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Introduction

At the University of Wisconsin Hospital, Dr. Wolberg (Wolberg et. al (1992)) collected breast tissue samples from women using fine needle aspiration cytology (FNAC)(Newcastle University (2022)). Histological examination of the tissue collected by this procedure allows for the physician to determine whether or not it is benign or malignant. Our objective is to build a classifier based on the cytological characteristics that determines whether a tissue sample is likely to be benign or malignant.

Data Description

Dr. Wolberg reported his data chronologically to the `mlbench` R package (Wolberg et. al (1992)). The FNAC procedure allows for the identification of nine cytological characteristics (Newcastle University (2022)): clump thickness (Cl.thickness / CT), uniformity of cell size (Cell.size / CS), uniformity of cell shape (Cell.shape / CSh), marginal adhesion (Marg.adhesion / MA), single epithelial cell size (Epith.c.size / E), bare nuclei (Bare.nuclei / BN), bland chromatin (Bl.chromatin / BC), normal nucleoli (Normal.nucleoli / NN) and mitoses (Mitoses M). These characteristics for each tissue sample are measured on a discrete scale of one to ten, where smaller numbers indicate that the sample is healthier (Newcastle University (2022)). To aid our analysis, the ordinal variables of this scale have been converted to quantitative variables.

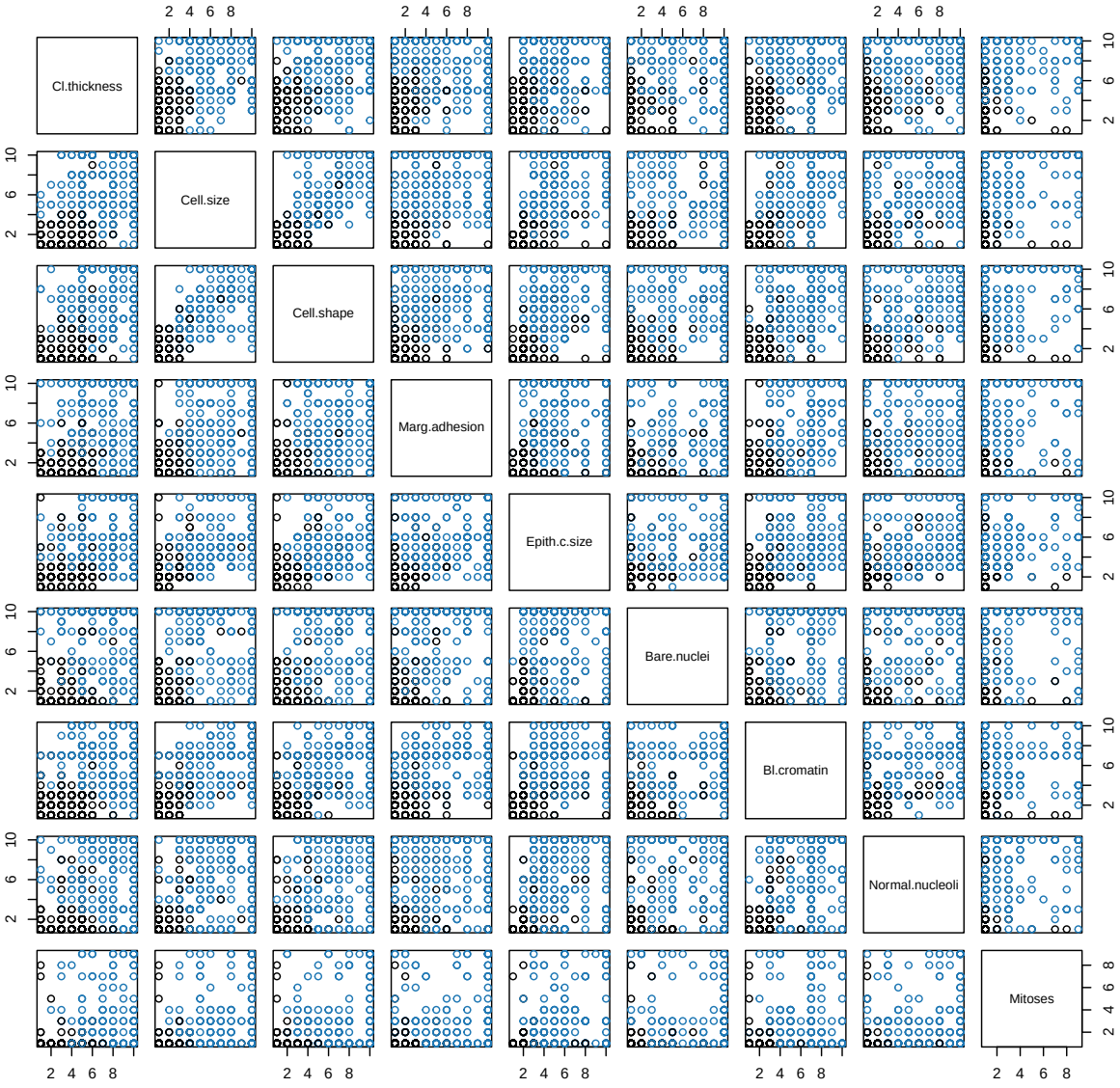
This report explores data from a sample of 699 women in the `BreastCancer` data set; please note that 16 of the 699 observations have been removed due to missing attribute values. It is assumed that this is a random sample of women experiencing symptoms of breast cancer (Newcastle University (2022)). Each woman is represented by a sample code number (Id) that reflects the chronological grouping of this data (Wolberg et. al (1992)). The data set also includes the result of further histological examination (Class), which confirms whether each woman's tissue sample was begin or malignant; this has been converted into a binary variable of 0 or 1, respectively.

