Model 3 Clustering Techniques

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2022-12-16

Packages used for clustering techniques

```
##
## 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

## Warning: package 'ggplot2' was built under R version 4.2.2

## Loading required package: foreach

## Loading required package: iterators

## Loading required package: parallel

## Warning: package 'rsample' was built under R version 4.2.2

## -- Attaching packages --------------------------------------- tidyverse
1.3.2 --

## v tibble  3.1.8     v purrr   0.3.5
## v tidyr   1.2.1     v stringr 1.5.0
## v readr   2.1.3     v forcats 0.5.2

## Warning: package 'stringr' was built under R version 4.2.2

## -- Conflicts ------------------------------------------
tidyverse_conflicts() --
## x purrr::accumulate() masks foreach::accumulate()
## x dplyr::filter()     masks stats::filter()
## x dplyr::lag()        masks stats::lag()
## x purrr::when()       masks foreach::when()
## Loading required package: lattice
##
##
```

```
## Attaching package: 'caret'
##
##
## The following object is masked from 'package:purrr':
##
##     lift
##
##
## Type 'citation("pROC")' for a citation.
##
##
## Attaching package: 'pROC'
##
##
## The following objects are masked from 'package:stats':
##
##     cov, smooth, var
```

Use `set.seed()` for reproducibility

```
# for reproducibility
set.seed(12345)
```

Import Packages

```
library(dplyr)         # for data manipulation
library(ggplot2)       # for awesome plotting
library(stringr)       # for string functionality
library(gridExtra)     # for manipulating the grid
library(tidyverse)     # for filtering
library(cluster)       # for general clustering algorithms
library(factoextra)    # for visualizing cluster results
library(readr)
library(mclust)        # for fitting clustering algorithms
library(bestNormalize)
```

Importing the dataset The dataset used in this model was imported from `radiomics data` .It has 197 observations and 431 variables.

```
datard <- read_csv("radiomics_completedata.csv", show_col_types = FALSE)
dim(datard)
```

```
## [1] 197 431
```

To check for the normality, the `shapiro.test` is used. *Checking for Normality*

```
datard1 = datard%>%select_if(is.numeric)
datadl1 = lapply(datard1[,-1], shapiro.test)
r = lapply(datadl1, function(x)x$p.value) #Extracting p-value only
s=unlist(r)    #to convert a list to vector
sum(s[s>0.05])

## [1] 0.1350113

r$Entropy_cooc.W.ADC

## [1] 0.1350113
```

Based on the normality test, there is only one variable that is normally distributed (*Entropy_cooc.W.ADC*), the rest is non normal. Hence, we will try to normalize the other variables using `orderNorm()` function.

Normalizing the dataset

The variables in the dataset, except *Entropy_cooc.W.ADC*, are to be normalized.

```
datard_norm = datard[,c(3,5:length(names(datard)))]
datard_norm = apply(datard_norm,2,orderNorm)
datard_norm = lapply(datard_norm, function(x) x$x.t)
datard_norm = datard_norm%>%as.data.frame()
```

Test again using shapiro-wilk's test.

```
datadl2 = lapply(datard_norm, shapiro.test)
r2 = lapply(datadl2, function(x) x$p.value)
s2 = unlist(r2)
sum(s2>0.05)

## [1] 428
```

Based on the results, the 428 variables are now normally distributed.

Inserting the normalized variables into the original dataset

Substituing the normalized variables into the original data, we have

```
r3 = select(datard, c("Failure.binary",  "Entropy_cooc.W.ADC"))
datard_n = cbind(r3,datard_norm)
```

1. K_MEANS CLUSTERING The **k-means algorithm** is perhaps the most often used clustering method. The k-means algorithm involves assigning each of the n examples to one of the k clusters, where k is a number that has been defined ahead of time. The goal is to minimize the differences within each cluster and maximize the differences between clusters. The basic idea behind k-means clustering is constructing clusters so that the total within-cluster variation is minimized.

In K-means, the commonly used rule of thumb for k is $k = \sqrt{n/2}$, where n is the number of observations to cluster. However, here we start at $k = 2$ and also a good

