

Exploratory Data Analysis of Breast Cancer Malignancy Data

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Research questions

Which attributes best predict breast cancer malignancy?

Is it possible to create a machine learning model that can predict breast cancer malignancy with an accuracy of 80% or higher?

Load libraries and read data

```
library(tibble)
library(dplyr)

##
## Attaching package: 'dplyr'
##
## The following objects are masked from 'package:stats':
##
##   filter, lag
##
## The following objects are masked from 'package:base':
##
##   intersect, setdiff, setequal, union

library(ggplot2)
library(ggrepel)
library(reshape2)
library(scales)
```

This breast cancer database was obtained from the University of Wisconsin Hospitals, Madison from Dr. William H. Wolberg.

The data provided does not have clear column names, but a description of each attribute has been given in the *breast-cancer-wisconsin.names* file. This allows us to assign representative names to every column. The code to do this is shown below.

```
# Read data
data <- read.csv("breast-cancer-wisconsin.data", na.strings = '?')
# Convert to tibble for readability later on
data <- as_tibble(data)
# Set column names
colnames(data) <- c("id", "Clump_Thickness", "Cell_Size_Uniformity", "Cell_Shape_Uniformity",
                    "Bland_Chromatin", "Normal_Nucleoli", "Mitoses", "Class")
```

Basic look at the data

```
# Look at head of data
data

## # A tibble: 698 x 11
##       id Clump_Thickness Cell_Size_Uniform~ Cell_Shape_Unifo~ Marginal_Adhesi~
##   <int>         <int>         <int>         <int>         <int>
## 1 1002945             5             4             4             5
## 2 1015425             3             1             1             1
## 3 1016277             6             8             8             1
## 4 1017023             4             1             1             3
## 5 1017122             8            10            10             8
## 6 1018099             1             1             1             1
```

```
## 7 1018561          2          1          2          1
## 8 1033078          2          1          1          1
## 9 1033078          4          2          1          1
## 10 1035283         1          1          1          1
```

```
## # ... with 688 more rows, and 6 more variables:
```

```
## #   Single_Epithelial_Cell_Size <int>, Bare_Nuclei <int>,
```

```
## #   Bland_Chromatin <int>, Normal_Nucleoli <int>, Mitoses <int>, Class <int>
```

```
# Summarize data
```

```
summary(data)
```

```
##          id          Clump_Thickness Cell_Size_Uniformity Cell_Shape_Uniformity
## Min.   : 61634   Min.   : 1.000   Min.   : 1.000   Min.   : 1.000
## 1st Qu.: 870258   1st Qu.: 2.000   1st Qu.: 1.000   1st Qu.: 1.000
## Median : 1171710   Median : 4.000   Median : 1.000   Median : 1.000
## Mean   : 1071807   Mean   : 4.417   Mean   : 3.138   Mean   : 3.211
## 3rd Qu.: 1238354   3rd Qu.: 6.000   3rd Qu.: 5.000   3rd Qu.: 5.000
## Max.   :13454352   Max.   :10.000   Max.   :10.000   Max.   :10.000
##
## Marginal_Adhesion Single_Epithelial_Cell_Size Bare_Nuclei
## Min.   : 1.000   Min.   : 1.000   Min.   : 1.000
## 1st Qu.: 1.000   1st Qu.: 2.000   1st Qu.: 1.000
## Median : 1.000   Median : 2.000   Median : 1.000
## Mean   : 2.809   Mean   : 3.218   Mean   : 3.548
## 3rd Qu.: 4.000   3rd Qu.: 4.000   3rd Qu.: 6.000
## Max.   :10.000   Max.   :10.000   Max.   :10.000
##
##                               NA's   :16
## Bland_Chromatin Normal_Nucleoli Mitoses Class
## Min.   : 1.000   Min.   : 1.00   Min.   : 1.00   Min.   :2.000
## 1st Qu.: 2.000   1st Qu.: 1.00   1st Qu.: 1.00   1st Qu.:2.000
## Median : 3.000   Median : 1.00   Median : 1.00   Median :2.000
## Mean   : 3.438   Mean   : 2.87   Mean   : 1.59   Mean   :2.691
## 3rd Qu.: 5.000   3rd Qu.: 4.00   3rd Qu.: 1.00   3rd Qu.:4.000
## Max.   :10.000   Max.   :10.00   Max.   :10.00   Max.   :4.000
##
```

All data has been normalized to fit a grading systems that grades the severity of each attribute. A detailed description of what each grade value means for each attribute can be found in the Breast Cancer Diagnosis Web User Interface.

