Nicholas Orriols

Statistical Learning

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generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAkACQAAD/4RDyRXhpZgAATU0AKgAAAAgABAE7AAIAAAANAAAISodpAAQAAAABAAAIWJydAAEAAAAaAAAQ0OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAE5pY2sgT3JyaW9scwAAAAWQAwACAAAAFAAAEKaQBAACAAAAFAAAELqSkQACAAAAAzY5AACSkgACAAAAAzY5AADqHAAHAAAIDAAACJoAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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2

2. (i) After loading the data, the following code fits the first model. It then produces a plot where filled triangles represent points in the training data and are colored according to whether they are classified as a success (blue) or failure (orange). The plot also contains a uniform grid of points which are colored according to whether the model predicts them as a success or failure. The color of grid a triangle is over represents how that point would be classified in the given model; in particular, if a triangle is colored differently than the portion it is above, that means the model would have classified it incorrectly.

> train.p2=read.csv("Problem2.csv")

> test.p2=read.csv("Problem2test.csv")

>

> library(MASS)

> library(ggplot2)

>

> buff = 2

> x1seq=seq(min(train.p2$X1)-buff,max(train.p2$X1)+buff,by=.1)

> x2seq=seq(min(train.p2$X2)-buff,max(train.p2$X2)+buff,by=.1)

> grid=expand.grid(X1=x1seq,X2=x2seq)

>

> # mod1

> mod1=glm(Y~X1+X2, family = binomial, data=train.p2)

>

> prob.grid1=predict.glm(mod1, newdata=grid, type="response")

> pred.grid1=as.numeric(prob.grid1 >= .5)

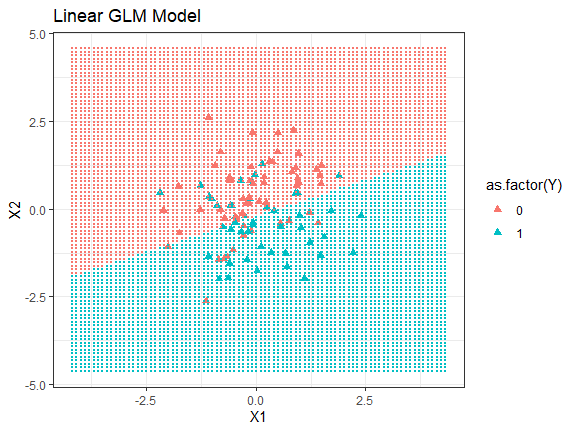
>

> ggplot(data=train.p2, aes(x=X1,y=X2)) +

+ geom\_point(aes(colour=as.factor(Y)), shape=17, size=2) +

+ geom\_point(data=grid,aes(x=X1,y=X2,colour=as.factor(pred.grid1)), size=.01) +

+ theme\_bw() + ggtitle("Linear GLM Model")



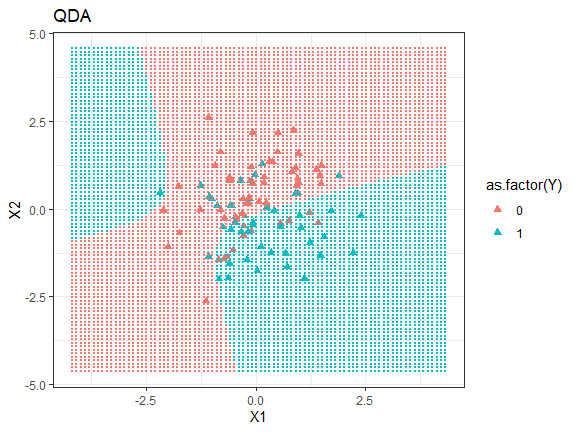
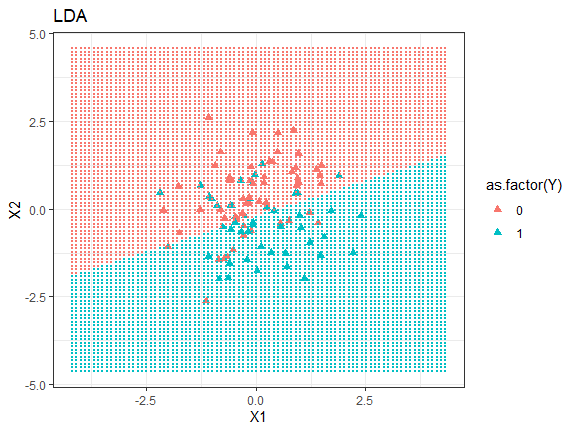
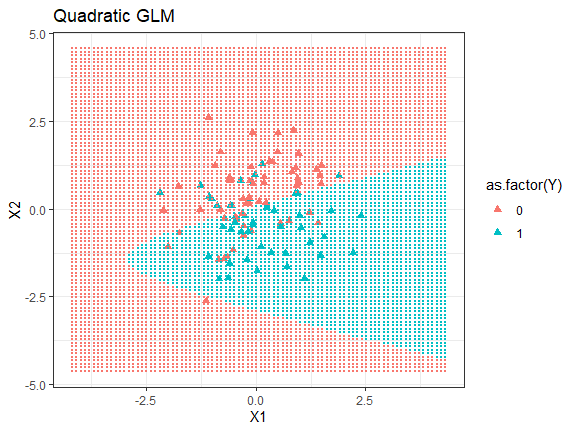
The following code fits the three other models.