rule for the number of random starts to apply is 10-20.

```
#Start at 2 clusters
km2 <- kmeans(datard_n, centers = 2, nstart = 20)
print(km2)

## K-means clustering with 2 clusters of sizes 147, 50
##
## Cluster means:
##   Failure.binary Entropy_cooc.W.ADC     Failure GLNU_align.H.PET
Min_hist.PET
## 1      0.3537415           12.26146 -0.02791162       0.03129052   -
0.2918799
## 2      0.3000000           12.32898  0.08209356      -0.09199414
0.8581268
##   Max_hist.PET Mean_hist.PET Variance_hist.PET Standard_Deviation_hist.PET
## 1   -0.2980267    -0.2958011        -0.1650487                  -0.2929993
## 2    0.8761984     0.8696553         0.4852431                   0.8614179
##   Skewness_hist.PET Kurtosis_hist.PET Energy_hist.PET Entropy_hist.PET
## 1        -0.2718789        0.01358323      -0.2787074       -0.4257957
## 2         0.7993239       -0.03993469       0.8193998        1.2518393
##   AUC_hist.PET  H_suv.PET Volume.PET X3D_surface.PET ratio_3ds_vol.PET
## 1   -0.4286066 -0.2987092 -0.1780536      -0.1829026        -0.3105447
## 2    1.2601035  0.8782050  0.5234776       0.5377336         0.9130014
##   ratio_3ds_vol_norm.PET irregularity.PET tumor_length.PET
Compactness_v1.PET
## 1             -0.3127313       -0.4286066       -0.3446723         -
0.3458196
## 2              0.9194300        1.2601035        1.0133370
1.0167104
##   Compactness_v2.PET Spherical_disproportion.PET Sphericity.PET
Asphericity.PET
## 1         -0.2318686                 -0.3127313     -0.2838920      -
0.3086283
## 2          0.6816948                  0.9194300      0.8346426
0.9073671
##   Center_of_mass.PET Max_3D_diam.PET Major_axis_length.PET
## 1         -0.2479285      -0.2756706            -0.2967017
## 2          0.7289097       0.8104716             0.8723031
##   Minor_axis_length.PET Least_axis_length.PET Elongation.PET Flatness.PET
## 1            -0.3534589            -0.3032342      -0.419592   -0.4080212
## 2             1.0391691             0.8915085       1.233600    1.1995823
##   Max_cooc.L.PET Average_cooc.L.PET Variance_cooc.L.PET Entropy_cooc.L.PET
## 1     -0.2878736         -0.4021963          -0.3247267         -0.4286066
## 2      0.8463483          1.1824572           0.9546964          1.2601035
##   DAVE_cooc.L.PET DVAR_cooc.L.PET DENT_cooc.L.PET SAVE_cooc.L.PET
## 1      -0.3838672      -0.3361767      -0.4286066      -0.4021057
## 2       1.1285694       0.9883594       1.2601035       1.1821908
##   SVAR_cooc.L.PET SENT_cooc.L.PET ASM_cooc.L.PET Contrast_cooc.L.PET
```

```
## 1      -0.3370833      -0.4286066     -0.2753336          -0.2715229
## 2       0.9910248       1.2601035      0.8094807           0.7982773
##   Dissimilarity_cooc.L.PET Inv_diff_cooc.L.PET Inv_diff_norm_cooc.L.PET
## 1               -0.3838672          -0.4243855               -0.4286066
## 2                1.1285694           1.2476933                1.2601035
##   IDM_cooc.L.PET IDM_norm_cooc.L.PET Inv_var_cooc.L.PET
Correlation_cooc.L.PET
## 1      -0.402806          -0.4286066         -0.4045551             -
0.3418632
## 2       1.184250           1.2601035          1.1893919
1.0050778
##   Autocorrelation_cooc.L.PET Tendency_cooc.L.PET Shade_cooc.L.PET
## 1                 -0.3047654          -0.3370833       -0.1574664
## 2                  0.8960104           0.9910248        0.4629514
##   Prominence_cooc.L.PET IC1_.L.PET IC2_.L.PET Coarseness_vdif_.L.PET
## 1            -0.2382949  0.1941286 -0.4272793             -0.2758677
## 2             0.7005870 -0.5707380  1.2562010              0.8110514
##   Contrast_vdif_.L.PET Busyness_vdif_.L.PET Complexity_vdif_.L.PET
## 1           -0.2287154           -0.1913848             -0.3804826
## 2            0.6724232            0.5626713              1.1186189
##   Strength_vdif_.L.PET SRE_align.L.PET LRE_align.L.PET GLNU_align.L.PET
## 1           -0.1696303      -0.4286066      -0.4286066       -0.1519569
## 2            0.4987130       1.2601035       1.2601035        0.4467533
##   RLNU_align.L.PET RP_align.L.PET LGRE_align.L.PET HGRE_align.L.PET
## 1       -0.1397754     -0.4286066       -0.3378113       -0.3141790
## 2        0.4109397      1.2601035        0.9931653        0.9236862
##   LGSRE_align.L.PET HGSRE_align.L.PET LGHRE_align.L.PET HGLRE_align.L.PET
## 1        -0.3392893        -0.3134642        -0.3276135        -0.3185186
## 2         0.9975106         0.9215848         0.9631838         0.9364447
##   GLNU_norm_align.L.PET RLNU_norm_align.L.PET GLVAR_align.L.PET
## 1            -0.3506692            -0.4286066        -0.3356735
## 2             1.0309673             1.2601035         0.9868800
##   RLVAR_align.L.PET Entropy_align.L.PET SZSE.L.PET LZSE.L.PET LGLZE.L.PET
## 1        -0.3458905          -0.4286066 -0.4286066 -0.3908681  -0.3430631
## 2         1.0169181           1.2601035  1.2601035  1.1491524   1.0086056
##   HGLZE.L.PET SZLGE.L.PET SZHGE.L.PET LZLGE.L.PET LZHGE.L.PET
GLNU_area.L.PET
## 1  -0.3182950  -0.3487345  -0.3178923  -0.2955421  -0.2971190      -
0.1557581
## 2   0.9357872   1.0252793   0.9346034   0.8688938   0.8735299
0.4579289
##   ZSNU.L.PET  ZSP.L.PET GLNU_norm.L.PET ZSNU_norm.L.PET GLVAR_area.L.PET
## 1 -0.1463867 -0.4286066      -0.3504574      -0.4286066       -0.3412766
## 2  0.4303770  1.2601035       1.0303448       1.2601035        1.0033531
##   ZSVAR.L.PET Entropy_area.L.PET Max_cooc.H.PET Average_cooc.H.PET
## 1  -0.3051123         -0.4286066     -0.1871997         -0.4286066
## 2   0.8970301          1.2601035      0.5503672          1.2601035
##   Variance_cooc.H.PET Entropy_cooc.H.PET DAVE_cooc.H.PET DVAR_cooc.H.PET
## 1          -0.4199659         -0.4045495      -0.4280782      -0.4253142
## 2           1.2346999          1.1893755       1.2585499       1.2504238
```

```
##   DENT_cooc.H.PET SAVE_cooc.H.PET SVAR_cooc.H.PET SENT_cooc.H.PET
## 1      -0.4102848      -0.4286066      -0.4216049      -0.3334444
## 2       1.2062372       1.2601035       1.2395185       0.9803265
##   ASM_cooc.H.PET Contrast_cooc.H.PET Dissimilarity_cooc.H.PET
## 1     -0.1920280          -0.4075524               -0.4280782
## 2      0.5645624           1.1982041                1.2585499
##   Inv_diff_cooc.H.PET Inv_diff_norm_cooc.H.PET IDM_cooc.H.PET
## 1          -0.3629543               -0.4286066     -0.3152425
## 2           1.0670858                1.2601035      0.9268130
##   IDM_norm_cooc.H.PET Inv_var_cooc_.H.PET Correlation_cooc.H.PET
## 1          -0.4286066          -0.3196903             -0.3454144
## 2           1.2601035           0.9398894              1.0155183
##   Autocorrelation_cooc.H.PET Tendency_cooc.H.PET Shade_cooc.H.PET
## 1                 -0.4241004          -0.4133528        0.2067804
## 2                  1.2468553           1.2152572       -0.6079343
##   Prominence_cooc.H.PET IC1_d.H.PET IC2_d.H.PET Coarseness_vdif.H.PET
## 1            -0.3164121  0.05998554  -0.4066459            -0.2721379
## 2             0.9302514 -0.17635749   1.1955390             0.8000853
##   Contrast_vdif.H.PET Busyness_vdif.H.PET Complexity_vdif.H.PET
## 1          -0.2116134          -0.1423862            -0.3266366
## 2           0.6221434           0.4186155             0.9603116
##   Strength_vdif.H.PET SRE_align.H.PET LRE_align.H.PET RLNU_align.H.PET
## 1          -0.1140841      -0.4286066      -0.3619642       -0.1401331
## 2           0.3354073       1.2601035       1.0641749        0.4119913
##   RP_align.H.PET LGRE_align.H.PET HGRE_align.H.PET LGSRE_align.H.PET
## 1     -0.4286066       -0.2759537       -0.4231998        -0.2759537
## 2      1.2601035        0.8113038        1.2442073         0.8113038
##   HGSRE_align.H.PET LGHRE_align.H.PET HGLRE_align.H.PET
GLNU_norm_align.H.PET
## 1        -0.4286066        -0.2767306        -0.2995582            -
0.2791624
## 2         1.2601035         0.8135873         0.8807012
0.8207375
##   RLNU_norm_align.H.PET GLVAR_align.H.PET RLVAR_align.H.PET
Entropy_align.H.PET
## 1            -0.4286066        -0.4064436        -0.2121376          -
0.4286066
## 2             1.2601035         1.1949441         0.6236846
1.2601035
##   SZSE.H.PET LZSE.H.PET LGLZE.H.PET HGLZE.H.PET SZLGE.H.PET SZHGE.H.PET
## 1 -0.4160878 -0.1335103  -0.2758313  -0.4215119  -0.2758037  -0.4076622
## 2  1.2232981  0.3925204   0.8109439   1.2392449   0.8108628   1.1985268
##   LZLGE.H.PET LZHGE.H.PET GLNU_area.H.PET ZSNU.H.PET  ZSP.H.PET
GLNU_norm.H.PET
## 1  -0.1559773  -0.1189968      -0.1641376 -0.1153619 -0.3544412      -
0.2881725
## 2   0.4585734   0.3498507       0.4825644  0.3391641  1.0420572
0.8472273
##   ZSNU_norm.H.PET GLVAR_area.H.PET ZSVAR_H.PET Entropy_area.H.PET
## 1      -0.3638285       -0.4012459  -0.1035769         -0.4286066
```

```
## 2       1.0696557        1.1796629   0.3045160          1.2601035
##   Max_cooc.W.PET Average_cooc.W.PET Variance_cooc.W.PET Entropy_cooc.W.PET
## 1     -0.2186164         -0.2896627          -0.1580777         -0.4234387
## 2      0.6427321          0.8516085           0.4647485          1.2449097
##   DAVE_cooc.W.PET DVAR_cooc.W.PET DENT_cooc.W.PET SAVE_cooc.W.PET
## 1      -0.2951551      -0.1668071      -0.4204337      -0.2892624
## 2       0.8677561       0.4904128       1.2360752       0.8504316
##   SVAR_cooc.W.PET SENT_cooc.W.PET ASM_cooc.W.PET Contrast_cooc.W.PET
## 1      -0.1538147      -0.4278614     -0.2390795          -0.1743678
## 2       0.4522152       1.2579126      0.7028941           0.5126415
##   Dissimilarity_cooc.W.PET Inv_diff_cooc.W.PET Inv_diff_norm_cooc.W.PET
## 1               -0.2951551          -0.3966254               -0.4286066
## 2                0.8677561           1.1660786                1.2601035
##   IDM_cooc.W.PET IDM_norm_cooc.W.PET Inv_var_cooc.W.PET
Correlation_cooc.W.PET
## 1     -0.3339890          -0.4286065         -0.3639256             -
0.3423431
## 2      0.9819276           1.2601035          1.0699412
1.0064888
##   Autocorrelation_cooc.W.PET Tendency_cooc.W.PET Shade_cooc.W.PET
## 1                 -0.1595493          -0.1538147      -0.06761321
## 2                  0.4690750           0.4522152       0.19878284
##   Prominence_cooc.W.PET IC1_d.W.PET IC2_d.W.PET Coarseness_vdif.W.PET
## 1           -0.08123456  0.08388662  -0.4238883            -0.2515803
## 2            0.23882962 -0.24662665   1.2462317             0.7396460
##   Contrast_vdif.W.PET Busyness_vdif.W.PET Complexity_vdif.W.PET
## 1          -0.2630003          -0.1556319            -0.1259231
## 2           0.7732209           0.4575578             0.3702140
##   Strength_vdif.W.PET SRE_align.W.PET LRE_align.W.PET GLNU_align.W.PET
## 1          -0.1930647      -0.4286066      -0.4124808       -0.1678253
## 2           0.5676102       1.2601035       1.2126937        0.4934063
##   RLNU_align.W.PET RP_align.W.PET LGRE_align.W.PET HGRE_align.W.PET
## 1       -0.1407402     -0.4286066       -0.2634431       -0.1606774
## 2        0.4137762      1.2601035        0.7745228        0.4723914
##   LGSRE_align.W.PET HGSRE_align.W.PET LGHRE_align.W.PET HGLRE_align.W.PET
## 1        -0.2782163        -0.1571458        -0.2124329        -0.1675603
## 2         0.8179559         0.4620087         0.6245529         0.4926271
##   GLNU_norm_align.W.PET RLNU_norm_align.W.PET GLVAR_align.W.PET
## 1            -0.2789769            -0.4286066        -0.1643718
## 2             0.8201921             1.2601035         0.4832532
##   RLVAR_align.W.PET Entropy_align.W.PET SZSE.W.PET LZSE.W.PET LGLZE.W.PET
## 1        -0.2364997          -0.4286066 -0.4286066 -0.2103706  -0.2742133
## 2         0.6953090           1.2601035  1.2601035  0.6184897   0.8061871
##   HGLZE.W.PET SZLGE.W.PET SZHGE.W.PET LZLGE.W.PET LZHGE.W.PET
GLNU_area.W.PET
## 1  -0.1624379  -0.3152701  -0.1589498  -0.1268493  -0.1830155      -
0.1695615
## 2   0.4775674   0.9268940   0.4673123   0.3729370   0.5380657
0.4985108
##   ZSNU.W.PET  ZSP.W.PET GLNU_norm.W.PET ZSNU_norm.W.PET GLVAR_area.W.PET
```

```
## 1 -0.1334956 -0.4262296      -0.2863378      -0.4236507       -0.1621864
## 2  0.3924770  1.2531151       0.8418332       1.2455332        0.4768281
##   ZSVAR.W.PET Entropy_area.W.PET Min_hist.ADC Max_hist.ADC Mean_hist.ADC
## 1  -0.1341767         -0.4286066   -0.1803357   -0.4267104    -0.4250511
## 2   0.3944796          1.2601035    0.5356019    1.2549000     1.2496503
##   Variance_hist.ADC Standard_Deviation_hist.ADC Skewness_hist.ADC
## 1        -0.2379076                   -0.384642        -0.1506029
## 2         0.6994483                    1.130847         0.4427724
##   Kurtosis_hist.ADC Energy_hist.ADC Entropy_hist.ADC AUC_hist.ADC
Volume.ADC
## 1        -0.1002981      -0.2750884       -0.4286066   -0.4286063 -
0.1725886
## 2         0.2948765       0.8087608        1.2601035    1.2601035
0.5074105
##   X3D_surface.ADC ratio_3ds_vol.ADC ratio_3ds_vol_norm.ADC
irregularity.ADC
## 1      -0.2109386        -0.3626111             -0.4286066       -
0.4286066
## 2       0.6201594         1.0660761              1.2601035
1.2601035
##   Compactness_v1.ADC Compactness_v2.ADC Spherical_disproportion.ADC
## 1         -0.3611189         -0.3748229                  -0.4286066
## 2          1.0616896          1.1019793                   1.2601035
##   Sphericity.ADC Asphericity.ADC Center_of_mass.ADC Max_3D_diam.ADC
## 1     -0.4286066      -0.3856671         -0.1535828      -0.3231646
## 2      1.2601035       1.1338612          0.4515334       0.9501040
##   Major_axis_length.ADC Minor_axis_length.ADC Least_axis_length.ADC
## 1            -0.3731461            -0.3350782            -0.3113378
## 2             1.0970495             0.9851300             0.9153330
##   Elongation.ADC Flatness.ADC Max_cooc.L.ADC Average_cooc.L.ADC
## 1     -0.4274457   -0.4177604     -0.3070770         -0.4261506
## 2      1.2566904    1.2282154      0.9028064          1.2528828
##   Variance_cooc.L.ADC Entropy_cooc.L.ADC DAVE_cooc.L.ADC DVAR_cooc.L.ADC
## 1          -0.3011432         -0.4286066      -0.3962922      -0.2976913
## 2           0.8853611          1.2601035       1.1650991       0.8752124
##   DENT_cooc.L.ADC SAVE_cooc.L.ADC SVAR_cooc.L.ADC SENT_cooc.L.ADC
## 1      -0.4286066      -0.4261506      -0.2919474      -0.3454882
## 2       1.2601035       1.2528828       0.8583253       1.0157352
##   ASM_cooc.L.ADC Contrast_cooc.L.ADC Dissimilarity_cooc.L.ADC
## 1     -0.2847126          -0.2766957               -0.3962922
## 2      0.8370442           0.8134852                1.1650991
##   Inv_diff_cooc.L.ADC Inv_diff_norm_cooc.L.ADC IDM_cooc.L.ADC
## 1          -0.4278549               -0.4286063     -0.4120866
## 2           1.2578935                1.2601024      1.2115347
##   IDM_norm_cooc.L.ADC Inv_var_cooc.L.ADC Correlation_cooc.L.ADC
## 1          -0.4286066         -0.4147342              -0.3472015
## 2           1.2601035          1.2193186               1.0207723
##   Autocorrelation_.L.ADC Tendency_cooc.L.ADC Shade_.L.ADC
Prominence_cooc.L.ADC
## 1             -0.3593742          -0.2919474  -0.08089823            -
```

```
0.1824200
## 2              1.0565602           0.8583253   0.23784081
0.5363148
##   IC1_.L.ADC IC2_.L.ADC Coarseness_vdif_.L.ADC Contrast_vdif_.L.ADC
## 1  0.1974209 -0.4247674             -0.2400560           -0.2290685
## 2 -0.5804176  1.2488160              0.7057617            0.6734613
##   Busyness_vdif_.L.ADC Complexity_vdif_.L.ADC Strength_vdif_.L.ADC
## 1           -0.2334486              -0.387351           -0.1360331
## 2            0.6863390               1.138812            0.3999373
##   SRE_align.L.ADC LRE_align.L.ADC GLNU_align.L.ADC RLNU_align.L.ADC
## 1      -0.4286066      -0.4286066       -0.1657920       -0.1719383
## 2       1.2601016       1.2601035        0.4874284        0.5054985
##   RP_align.L.ADC LGRE_align.L.ADC HGRE_align.L.ADC LGSRE_align.L.ADC
## 1     -0.4286066       -0.2692384       -0.3847738        -0.2696881
## 2      1.2601035        0.7915610        1.1312349         0.7928837
##   HGSRE_align.L.ADC LGHRE_align.L.ADC HGLRE_align.L.ADC
GLNU_norm_align.L.ADC
## 1        -0.3854391        -0.2648096        -0.3846236            -
0.3958871
## 2         1.1331911         0.7785402         1.1307935
1.1639080
##   RLNU_norm_align.L.ADC GLVAR_align.L.ADC RLVAR_align.L.ADC
Entropy_align.L.ADC
## 1            -0.4286067        -0.3183272        -0.3662759          -
0.4286066
## 2             1.2601035         0.9358820         1.0768529
1.2601035
##   SZSE.L.ADC LZSE.L.ADC LGLZE.L.ADC HGLZE.L.ADC SZLGE.L.ADC SZHGE.L.ADC
## 1 -0.4286067 -0.4083135  -0.2725057  -0.3905358  -0.2731619  -0.3888874
## 2  1.2601035  1.2004418   0.8011667   1.1481754   0.8030950   1.1433289
##   LZLGE.L.ADC LZHGE.L.ADC GLNU_area.L.ADC ZSNU.L.ADC  ZSP.L.ADC
GLNU_norm.L.ADC
## 1  -0.2379409  -0.3658821      -0.1676727 -0.1734546 -0.4286066      -
0.3937176
## 2   0.6995465   1.0756933       0.4929578  0.5099565  1.2601035
1.1575302
##   ZSNU_norm.L.ADC GLVAR_area.L.ADC ZSVAR.L.ADC Entropy_area.L.ADC
## 1      -0.4286064       -0.3228106  -0.2564626         -0.4286066
## 2       1.2601012        0.9490632   0.7539999          1.2601035
##   Max_cooc.H.ADC Average_cooc.H.ADC Variance_cooc.H.ADC Entropy_cooc.H.ADC
## 1     -0.2791249         -0.4286066          -0.4286066         -0.4286066
## 2      0.8206280          1.2601035           1.2601035          1.2601035
##   DAVE_cooc.H.ADC DVAR_cooc.H.ADC DENT_cooc.H.ADC SAVE_cooc.H.ADC
## 1      -0.4286066      -0.4277528      -0.4286066      -0.4286066
## 2       1.2601035       1.2575931       1.2600955       1.2601035
##   SVAR_cooc.H.ADC SENT_cooc.H.ADC ASM_cooc.H.ADC Contrast_cooc.H.ADC
## 1      -0.4286066      -0.4286066     -0.2753277          -0.4122315
## 2       1.2601035       1.2601035      0.8094090           1.2119605
##   Dissimilarity_cooc.H.ADC Inv_diff_cooc.H.ADC Inv_diff_norm_cooc.H.ADC
## 1               -0.4286066          -0.4284984               -0.4286066
```

```
## 2                1.2601035           1.2597865                1.2601035
##   IDM_cooc.H.ADC IDM_norm_cooc.H.ADC Inv_var_cooc.H.ADC
Correlation_cooc.H.ADC
## 1     -0.4213064          -0.4286066         -0.4223303              -
0.346051
## 2      1.2386408           1.2601035          1.2416511
1.017390
##   Autocorrelation_cooc.H.ADC Tendency_cooc.H.ADC Shade_cooc.H.ADC
## 1                 -0.4286066          -0.4286066       -0.1324663
## 2                  1.2601035           1.2601035        0.3894511
##   Prominence_cooc.H.ADC IC1_d.H.ADC IC2_d.H.ADC Coarseness_vdif.H.ADC
## 1            -0.4286066   0.1586805  -0.4276725            -0.2397074
## 2             1.2601035  -0.4665213   1.2573571             0.7047403
##   Contrast_vdif.H.ADC Busyness_vdif.H.ADC Complexity_vdif.H.ADC
## 1          -0.4284988          -0.2072457            -0.4266154
## 2           1.2597865           0.6093025             1.2542493
##   Strength_vdif.H.ADC SRE_align.H.ADC LRE_align.H.ADC GLNU_align.H.ADC
## 1          -0.1201658      -0.4286065      -0.4286066       -0.1748971
## 2           0.3532876       1.2601035       1.2601035        0.5141974
##   RLNU_align.H.ADC RP_align.H.ADC LGRE_align.H.ADC HGRE_align.H.ADC
## 1       -0.1756938     -0.4286067       -0.3542342       -0.4286066
## 2        0.5165398      1.2601035        1.0414292        1.2601035
##   LGSRE_align.H.ADC HGSRE_align.H.ADC LGHRE_align.H.ADC HGLRE_align.H.ADC
## 1        -0.3514752        -0.4286066        -0.3753355        -0.4286066
## 2         1.0333211         1.2601035         1.1034864         1.2601035
##   GLNU_norm_align.H.ADC RLNU_norm_align.H.ADC GLVAR_align.H.ADC
## 1            -0.3355290            -0.4286067        -0.4286066
## 2             0.9864517             1.2601035         1.2601035
##   RLVAR_align.H.ADC Entropy_align.H.ADC SZSE.H.ADC LZSE.H.ADC LGLZE.H.ADC
## 1        -0.3650968          -0.4286067 -0.4286069 -0.4285691   -0.348696
## 2         1.0733846           1.2601035  1.2601035  1.2601035    1.025167
##   HGLZE.H.ADC SZLGE.H.ADC SZHGE.H.ADC LZLGE.H.ADC LZHGE.H.ADC
GLNU_area.H.ADC
## 1  -0.4286066  -0.3382493  -0.4286066  -0.3547563  -0.4282797      -
0.1749084
## 2   1.2601035   0.9944530   1.2601035   1.0429835   1.2591423
0.5142307
##   ZSNU.H.ADC  ZSP.H.ADC GLNU_norm.H.ADC ZSNU_norm.H.ADC GLVAR_area.H.ADC
## 1 -0.1757982 -0.4286069      -0.3355441      -0.4286069       -0.4286066
## 2  0.5168978  1.2601035       0.9860426       1.2601035        1.2601035
##   ZSVAR.H.ADC Entropy_area.H.ADC Max_cooc.W.ADC Average_cooc.W.ADC
## 1  -0.2786455         -0.4286066     -0.2756021         -0.3506321
## 2   0.8192230          1.2601035      0.8102563          1.0308583
##   Variance_cooc.W.ADC DAVE_cooc.W.ADC DVAR_cooc.W.ADC DENT_cooc.W.ADC
## 1          -0.2278081      -0.3984697      -0.2464992      -0.4286066
## 2           0.6697559       1.1715010       0.7247077       1.2601035
##   SAVE_cooc.W.ADC SVAR_cooc.W.ADC SENT_cooc.W.ADC ASM_cooc.W.ADC
## 1      -0.3510982      -0.2107892      -0.3367989     -0.2753303
## 2       1.0322287       0.6197202       0.9901887      0.8094624
##   Contrast_cooc.W.ADC Dissimilarity_cooc.W.ADC Inv_diff_cooc.W.ADC
```