Correlation

To get a sense of which attributes are best suited to predict the class, it is helpful to take a look at the correlation. Below is a piece of code that prints the column names of the columns with a correlation of 0.8 or higher to the Class attribute.

```
# Get correlation
data.cor <- cor(data[,-1], use = "complete.obs")
data.cor <- as.data.frame(data.cor)
# Keep all correlations that are higher than 0.8
cor.names <- names(data.cor)[which(data.cor$Class > 0.8)]
# Print
cat(cor.names)
```

```
## Cell_Size_Uniformity Cell_Shape_Uniformity Bare_Nuclei Class
```

This gives us just three attributes of interest besides the Class attribute which obviously fully correlates

to itself. This is good, because this means the model we will train later will likely only need these three attributes to accurately predict the Malignancy of a cancer clump. A simple model is always better, because less data needs to be acquired in order to use it. However, to make sure we do not miss any value information, it is useful to make a heat map of the correlation table. The heat map and corresponding code is shown below.

```
# Make correlation matrix
cormat <- cor(na.omit(data[, -1]))
# Melt to correct format
melted.cormat <- melt(cormat)
melted.cormat
```

##	Var1	Var2	value
## 1	Clump_Thickness	Clump_Thickness	1.0000000
## 2	Cell_Size_Uniformity	Clump_Thickness	0.6429362
## 3	Cell_Shape_Uniformity	Clump_Thickness	0.6539679
## 4	Marginal_Adhesion	Clump_Thickness	0.4881746
## 5	Single_Epithelial_Cell_Size	Clump_Thickness	0.5238909
## 6	Bare_Nuclei	Clump_Thickness	0.5935238
## 7	Bland_Chromatin	Clump_Thickness	0.5538245
## 8	Normal_Nucleoli	Clump_Thickness	0.5344063
## 9	Mitoses	Clump_Thickness	0.3510996
## 10	Class	Clump_Thickness	0.7153057
## 11	Clump_Thickness	Cell_Size_Uniformity	0.6429362
## 12	Cell_Size_Uniformity	Cell_Size_Uniformity	1.0000000
## 13	Cell_Shape_Uniformity	Cell_Size_Uniformity	0.9071584
## 14	Marginal_Adhesion	Cell_Size_Uniformity	0.7067860
## 15	Single_Epithelial_Cell_Size	Cell_Size_Uniformity	0.7534148
## 16	Bare_Nuclei	Cell_Size_Uniformity	0.6914868
## 17	Bland_Chromatin	Cell_Size_Uniformity	0.7556635
## 18	Normal_Nucleoli	Cell_Size_Uniformity	0.7191730
## 19	Mitoses	Cell_Size_Uniformity	0.4606035
## 20	Class	Cell_Size_Uniformity	0.8206666
## 21	Clump_Thickness	Cell_Shape_Uniformity	0.6539679
## 22	Cell_Size_Uniformity	Cell_Shape_Uniformity	0.9071584
## 23	Cell_Shape_Uniformity	Cell_Shape_Uniformity	1.0000000
## 24	Marginal_Adhesion	Cell_Shape_Uniformity	0.6857348
## 25	Single_Epithelial_Cell_Size	Cell_Shape_Uniformity	0.7223130
## 26	Bare_Nuclei	Cell_Shape_Uniformity	0.7136609
## 27	Bland_Chromatin	Cell_Shape_Uniformity	0.7354603
## 28	Normal_Nucleoli	Cell_Shape_Uniformity	0.7177840
## 29	Mitoses	Cell_Shape_Uniformity	0.4410959
## 30	Class	Cell_Shape_Uniformity	0.8217487
## 31	Clump_Thickness	Marginal_Adhesion	0.4881746
## 32	Cell_Size_Uniformity	Marginal_Adhesion	0.7067860
## 33	Cell_Shape_Uniformity	Marginal_Adhesion	0.6857348
## 34	Marginal_Adhesion	Marginal_Adhesion	1.0000000
## 35	Single_Epithelial_Cell_Size	Marginal_Adhesion	0.5943395
## 36	Bare_Nuclei	Marginal_Adhesion	0.6704341
## 37	Bland_Chromatin	Marginal_Adhesion	0.6686132
## 38	Normal_Nucleoli	Marginal_Adhesion	0.6028932
## 39	Mitoses	Marginal_Adhesion	0.4187345
## 40	Class	Marginal_Adhesion	0.7060966
## 41	Clump_Thickness	Single_Epithelial_Cell_Size	0.5238909
## 42	Cell_Size_Uniformity	Single_Epithelial_Cell_Size	0.7534148