Data Exploration

Of the tissues samples from 683 women, 239 are confirmed as malignant; in our sample, 53.83% of the women who are experiencing breast cancer symptoms have malignant tissue.

Whether the tissue is benign or malignant is considered the response variable, and the cytological characteristics of tissue are considered as the predictor variables. The characteristics of malignant tend to have higher numbers on the scale one to ten; this is visualized by the density distributions provided in `Appendix A`. All nine cytological characteristics of the tissue samples are presented below in a scatter plot matrix, where blue indicates the tissue is malignant.

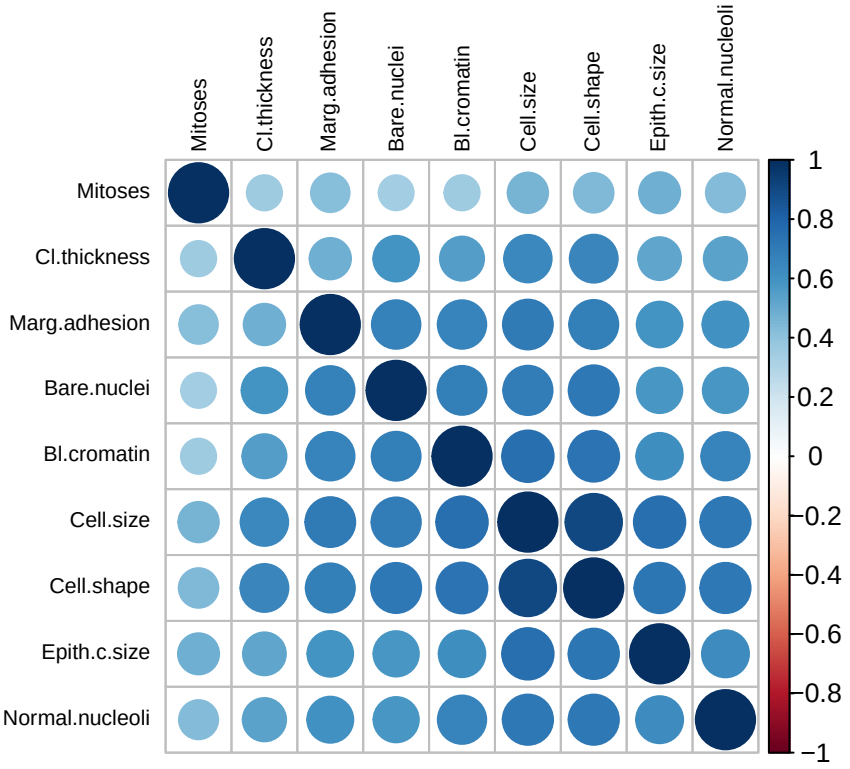
Plot 1: Scatter Plot Matrix of All Cytological Characteristics



This plot visualises the relationship between the characteristics; it suggests that there is a strong relationship between CS and CSh, indicating that larger cells have a more significant shape and are likely to be malignant. Whether this relationship is causal or correlated is worthy of further investigation.

