

Class08_Mini-project

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The goal of this mini-project is for you to explore a complete analysis using the unsupervised learning techniques covered in class. You'll extend what you've learned by combining PCA as a preprocessing step to clustering using data that consist of measurements of cell nuclei of human breast masses. This expands on our RNA-Seq analysis from last day. The data itself comes from the Wisconsin Breast Cancer Diagnostic Data Set first reported by K. P. Benne and O. L. Mangasarian: "Robust Linear Programming Discrimination of Two Linearly Inseparable Sets".

Values in this data set describe characteristics of the cell nuclei present in digitized images of a fine needle aspiration (FNA) of a breast mass. FNA is a type of biopsy procedure where a very thin needle is inserted into an area of abnormal tissue or cells with a guide of CT scan or ultrasound monitors (Figure 1). The collected sample is then transferred to a pathologist to study it under a microscope and examine whether cells in the biopsy are normal or not. For example radius (i.e. mean of distances from center to points on the perimeter), texture (i.e. standard deviation of gray-scale values), and smoothness (local variation in radius lengths). Summary information is also provided for each group of cells including diagnosis (i.e. benign (not cancerous) and malignant (cancerous)).

Data import

I need to first import our data from our class website. After importing the data, I can check the content of the data and name the data properly.

```
# Save your input data file into your Project directory
fna.data <- "WisconsinCancer.csv"
# Complete the following code to input the data and store as wisc.df
wisc.df <- read.csv(fna.data, row.names=1)
# Create diagnosis vector for later
diagnosis <- factor(wisc.df$diagnosis)
# We can use -1 here to remove the first column
wisc.data <- wisc.df[, -1]
#View the imported data
head(wisc.data)
```

	radius_mean	texture_mean	perimeter_mean	area_mean	smoothness_mean
842302	17.99	10.38	122.80	1001.0	0.11840
842517	20.57	17.77	132.90	1326.0	0.08474
84300903	19.69	21.25	130.00	1203.0	0.10960
84348301	11.42	20.38	77.58	386.1	0.14250
84358402	20.29	14.34	135.10	1297.0	0.10030
843786	12.45	15.70	82.57	477.1	0.12780
	compactness_mean	concavity_mean	concave.points_mean	symmetry_mean	
842302	0.27760	0.3001		0.14710	0.2419
842517	0.07864	0.0869		0.07017	0.1812
84300903	0.15990	0.1974		0.12790	0.2069
84348301	0.28390	0.2414		0.10520	0.2597
84358402	0.13280	0.1980		0.10430	0.1809
843786	0.17000	0.1578		0.08089	0.2087
	fractal_dimension_mean	radius_se	texture_se	perimeter_se	area_se
842302		0.07871	1.0950	0.9053	8.589 153.40
842517		0.05667	0.5435	0.7339	3.398 74.08
84300903		0.05999	0.7456	0.7869	4.585 94.03
84348301		0.09744	0.4956	1.1560	3.445 27.23
84358402		0.05883	0.7572	0.7813	5.438 94.44
843786		0.07613	0.3345	0.8902	2.217 27.19
	smoothness_se	compactness_se	concavity_se	concave.points_se	
842302	0.006399	0.04904	0.05373		0.01587
842517	0.005225	0.01308	0.01860		0.01340
84300903	0.006150	0.04006	0.03832		0.02058
84348301	0.009110	0.07458	0.05661		0.01867

84358402	0.011490	0.02461	0.05688	0.01885
843786	0.007510	0.03345	0.03672	0.01137
	symmetry_se	fractal_dimension_se	radius_worst	texture_worst
842302	0.03003	0.006193	25.38	17.33
842517	0.01389	0.003532	24.99	23.41
84300903	0.02250	0.004571	23.57	25.53
84348301	0.05963	0.009208	14.91	26.50
84358402	0.01756	0.005115	22.54	16.67
843786	0.02165	0.005082	15.47	23.75
	perimeter_worst	area_worst	smoothness_worst	compactness_worst
842302	184.60	2019.0	0.1622	0.6656
842517	158.80	1956.0	0.1238	0.1866
84300903	152.50	1709.0	0.1444	0.4245
84348301	98.87	567.7	0.2098	0.8663
84358402	152.20	1575.0	0.1374	0.2050
843786	103.40	741.6	0.1791	0.5249
	concavity_worst	concave.points_worst	symmetry_worst	
842302	0.7119	0.2654	0.4601	
842517	0.2416	0.1860	0.2750	
84300903	0.4504	0.2430	0.3613	
84348301	0.6869	0.2575	0.6638	
84358402	0.4000	0.1625	0.2364	
843786	0.5355	0.1741	0.3985	
	fractal_dimension_worst			
842302		0.11890		
842517		0.08902		
84300903		0.08758		
84348301		0.17300		
84358402		0.07678		
843786		0.12440		

The first column **diagnosis** is the expert opinion on the whether the tumor is malignant or benign. We remove the column because we do not want to see it before our data analysis.

Exploratory data analysis

Now, I can answer some exploratory data analysis questions in the lab sheet

Q1. How many observations are in this dataset?

```
dim(wisc.df)
```

```
[1] 569 31
```

There are 569 rows in this dataset, which means there are 569 patients in total. For each patient, there are 31 parameters measured, and this is why there are 31 columns here (if we include the diagnosis column here).