## 43	Cell_Shape_Uniformity	Single_Epithelial_Cell_Size	0.7223130
## 44	Marginal_Adhesion	Single_Epithelial_Cell_Size	0.5943395
## 45	Single_Epithelial_Cell_Size	Single_Epithelial_Cell_Size	1.0000000
## 46	Bare_Nuclei	Single_Epithelial_Cell_Size	0.5854889
## 47	Bland_Chromatin	Single_Epithelial_Cell_Size	0.6181347
## 48	Normal_Nucleoli	Single_Epithelial_Cell_Size	0.6287425
## 49	Mitoses	Single_Epithelial_Cell_Size	0.4804510
## 50	Class	Single_Epithelial_Cell_Size	0.6907894
## 51	Clump_Thickness	Bare_Nuclei	0.5935238
## 52	Cell_Size_Uniformity	Bare_Nuclei	0.6914868
## 53	Cell_Shape_Uniformity	Bare_Nuclei	0.7136609
## 54	Marginal_Adhesion	Bare_Nuclei	0.6704341
## 55	Single_Epithelial_Cell_Size	Bare_Nuclei	0.5854889
## 56	Bare_Nuclei	Bare_Nuclei	1.0000000
## 57	Bland_Chromatin	Bare_Nuclei	0.6806888
## 58	Normal_Nucleoli	Bare_Nuclei	0.5840221
## 59	Mitoses	Bare_Nuclei	0.3390050
## 60	Class	Bare_Nuclei	0.8225632
## 61	Clump_Thickness	Bland_Chromatin	0.5538245
## 62	Cell_Size_Uniformity	Bland_Chromatin	0.7556635
## 63	Cell_Shape_Uniformity	Bland_Chromatin	0.7354603
## 64	Marginal_Adhesion	Bland_Chromatin	0.6686132
## 65	Single_Epithelial_Cell_Size	Bland_Chromatin	0.6181347
## 66	Bare_Nuclei	Bland_Chromatin	0.6806888
## 67	Bland_Chromatin	Bland_Chromatin	1.0000000
## 68	Normal_Nucleoli	Bland_Chromatin	0.6656376
## 69	Mitoses	Bland_Chromatin	0.3459572
## 70	Class	Bland_Chromatin	0.7583497
## 71	Clump_Thickness	Normal_Nucleoli	0.5344063
## 72	Cell_Size_Uniformity	Normal_Nucleoli	0.7191730
## 73	Cell_Shape_Uniformity	Normal_Nucleoli	0.7177840
## 74	Marginal_Adhesion	Normal_Nucleoli	0.6028932
## 75	Single_Epithelial_Cell_Size	Normal_Nucleoli	0.6287425
## 76	Bare_Nuclei	Normal_Nucleoli	0.5840221
## 77	Bland_Chromatin	Normal_Nucleoli	0.6656376
## 78	Normal_Nucleoli	Normal_Nucleoli	1.0000000
## 79	Mitoses	Normal_Nucleoli	0.4336022
## 80	Class	Normal_Nucleoli	0.7184993
## 81	Clump_Thickness	Mitoses	0.3510996
## 82	Cell_Size_Uniformity	Mitoses	0.4606035
## 83	Cell_Shape_Uniformity	Mitoses	0.4410959
## 84	Marginal_Adhesion	Mitoses	0.4187345
## 85	Single_Epithelial_Cell_Size	Mitoses	0.4804510
## 86	Bare_Nuclei	Mitoses	0.3390050
## 87	Bland_Chromatin	Mitoses	0.3459572
## 88	Normal_Nucleoli	Mitoses	0.4336022
## 89	Mitoses	Mitoses	1.0000000
## 90	Class	Mitoses	0.4232778
## 91	Clump_Thickness	Class	0.7153057
## 92	Cell_Size_Uniformity	Class	0.8206666
## 93	Cell_Shape_Uniformity	Class	0.8217487
## 94	Marginal_Adhesion	Class	0.7060966
## 95	Single_Epithelial_Cell_Size	Class	0.6907894
## 96	Bare_Nuclei	Class	0.8225632

```
## 97          Bland_Chromatin          Class 0.7583497
## 98          Normal_Nucleoli          Class 0.7184993
## 99          Mitoses                  Class 0.4232778
## 100         Class                    Class 1.0000000

colnames(melted.cormat) <- c("Var1", "Var2", "correlation")
# head(melted.cormat) # <- uncomment this to look at the new matrix

# Make heatmap with ggplot
ggplot(data = melted.cormat, aes(x=Var1, y=Var2, fill=correlation)) +
  geom_tile() + # geom_tile makes the heatmap tiles
  scale_fill_gradient(low = rgb(0, 0, 0),
                      high = rgb(0, 1, 1),
                      guide = "colorbar") + # sets color the gradient for tiles

  ylab('') +
  xlab('') + # the x and y axes have no useful names, and are thus left blank
  labs(caption =
       "Figure 1 ~ Correlation Heatmap of the breast cancer data set.
       The lighter the color, the better the correlation between the two columns.") + # adds caption
  theme_minimal() + # set theme to minimal
  theme(axis.text.x = element_text(angle = 45, hjust = 1), # adjust x labels to be diagonal
        plot.caption = element_text(hjust = 0.7)) # adjust caption position
```

