

# Naive Bayes Classification in R

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# Naive Bayes Classifier

- Supervised, probabilistic classifier based on Bayes Theorem
- Strong independence assumptions
- A famous use case is spam filtering of emails
- **Factor variable** - Multinomial Naive Bayes Classifier
- **Continuous variables** - Gaussian Naive Bayes Classifier

# Data

- We are going to use **Class**, **Sex** and **Age** data to predict **Survival** on the Titanic
- We first need to get the data and do a bit of wrangling

```
data(Titanic)
str(Titanic)

#function to convert to long format (one passenger per row)
counts_to_cases <- function(x){
  #how many time to repeat each row
  inds <- rep.int(seq_len(nrow(x)), times = x[["Freq"]])
  #remove frequency column
  x <- select(x, -Freq)
  #get rows from x
  x[inds,]
}

case_titanic <- counts_to_cases(as.data.frame(Titanic))

#head(case_titanic, 3)
#dim(case_titanic)
```

# Split into test and training

- We will train our Naive Bayes Classifier on 80% of the data
- We can use the caret package to split the data

```
library(caret, warn.conflicts = F, quietly = T)

set.seed(1234)
split <- createDataPartition(case_titanic$Survived, p = 0.8, list = FALSE)

train <- case_titanic[split, ]
test <- case_titanic[-split, ]

c(nrow(train), nrow(test)) # print number of observations in test vs. train
table(train$Survived) %>% prop.table() # Proportions of Survived Yes and No
```

# Naive Bayes: An Overview

- Bayes Theorem, by Reverend Thomas Bayes, is about **conditional probability**; the probability of A given that B occurred [denoted as  $P(A|B)$ ]
- In our Titanic example, the probability of a passenger having survived  $S_k$  (where  $S_{yes}$  = survived and  $S_{no}$  = did not survive), given that its predictor values are  $x_1, x_2, \dots, x_p$  [denoted as  $P(S_k|x_1, \dots, x_p)$ ].

# Naive Bayes: An Overview

Bayes Theorem looks like this:

$$P(S_k|X) = \frac{P(X|S_k) \cdot P(S_k)}{P(X)}$$

where:

- $P(S_k)$  The **prior probability** of the outcome - based on the training data, what is the probability of a person surviving or not? Our prior probability of survival is ~32% and the probability of not surviving is ~68%.
- $P(X)$  The probability of observing the predictor variables.
- $P(X|S_k)$  The **conditional probability** or **likelihood**, For each class (*i.e.* survived and no survived), what is the probability of observing the predictors.
- $P(S_k|X)$  The **posterior probability**. We update our prior probabilities with our observed information to find the posterior probability that an observation has class  $S_k$ .

# Naive Bayes: An Overview

$$P(S_{yes}|X) < P(S_{no}|X)$$

$$P(S_{yes}|X) = P(S_{no}|X)$$

$$P(S_{yes}|X) > P(S_{no}|X)$$

- Because we are comparing **between** classes, we don't need the denominator  $P(X)$  as it will be the same in both classes.
- So what we actually end up calculating is proportional (not equal to) to  $P(S_k|X)$