Q2. How many of the observations have a malignant diagnosis?

```
table(wisc.df$diagnosis)
```

	B	M
357	212	

In total, there are 212 observations having a malignant diagnosis

Q3. How many variables/features in the data are suffixed with `_mean`?

```
length(grep("_mean", colnames(wisc.df)))
```

```
[1] 10
```

There are 10 variables/features in the data suffixed with `_mean`.

Principal Component Analysis

The next step of the analysis is to perform PCA.

It is important to check if the data need to be scaled before performing PCA. Recall two common reasons for scaling data include: 1. The input variables use different units of measurement. 2. The input variables have significantly different variances.

```
# Check column means and standard deviations  
colMeans(wisc.data)
```

radius_mean	texture_mean	perimeter_mean
1.412729e+01	1.928965e+01	9.196903e+01
area_mean	smoothness_mean	compactness_mean
6.548891e+02	9.636028e-02	1.043410e-01
concavity_mean	concave.points_mean	symmetry_mean
8.879932e-02	4.891915e-02	1.811619e-01
fractal_dimension_mean	radius_se	texture_se
6.279761e-02	4.051721e-01	1.216853e+00
perimeter_se	area_se	smoothness_se
2.866059e+00	4.033708e+01	7.040979e-03
compactness_se	concavity_se	concave.points_se
2.547814e-02	3.189372e-02	1.179614e-02
symmetry_se	fractal_dimension_se	radius_worst
2.054230e-02	3.794904e-03	1.626919e+01
texture_worst	perimeter_worst	area_worst
2.567722e+01	1.072612e+02	8.805831e+02
smoothness_worst	compactness_worst	concavity_worst
1.323686e-01	2.542650e-01	2.721885e-01
concave.points_worst	symmetry_worst	fractal_dimension_worst
1.146062e-01	2.900756e-01	8.394582e-02

```
apply(wisc.data, 2, sd)
```

radius_mean	texture_mean	perimeter_mean
3.524049e+00	4.301036e+00	2.429898e+01
area_mean	smoothness_mean	compactness_mean
3.519141e+02	1.406413e-02	5.281276e-02
concavity_mean	concave.points_mean	symmetry_mean
7.971981e-02	3.880284e-02	2.741428e-02
fractal_dimension_mean	radius_se	texture_se
7.060363e-03	2.773127e-01	5.516484e-01
perimeter_se	area_se	smoothness_se
2.021855e+00	4.549101e+01	3.002518e-03
compactness_se	concavity_se	concave.points_se
1.790818e-02	3.018606e-02	6.170285e-03
symmetry_se	fractal_dimension_se	radius_worst
8.266372e-03	2.646071e-03	4.833242e+00
texture_worst	perimeter_worst	area_worst
6.146258e+00	3.360254e+01	5.693570e+02
smoothness_worst	compactness_worst	concavity_worst
2.283243e-02	1.573365e-01	2.086243e-01
concave.points_worst	symmetry_worst	fractal_dimension_worst

6.573234e-02

6.186747e-02

1.806127e-02

The variances of different columns are largely different, and different columns have different units. We need to scale the data before doing PCA, so that we can get a more informative PCA result. **In general, we always want to scale the data before performing a PCA, so that the analysis is not dominated by variables in the dataset with high standard deviations just because of their units**

The `prcomp()` function is the main function in R to do PCA

```
wisc.pr <- prcomp(wisc.data, scale = TRUE)
summary(wisc.pr)
```

Importance of components:

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Standard deviation	3.6444	2.3857	1.67867	1.40735	1.28403	1.09880	0.82172
Proportion of Variance	0.4427	0.1897	0.09393	0.06602	0.05496	0.04025	0.02251
Cumulative Proportion	0.4427	0.6324	0.72636	0.79239	0.84734	0.88759	0.91010
	PC8	PC9	PC10	PC11	PC12	PC13	PC14
Standard deviation	0.69037	0.6457	0.59219	0.5421	0.51104	0.49128	0.39624
Proportion of Variance	0.01589	0.0139	0.01169	0.0098	0.00871	0.00805	0.00523
Cumulative Proportion	0.92598	0.9399	0.95157	0.9614	0.97007	0.97812	0.98335
	PC15	PC16	PC17	PC18	PC19	PC20	PC21
Standard deviation	0.30681	0.28260	0.24372	0.22939	0.22244	0.17652	0.1731
Proportion of Variance	0.00314	0.00266	0.00198	0.00175	0.00165	0.00104	0.0010
Cumulative Proportion	0.98649	0.98915	0.99113	0.99288	0.99453	0.99557	0.9966
	PC22	PC23	PC24	PC25	PC26	PC27	PC28
Standard deviation	0.16565	0.15602	0.1344	0.12442	0.09043	0.08307	0.03987
Proportion of Variance	0.00091	0.00081	0.0006	0.00052	0.00027	0.00023	0.00005
Cumulative Proportion	0.99749	0.99830	0.9989	0.99942	0.99969	0.99992	0.99997
	PC29	PC30					
Standard deviation	0.02736	0.01153					
Proportion of Variance	0.00002	0.00000					
Cumulative Proportion	1.00000	1.00000					

Q4. From your results, what proportion of the original variance is captured by the first principal components (PC1)?