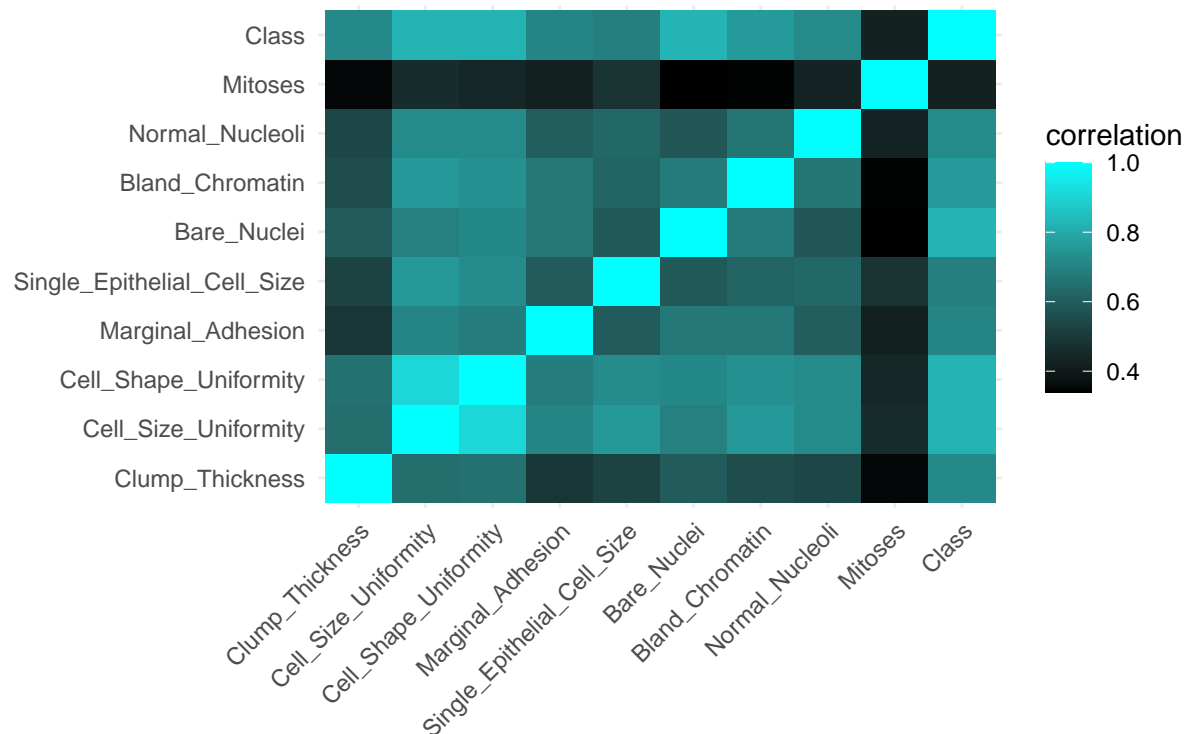


Figure 1 ~ Correlation Heatmap of the breast cancer data set.
The lighter the color, the better the correlation between the two columns.

Looking at 'Class' column of the heat map in figure 1, the Bland_Chromatin correlation is the lightest color visible besides the three attributes found earlier (Cell_Size_Uniformity, Cell_Shape_Uniformity Bare_Nuclei). The following code takes a look at the exact correlation of this attribute.

```
# Print correlation of Bland_Chromatin to Class
cormat["Bland_Chromatin", "Class"]
```

```
## [1] 0.7583497
```

The correlation is roughly 0.76, which is close to the 0.8 threshold set earlier. Bland_Chromatin might be another attribute of interest.

Another thing that stands out in figure 1 is that Cell_Shape_Uniformity and Cell_Size_Uniformity show a high correlation as depicted by the light 4x4 square at the bottom left of the figure. This will be discussed further later on.

Class Distribution

Change Class to be factor

The code shown below substitutes the previously numeric data in the Class column of the data set to a factor with two labels: B for benign and M for malignant. This makes following visualizations easier and is also needed when eventually classifying the data with our model.