> mod2=glm(Y~X1+I(X1\*\*2)+X2+I(X2\*\*2), family=binomial, data=train.p2)

> mod3=lda(Y~X1+X2, data=train.p2)

> mod4=qda(Y~X1+X2, data=train.p2)

Then the 1st block of code (with minor modifications for each different model) can be used to produce the following graphs.



(ii) The linear GLM and LDA model (and their plots) have a single, linear decision boundary and are nearly identical (their decision boundaries are extremely similar but not identical). The quadratic GLM has a parabolic decision boundary, and the QDA model has 2 somewhat parabolic decision boundaries.

All the models have smooth decision boundaries, but the QDA model has the largest variance (which was expected since it estimates more parameters than the other models). Therefore, the QDA model is the most likely to be overfit to the data, but we need to see its testing error rate to confirm this.

(iii) The following code computes the testing error rate for each model.

> t1=predict.glm(mod1, newdata = test.p2[,-1], type="response")

> v1=as.numeric(t1 >= .5)

> mean(v1 != test.p2[,1])

[1] 0.296

>

> t2=predict.glm(mod2, newdata=test.p2[,-1], type="response")

> v2=as.numeric(t2 >= .5)

> mean(v2 != test.p2[,1])

[1] 0.3066667

>

> v3=predict(mod3, newdata=test.p2[,-1])$class

> mean(v3 != test.p2[,1])

[1] 0.2966667

>

> v4=predict(mod4, newdata=test.p2[,-1])$class

> mean(v4 != test.p2[,1])

[1] 0.3133333

The linear GLM and LDA model have nearly identical error rates which is consistent with their graphs being nearly identical; their error rates are also the smallest. The quadratic GLM has the 2nd largest error rate, and the QDA model has the highest error rate.

Although the QDA model introduces the most variance, because its testing error rate is not very large, it seems it is not overfit to the data. A typical symptom of model overfitting is the model having a low training error rate and a high testing error rate. The following computes the training error rate for each model.

> pred.train1=predict.glm(mod1, newdata=train.p2[,-1], type="response")

> p1=as.numeric(pred.train1 >= .5)

> mean(p1 != train.p2[,1])

[1] 0.33

> pred.train2=predict.glm(mod2, newdata=train.p2[,-1],type="response")

> p2=as.numeric(pred.train2 >= .5)

> mean(p != train.p2[,1])

[1] 0.32

> pred.train3=predict(mod3, newdata=train.p2[,-1])

> mean(pred.train3$class != train.p2[,1])

[1] 0.34

> pred.train4=predict(mod4, data=train.p2[,-1])

> mean(pred.train4$class != train.p2[,1])

[1] 0.31

Since the training error rates for each model are not much lower than the corresponding testing error rates, it seems none of the models are overfit to the data.

3. (i) The following code loads the data, fits the LDA and QDA models, and produces the following plots.

> train.p3 = read.csv("Problem3.csv")

> test.p3 = read.csv("Problem3test.csv")

>

> lda=lda(Y~X1+X2, data=train.p3)

> qda=qda(Y~X1+X2, data=train.p3)

>

> buff = 2

> x1seq=seq(min(train.p3$X1)-buff,max(train.p3$X1)+buff,by=.1)

> x2seq=seq(min(train.p3$X2)-buff,max(train.p3$X2)+buff,by=.1)

> grid=expand.grid(X1=x1seq,X2=x2seq)