44.27% of the original variance is captured by PC1.

Q5. How many principal components (PCs) are required to describe at least 70% of the original variance in the data?

We need at least three: PC1, PC2 and PC3.

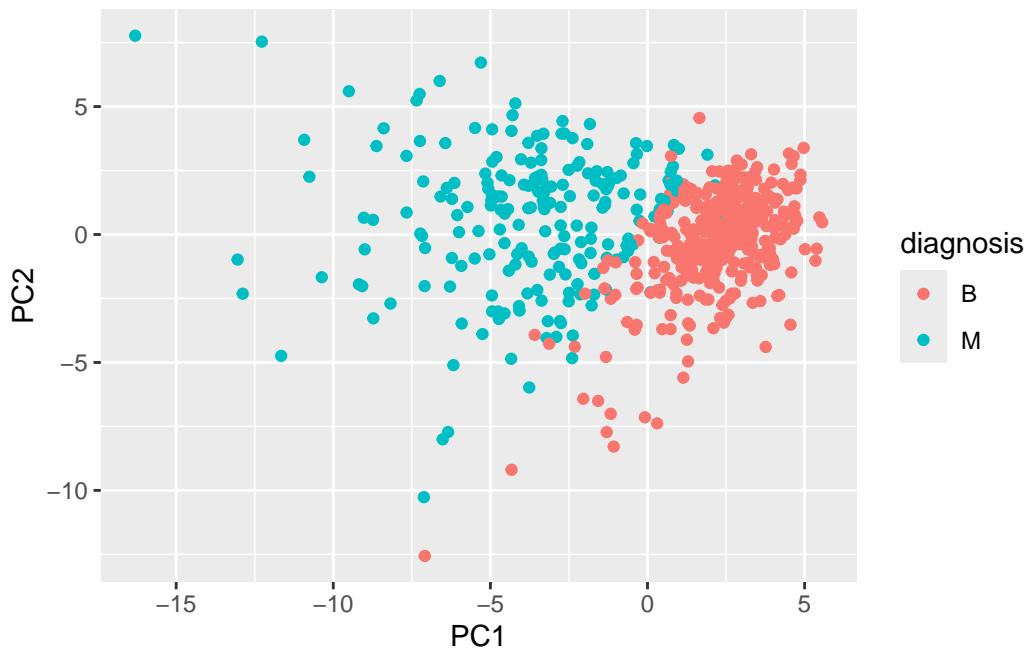
Q6. How many principal components (PCs) are required to describe at least 90% of the original variance in the data?

We need at least seven: PC1, PC2, PC3, PC4, PC5, PC6 and PC7.

The main PC result figure is called a “score plot” or “PC”plot” (it also has many other names...)

```
library(ggplot2)

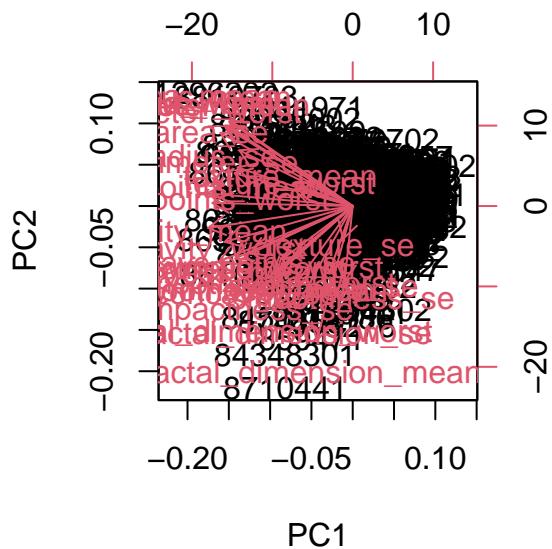
ggplot(wisc.pr$x) +
  aes(PC1,PC2, col = diagnosis) +
  geom_point()
```



It can be clearly observed that benign tumors and malignant tumors are somehow separated by the PCA plot.