The correlations between other characteristics are not initially obvious and require deeper analysis. A sample correlation matrix quantifies the strength of a linear relationship between the characteristics, and is visualised by the correlation plot below.

Plot 2: Cytological Characteristics Correlation



In this plot, the correlation is more significant when the circle is both darker and larger. This plot confirms the strong linear relationship between cell shape and cell size, which suggests that any regression model is unlikely to need both. These characteristics also appear to have stronger relationships with CT, MA, E, BN, BC, and NN. M does not appear to have a significant correlation with any of the characteristics. This indicates that a selection of the predictor variables could be used to build an accurate classifier.

The two single measures of multivariate scatter help us generalise how our data varies: generalised variance and total variation. For our data, the generalised variance is 55382860.00 and the total variation is 33283.24. This tells us there is a high degree of scatter about the sample means of each variable, highlighting that it will be important to transform our data so that it is standardised, putting all the variables on a common scale.

The mean, median and standard deviation for the nine cytological characteristics of the tissue samples are also presented on the next page.

Table 1: Summary Statistics of Cytological Characteristics

Variable	CT	CS	CSh	MA	E	BN	BC	NN	M
Median	4.00	1.00	1.00	1.00	2.00	1.00	3.00	1.00	1.00
Mean	4.44	3.15	3.22	2.83	3.23	2.54	3.45	2.87	1.58
SD	2.82	3.07	2.99	2.86	2.22	3.64	2.45	3.05	1.64

Table 1 shows us that the mean is notably higher than the median for CS, CSh, BN and NN, suggesting that characteristics of malignant tissue are skewing the mean. The standard deviation is also quite large. The table below investigates these findings in more detail with separate summary statistics for benign and malignant tissue.

Table 2: Summary Statistics by Class

	Benign			Malignant		
Variable	Mean	SD	Median	Mean	SD	Median
CT	2.96	1.67	3.00	7.19	2.44	8.00
CS	1,31	0.86	1.00	6.58	2.72	6.00
CSh	1.14	0.96	1.00	6.56	2.57	6.00
MA	1.35	0.92	1.00	5.59	3.20	5.00
E	2.11	0.88	2.00	5.33	2.44	5.00
BN	1.35	1.18	1.00	7.63	3.12	10.00
BC	2.08	1.06	2.00	5.97	2.28	7.00
NN	1.26	0.95	1.00	5.86	3.35	6.00
M	1.07	0.51	1.00	2.54	2.40	1.00

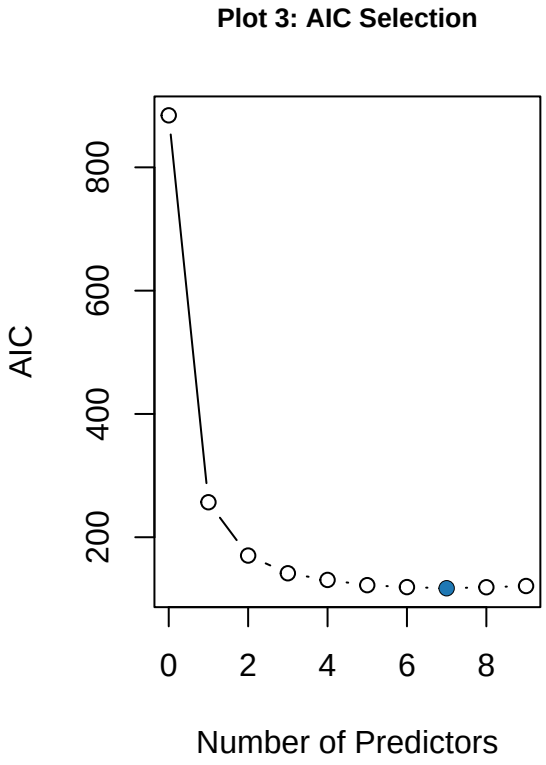
Table 2 clearly demonstrates that there is a significant difference between the characteristics of benign and malignant tissue. This is especially true for CT, BN and BC, indicating they may be the most important predictor variables.