>

> pred.grid1=predict(lda, newdata=grid)$class

>

> ggplot(data=train.p3, aes(x=X1,y=X2)) +

+ geom\_point(data=train.p3,aes(x=X1,y=X2,colour=as.factor(Y)), shape=17, size=2) +

+ geom\_point(data=grid,aes(x=X1,y=X2,colour=as.factor(pred.grid1)), size=.01) +

+ theme\_bw() + ggtitle("LDA")

>

> pred.grid2=predict(qda, newdata=grid)$class

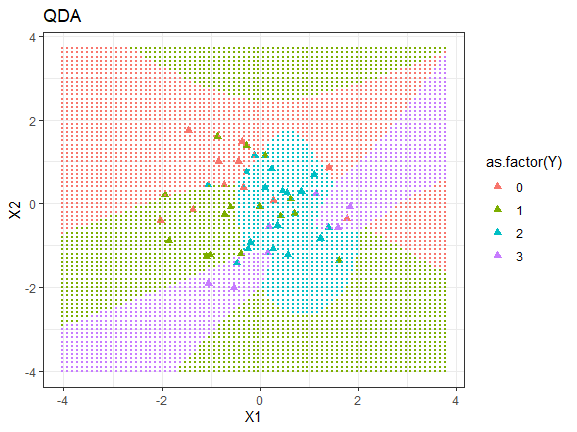
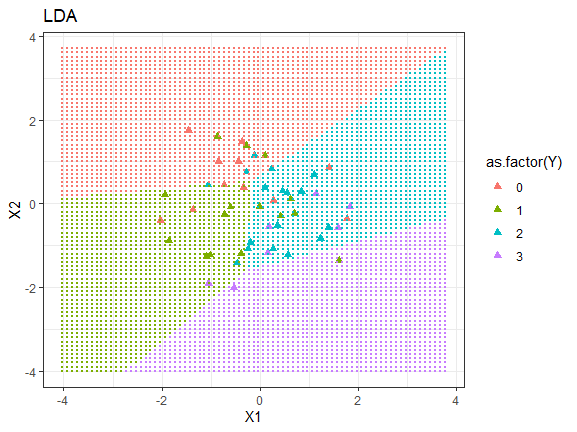
>

> ggplot(data=train.p3, aes(x=X1,y=X2)) +

+ geom\_point(data=train.p3,aes(x=X1,y=X2,colour=as.factor(Y)), shape=17, size=2) +

+ geom\_point(data=grid,aes(x=X1,y=X2,colour=as.factor(pred.grid2)), size=.01) +

+ theme\_bw() + ggtitle("QDA")



(ii) The following code computes the testing error rates for each model.

> t1=predict(lda, newdata = test.p3[,-1])$class

> mean(t1 != test.p3[,1])

[1] 0.56

>

> t2=predict(qda, newdata=test.p3[,-1])$class

> mean(t2 != test.p3[,1])

[1] 0.5953333

These error rates are significantly larger than those of the previous problem, but this is not too surprising because we are not predicting a response with 4 possible values instead of only 2. To be cautious, we can check the testing error rates: if they are very low, the models may be overfit.

> lda.train=predict(lda, newdata=train.p3[,-1])

> mean(lda.train$class != train.p3[,1])

[1] 0.5

> qda.train=predict(qda, newdata=train.p3[,-1])

> mean(qda.train$class != train.p3[,1])

[1] 0.46

Although the training error rates are lower than the testing error rates, they are not low enough to suggest overfitting.

Additionally, because the training data had 50 samples over 4 potential outcomes, we did not have many occurrences of each potential outcome. The following code finds the number of occurrences of each outcome below.

> table(train.p3[,1])

0 1 2 3

11 15 17 7

The data in question 2 had at least 46 occurrences of each potential outcome (seen with similar code to what is above), compared to at most 17 occurrences for the question 3 data. Consequently, it is plausible the models in question 3 did not have enough samples of each outcome to ‘learn’ the classifier. This is another reason likely contributing to the higher testing error rates.

(iii) It should not be of concern that the testing error rate is above 50%. Since there are 4 potential classifications for each point, if we were to classify points randomly, we would expect to be correct about 25% of the time; in other words, we would expect approximately a 75% testing error rate. Since both models have testing error rates significantly lower than that, our models are somewhat predictive of the true classifier. Additionally, as discussed in part (ii), the error rates are likely not a result of overfitting and may be related to size of the training data.

(iv) If we were to randomly guess each point’s classification, we would expect an error rate of about 75%. Since the test error rate for QDA is lower than that, then QDA is more predictive of the outcome than random guessing.