We can also try biplot

```
biplot(wisc.pr)
```



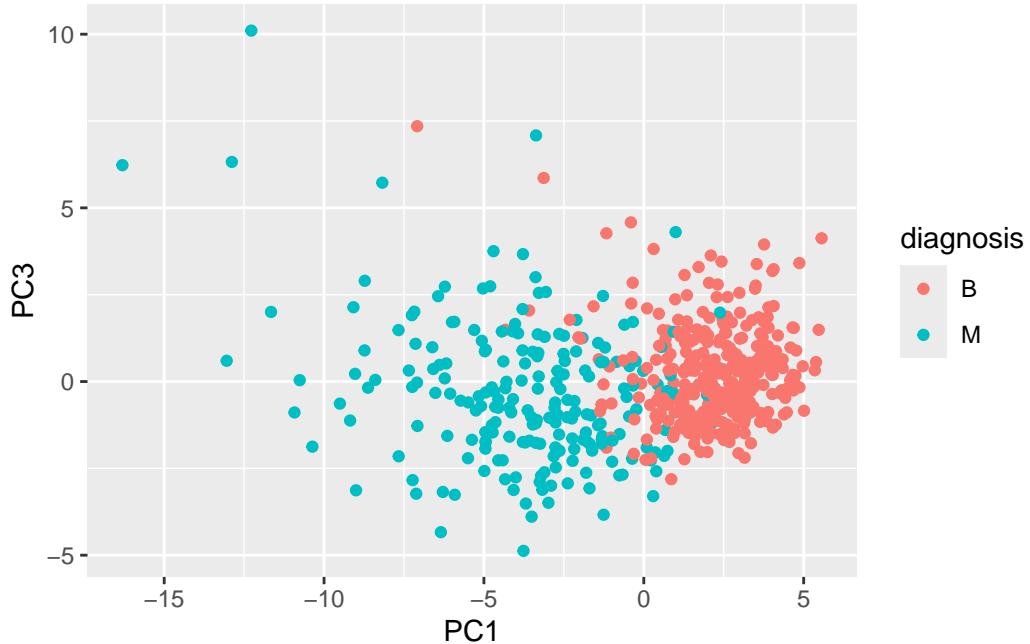
Q7. What stands out to you about this plot? Is it easy or difficult to understand?
Why?

The points in the plot are extremely crowded, and the labels are largely overlapping with each other. In addition, we are missing the color coding – the most important feature (malignant vs. begin) is not even shown here. Together, these make the plot very difficult to understand.

Previously, we already generated the PCA plot with PC1 and PC2. This time we can try with PC1 and PC3 and see what is the difference. > Q8. Generate a similar plot for principal components 1 and 3. What do you notice about these plots?

```
library(ggplot2)

ggplot(wisc.pr$x) +
  aes(PC1,PC3, col = diagnosis) +
  geom_point()
```



It can be found that in the plot of PC1 vs PC3, the benign tumors and malignant tumors are not separated so well as the case in the plot of PC1 vs PC2. This is because PC3 explains less original variance, compared with PC2.

Variance explained

First, let us calculate the variance of each component

```
# Calculate variance of each component
pr.var <- wisc.pr$sdev^2
head(pr.var)
```

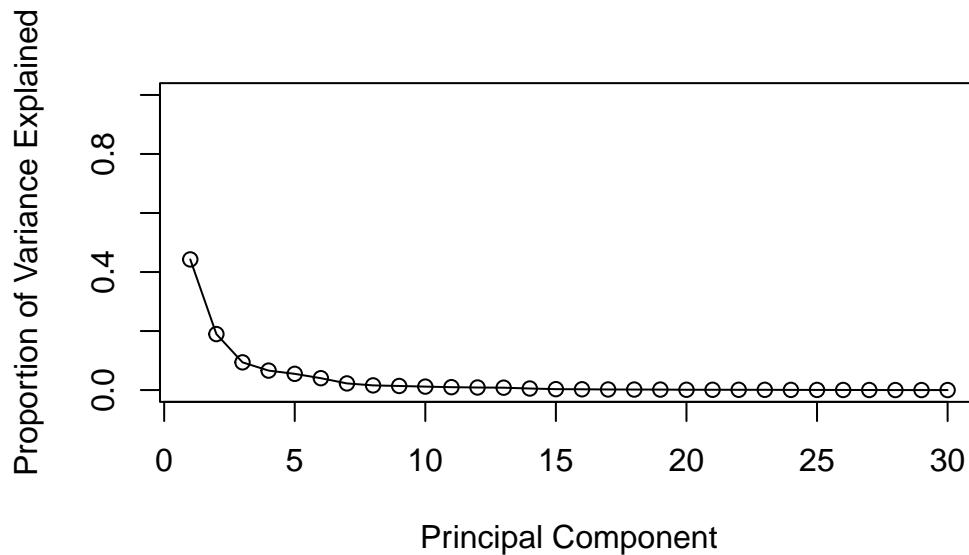
```
[1] 13.281608 5.691355 2.817949 1.980640 1.648731 1.207357
```

Then, let us calculate the variance explained by each principal component by dividing by the total variance explained of all principal components.

```
# Variance explained by each principal component: pve
pve <- pr.var / sum(pr.var)

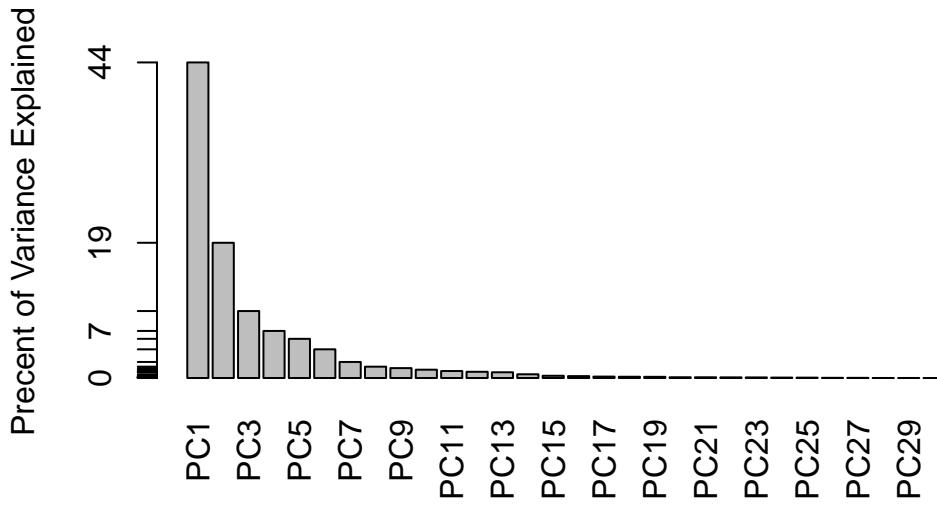
# Plot variance explained for each principal component
plot(pve, xlab = "Principal Component",
```

```
ylab = "Proportion of Variance Explained",
ylim = c(0, 1), type = "o")
```