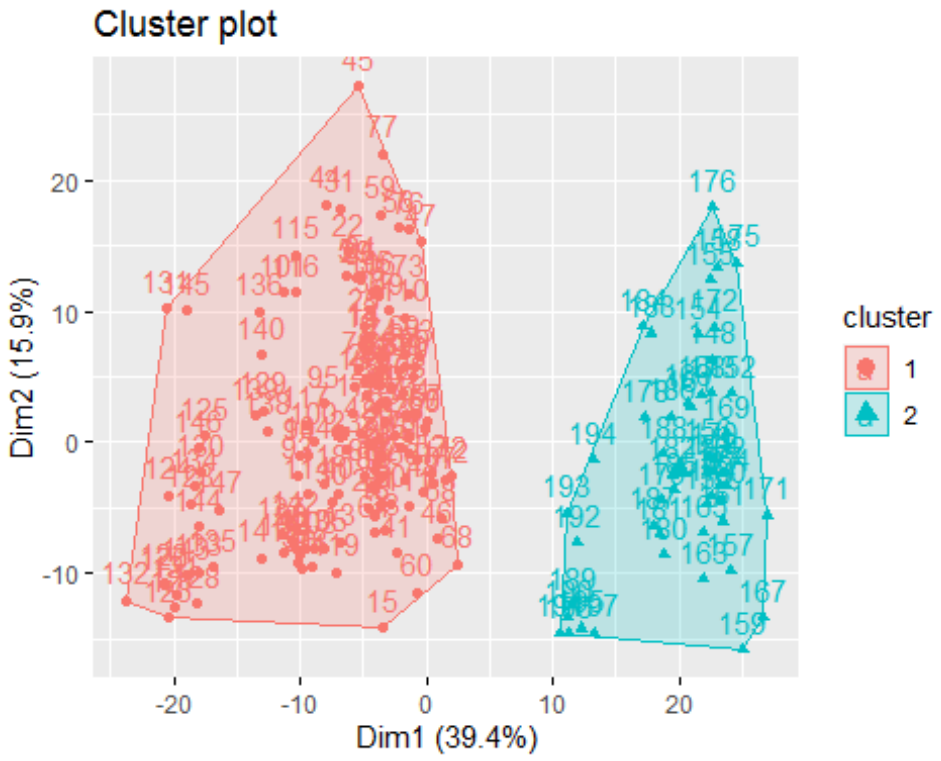
```
## 1          -0.2522659               -0.3984697          -0.4056228
## 2           0.7416618                1.1715010           1.1925307
##   Inv_diff_norm_cooc.W.ADC IDM_cooc.W.ADC IDM_norm_cooc.W.ADC
## 1               -0.4286066     -0.4077323          -0.4286066
## 2                1.2601035      1.1987330           1.2601035
##   Inv_var_cooc.W.ADC Correlation_cooc.W.ADC Autocorrelation_cooc.W.ADC
## 1          -0.405036             -0.3471036                 -0.2431931
## 2           1.190806              1.0204847                  0.7149876
##   Tendency_cooc.W.ADC Shade_cooc.W.ADC Prominence_cooc.W.ADC IC1_d.W.ADC
## 1          -0.2107892      -0.06333191            -0.1034179   0.2030385
## 2           0.6197202       0.18619581             0.3040448  -0.5969332
##   IC2_d.W.ADC Coarseness_vdif.W.ADC Contrast_vdif.W.ADC
Busyness_vdif.W.ADC
## 1  -0.4286066            -0.2498473          -0.2279747          -
0.3357031
## 2   1.2601035             0.7345515           0.6702456
0.9869673
##   Complexity_vdif.W.ADC Strength_vdif.W.ADC SRE_align.W.ADC
LRE_align.W.ADC
## 1            -0.1675949          -0.1971830      -0.4286066      -
0.4286066
## 2             0.4927289           0.5797181       1.2601035
1.2601035
##   GLNU_align.W.ADC RLNU_align.W.ADC RP_align.W.ADC LGRE_align.W.ADC
## 1       -0.1936244       -0.1714596     -0.4286066       -0.2693426
## 2        0.5692557        0.5040911      1.2601035        0.7918681
##   HGRE_align.W.ADC LGSRE_align.W.ADC HGSRE_align.W.ADC LGHRE_align.W.ADC
## 1       -0.2493557        -0.2701505        -0.2492631         -0.264635
## 2        0.7331058         0.7942434         0.7328334          0.778014
##   HGLRE_align.W.ADC GLNU_norm_align.W.ADC RLNU_norm_align.W.ADC
## 1        -0.2516480            -0.3191516            -0.4286067
## 2         0.7398451             0.9383067             1.2601035
##   GLVAR_align.W.ADC RLVAR_align.W.ADC Entropy_align.W.ADC SZSE.W.ADC
LZSE.W.ADC
## 1        -0.2414478        -0.3434379          -0.4286066 -0.4286066 -
0.4286066
## 2         0.7098564         1.0097017           1.2601035  1.2601035
1.2601035
##   LGLZE.W.ADC HGLZE.W.ADC SZLGE.W.ADC SZHGE.W.ADC LZLGE.W.ADC LZHGE.W.ADC
## 1  -0.2712675  -0.2494505  -0.2727780  -0.2488736  -0.2433616  -0.2572998
## 2   0.7975267   0.7333844   0.8019663   0.7316883   0.7154832   0.7564613
##   GLNU_area.W.ADC ZSNU.W.ADC  ZSP.W.ADC GLNU_norm.W.ADC ZSNU_norm.W.ADC
## 1      -0.1948427 -0.1675304 -0.4286066      -0.3128771      -0.4286066
## 2       0.5728375  0.4925395  1.2601035       0.9198583       1.2601035
##   GLVAR_area.W.ADC ZSVAR.W.ADC Entropy_area.W.ADC
## 1       -0.2438430  -0.3478209         -0.4286066
## 2        0.7168983   1.0225936          1.2601035
##
## Clustering vector:
##   [1] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