# Naive Bayes: Why Naive?

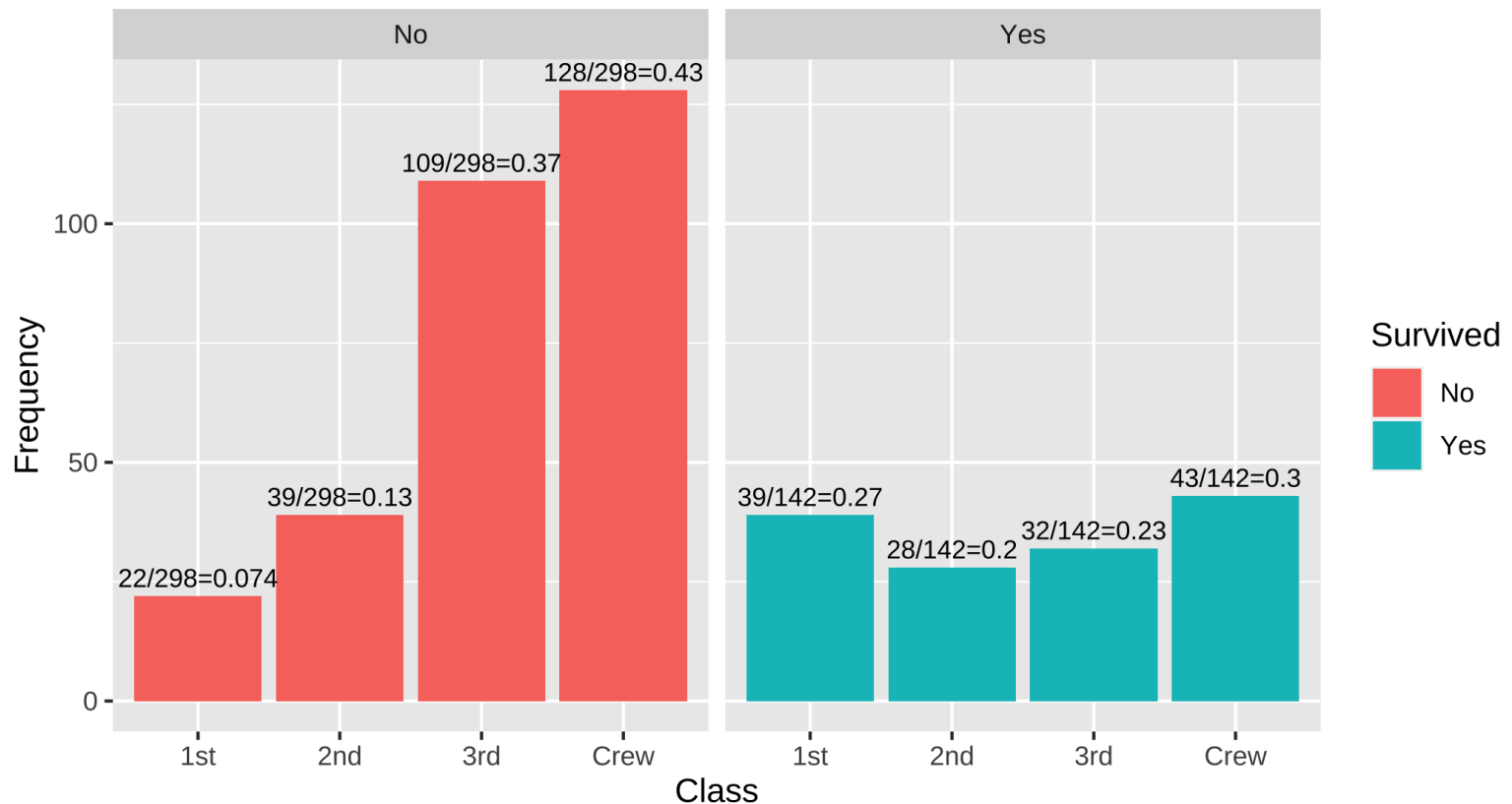
- To compute the posterior probability for a response variable with  $m$  classes and  $p$  variables would require  $m^p$  probabilities computed. e.g. 30 variables in 2 classes =  $2^{30} = 1073741824$  probabilities.
- Naive Bayes makes the assumption that the predictor variables are all *conditionally independent* of each other
- This is to simplify the calculation, the number of probabilities to compute is now  $m * p$