```
# Change class values to B for benign and M for Malignant instead of 2 and 4
data$Class[data$Class == 2] <- 'B'
data$Class[data$Class == 4] <- 'M'
data["Class"]
```

```
## # A tibble: 698 x 1
##   Class
##   <chr>
## 1 B
## 2 B
## 3 B
## 4 B
## 5 M
## 6 B
## 7 B
## 8 B
## 9 B
## 10 B
## # ... with 688 more rows
```

Pie Chart

To visualize the distribution of instances over the two classes a pie chart is made.

```
# Get class counts
m.count <- length(data$Class[data$Class == 'M'])
b.count <- length(data$Class[data$Class == 'B'])
# Combine in data frame
count.data <- data.frame(Class = c('Malignant', 'Benign'), Value = c(m.count, b.count))

count.data %>%
  arrange(desc(Value)) %>%
  mutate(prop = percent(Value / sum(Value), accuracy = 0.1)) -> count.data

# Make pie chart
ggplot(count.data, aes(x = "", y = Value, fill = Class)) +
  geom_bar(stat="identity", width=1, color="white") +
  coord_polar("y", start=0) +
  geom_label_repel(aes(label = prop), size=5, show.legend = F, nudge_x = -1, segment.colour= NA) +
  labs(caption="Figure 2 ~ A pie chart of the distrubtion of the classes in the dataset.") +
```

```
theme_void() +
theme(plot.caption = element_text(hjust = 1))
```