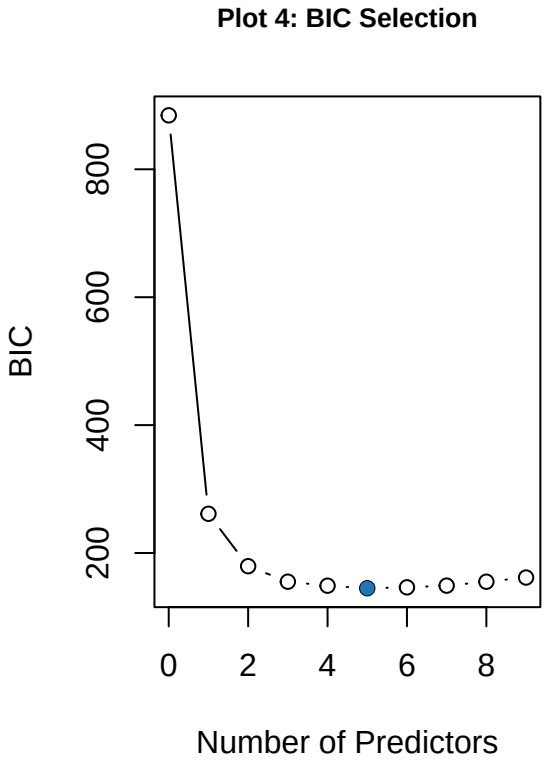
Subset Selection

The exploratory data analysis suggests that some predictor variables are likely to be better at predicting our response variable than others. If this proves to be correct, this will allow us to learn the effects of fewer predictor variables more precisely.

As our response variable is binary (benign or malignant), apply logistic regression is an appropriate approach to identify the best subset of predictor variables. After fitting the logistic regression model for `Class` to standardised data it is clear that CT, BN, MA and BC have a coefficient which is significantly different to zero when testing at the 5% level.

To confirm how many predictor variables would be the best subset selection, the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are applied. The results are presented in the two plots below.





In both plots, the blue dot is number of predictor variables identified by the best subset selection approach. It appears that a model with six variables is likely to be a good compromise between five and seven. The cytological characteristics for these six variables are CT, CSh, MA, BN, BC, and NN. These align closely to the strongly correlated variables identified in our correlation matrix above.

Modelling

To increase the reliability of our approach, the data is divided in two to allow for out-of-sample validation. In this project, 80% of the data is randomly allocated to a training data set to construct our classifier, with the remaining 20% becoming the testing data set to compute our test errors.