$$P(S_k|X) \propto P(S_k) \cdot \prod_{i=1}^n P(x_i|S_k)$$



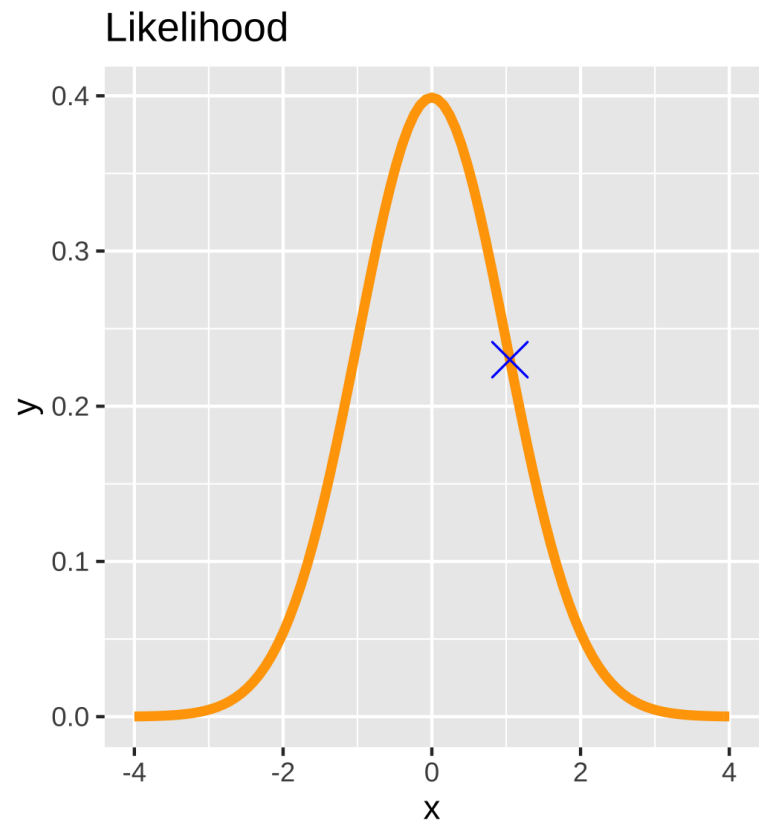
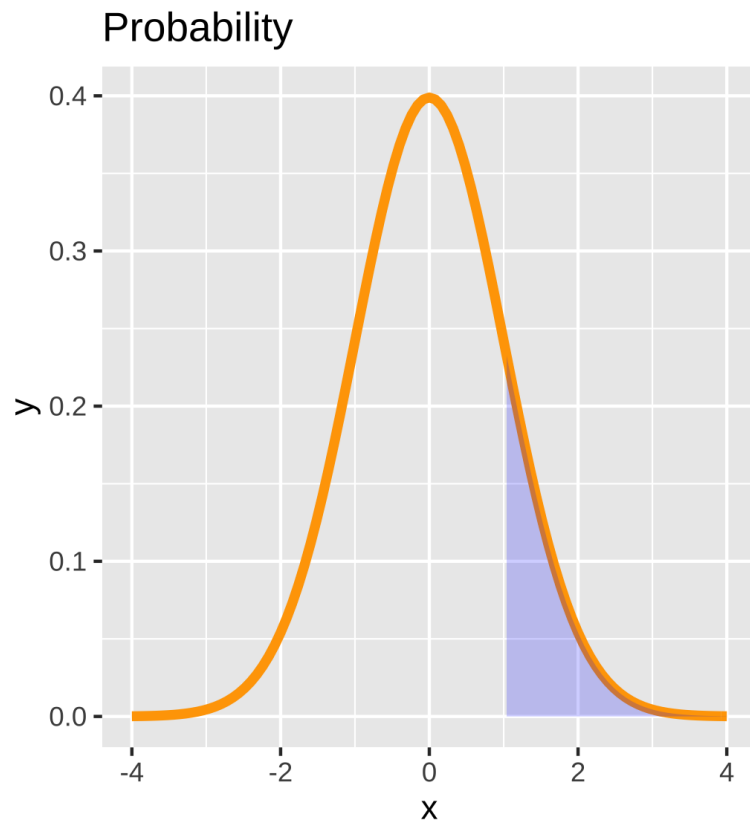
# Calculating Likelihoods

- **Factor Variables** - use frequencies from the training data to calculate probabilities of the each predictor in each class (like our Titanic data).
- For factor variables, **probabilities = likelihoods**.



# Calculating Likelihoods

- **Continuous Variables** - use a probability density function (PDF), e.g. Gaussian, to calculate the **likelihood** of each predictor in a class.
- n.b. For continuous variable, **probabilities and likelihoods are different**



# Naive Bayes Classifier with factor variables - Titanic Survival

There are lots of R packages to apply naive bayes (e1071, klaR, naivebayes etc...) but I like caret - common framework for many algorithms.

```
predictors <- names(train)[1:3] #Create response and predictor data

x <- train[,predictors] #predictors
y <- train$Survived #response

train_control <- trainControl(method = "cv", number = 10) #set up 10 fo.

survival_mod1 <- train( #train the model
  x = x,
  y = y,
  method = "nb",
  trControl = train_control
)

confusionMatrix(survival_mod1) #results of model on training data

pred <- predict(survival_mod1, newdata = test) #make predictions

confusionMatrix(pred, test$Survived) #assessing the classifier
```

# Gaussian Naive Bayes - Iris dataset

- Predict Species based on sepal length, sepal width, petal length and petal width.