We can also use an alternative way to plot the same data

```
# Alternative scree plot of the same data, note data driven y-axis
barplot(pve, ylab = "Percent of Variance Explained",
         names.arg=paste0("PC",1:length(pve)), las=2, axes = FALSE)
axis(2, at=pve, labels=round(pve,2)*100 )
```



Q9. For the first principal component, what is the component of the loading vector (i.e. `wisc.pr$rotation[,1]`) for the feature `concave.points_mean`?

```
wisc.pr$rotation["concave.points_mean", "PC1"]
```

```
[1] -0.2608538
```

The component of the loading vector for the feature `concave.points_mean` is -0.2608538.

Q10. What is the minimum number of principal components required to explain 80% of the variance of the data?

We need at least five principal components: PC1, PC2, PC3, PC4 and PC5

Hierarchical clustering

Just clustering the original data is not very informative or helpful

```

# Scale the wisc.data data using the "scale()" function
data.scaled <- scale(wisc.data)
#Calculate the (Euclidean) distances between all pairs of observations
data.dist <- dist(data.scaled)
#Create a hierarchical clustering model using complete linkage.
wisc.hclust <- hclust(data.dist, "complete")

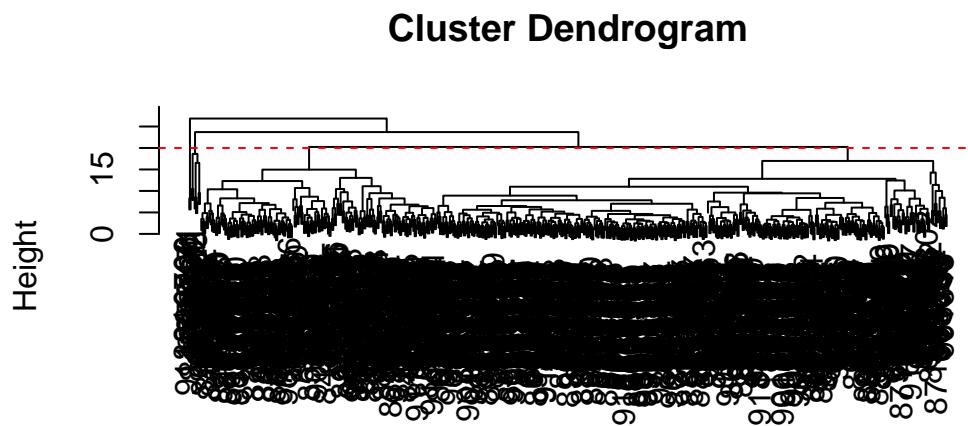
```

Q11. Using the plot() and abline() functions, what is the height at which the clustering model has 4 clusters?

```

plot(wisc.hclust)
abline(h = 20, col="red", lty=2)

```



data.dist
 hclust (*, "complete")

```
table(cutree(wisc.hclust, h = 19))
```

1	2	3	4
177	7	383	2

When we cut the tree with the height = 19 or 20, the clustering model has 4 clusters.

With the cutree function, we can select the specific clusters.

```
wisc.hclust.clusters <- cutree(wisc.hclust, h = 19)
```

We can use the table() function to compare the cluster membership to the actual diagnoses.

```
table(wisc.hclust.clusters, diagnosis)
```

	diagnosis	
wisc.hclust.clusters	B	M
1	12	165
2	2	5
3	343	40
4	0	2

Q12. Can you find a better cluster vs diagnoses match by cutting into a different number of clusters between 2 and 10?

```
wisc.hclust.clusters3 <- cutree(wisc.hclust, k = 3)
table(wisc.hclust.clusters3, diagnosis)
```

	diagnosis	
wisc.hclust.clusters3	B	M
1	355	205
2	2	5
3	0	2

If we cut the tree into 3 clusters, cluster 1 almost does not reflect cluster vs diagnoses match at all. Therefore, reducing the cluster numbers to those smaller than 4 is likely not a good choice.

```
wisc.hclust.clusters5 <- cutree(wisc.hclust, k = 5)
table(wisc.hclust.clusters5, diagnosis)
```

	diagnosis	
wisc.hclust.clusters5	B	M
1	12	165
2	0	5
3	343	40
4	2	0
5	0	2

If we cut the tree into 5 clusters, this is somewhat better than 4 clusters. When we cut the tree into 4 clusters, cluster 2 contains 2 benign tumors and 5 malignant tumors. When we cut the tree into 5 clusters, the original cluster 2 is now separated to the new cluster 2 – which contains 5 malignant tumors only – and the new cluster 4, which contains 2 benign tumors only. However, since the new cluster 2 and new cluster 4 do not contain that many tumors, the benefit is not that significant.

```
wisc.hclust.clusters10 <- cutree(wisc.hclust, k = 10)
table(wisc.hclust.clusters10, diagnosis)
```

	diagnosis	
wisc.hclust.clusters10	B	M
1	12	86
2	0	59
3	0	3
4	331	39
5	0	20
6	2	0
7	12	0
8	0	2
9	0	2
10	0	1