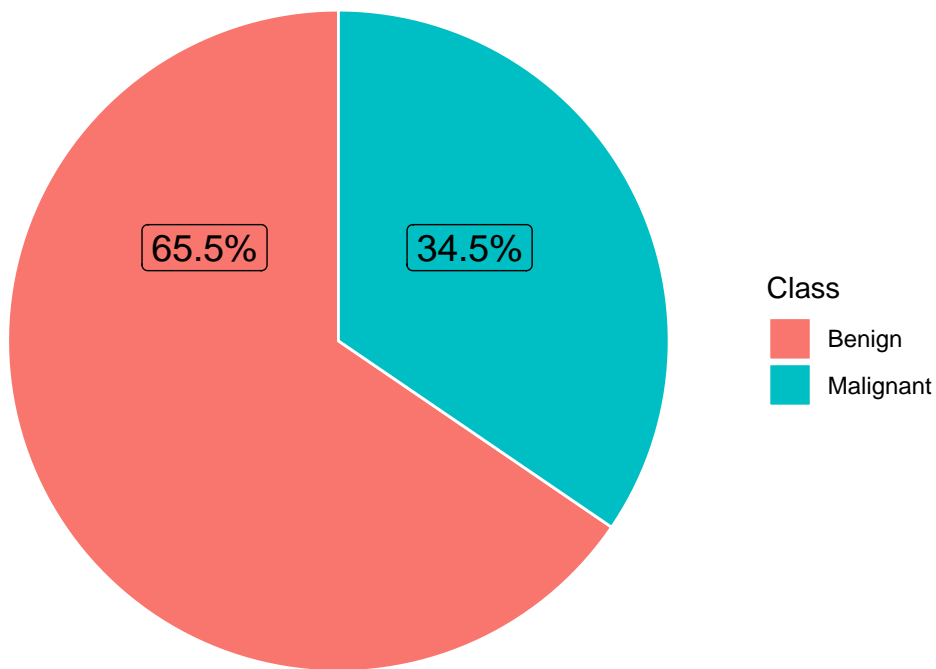


Figure 2 ~ A pie chart of the distrubtion of the classes in the dataset.

```
# Calculate exact percentage
m.count / (m.count + b.count) * 100

## [1] 34.52722
```

Figure 2 shows that roughly two thirds of the data consists of Benign instances. When calculated, we find that only 34.5% of the instances are malignant. This should be kept in mind when testing the model. A ZeroR algorithm would for instance already classify 65.5% of the instances correctly by pure chance. Although this seems accurate, this would obviously not be a good model, since ZeroR ignores all predictors and simply picks the majority category.

Further Visualization

Correlation Cell Size, Cell Shape

The following graph shows the relation between Cell Size and Cell Shape as discussed earlier when looking at figure 1.

```
# Make plot
# coef(linear.model <- lm(Cell_Shape_Uniformity ~ Cell_Size_Uniformity, data = data))

ggplot(data = data, mapping = aes(x = Cell_Size_Uniformity, y = Cell_Shape_Uniformity)) +
  # Add points
  geom_point(aes(col = Class), alpha = 0.5) +
  # Add linear regression line
  geom_smooth(method = "lm", se = T, col='darkgrey') +
  # Set axis labels
  xlab("Cell Size Uniformity (grade 1-10)") +
```



```

ylab("Cell Shape Uniformity (grade 1-10)") +
# Scale x and y axis to represent the 1 - 10 grading
ylim(0, 10) +
scale_y_continuous(breaks = seq(0, 10, by = 2)) +
xlim(0, 10) +
scale_x_continuous(breaks = seq(0, 10, by = 2)) +
labs(caption="Figure 3 ~ Cell Shape as a function of Cell Size.
      The color of the points show their class, red being benign, blue being malignant.") +
# Make theme minimal
theme_minimal() +
theme(plot.caption = element_text(hjust = 0.5))