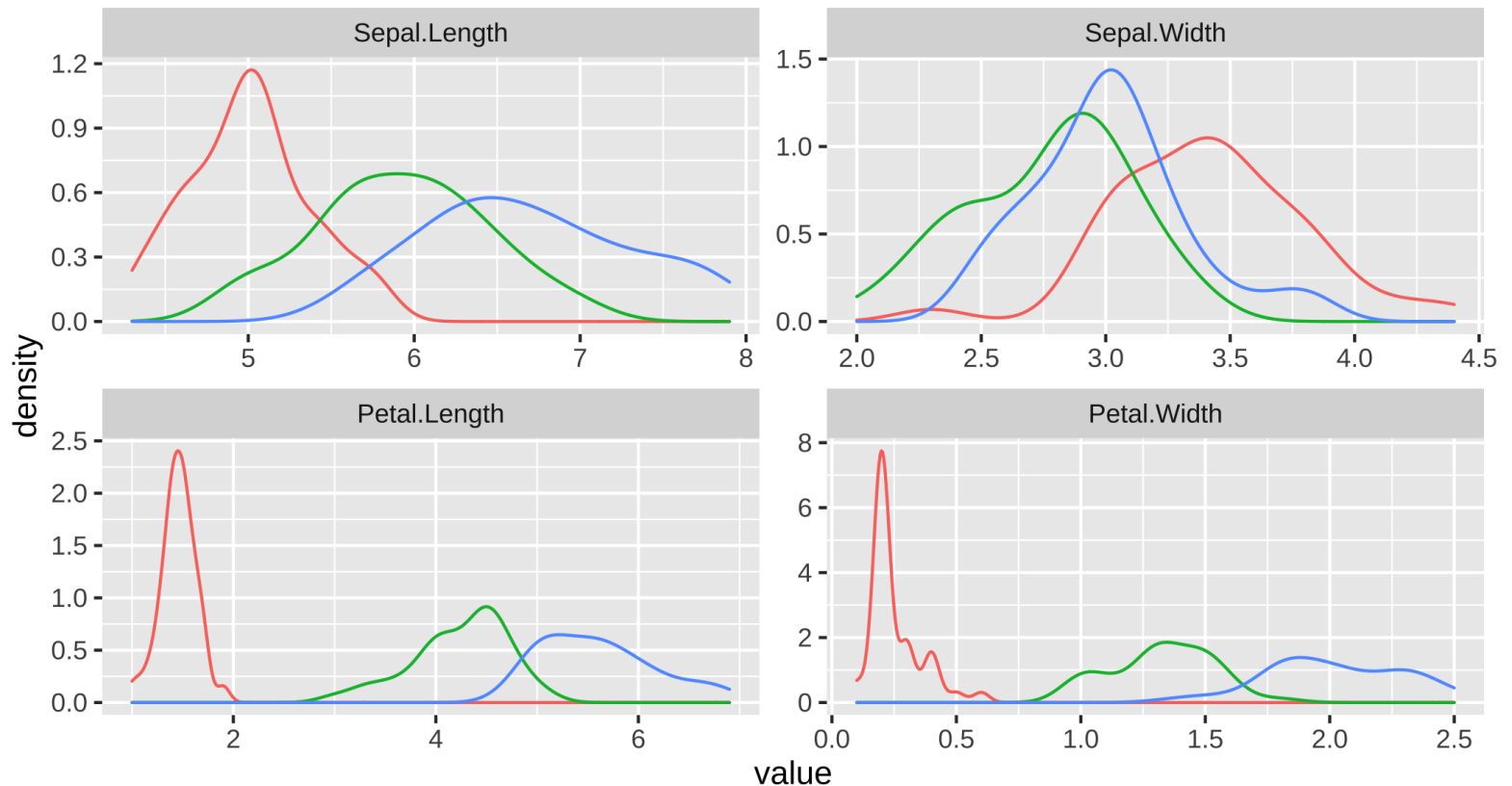
```
set.seed(1234)
split <- createDataPartition(iris$Species, p = 0.8, list = FALSE)

train <- iris[split, ]
test <- iris[-split, ]

c(nrow(train), nrow(test)) # print number of observations in test vs. train
table(train$Species) %>% prop.table() # Proportions of Survived Yes and No
```

# Gaussian Naive Bayes - Iris dataset

- Checking assumption of gaussian distribution
- Are data normally distributed? Do we need to transform? Or should we use non-parametric kernel density distribution instead? (Actually we will try both by tuning the model)



# Gaussian Naive Bayes - Iris dataset

- First, fit a model with 10 fold cross validation

```
predictors <- names(train)[1:4] #Create response and predictor data

x <- train[,predictors] #predictors
y <- train$Species #response

train_control <- trainControl(method = "cv", number = 10) #set up 10 fo.

species_mod1 <- train( #train the model
  x = x,
  y = y,
  method = "nb",
  trControl = train_control
)

confusionMatrix(species_mod1) #results of model on training data
```