Finally, let us cut the tree into 10 clusters. This again becomes somewhat better than 5 clusters, because now there are more clusters that contain benign tumors only or malignant tumors only. However, as the case of 5 clusters, these newly created clusters do not contain that many tumors.

Therefore, my conclusion is that cutting the tree into less clusters does not work. On the other hand, cutting the tree into more clusters (up to 10) can help us find more clusters that contain only benign or only malignant tumors. However, since these newly created clusters have relatively small sizes, it is not a remarkable benefit.

As we discussed in our last class videos there are number of different “methods” we can use to combine points during the hierarchical clustering procedure. These include “single”, “complete”, “average” and “ward.D2”.

Q13. Which method gives your favorite results for the same data.dist dataset?
Explain your reasoning.

My favorite method is the “complete” method. It gives the best results because it produces more compact, spherical clusters by using the maximum distance between clusters. This helps avoid the “chaining” problem seen in single linkage and creates better-separated groups, which is important for distinguishing between malignant and benign diagnoses.

K-means

Let's also try K-means clustering

```
wisc.km <- kmeans(scale(wisc.data), centers=2, nstart=20)
table(wisc.hclust.clusters, wisc.km$cluster)
```

```
wisc.hclust.clusters   1   2
                      1 17 160
                      2  0  7
                      3 363 20
                      4  0  2
```

Combining different methods

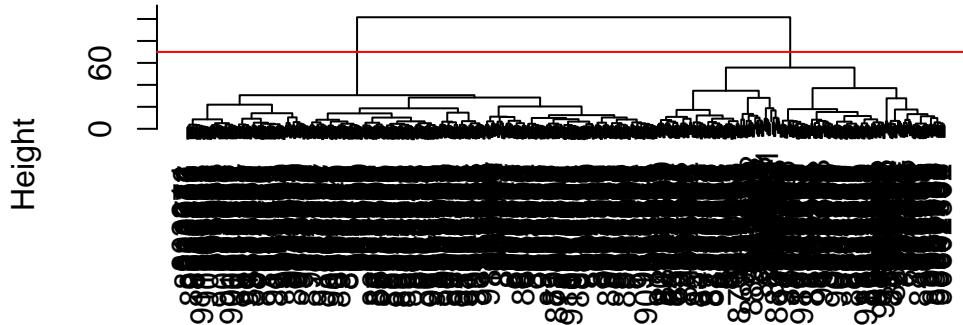
By combining the PCA method and the hierarchical clustering method, we can better analyze the data.

```
#Take the first 7 PCs so that at least 90% of the original variance is captured
dist.pc <- dist(wisc.pr$x[,1:7])
wisc.pr.hclust <- hclust(dist.pc, method = "ward.D2")
```

View the tree...

```
plot(wisc.pr.hclust)
abline(h = 70, col = "red")
```

Cluster Dendrogram



```
dist.pc  
hclust (*, "ward.D2")
```

To get our clustering membership vector (i.e. our main clustering result), we “cut” the tree at a desired height to yield a desired number of “k” groups.

```
grps <- cutree(wisc.pr.hclust, h = 70)  
table(grps)
```

```
grps  
 1   2  
216 353
```

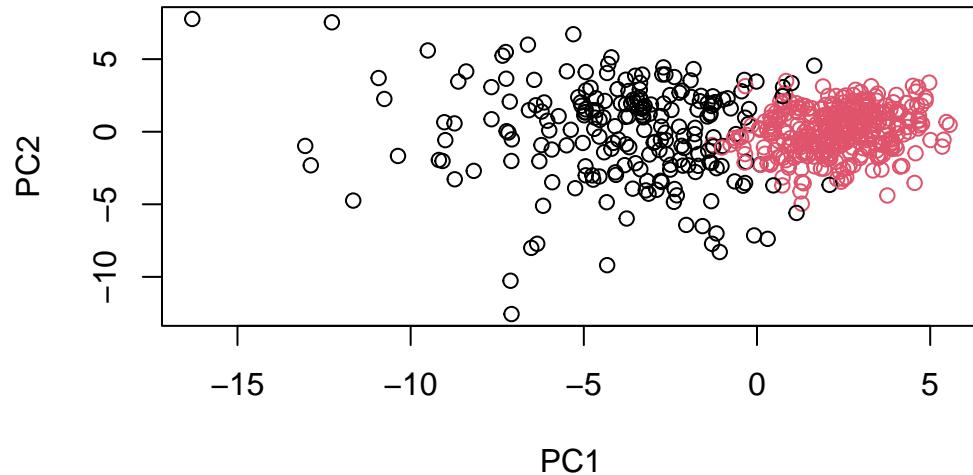
How does this clustering looks compared to the diagnosis from the experts?

```
table(grps, diagnosis)
```

```
diagnosis  
grps   B   M  
 1  28 188  
 2 329  24
```

