101+2018_T2/about?

AISHWARYA SINGH **Reply**

ticsvidhya.com/blog/2017/09/naive-bayes-explained/#comment-153068)

d y is used for target variable (which is to be predicted).

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(https://www.analyticsvidhya.com/blog/2017/09/understaing-support-vector-machine-example-code/)

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thm (with codes in Python and R)
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lified (with implementation in Python)
8/03/introduction-k-neighbours-algorithm-clustering/)

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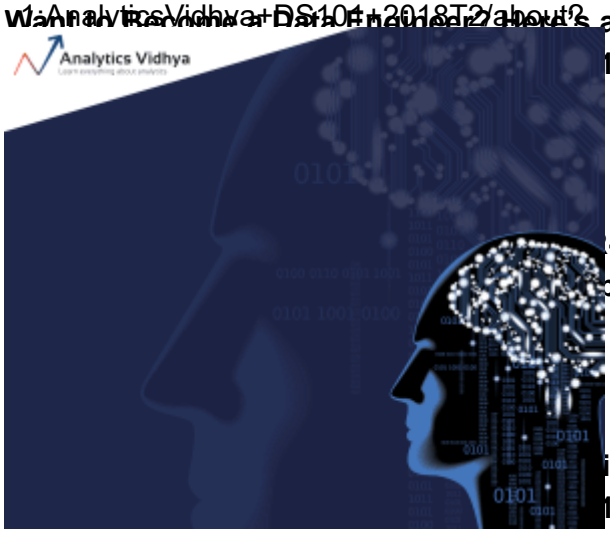

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ies & Reddit Discussions (October 2018)
18/11/best-machine-learning-github-repositories-reddit-
(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+CVDL101+CVDL101_T1/about?utm_source=CV101AVBlogBanner&utm_medium=Stickybanner2utm_campaign=CV101banner)

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(https://www.analyticsvidhya.com/blog/2018/11/introduction-text-summarization-textrank-python/)

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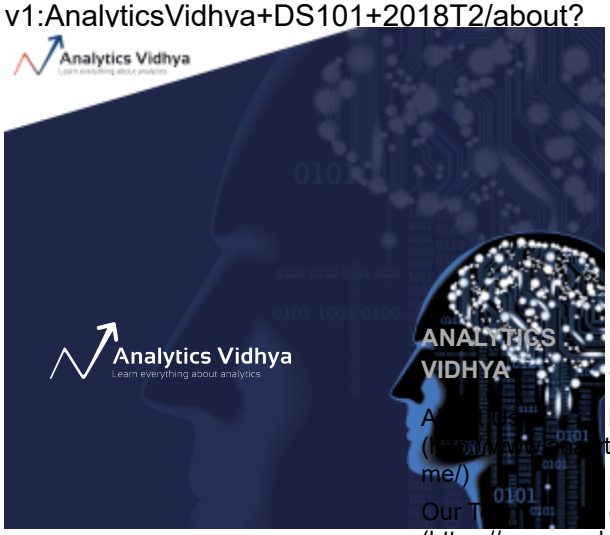
(http://www.edvancer.in/certified-data-scientist-with-python-s&utm_campaign=AVadsnonfc&utm_content=pythonavad)



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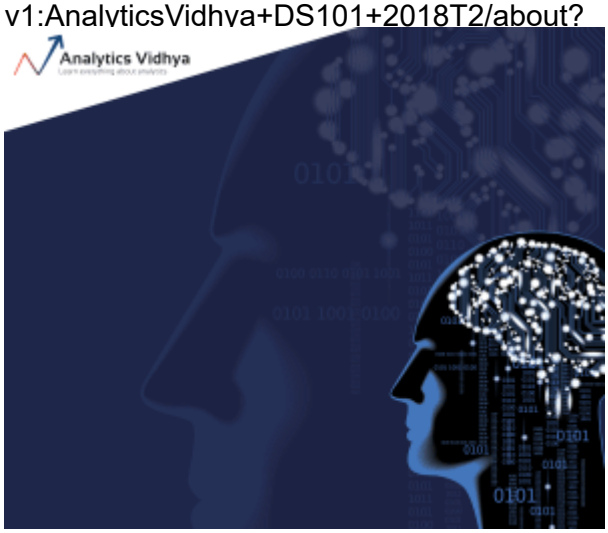
(https://trainings.analyticsvidhya.com/courses/course-v1:AnalyticsVidhya+DS101+2018T2/about?



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