Logistic Regression

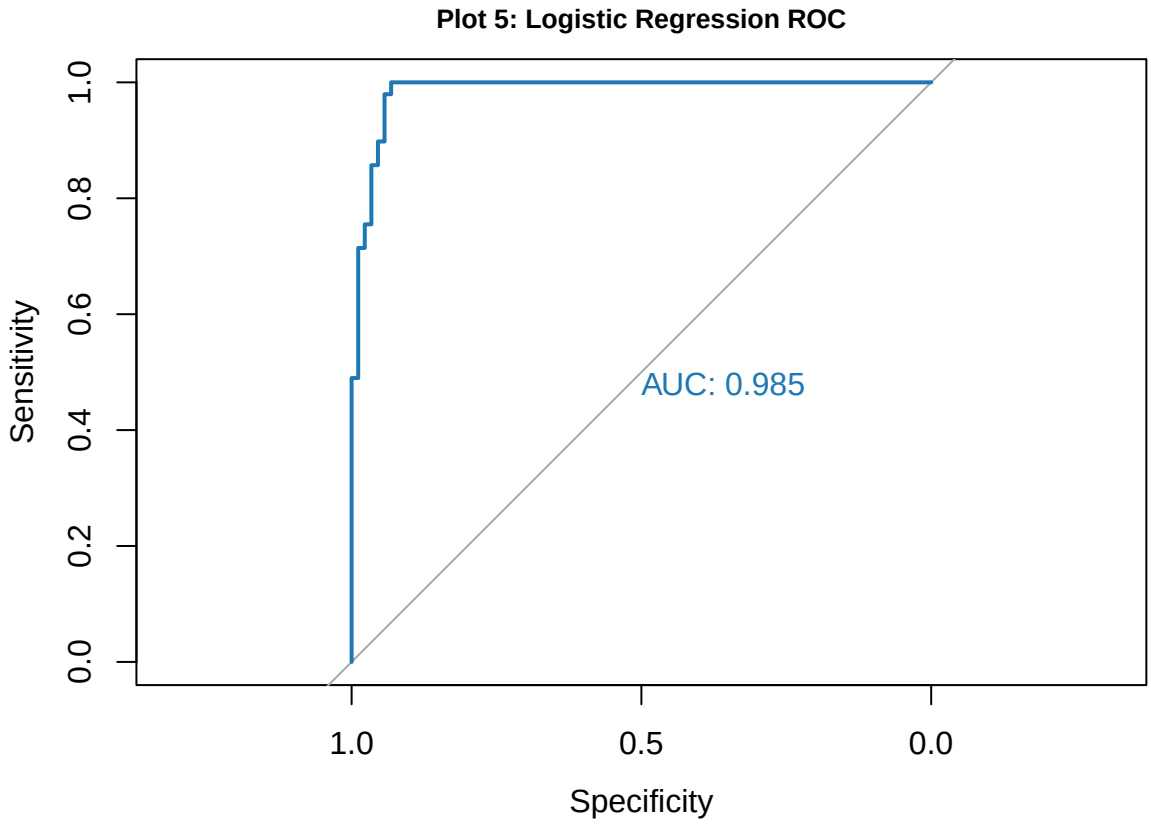
Logistic regression is used to assign observations to discrete response variables. When applied to our complete data set of six predictor variables, the maximum likelihood estimates of the regression coefficients are presented on the next page.

Table 3: Estimates of Regression Coefficients for Logistic Regression

	Intercept	CT	CSh	MA	BN	BC	NN
Estimates	-1.28	2.08	1.14	1.39	1.69	1.52	0.87

With 'in-sample validation,' the training error is 2.02%. This is not very interesting as only the test error measures how well the method performs on previously unseen data (Newcastle University (2022)). When using our train and test data sets for out-of-sample validation, the test error is 5.85%. This is slightly larger than the training error, which may indicate that unnecessary predictor variables have been included.

The accuracy of our model is visualised by the Receiver Operating Characteristic (ROC) curve below.