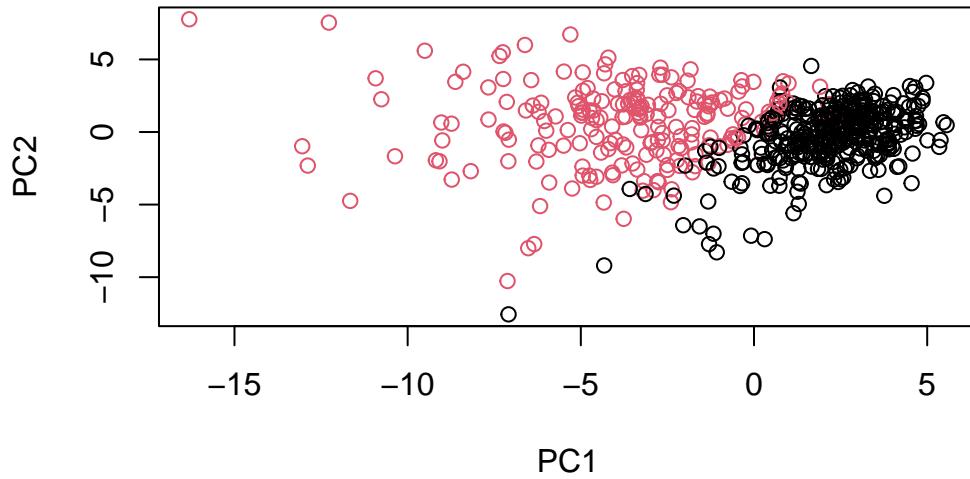
Let us plot the clustering result and use the color to encode the groups we found

```
plot(wisc.pr$x[,1:2], col=grps)
```



Make another plot. This time, we use the color to encode the diagnosis by the experts.

```
plot(wisc.pr$x[,1:2], col=diagnosis)
```



We can see that these two plots are largely similar to each other.

Let's put all the results of all the methods together using the `table()` function

```
#The result of combining PCA and hierarchical clustering


```

	diagnosis	
grps	B	M
1	28	188
2	329	24

```
# The result of using K-means clustering


```

	diagnosis	
	B	M
1	343	37
2	14	175

```
# The result of using hierarchical clustering


```

diagnosis		
wisc.hclust.clusters	B	M
1	12	165
2	2	5
3	343	40
4	0	2

Q15. How well does the newly created model with four (should actually be 2) clusters separate out the two diagnoses?

The 2-cluster model created by combining PCA hierarchical clustering performs reasonably well at separating the diagnoses with 90.9% overall accuracy (517/569 correct classifications). Cluster 1: Primarily Malignant (87% purity) - 188 M, 28 B. Cluster 2: Primarily Benign (93% purity) - 329 B, 24 M. The model correctly identifies most cases but has 52 misclassifications: 28 Benign cases wrongly grouped with Malignant, and 24 Malignant cases wrongly grouped with Benign. Cluster 2 shows better separation than Cluster 1.

Q16. How well do the k-means and hierarchical clustering models you created in previous sections (i.e. before PCA) do in terms of separating the diagnoses? Again, use the table() function to compare the output of each model (wisc.km\$cluster and wisc.hclust.clusters) with the vector containing the actual diagnoses.

K-means clustering: 91.0% accuracy (518/569 correct); Cluster 1: 175 M, 14 B (93% Malignant); Cluster 2: 343 B, 37 M (90% Benign); Total misclassifications: 51

Hierarchical clustering: 90.5% accuracy (515/569 correct); Cluster 1: 165 M, 12 B (93% Malignant); Cluster 2: 5 M, 2 B (very small, 71% Malignant the 2 benign tumors are considered as misclassifications); Cluster 3: 40 M, 343 B (90% Benign); Cluster 4: 2 M, 0 B (very small, 100% Malignant); Total misclassifications: 54

The overall correct rates for all these three methods are very similar to each other – all around 90%. The method using K-means only performs slightly better than the other two methods. The method using hierarchical clustering only creates fragmented clusters with some very small groups (clusters 2 and 4), making it less practical for diagnosis separation.

Sensitivity and Specificity

Sensitivity refers to a test's ability to correctly detect ill patients who do have the condition. In our example here the sensitivity is the total number of samples in the cluster identified as predominantly malignant (cancerous) divided by the total number of known malignant samples. In other words: $TP/(TP+FN)$.

Specificity relates to a test's ability to correctly reject healthy patients without a condition. In our example specificity is the proportion of benign (not cancerous) samples in the

cluster identified as predominantly benign that are known to be benign. In other words: $\text{TN}/(\text{TN}+\text{FN})$.

Q17. Which of your analysis procedures resulted in a clustering model with the best specificity? How about sensitivity?

