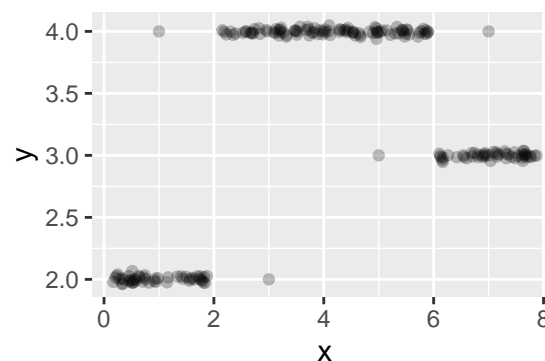


**Exercise 1:**

You are given the following table with the target variable **Banana**:

ID	Color	Form	Origin	Banana?
1	yellow	oblong	imported	yes
2	yellow	round	domestic	no
3	yellow	oblong	imported	no
4	brown	oblong	imported	yes
5	brown	round	domestic	no
6	green	round	imported	yes
7	green	oblong	domestic	no
8	red	round	imported	no

- We want to use a Naive Bayes classifier to predict whether a new fruit is a **Banana** or not. Calculate the posterior probability  $\hat{\pi}(\mathbf{x}_*)$  for a new observation  $\mathbf{x}_* = (\text{yellow}, \text{round}, \text{imported})$ . How would you classify the object?
- Assume you have an additional feature **Length** that measures the length in cm. Describe in 1-2 sentences how you would handle this numeric feature with Naive Bayes.

**Exercise 2:**

The above plot shows  $\mathcal{D} = ((\mathbf{x}^{(1)}, y^{(1)}), \dots, (\mathbf{x}^{(n)}, y^{(n)}))$ , a data set with  $n = 200$  observations of a continuous target variable  $y$  and a continuous, 1-dimensional feature variable  $\mathbf{x}$ . In the following, we aim at predicting  $y$  with a machine learning model that takes  $\mathbf{x}$  as input.

- To prepare the data for classification, we categorize the target variable  $y$  in 3 classes and call the transformed target variable  $z$ , as follows:

$$z^{(i)} = \begin{cases} 1, & y^{(i)} \in (-\infty, 2.5] \\ 2, & y^{(i)} \in (2.5, 3.5] \\ 3, & y^{(i)} \in (3.5, \infty) \end{cases}$$

Now we can apply quadratic discriminant analysis (QDA):

- Estimate the class means  $\mu_k = \mathbb{E}(\mathbf{x}|z = k)$  for each of the three classes  $k \in \{1, 2, 3\}$  visually from the plot. Do not overcomplicate this, a rough estimate is sufficient here.
- Make a hand-drawn plot that visualizes the different estimated densities per class.

- iii) How would your drawing from ii) change if we used linear discriminant analysis (LDA) instead of QDA? Explain your answer.
- iv) Why is QDA preferable over LDA for this data?
- b) Given are two new observations  $\mathbf{x}_{*1} = -10$  and  $\mathbf{x}_{*2} = 7$ . State the prediction for QDA and explain how you arrive there.
- c) We will now derive the LDA decision boundary for a binary problem in two dimensions. For this, we employ the alternative description of the LDA decision rule we (implicitly) used to demonstrate LDA's linearity:

$$\delta_k(\mathbf{x}) = \log \pi_k - \frac{1}{2} \boldsymbol{\mu}_k^T \boldsymbol{\Sigma}^{-1} \boldsymbol{\mu}_k + \mathbf{x}^T \boldsymbol{\Sigma}^{-1} \boldsymbol{\mu}_k, \quad k \in \{1, 2\},$$

which is also maximized to find the loss-optimal prediction. Explicitly state the equation for the boundary between the two classes.

(Hint: first think about the relation of the two discriminant functions on the decision boundary.)

- d) Implement your own version of QDA:

```
train_qda <- function(target, data) {...}
predict_qda <- function(target, data) {...}
```

The first function should return the fitted model (use an adequate structure for the model!). The second function should return a factor of classes for `type = 'class'` and a matrix of predicted probabilities for `type = 'prob'` (similar to the standard `mlr3` output options). Your method only needs to work for numeric features. Check your implementation on the `iris` data and compare your results of both types with the `qda()` function from package `MASS`.

- e) Turn your QDA classifier into a Naive Bayes classifier by appropriate modification. Can you see why NB is more “naive” than general QDA?