```
1 1 1
##  [38] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1
##  [75] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1
## [112] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 2
## [149] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2
## [186] 2 2 2 2 2 2 2 2 2 2 2 2
##
## Within cluster sum of squares by cluster:
## [1] 42691.43 13414.89
##  (between_SS / total_SS =  33.2 %)
##
## Available components:
##
## [1] "cluster"      "centers"      "totss"        "withinss"
"tot.withinss"
## [6] "betweenss"    "size"         "iter"         "ifault"
```

From the results, we have 2 K-means clusters of sizes 50, 147.

To see the plot of `km2` we use the function `fviz_cluster()`. `fviz_cluster()` provides ggplot, the observations are represented by points in the plot.

```
#plot the 2 K Means clusters
fviz_cluster(km2, data = datard_n)
```




```
#with K means cluster = 3
km3 <- kmeans(datard_n, centers = 3, nstart = 20)
print(km3)

## K-means clustering with 3 clusters of sizes 50, 103, 44
##
## Cluster means:
##   Failure.binary Entropy_cooc.W.ADC     Failure GLNU_align.H.PET
Min_hist.PET
## 1      0.3000000           12.32898  0.08209356     -0.091994139
0.85812682
## 2      0.3495146           12.23104  0.06533738     -0.009427189  -
0.43614178
## 3      0.3636364           12.33268 -0.24619905      0.126606986
0.04582414
##   Max_hist.PET Mean_hist.PET Variance_hist.PET Standard_Deviation_hist.PET
## 1   0.87619837    0.86965533         0.4852431                  0.86141787
## 2  -0.46164331   -0.45835946        -0.3328592                 -0.43567962
## 3   0.08498506    0.08473313         0.2277805                  0.04100243
##   Skewness_hist.PET Kurtosis_hist.PET Energy_hist.PET Entropy_hist.PET
## 1         0.7993239       -0.03993469       0.8193998        1.2518393
## 2        -0.1562938        0.04875016       0.1318335       -0.5421416
## 3        -0.5424529       -0.06873937      -1.2397463       -0.1534404
##   AUC_hist.PET  H_suv.PET Volume.PET X3D_surface.PET ratio_3ds_vol.PET
## 1   1.26010348  0.8782050  0.5234776       0.5377336       0.913001395
## 2  -0.09783915 -0.3528293 -0.4469966      -0.3135307      -0.002503013
## 3  -1.20290321 -0.1720189  0.4515175       0.1228859      -1.031642260
```

```
##   ratio_3ds_vol_norm.PET irregularity.PET tumor_length.PET
Compactness_v1.PET
## 1              0.9194300        1.2601035        1.0133370
1.01671038
## 2             -0.0514460       -0.2024322       -0.3575160        -
0.04050121
## 3             -0.9243764       -0.9580603       -0.3146062        -
1.06054229
##   Compactness_v2.PET Spherical_disproportion.PET Sphericity.PET
Asphericity.PET
## 1       0.6816947970                   0.9194300    0.834642568
0.90736711
## 2      -0.3312421924                  -0.0514460   -0.408748277     -
0.04630539
## 3       0.0007560935                  -0.9243764    0.008385093     -
0.92270228
##   Center_of_mass.PET Max_3D_diam.PET Major_axis_length.PET
## 1          0.7289097       0.8104716             0.8723031
## 2         -0.2828044      -0.5662795            -0.5482485
## 3         -0.1662871       0.4046184             0.2921464
##   Minor_axis_length.PET Least_axis_length.PET Elongation.PET Flatness.PET
## 1            1.03916907             0.8915085      1.2336004    1.1995823
## 2           -0.54506409            -0.5442359     -0.2537675   -0.3405795
## 3            0.09507154             0.2609288     -0.8077720   -0.5658959
##   Max_cooc.L.PET Average_cooc.L.PET Variance_cooc.L.PET Entropy_cooc.L.PET
## 1      0.8463483          1.1824572           0.9546964          1.2601035
## 2      0.1175010         -0.3623110          -0.1757674         -0.4970677
## 3     -1.2368186         -0.4955642          -0.6734268         -0.2683455
##   DAVE_cooc.L.PET DVAR_cooc.L.PET DENT_cooc.L.PET SAVE_cooc.L.PET
## 1       1.1285694       0.9883594       1.2601035       1.1821908
## 2      -0.2723810      -0.1908866      -0.3104527      -0.3629185
## 3      -0.6448461      -0.6762875      -0.7051941      -0.4938394
##   SVAR_cooc.L.PET SENT_cooc.L.PET ASM_cooc.L.PET Contrast_cooc.L.PET
## 1       0.9910248       1.2601035      0.8094807           0.7982773
## 2      -0.1976191      -0.2139714      0.1318891          -0.1506873
## 3      -0.6635562      -0.9310482     -1.2286049          -0.5543879
##   Dissimilarity_cooc.L.PET Inv_diff_cooc.L.PET Inv_diff_norm_cooc.L.PET
## 1                1.1285694           1.2476933                1.2601035
## 2               -0.2723810          -0.2737576               -0.2641384
## 3               -0.6448461          -0.7769917               -0.8136118
##   IDM_cooc.L.PET IDM_norm_cooc.L.PET Inv_var_cooc.L.PET
Correlation_cooc.L.PET
## 1      1.1842495           1.2601035          1.1893919
1.0050778
## 2     -0.1967642          -0.1986930         -0.1926182             -
0.3347999
## 3     -0.8851310          -0.9668136         -0.9006801             -
0.3583977
##   Autocorrelation_cooc.L.PET Tendency_cooc.L.PET Shade_cooc.L.PET
## 1                  0.8960104           0.9910248       0.46295135
```

```
## 2                 -0.2521613          -0.1976191      -0.06384699
## 3                 -0.4279069          -0.6635562      -0.37662109
##   Prominence_cooc.L.PET  IC1_.L.PET IC2_.L.PET Coarseness_vdif_.L.PET
## 1            0.70058703 -0.57073804  1.2562010              0.8110514
## 2           -0.06485971  0.28929559 -0.1824053              0.1388886
## 3           -0.64429095 -0.02864872 -1.0005069             -1.2467745
##   Contrast_vdif_.L.PET Busyness_vdif_.L.PET Complexity_vdif_.L.PET
## 1           0.67242321            0.5626713              1.1186189
## 2          -0.02509042           -0.3707759             -0.1974261
## 3          -0.70538289            0.2285534             -0.8090014
##   Strength_vdif_.L.PET SRE_align.L.PET LRE_align.L.PET GLNU_align.L.PET
## 1            0.4987130      1.26010348       1.2601035        0.4467533
## 2            0.1337268     -0.06234094      -0.2798127       -0.3993524
## 3           -0.8797615     -1.28600130      -0.7769197        0.4271735
##   RLNU_align.L.PET RP_align.L.PET LGRE_align.L.PET HGRE_align.L.PET
## 1        0.4109397     1.26010348     0.9931653287        0.9236862
## 2       -0.4020416    -0.06596095     0.0003066527       -0.2605452
## 3        0.4741659    -1.27752719    -1.1293148105       -0.4397308
##   LGSRE_align.L.PET HGSRE_align.L.PET LGHRE_align.L.PET HGLRE_align.L.PET
## 1        0.99751061         0.9215848      0.9631837619         0.9364447
## 2        0.00150105        -0.2532377     -0.0002880775        -0.2914542
## 3       -1.13704860        -0.4544490     -1.0938526389        -0.3818739
##   GLNU_norm_align.L.PET RLNU_norm_align.L.PET GLVAR_align.L.PET
## 1            1.03096731            1.26010348         0.9868800
## 2            0.05022954           -0.08924613        -0.2126497
## 3           -1.28913655           -1.22301869        -0.6236610
##   RLVAR_align.L.PET Entropy_align.L.PET SZSE.L.PET LZSE.L.PET  LGLZE.L.PET
## 1        1.01691811           1.2601035  1.2601035  1.1491524  1.008605590
## 2       -0.02323398          -0.4815782 -0.1120901 -0.4485566 -0.002220365
## 3       -1.10120014          -0.3046051 -1.1695429 -0.2558248 -1.140945043
##   HGLZE.L.PET  SZLGE.L.PET SZHGE.L.PET LZLGE.L.PET LZHGE.L.PET
GLNU_area.L.PET
## 1   0.9357872  1.025279294   0.9346034  0.86889376   0.8735299
0.4579289
## 2  -0.2601593  0.001671419  -0.2327100 -0.02472047  -0.3085215      -
0.4001837
## 3  -0.4543853 -1.169002746  -0.5172963 -0.92951089  -0.2704267
0.4164200
##   ZSNU.L.PET  ZSP.L.PET GLNU_norm.L.PET ZSNU_norm.L.PET GLVAR_area.L.PET
## 1  0.4303770  1.2601035      1.03034483       1.2601035        1.0033531
## 2 -0.4102506 -0.1545715      0.04986928      -0.1800621       -0.2146953
## 3  0.4712947 -1.0700979     -1.28758586      -1.0104268       -0.6375918
##   ZSVAR.L.PET Entropy_area.L.PET Max_cooc.H.PET Average_cooc.H.PET
## 1   0.8970301          1.2601035      0.5503672          1.2601035
## 2  -0.2132431         -0.5135166      0.1787787         -0.2414238
## 3  -0.5201697         -0.2298400     -1.0439220         -0.8667845
##   Variance_cooc.H.PET Entropy_cooc.H.PET DAVE_cooc.H.PET DVAR_cooc.H.PET
## 1           1.2346999          1.1893755       1.2585499       1.2504238
## 2          -0.5534078         -0.5127561      -0.4670489      -0.4579410
## 3          -0.1075906         -0.1512476      -0.3368512      -0.3489379
```