```

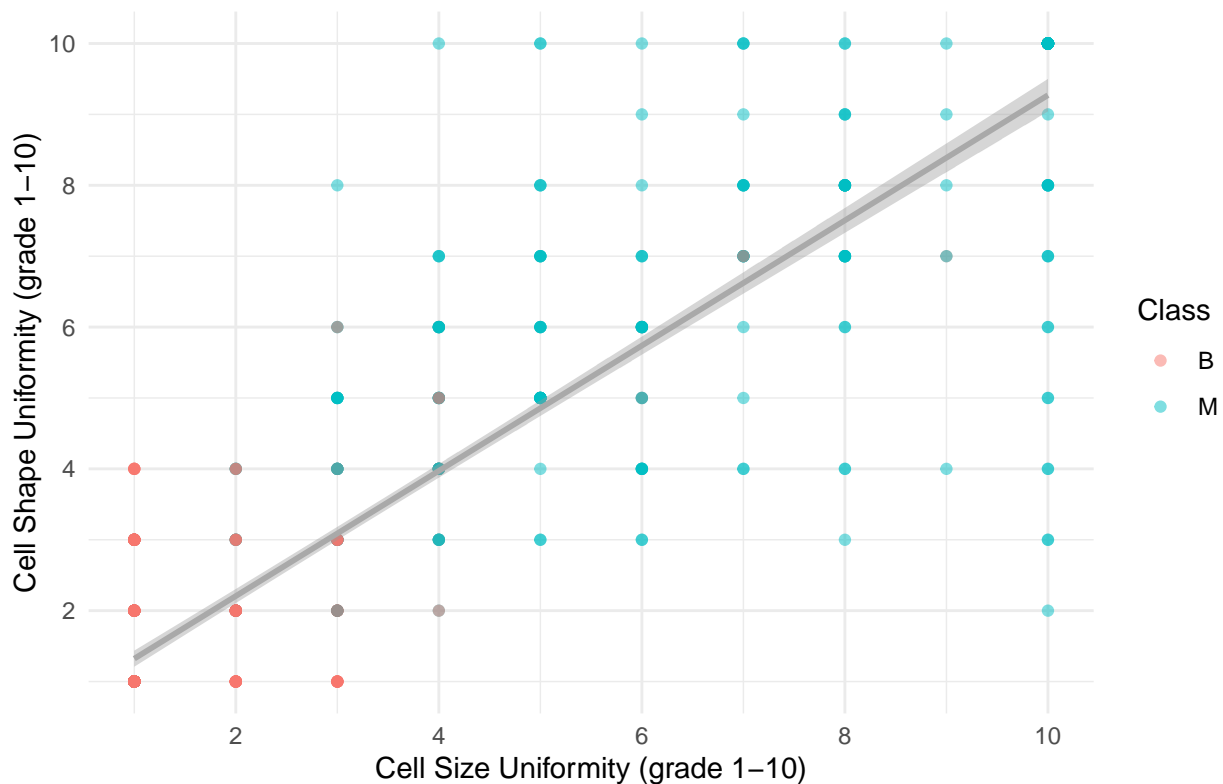


Figure 3 ~ Cell Shape as a function of Cell Size.
The color of the points show their class, red being benign, blue being malignant.

Figure 3 shows the correlation between the attributes `Cell_Shape_Uniformity` and `Cell_Size_Uniformity`. When looking at the spread of the two colors in this graph, the benign instances seem to form a group in the bottom left, while the malignant cases are spread across the middle and the top right. This division suggests these attributes would be good predictors for breast cancer malignancy. A simple perceptron could divide the two classes with some accuracy based on these two attributes alone.