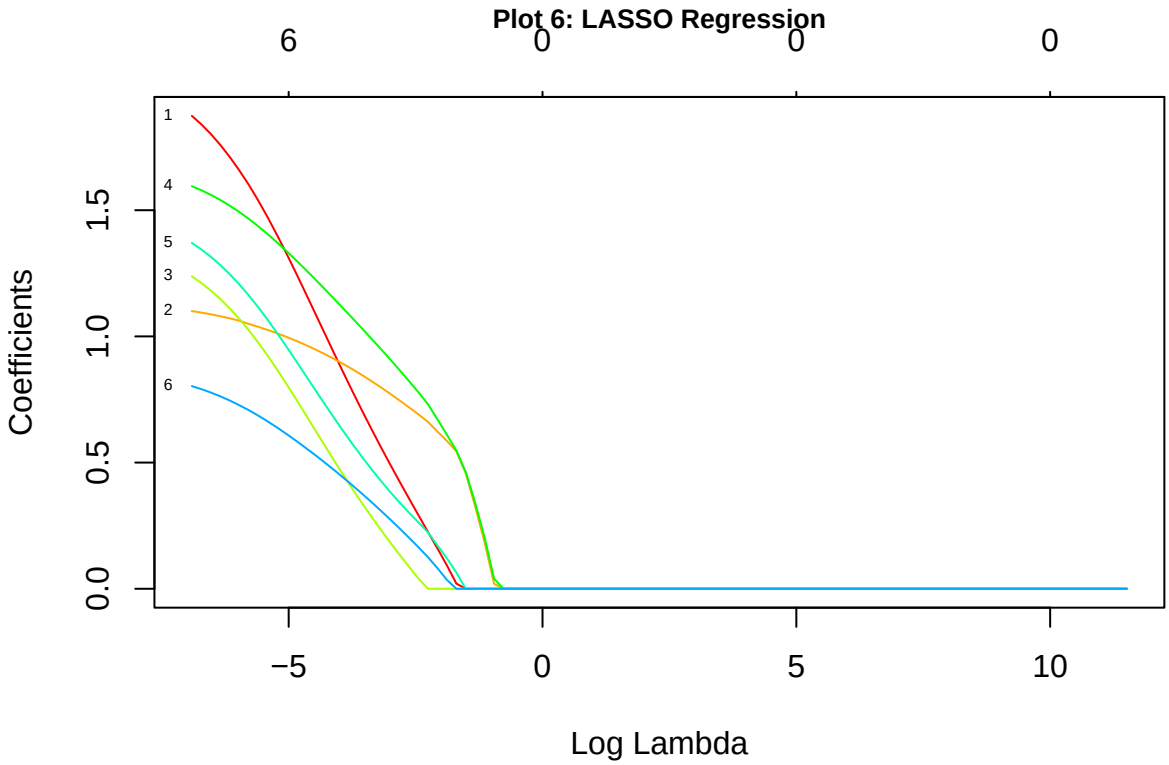


The measure of accuracy is the area under the ROC curve. This curve is far from the diagonal and is quite close to the perfect accuracy area of 1.00. Helpfully, the plot specifies the accuracy of our model as 0.99.

LASSO Regression

Regularisation methods, such as LASSO, are shrinkage methods; they work to minimise the loss function and shrink the maximum likelihood estimates of regression coefficients to zero. LASSO performs subset selection in addition to shrinkage; given that the test error

was higher than the training error for logistic regression, this method is selected over ridge regression. The LASSO regression applied to the same training data as above is visualised below.



This plot presents the coefficients of the LASSO regression and the effect of the turning parameter when applying LASSO to our training data set. It shows us that the third variable, MA (green), is the first to drop out of the model, followed by our 6th variable, NN (blue), and so on.

To choose an appropriate value for the turning parameter of LASSO, 10-fold cross-validation is used. This allows the optimal turning parameter and mean MSE to be calculated, which are 0.001 and 0.004222146, respectively. The regression coefficients obtained by performing the LASSO with the optimal turning parameter are shown in the table below.

When using our train and test data sets for out-of-sample validation, the test error is 25.75%, so significantly higher than the logistic regression.

Discriminant Analysis

Discriminant analysis is a technique used to classify observations into groups that do not overlap. Linear Discriminant Analysis (LDA) assumes that the common covariance matrix of the predictor variables is the same. Quadratic Discriminant Analysis (QDA) does not assume this. However, in practice, whether the common covariance is generally unknown.

The density distributions in `Appendix A` and boxplots in `Appendix B` suggest that our data is not normally distributed and indicates non-equal variances (respectively). QDA is likely

to be more appropriate than LDA. The group means generated by both LDA and QDA are the same, and so only one version of the group means is presented in the table on the next page.

Table 4: LDA and QDA Group Means

	CT	CSh	MA	BN	BC	NN
Benign	-0.56	-0.61	-0.53	-0.61	-0.57	-0.53
Malignant	0.95	1.13	0.96	1.15	1.03	0.99

When using our train and test data sets for out-of-sample validation, the test error for LDA is 7.30% and QDA is 6.57%. As expected QDA has the lower test error.

Evaluation

Based on the predictive performance of the three models applied, the logistic regression has the lowest test error at 5.85%. It if followed by QDA (6.57%), LDA (7.30%) and, lastly, the LASSO regression with a test error of 25.75%. I had hoped to be able to compare all the models with ROC plots, and unfortunately there was an issue with the code for LASSO and the decriminant analyses. Smaller test errors indicate more accurate models, so our logistic regression would be the best classifier.