```
##   DENT_cooc.H.PET SAVE_cooc.H.PET SVAR_cooc.H.PET SENT_cooc.H.PET
## 1       1.2062372       1.2601035       1.2395185       0.9803265
## 2      -0.5101347      -0.2968597      -0.5086056      -0.1373389
## 3      -0.1765452      -0.7370141      -0.2179443      -0.7925095
##   ASM_cooc.H.PET Contrast_cooc.H.PET Dissimilarity_cooc.H.PET
## 1      0.5645624           1.1982041                1.2585499
## 2      0.2172291          -0.4438519               -0.4670489
## 3     -1.1500618          -0.3225785               -0.3368512
##   Inv_diff_cooc.H.PET Inv_diff_norm_cooc.H.PET IDM_cooc.H.PET
## 1           1.0670858               1.2601035     0.92681301
## 2          -0.1145474              -0.1151856    -0.05599947
## 3          -0.9444524              -1.1622969    -0.92210693
##   IDM_norm_cooc.H.PET Inv_var_cooc_.H.PET Correlation_cooc.H.PET
## 1          1.26010348          0.93988938              1.0155183
## 2         -0.08588108          0.03014244             -0.3674791
## 3         -1.23089598         -1.13861682             -0.2937629
##   Autocorrelation_cooc.H.PET Tendency_cooc.H.PET Shade_cooc.H.PET
## 1                  1.2468553          1.21525719      -0.60793428
## 2                 -0.2311291         -0.55484894       0.28955287
## 3                 -0.8758287         -0.08212314       0.01301747
##   Prominence_cooc.H.PET IC1_d.H.PET IC2_d.H.PET Coarseness_vdif.H.PET
## 1            0.93025143  -0.1763575   1.1955390             0.8000853
## 2           -0.47574640   0.3320062  -0.4234805             0.1365392
## 3            0.05657518  -0.5767901  -0.3672377            -1.2288138
##   Contrast_vdif.H.PET Busyness_vdif.H.PET Complexity_vdif.H.PET
## 1          0.62214341           0.4186155            0.96031165
## 2         -0.05874494          -0.4356625           -0.07505258
## 3         -0.56946460           0.5441468           -0.91557198
##   Strength_vdif.H.PET SRE_align.H.PET LRE_align.H.PET RLNU_align.H.PET
## 1           0.3354073       1.2601035       1.0641749        0.4119913
## 2           0.2374769      -0.3701632      -0.2153213       -0.4136037
## 3          -0.9370565      -0.5654173      -0.7052421        0.5000366
##   RP_align.H.PET LGRE_align.H.PET HGRE_align.H.PET LGSRE_align.H.PET
## 1      1.2601035        0.8113038        1.2442073         0.8113038
## 2     -0.3896171        0.1184110       -0.2735091         0.1187439
## 3     -0.5198775       -1.1991256       -0.7736121        -1.1999048
##   HGSRE_align.H.PET LGHRE_align.H.PET HGLRE_align.H.PET
GLNU_norm_align.H.PET
## 1         1.2601035         0.8135873         0.8807012
0.82073753
## 2        -0.3249637         0.1172528        -0.1800196
0.03756653
## 3        -0.6712253        -1.1990100        -0.5793873          -
1.02059613
##   RLNU_norm_align.H.PET GLVAR_align.H.PET RLVAR_align.H.PET
Entropy_align.H.PET
## 1             1.2601035        1.19494406        0.62368460
1.26010348
## 2            -0.4317955       -0.54757978       -0.01909491         -
0.57137386
```

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## 3            -0.4211417       -0.07605649       -0.66403304         -
0.09440151
##   SZSE.H.PET  LZSE.H.PET LGLZE.H.PET HGLZE.H.PET SZLGE.H.PET SZHGE.H.PET
## 1  1.2232981  0.39252039   0.8109439   1.2392449   0.8108628   1.1985268
## 2 -0.4030065 -0.07461144   0.1185232  -0.3368316   0.1195423  -0.3805777
## 3 -0.4467099 -0.27138729  -1.1989792  -0.6197406  -1.2012727  -0.4710644
##   LZLGE.H.PET  LZHGE.H.PET GLNU_area.H.PET ZSNU.H.PET  ZSP.H.PET
## 1   0.4585734  0.349850687       0.4825644  0.3391641  1.0420572
## 2   0.1834368  0.002522648      -0.4063182 -0.3657920 -0.3878684
## 3  -0.9505149 -0.403462890       0.4027853  0.4708721 -0.2761913
##   GLNU_norm.H.PET ZSNU_norm.H.PET GLVAR_area.H.PET ZSVAR_H.PET
## 1      0.84722728       1.0696557        1.1796629  0.30451604
## 2      0.01917366      -0.3840552       -0.5267189  0.02642073
## 3     -1.00764207      -0.3164794       -0.1075251 -0.40788949
##   Entropy_area.H.PET Max_cooc.W.PET Average_cooc.W.PET Variance_cooc.W.PET
## 1         1.26010348      0.6427321          0.8516085           0.4647485
## 2        -0.58988871      0.2202280         -0.4613212          -0.3253769
## 3        -0.05105993     -1.2459112          0.1121741           0.2335546
##   Entropy_cooc.W.PET DAVE_cooc.W.PET DVAR_cooc.W.PET DENT_cooc.W.PET
## 1          1.2449097     0.867756082       0.4904128       1.2360752
## 2         -0.5584923    -0.424119492      -0.3222303      -0.5229929
## 3         -0.1072905     0.006738718       0.1970246      -0.1803521
##   SAVE_cooc.W.PET SVAR_cooc.W.PET SENT_cooc.W.PET ASM_cooc.W.PET
## 1       0.8504316       0.4522152       1.2579126      0.7028941
## 2      -0.4622211      -0.3284163      -0.4561071      0.1984999
## 3       0.1156181       0.2549118      -0.3617410     -1.2634130
##   Contrast_cooc.W.PET Dissimilarity_cooc.W.PET Inv_diff_cooc.W.PET
## 1           0.5126415              0.867756082           1.1660786
## 2          -0.3223858             -0.424119492          -0.1655483
## 3           0.1721288              0.006738718          -0.9375557
##   Inv_diff_norm_cooc.W.PET IDM_cooc.W.PET IDM_norm_cooc.W.PET
## 1                1.2601035     0.98192759           1.2601035
## 2               -0.2461061    -0.08797305          -0.1918482
## 3               -0.8558238    -0.90988988          -0.9828363
##   Inv_var_cooc.W.PET Correlation_cooc.W.PET Autocorrelation_cooc.W.PET
## 1          1.0699412              1.0064888                  0.4690750
## 2         -0.1190777             -0.3422077                 -0.3619782
## 3         -0.9370922             -0.3426602                  0.3143182
##   Tendency_cooc.W.PET Shade_cooc.W.PET Prominence_cooc.W.PET IC1_d.W.PET
## 1           0.4522152        0.1987828             0.2388296  -0.2466266
## 2          -0.3284163       -0.1930359            -0.2585297   0.3870571
## 3           0.2549118        0.2259899             0.3337971  -0.6258080
##   IC2_d.W.PET Coarseness_vdif.W.PET Contrast_vdif.W.PET
Busyness_vdif.W.PET
## 1   1.2462317             0.7396460          0.7732209
0.4575578
## 2  -0.3970734             0.1742902         -0.2217484          -
0.1646606
## 3  -0.4866597            -1.2485044         -0.3595673          -
0.1344966
```