# Gaussian Naive Bayes - Iris dataset

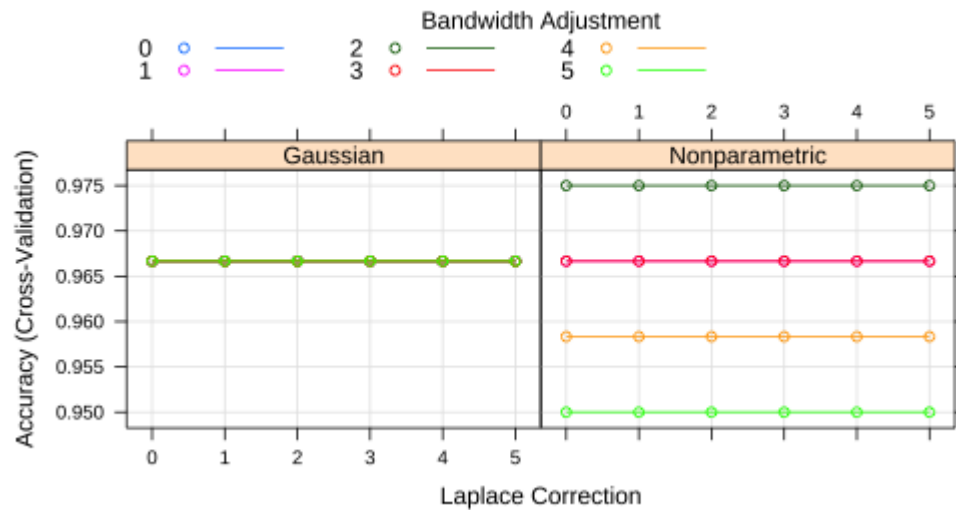
- Can we do any better?
- Tuning parameters = `usekernel`, `adjust`, `fL`

```
tune_params <- expand.grid( #define tuning parameters
  usekernel = c(TRUE, FALSE),
  fL = 0:5,
  adjust = 0:5
)

# train model
species_mod2 <- train(
  x = x,
  y = y,
  method = "nb",
  trControl = train_control,
  tuneGrid = tune_params
)
```

# Gaussian Naive Bayes - Iris dataset

```
plot(species_mod2)
```



- Laplace smoother makes no difference
- Non parametric Kernel with Bandwidth = 2 is best



# Gaussian Naive Bayes - Iris dataset

- Results for best model

```
confusionMatrix(species_mod2) #results of model on training data  
                                # we have improved accuracy a tiny bit  
  
pred <- predict(species_mod2, newdata = test) #make predictions  
  
confusionMatrix(pred, test$Species) #assessing the classifier
```

# Overcoming randomness of splitting data

- Split data into test and training 10 times, and perform tuning & cross validation within each one

```
n <- nrow(iris) #number of observations in iris

splits <- createDataPartition(iris$Species, p = 0.8, list = FALSE, times = 10)
train_control <- trainControl(method = "cv", number = 10) #set up 10 folds
tune_params <- expand.grid(#define tuning parameters
  usekernel = c(TRUE, FALSE),
  fl = 0:5,
  adjust = 0:5
)
```

# Overcoming randomness of splitting data

- Split data into test and training 10 times, and perform tuning & cross validation within each one

```
all_mods <- lapply(seq_len(ncol(splits)), function(i){  
  
  train <- iris[splits[,i], ] #split into i'th test and train  
  test <- iris[-splits[,i], ]  
  
  predictors <- names(train)[1:4] #Create response and predictor data  
  
  x <- train[,predictors] #predictors  
  y <- train$Species #response  
  
  species_mod <- train( #fit models with tuning and cv  
    x = x,  
    y = y,  
    method = "nb",  
    trControl = train_control,  
    tuneGrid = tune_params  
  )  
  
  pred <- predict(species_mod, newdata = test) #make predictions  
  
  confusionMatrix(pred, test$Species)$overall["Accuracy"] #assessing the  
})
```

# Overcoming randomness of splitting data

- Split data into test and training 10 times, and perform tuning & cross validation within each one

```
mean(unlist(all_mods))  
sd(unlist(all_mods))
```

# Naive Bayes Pros and Cons

## Pros

- Simple
- Fast
- Scales well

## Cons

- Assumes independence of variables
- Assumes all variables are equally important
- Not as accurate as other methods e.g. Random Forests

# Extra reading/listening

Confused? Go here:

- A great conceptual overview [StatQuest](#)

Feeling confident? Try this:

- Use the caret *preProc* argument in [train\(\)](#) to see if preprocessing the iris dataset improves model accuracy
- Try using the [h2o](#) package instead

Just for fun:

- Listen to this [Data Skeptic](#) podcast

## References

- UC Business Analytics Tutorial
- Zhang, 2016