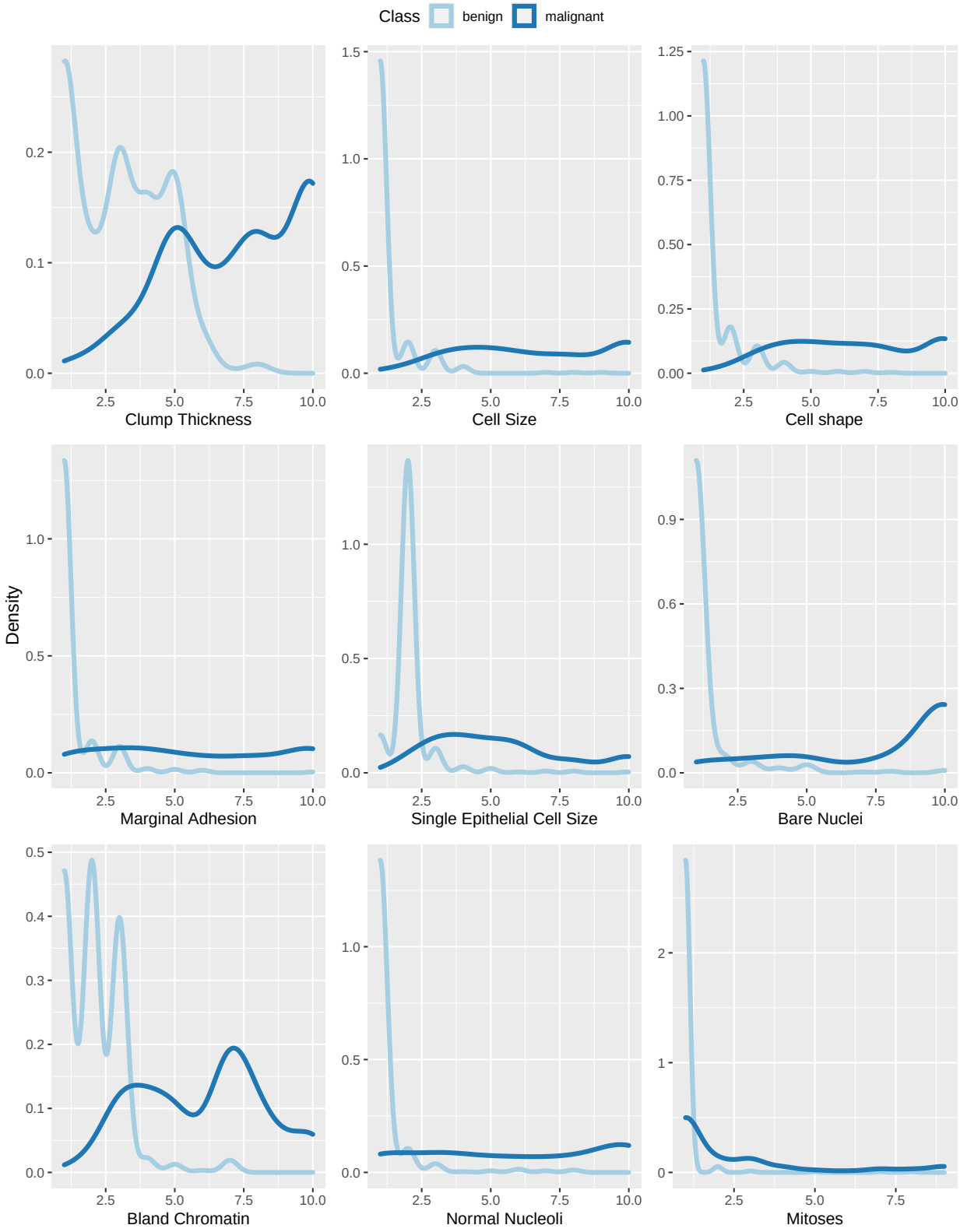
Our best classifier does not include all nine cytological characteristics. Using the methods of AIC and BIC for best subset selection, it was determined that six predictor variables was likely to provide the most accurate model. There were: CT, CSh, MA, BN, BC, and NN.

However, as mentioned in the logistic regression section, the test error was slightly larger than the training error. This indicates unnecessary predictor variables have been included. Cell Shape (CSh) had the largest p-value of the chosen six variables, so the classifier may benefit from re-running the logistic regression without this variable.