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##   Complexity_vdif.W.PET Strength_vdif.W.PET SRE_align.W.PET
LRE_align.W.PET
## 1             0.3702140          0.56761023       1.2601035
1.2126937
## 2            -0.3064288         -0.09767275      -0.2821763      -
0.2476012
## 3             0.2966242         -0.41636860      -0.7713867      -
0.7984492
##   GLNU_align.W.PET RLNU_align.W.PET RP_align.W.PET LGRE_align.W.PET
## 1        0.4934063        0.4137762      1.2601035       0.77452284
## 2       -0.3661553       -0.4103442     -0.3195602       0.04873235
## 3        0.2964473        0.4903783     -0.6838744      -0.99421758
##   HGRE_align.W.PET LGSRE_align.W.PET HGSRE_align.W.PET LGHRE_align.W.PET
## 1        0.4723914        0.81795589         0.4620087        0.62455287
## 2       -0.3648013        0.03592996        -0.3575084        0.07771776
## 3        0.3171582       -1.01360410         0.3118848       -0.89164937
##   HGLRE_align.W.PET GLNU_norm_align.W.PET RLNU_norm_align.W.PET
## 1         0.4926271            0.82019209             1.2601035
## 2        -0.3794703            0.09070163            -0.3832069
## 3         0.3285020           -1.14436073            -0.5348833
##   GLVAR_align.W.PET RLVAR_align.W.PET Entropy_align.W.PET SZSE.W.PET
## 1         0.4832532        0.69530904          1.26010348  1.2601035
## 2        -0.3400889        0.03912658         -0.57369063 -0.3785226
## 3         0.2469658       -0.88171590         -0.08897816 -0.5458488
##    LZSE.W.PET LGLZE.W.PET HGLZE.W.PET SZLGE.W.PET SZHGE.W.PET LZLGE.W.PET
## 1  0.61848970  0.80618711   0.4775674  0.92689401   0.4673123   0.3729370
## 2 -0.05493204  0.03609125  -0.3612973  0.01377567  -0.3411788   0.1221971
## 3 -0.57423830 -1.00060806   0.3030741 -1.08553622   0.2676319  -0.7098443
##   LZHGE.W.PET GLNU_area.W.PET ZSNU.W.PET  ZSP.W.PET GLNU_norm.W.PET
## 1   0.5380657       0.4985108  0.3924770  1.2531151      0.84183325
## 2  -0.3855402      -0.3914134 -0.3951841 -0.4241199      0.07906742
## 3   0.2910763       0.3497735  0.4790935 -0.4311684     -1.14171833
##   ZSNU_norm.W.PET GLVAR_area.W.PET ZSVAR.W.PET Entropy_area.W.PET
Min_hist.ADC
## 1       1.2455332        0.4768281  0.39447957         1.26010348
0.5356019
## 2      -0.4342701       -0.3293288  0.05364306        -0.58783229   -
0.1360750
## 3      -0.3987918        0.2290786 -0.57384578        -0.05587383   -
0.2839460
##   Max_hist.ADC Mean_hist.ADC Variance_hist.ADC Standard_Deviation_hist.ADC
## 1    1.2549000     1.2496503        0.69944832                    1.1308474
## 2   -0.4109585    -0.4404749       -0.09465534                   -0.2637073
## 3   -0.4635840    -0.3889453       -0.57324808                   -0.6677390
##   Skewness_hist.ADC Kurtosis_hist.ADC Energy_hist.ADC Entropy_hist.ADC
## 1        0.44277242        0.29487646       0.8087608        1.2601035
## 2       -0.18754348       -0.16659367       0.1306280       -0.4216926
## 3       -0.06412824        0.05489374      -1.2248338       -0.4447917
##   AUC_hist.ADC Volume.ADC X3D_surface.ADC ratio_3ds_vol.ADC
## 1    1.2601035  0.5074105      0.62015938         1.0660761
```

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## 2   -0.2619403 -0.4230570     -0.27514913        -0.1973241
## 3   -0.8187563  0.4137352     -0.06062747        -0.7495328
##   ratio_3ds_vol_norm.ADC irregularity.ADC Compactness_v1.ADC
Compactness_v2.ADC
## 1              1.2601035        1.2601035         1.06168964
1.1019793
## 2             -0.3696801       -0.3302445         0.03139817         -
0.2320236
## 3             -0.5665482       -0.6588633        -1.27996576         -
0.7091030
##   Spherical_disproportion.ADC Sphericity.ADC Asphericity.ADC
Center_of_mass.ADC
## 1                   1.2601035      1.2601035       1.1338612
0.45153340
## 2                  -0.3696801     -0.2587123      -0.3555244        -
0.08723432
## 3                  -0.5665482     -0.8263138      -0.4562283        -
0.30889853
##   Max_3D_diam.ADC Major_axis_length.ADC Minor_axis_length.ADC
## 1       0.9501040             1.0970495             0.9851300
## 2      -0.3641393            -0.4002567            -0.3810801
## 3      -0.2272466            -0.3096826            -0.2273920
##   Least_axis_length.ADC Elongation.ADC Flatness.ADC Max_cooc.L.ADC
## 1             0.9153330      1.2566904    1.2282154     0.90280642
## 2            -0.3766661     -0.4154356   -0.4102787     0.08247576
## 3            -0.1584101     -0.4555603   -0.4352743    -1.21898466
##   Average_cooc.L.ADC Variance_cooc.L.ADC Entropy_cooc.L.ADC
DAVE_cooc.L.ADC
## 1          1.2528828           0.8853611          1.2601035
1.1650991
## 2         -0.4657713          -0.1418733         -0.3448756      -
0.2975032
## 3         -0.3334022          -0.6739796         -0.6246132      -
0.6275483
##   DVAR_cooc.L.ADC DENT_cooc.L.ADC SAVE_cooc.L.ADC SVAR_cooc.L.ADC
## 1       0.8752124       1.2601035       1.2528828       0.8583253
## 2      -0.1346799      -0.3056692      -0.4658976      -0.1328135
## 3      -0.6792861      -0.7163919      -0.3331065      -0.6644654
##   SENT_cooc.L.ADC ASM_cooc.L.ADC Contrast_cooc.L.ADC
Dissimilarity_cooc.L.ADC
## 1       1.0157352      0.8370442           0.8134852
1.1650991
## 2      -0.3227867      0.1096301          -0.1425577               -
0.2975032
## 3      -0.3986302     -1.2078330          -0.5907004               -
0.6275483
##   Inv_diff_cooc.L.ADC Inv_diff_norm_cooc.L.ADC IDM_cooc.L.ADC
## 1           1.2578935                1.260102      1.2115347
## 2          -0.2643399               -0.170323     -0.2353613
## 3          -0.8106287               -1.033224     -0.8257846
```

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##   IDM_norm_cooc.L.ADC Inv_var_cooc.L.ADC Correlation_cooc.L.ADC
## 1           1.2601035          1.2193186              1.0207723
## 2          -0.1048688         -0.2448072             -0.2079255
## 3          -1.1864475         -0.8125180             -0.6732339
##   Autocorrelation_.L.ADC Tendency_cooc.L.ADC Shade_.L.ADC
Prominence_cooc.L.ADC
## 1              1.0565602           0.8583253   0.23784081
0.536314765
## 2             -0.3806305          -0.1328135  -0.08926511
0.009639142
## 3             -0.3096152          -0.6644654  -0.06131213          -
0.632012951
##   IC1_.L.ADC IC2_.L.ADC Coarseness_vdif_.L.ADC Contrast_vdif_.L.ADC
## 1 -0.5804176  1.2488160              0.7057617           0.67346133
## 2  0.4221620 -0.2429369              0.1831016          -0.00426411
## 3 -0.3286775 -0.8504159             -1.2306293          -0.75531507
##   Busyness_vdif_.L.ADC Complexity_vdif_.L.ADC Strength_vdif_.L.ADC
## 1            0.6863390              1.1388120           0.39993735
## 2           -0.1266996             -0.2878726          -0.04138263
## 3           -0.4833384             -0.6202209          -0.35760129
##   SRE_align.L.ADC LRE_align.L.ADC GLNU_align.L.ADC RLNU_align.L.ADC
## 1      1.26010162       1.2601035      0.487428372       0.50549851
## 2     -0.08697493      -0.2825775     -0.240760507      -0.22537592
## 3     -1.22833517      -0.7704476      0.009702583      -0.04684558
##   RP_align.L.ADC LGRE_align.L.ADC HGRE_align.L.ADC LGSRE_align.L.ADC
## 1      1.2601035        0.7915610        1.1312349         0.7928837
## 2     -0.1056257        0.1448884       -0.3944579         0.1441628
## 3     -1.1846756       -1.2386718       -0.3621041        -1.2384754
##   HGSRE_align.L.ADC LGHRE_align.L.ADC HGLRE_align.L.ADC
GLNU_norm_align.L.ADC
## 1         1.1331911         0.7785402         1.1307935
1.16390802
## 2        -0.3912582         0.1518783        -0.4119247           -
0.04113242
## 3        -0.3718172        -1.2402380        -0.3207144           -
1.22633549
##   RLNU_norm_align.L.ADC GLVAR_align.L.ADC RLVAR_align.L.ADC
Entropy_align.L.ADC
## 1             1.2601035         0.9358820         1.0768529
1.2601035
## 2            -0.1603942        -0.1602669        -0.0982178          -
0.2949903
## 3            -1.0564678        -0.6883319        -0.9937756          -
0.7413903
##   SZSE.L.ADC LZSE.L.ADC LGLZE.L.ADC HGLZE.L.ADC SZLGE.L.ADC SZHGE.L.ADC
## 1  1.2601035  1.2004418   0.8011667   1.1481754   0.8030950   1.1433289
## 2 -0.1625277 -0.3953429   0.1399974  -0.4018017   0.1376303  -0.3949377
## 3 -1.0514733 -0.4386766  -1.2381380  -0.3641634  -1.2347891  -0.3747242
##   LZLGE.L.ADC LZHGE.L.ADC GLNU_area.L.ADC  ZSNU.L.ADC  ZSP.L.ADC
## 1   0.6995465   1.0756933     0.492957756  0.50995654  1.2601035
```

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## 2   0.1872096  -0.4080677    -0.238004422 -0.22780845 -0.2352542
## 3  -1.2331796  -0.2671294    -0.003032553 -0.04621719 -0.8812271
##   GLNU_norm.L.ADC ZSNU_norm.L.ADC GLVAR_area.L.ADC ZSVAR.L.ADC
## 1      1.15753016       1.2601012        0.9490632   0.7539999
## 2     -0.03057441      -0.2520807       -0.1626997  -0.1999883
## 3     -1.24380273      -0.8418370       -0.6976156  -0.3886638
##   Entropy_area.L.ADC Max_cooc.H.ADC Average_cooc.H.ADC Variance_cooc.H.ADC
## 1          1.2601035      0.8206280          1.2601035           1.2601035
## 2         -0.3140165      0.1226214         -0.4131354          -0.4428532
## 3         -0.6968516     -1.2195763         -0.4648233          -0.3952568
##   Entropy_cooc.H.ADC DAVE_cooc.H.ADC DVAR_cooc.H.ADC DENT_cooc.H.ADC
## 1          1.2601035       1.2601035       1.2575931       1.2600955
## 2         -0.5067629      -0.4362605      -0.4222198      -0.4035056
## 3         -0.2456499      -0.4106896      -0.4407048      -0.4873658
##   SAVE_cooc.H.ADC SVAR_cooc.H.ADC SENT_cooc.H.ADC ASM_cooc.H.ADC
## 1       1.2601035       1.2601035       1.2601035      0.8094090
## 2      -0.4162940      -0.3757314      -0.4055264      0.1276736
## 3      -0.4574294      -0.5523827      -0.4826353     -1.2187170
##   Contrast_cooc.H.ADC Dissimilarity_cooc.H.ADC Inv_diff_cooc.H.ADC
## 1           1.2119605                1.2601035           1.2597865
## 2          -0.4341280               -0.4362605          -0.1075456
## 3          -0.3609737               -0.4106896          -1.1798197
##   Inv_diff_norm_cooc.H.ADC IDM_cooc.H.ADC IDM_norm_cooc.H.ADC
## 1                1.2601035     1.23864077          1.26010348
## 2               -0.1089083    -0.08629617         -0.09378679
## 3               -1.1769913    -1.20553484         -1.21238942
##   Inv_var_cooc.H.ADC Correlation_cooc.H.ADC Autocorrelation_cooc.H.ADC
## 1          1.2416511              1.0173899                  1.2601035
## 2         -0.0746561             -0.2053340                 -0.3728050
## 3         -1.2362039             -0.6754567                 -0.5592331
##   Tendency_cooc.H.ADC Shade_cooc.H.ADC Prominence_cooc.H.ADC IC1_d.H.ADC
## 1           1.2601035       0.38945107             1.2601035  -0.4665213
## 2          -0.3757314      -0.17187278            -0.3863805   0.3516626
## 3          -0.5523827      -0.04021948            -0.5274542  -0.2930730
##   IC2_d.H.ADC Coarseness_vdif.H.ADC Contrast_vdif.H.ADC
Busyness_vdif.H.ADC
## 1   1.2573571             0.7047403           1.2597865
0.6093025
## 2  -0.2794834             0.1822561          -0.4186159          -
0.1961535
## 3  -0.7745696            -1.2274857          -0.4516339          -
0.2332118
##   Complexity_vdif.H.ADC Strength_vdif.H.ADC SRE_align.H.ADC
LRE_align.H.ADC
## 1             1.2542493          0.35328758      1.26010348
1.2601035
## 2            -0.4475287         -0.03715531     -0.06273425      -
0.1427629
## 3            -0.3776594         -0.31448595     -1.28508015      -
1.0977408
```