We can get the TP, FN, TN and FP numbers for each of the three methods using the summary that we wrote above.

```
# K-means Clustering
TP_k <- 175
FN_k <- 37
TN_k <- 343
FP_k <- 14

sensitivity_k <- TP_k / (TP_k + FN_k)
specificity_k <- TN_k / (TN_k + FP_k)

# Hierarchical Clustering (4 clusters)
TP_h <- 172
FN_h <- 40
TN_h <- 343
FP_h <- 14

sensitivity_h <- TP_h / (TP_h + FN_h)
specificity_h <- TN_h / (TN_h + FP_h)

# PCA + Hierarchical (2 clusters)
TP_pca <- 188
FN_pca <- 24
TN_pca <- 329
FP_pca <- 28

sensitivity_pca <- TP_pca / (TP_pca + FN_pca)
specificity_pca <- TN_pca / (TN_pca + FP_pca)

# Print results
cat("K-means: Sensitivity =", sensitivity_k, "Specificity =", specificity_k, "\n")
```

K-means: Sensitivity = 0.8254717 Specificity = 0.9607843

```

cat("Hierarchical: Sensitivity =", sensitivity_h, "Specificity =", specificity_h, "\n")

Hierarchical: Sensitivity = 0.8113208 Specificity = 0.9607843

cat("PCA + Hierarchical: Sensitivity =", sensitivity_pca,
    "Specificity =", specificity_pca, "\n")

PCA + Hierarchical: Sensitivity = 0.8867925 Specificity = 0.9215686

```

Prediction

We can use our PCA model for prediction with new input patient samples.

```

url <- "https://tinyurl.com/new-samples-CSV"
new <- read.csv(url)
npc <- predict(wisc.pr, newdata=new)
npc

```

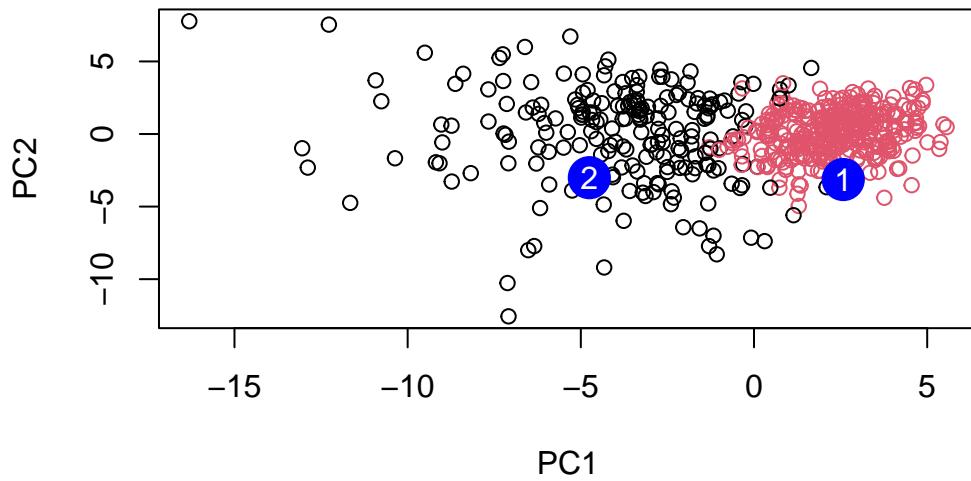
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
[1,]	2.576616	-3.135913	1.3990492	-0.7631950	2.781648	-0.8150185	-0.3959098
[2,]	-4.754928	-3.009033	-0.1660946	-0.6052952	-1.140698	-1.2189945	0.8193031
	PC8	PC9	PC10	PC11	PC12	PC13	PC14
[1,]	-0.2307350	0.1029569	-0.9272861	0.3411457	0.375921	0.1610764	1.187882
[2,]	-0.3307423	0.5281896	-0.4855301	0.7173233	-1.185917	0.5893856	0.303029
	PC15	PC16	PC17	PC18	PC19	PC20	
[1,]	0.3216974	-0.1743616	-0.07875393	-0.11207028	-0.08802955	-0.2495216	
[2,]	0.1299153	0.1448061	-0.40509706	0.06565549	0.25591230	-0.4289500	
	PC21	PC22	PC23	PC24	PC25	PC26	
[1,]	0.1228233	0.09358453	0.08347651	0.1223396	0.02124121	0.078884581	
[2,]	-0.1224776	0.01732146	0.06316631	-0.2338618	-0.20755948	-0.009833238	
	PC27	PC28	PC29	PC30			
[1,]	0.220199544	-0.02946023	-0.015620933	0.005269029			
[2,]	-0.001134152	0.09638361	0.002795349	-0.019015820			

Then, let's plot the new patients in our original PCA plot.

```

plot(wisc.pr$x[,1:2], col=grps)
points(npc[,1], npc[,2], col="blue", pch=16, cex=3)
text(npc[,1], npc[,2], c(1,2), col="white")

```



Q18. Which of these new patients should we prioritize for follow up based on your results?

Patient 2. This is because patient 2 falls into the group that primarily contains the malignant tumors based on our analysis. This means patient 2 will likely have a relatively poor prognosis