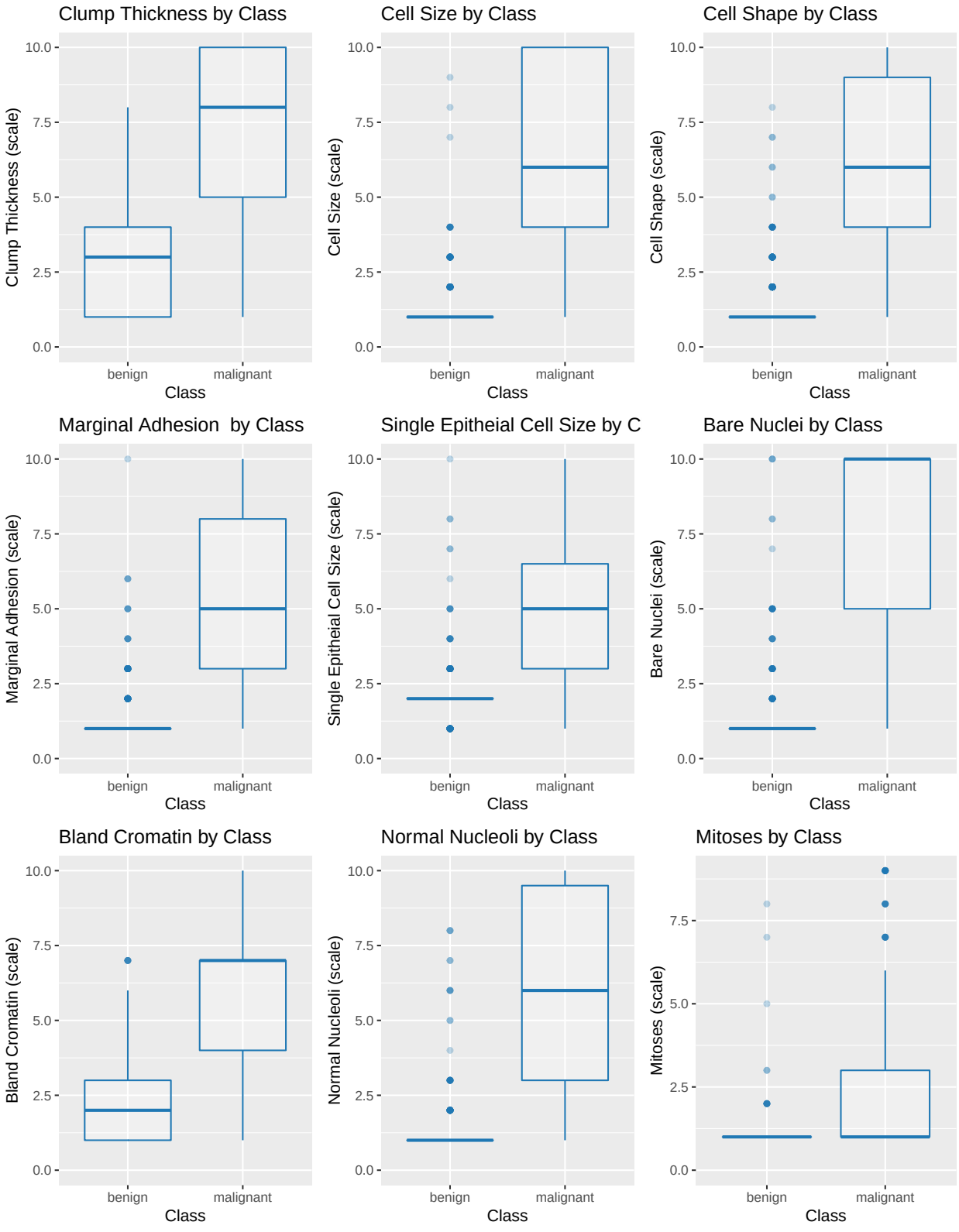
Similarly, it was interesting that the LASSO regression did conduct any further subset selection from the six variables. It would be interesting to re-run the LASSO regression on the original standardised data, before best subset selection with the logistic regression, to determine whether this would improve the accuracy of the model.

All of the models applied in this report have test error rates that would be impractical in a clinical setting. Further investigation would be beneficial to improve the accuracy of the models; this could include different methods of best subset selection, dividing the test and train data differently (perhaps by only using cross-validation k-folds), and, ideally, access to a much larger data set to avoid over-fitting the models.

Appendix A: Denisty Distributions of Cytological Characteristics by Class



Appendix B: Boxplots of Cytological Characteristics by Class



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