How does cell shape relate to malignancy

Below we see how cell shape relates to malignancy, by plotting points with jitter to show how many points represent each grade.

```

ggplot(data = data, mapping = aes(x = Class, y = Cell_Shape_Uniformity)) +
  geom_jitter(width = 0.05, height = 0.2, col = "forestgreen", alpha = 0.5) +
  ylim(0, 10) +
  xlab("Class (B or M)") +
  ylab("Cell Shape Uniformity (grade 1-10)") +

```

```
scale_y_continuous(breaks = seq(0, 10, by = 2)) +
labs(caption="Figure 4 ~ Cell Shape as a function of Class. Jitter and transparency is added to show the density of points at each grade.") +
theme_minimal()
```

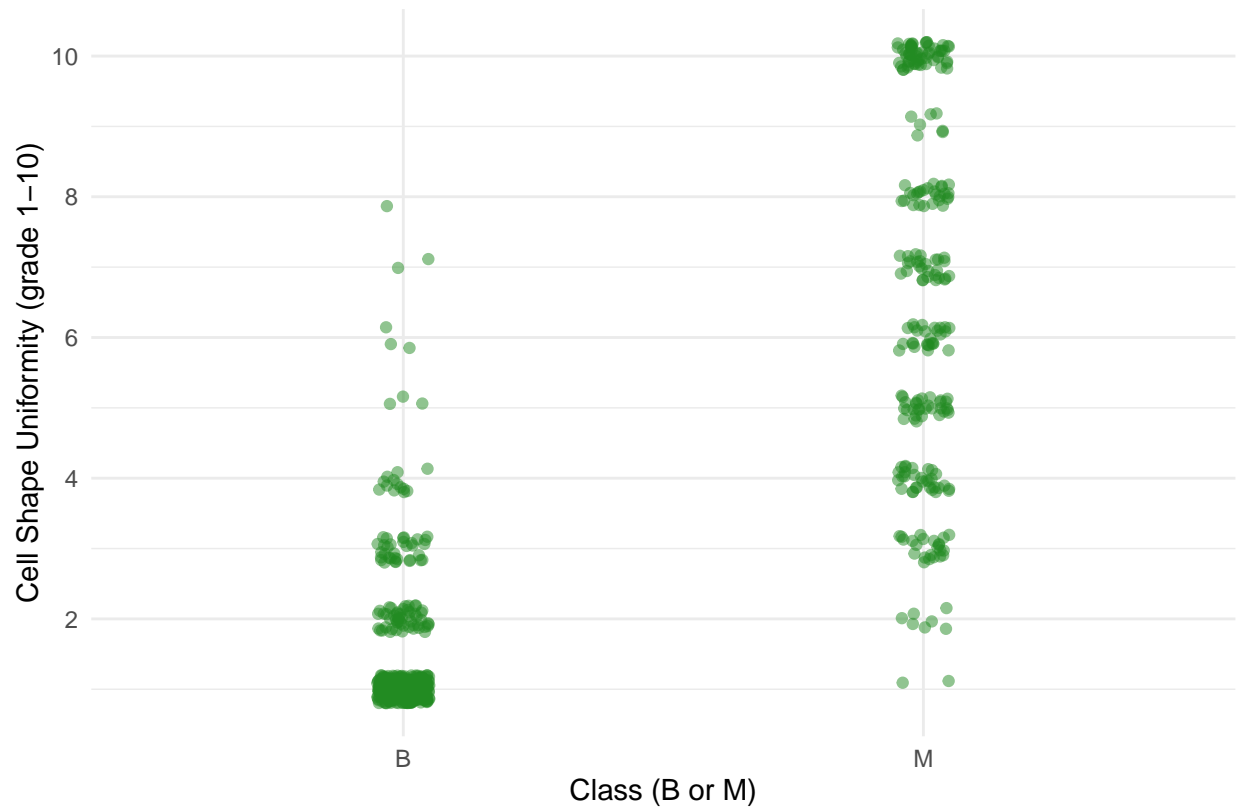


Figure 4 ~ Cell Shape as a function of Class. Jitter and transparency is added to show the density of points at each grade.

Looking at figure 4, we can conclude that most of benign cases will get a cell shape grade of 2 or lower. The malignant cases, however, appear more spread out. This would cause inaccuracy when classifying with this attribute only.