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##   GLNU_align.H.ADC RLNU_align.H.ADC RP_align.H.ADC LGRE_align.H.ADC
## 1       0.51419743       0.51653976     1.26010348       1.04142924
## 2      -0.22752508      -0.22997103    -0.06802005       0.03984021
## 3      -0.05169972      -0.04863572    -1.27270722      -1.27672651
##   HGRE_align.H.ADC LGSRE_align.H.ADC HGSRE_align.H.ADC LGHRE_align.H.ADC
## 1        1.2601035        1.03332111         1.2601035       1.103486399
## 2       -0.3709597        0.04334384        -0.4112440       0.007470147
## 3       -0.5635528       -1.27571074        -0.4692509      -1.271448876
##   HGLRE_align.H.ADC GLNU_norm_align.H.ADC RLNU_norm_align.H.ADC
## 1         1.2601035            0.98645175            1.26010348
## 2        -0.4443787            0.05815368           -0.09841951
## 3        -0.3916857           -1.25710430           -1.20154494
##   GLVAR_align.H.ADC RLVAR_align.H.ADC Entropy_align.H.ADC SZSE.H.ADC
LZSE.H.ADC
## 1         1.2601035       1.073384619           1.2601035  1.2601035
1.2601035
## 2        -0.4158694       0.006015476          -0.3107856 -0.1277969 -
0.3008986
## 3        -0.4584233      -1.233836931          -0.7044152 -1.1327756 -
0.7274341
##   LGLZE.H.ADC HGLZE.H.ADC SZLGE.H.ADC SZHGE.H.ADC LZLGE.H.ADC LZHGE.H.ADC
## 1  1.02516668   1.2601035  0.99445300   1.2601035  1.04298353   1.2591423
## 2  0.04239107  -0.3453515  0.05393276  -0.4141100 -0.00305751  -0.3702458
## 3 -1.26419521  -0.6234993 -1.25631169  -0.4625418 -1.17805121  -0.5641318
##   GLNU_area.H.ADC ZSNU.H.ADC  ZSP.H.ADC GLNU_norm.H.ADC ZSNU_norm.H.ADC
## 1      0.51423069  0.5168978  1.2601035      0.98604257       1.2601035
## 2     -0.22985144 -0.2346340 -0.1849442      0.05936074      -0.2385781
## 3     -0.04629173 -0.0380691 -0.9989990     -1.25998052      -0.8734469
##   GLVAR_area.H.ADC ZSVAR.H.ADC Entropy_area.H.ADC Max_cooc.W.ADC
## 1        1.2601035  0.81922296          1.2601035      0.8102563
## 2       -0.4425550 -0.02618112         -0.3478789      0.1289851
## 3       -0.3959549 -0.86964158         -0.6175828     -1.2227040
##   Average_cooc.W.ADC Variance_cooc.W.ADC DAVE_cooc.W.ADC DVAR_cooc.W.ADC
## 1          1.0308583          0.66975588       1.1715010       0.7247077
## 2         -0.3720482         -0.08003143      -0.2959584      -0.0907048
## 3         -0.3004989         -0.57373994      -0.6384395      -0.6111998
##   DENT_cooc.W.ADC SAVE_cooc.W.ADC SVAR_cooc.W.ADC SENT_cooc.W.ADC
## 1       1.2601035       1.0322287      0.61972023       0.9901887
## 2      -0.3065120      -0.3678297     -0.07787238      -0.3281686
## 3      -0.7144191      -0.3119314     -0.52193538      -0.3570017
##   ASM_cooc.W.ADC Contrast_cooc.W.ADC Dissimilarity_cooc.W.ADC
## 1      0.8094624           0.7416618                1.1715010
## 2      0.1275774          -0.1101784               -0.2959584
## 3     -1.2185004          -0.5848798               -0.6384395
##   Inv_diff_cooc.W.ADC Inv_diff_norm_cooc.W.ADC IDM_cooc.W.ADC
## 1           1.1925307                1.2601035     1.19873300
## 2          -0.1118448               -0.1706458    -0.09016671
## 3          -1.0933303               -1.0324694    -1.15112454
##   IDM_norm_cooc.W.ADC Inv_var_cooc.W.ADC Correlation_cooc.W.ADC
## 1            1.260103         1.19080576              1.0204847
```
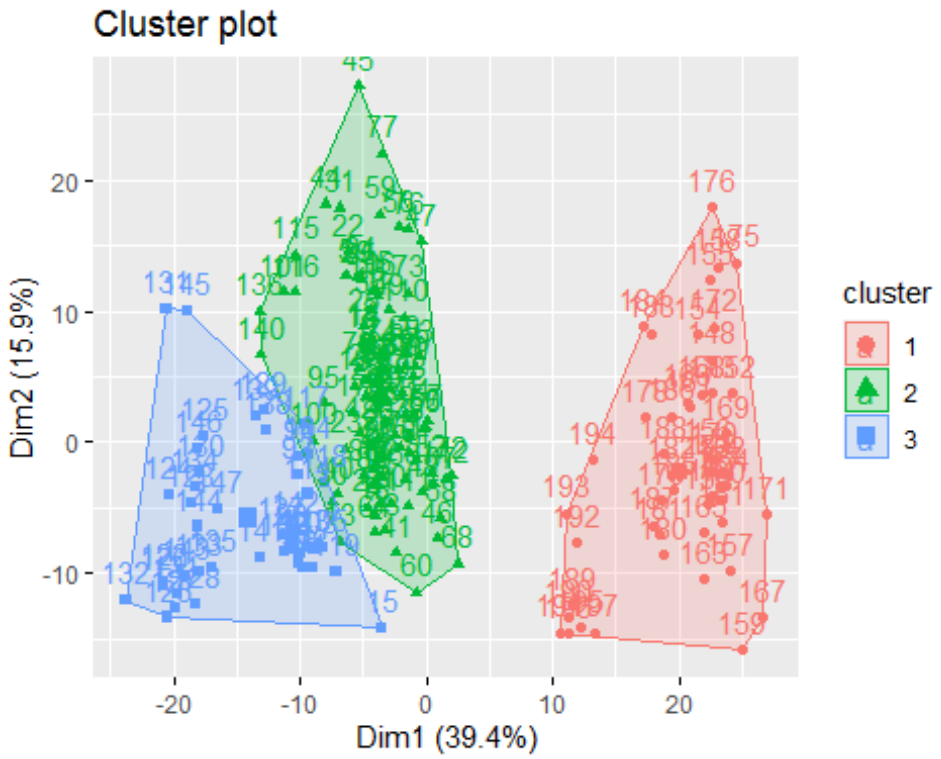

```
## 2           -0.106092        -0.09544937             -0.2087147
## 3           -1.183584        -1.12975006             -0.6710596
##   Autocorrelation_cooc.W.ADC Tendency_cooc.W.ADC Shade_cooc.W.ADC
## 1                  0.7149876          0.61972023       0.18619581
## 2                 -0.2456825         -0.07787238      -0.08227907
## 3                 -0.2373656         -0.52193538      -0.01897833
##   Prominence_cooc.W.ADC IC1_d.W.ADC IC2_d.W.ADC Coarseness_vdif.W.ADC
## 1            0.30404482 -0.59693323   1.2601035             0.7345515
## 2            0.02841938  0.32916605  -0.2632300             0.1693522
## 3           -0.41203710 -0.09221458  -0.8157384            -1.2311552
##   Contrast_vdif.W.ADC Busyness_vdif.W.ADC Complexity_vdif.W.ADC
## 1          0.67024557          0.98696733             0.4927289
## 2         -0.03593965         -0.01151753            -0.1147268
## 3         -0.67751125         -1.09459202            -0.2913541
##   Strength_vdif.W.ADC SRE_align.W.ADC LRE_align.W.ADC GLNU_align.W.ADC
## 1          0.57971814      1.26010348       1.2601035       0.56925565
## 2         -0.04365878     -0.05916419      -0.1166881      -0.28907241
## 3         -0.55656938     -1.29343778      -1.1587796       0.02981081
##   RLNU_align.W.ADC RP_align.W.ADC LGRE_align.W.ADC HGRE_align.W.ADC
## 1       0.50409113     1.26010348        0.7918681        0.7331058
## 2      -0.22807570    -0.06046407        0.1437900       -0.2416115
## 3      -0.03892635    -1.29039489       -1.2364486       -0.2674843
##   LGSRE_align.W.ADC HGSRE_align.W.ADC LGHRE_align.W.ADC HGLRE_align.W.ADC
## 1         0.7942434         0.7328334         0.7780140         0.7398451
## 2         0.1423437        -0.2403440         0.1509209        -0.2440651
## 3        -1.2357620        -0.2701417        -1.2374136        -0.2693989
##   GLNU_norm_align.W.ADC RLNU_norm_align.W.ADC GLVAR_align.W.ADC
## 1            0.93830670            1.26010348        0.70985644
## 2            0.07440259           -0.07235316       -0.09716138
## 3           -1.24042618           -1.26256386       -0.57920910
##   RLVAR_align.W.ADC Entropy_align.W.ADC  SZSE.W.ADC LZSE.W.ADC LGLZE.W.ADC
## 1        1.00970174           1.2601035  1.26010348  1.2601035   0.7975267
## 2        0.03268583          -0.4311495 -0.09510682 -0.2380116   0.1396824
## 3       -1.22390939          -0.4226539 -1.20929938 -0.8747723  -1.2332639
##   HGLZE.W.ADC SZLGE.W.ADC SZHGE.W.ADC LZLGE.W.ADC LZHGE.W.ADC
GLNU_area.W.ADC
## 1   0.7333844   0.8019663   0.7316883   0.7154832   0.7564613
0.57283746
## 2  -0.2415063   0.1359966  -0.2401366   0.1826938  -0.2542061     -
0.29214726
## 3  -0.2680471  -1.2296821  -0.2693260  -1.2407187  -0.2645417
0.03293853
##    ZSNU.W.ADC  ZSP.W.ADC GLNU_norm.W.ADC ZSNU_norm.W.ADC GLVAR_area.W.ADC
## 1  0.49253950  1.2601035      0.91985828        1.260103        0.7168983
## 2 -0.22612770 -0.1099147      0.08398451       -0.152807       -0.1003412
## 3 -0.03035959 -1.1746353     -1.24189406       -1.074228       -0.5797675
##   ZSVAR.W.ADC Entropy_area.W.ADC
## 1  1.02259359          1.2601035
## 2 -0.03694412         -0.3862893
## 3 -1.07555535         -0.5276676
```

```
##
## Clustering vector:
##   [1] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 3 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2
##  [38] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2
##  [75] 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 2 3 3 3 2 2 2 3 3 3 3 2 2 2 2
2 2 2
## [112] 2 3 3 2 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 2 3 3 3 2 3 3 3 3 3
3 3 1
## [149] 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1
## [186] 1 1 1 1 1 1 1 1 1 1 1 1
##
## Within cluster sum of squares by cluster:
## [1] 13414.89 24993.64 10410.33
##  (between_SS / total_SS =  41.9 %)
##
## Available components:
##
## [1] "cluster"      "centers"      "totss"        "withinss"
"tot.withinss"
## [6] "betweenss"    "size"         "iter"         "ifault"
```

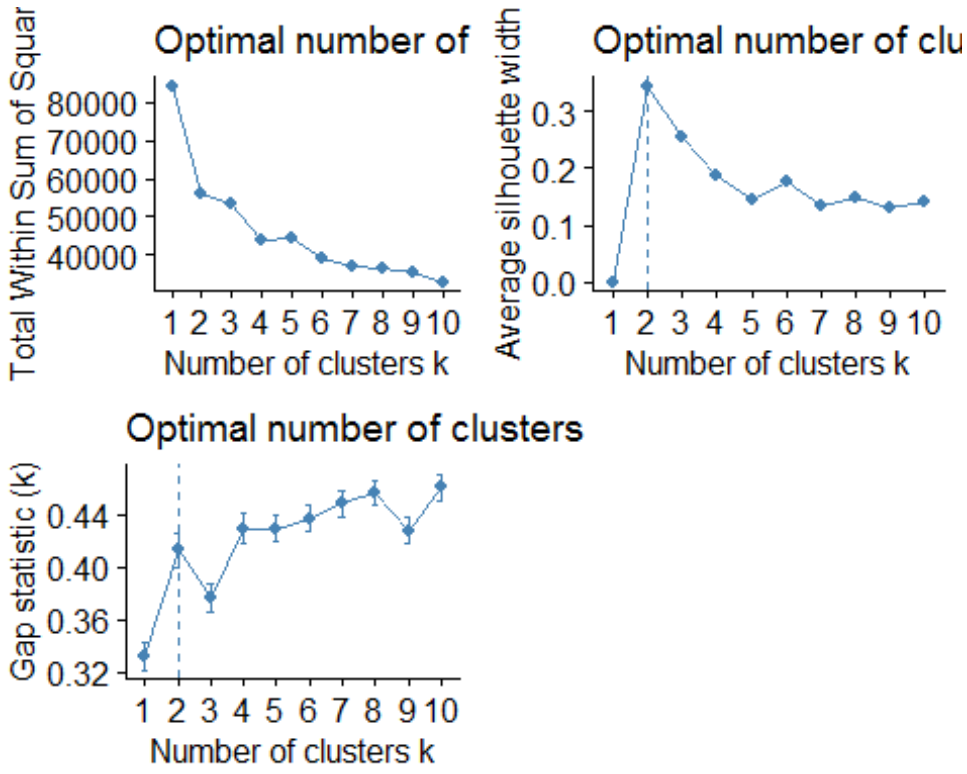
Based on the results, the 3 K-means clusters is of sizes 44, 50, 103.

```
#plot the 3 K Means clusters
fviz_cluster(km3, data = datard_n)
```



Plotting of clusters To determine and visualize the optimal number of clusters using different methods: *wws*, *silhoutte*, and *gap statistics*, we use the function `fviz_nbclust`.

```
plot1 <- fviz_nbclust(datard_n, kmeans, method = "wss")
plot2 <- fviz_nbclust(datard_n, kmeans, method = "silhouette")
plot3 <- fviz_nbclust(datard_n, kmeans, method = "gap_stat")

grid.arrange(plot1, plot2, plot3, nrow=2)
```



The location of a knee in the plot is usually considered as an indicator of the appropriate number of clusters because it means that adding another cluster does not improve much better the partition. Based on the plot, the three methods seems to suggest 2 clusters.
Quality of 2 means partition

```
#The quality of the 2K means partition
km2$betweenss / km2$totss

## [1] 0.3322453
```

The quality of the 2 means partition is 0.3322453 or 33.22%.
Quality of 3 means partition

```
#The quality of the 3 K means partition
km3$betweenss / km3$totss

## [1] 0.4189776
```

The quality of the 3 means partition is 0.4189776 or 41.9%.
2. HIERARCHICAL CLUSTERING

Hierarchical clustering is an alternative approach to k-means clustering for identifying groups in a data set. The difference with the partition by k-means is that for hierarchical clustering, the number of classes is not specified in advance. Furthermore, hierarchical clustering has an added advantage over k-means clustering in that its results can be easily

visualized using an attractive tree-based representation called a *dendrogram*. It will also help to determine the optimal number of clusters.
Data manipulation

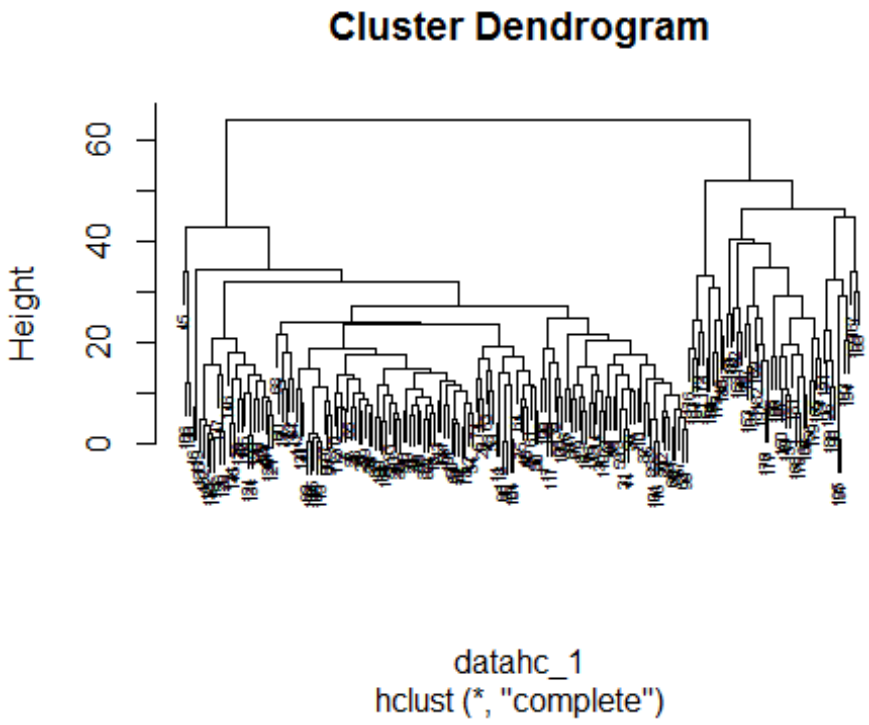
```
datahc <- datard %>%
  select_if(is.numeric) %>%      # select numeric columns
  select(-Failure.binary) %>%    # remove Failure.binary
  mutate_all(as.double) %>%      # coerce to double type
  scale()                        # center & scale the resulting columns
```

Dissimilarity and agglomeration To perform **Agglomerative HC**, we first compute the dissimilarity values with `dist()` and then feed these values into `hclust()` and specify the agglomeration method to be used ie.`ward.D`, `ward.D2`, `single`, `complete`, `average`. Note that the `hclust()` function requires a distance matrix. If your data is not already a distance matrix, you can transform it into a distance matrix with the `dist()` function like we did.

```
datahc_1 <- dist(datahc, method = "euclidean")

# Hierarchical clustering using Complete Linkage
hc1 <- hclust(datahc_1, method = "complete")
```

Dendogram To plot the dendogram, we can use the following syntax

```
plot(hc1, cex = 0.5)
```



Measure of clustering structure A different option is to utilize the `agnes()` function.

Similarly to `hclust()` function, it also provides the Agglomerative coefficient (AC), a measure of the amount of clustering structure found.

```
#AGNES
set.seed(123) #for reproducibility
ag <- agnes(datahc, method = "complete")
ag$ac

## [1] 0.8489113
```

The AC value is 0.8489113 which is closer to 1, hence it suggests a more balanced clustering structure.
Agglomerative coefficient To get the Agglomerative coefficient for each linkage method

```
# methods to assess
meth <- c( "average", "single", "complete", "ward")
names(meth) <- c( "average", "single", "complete", "ward")

# function to compute coefficient
AC <- function(x) {
  agnes(datahc, method = x)$ac
}

# get Agglomerative coefficient for each linkage method
purrr::map_dbl(meth, AC)

##   average    single  complete      ward
## 0.7616680 0.7098672 0.8489113 0.9654737
```

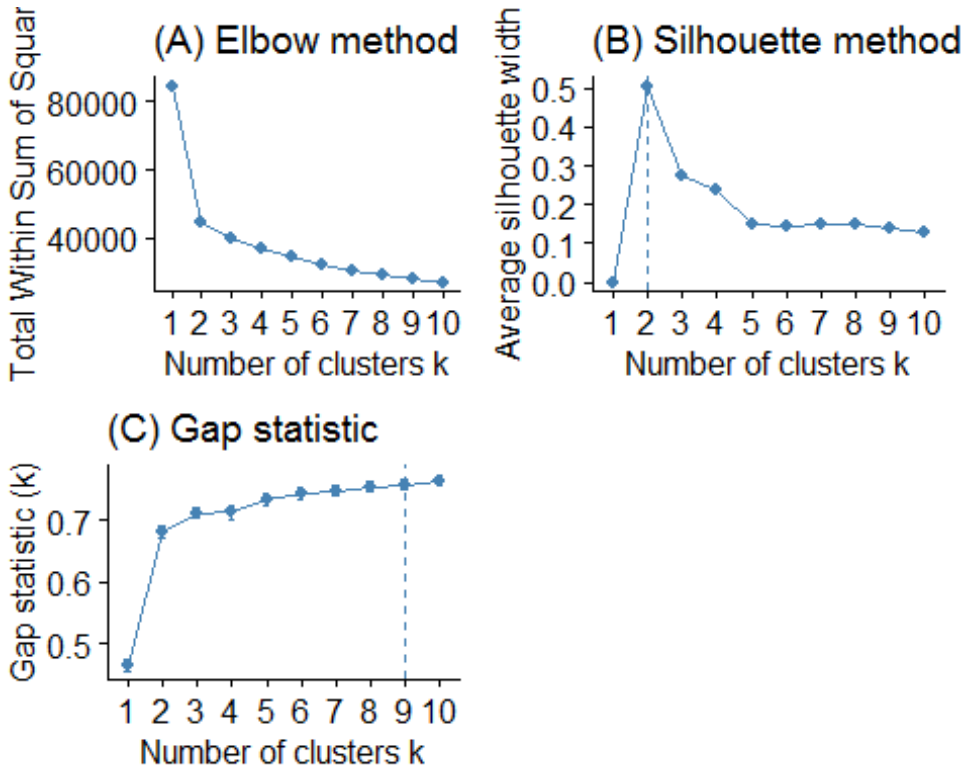
`Diana` a mesure of group distinctions The function `diana()` allows us to perform **Divisive HC**. `diana()` works similar to `agnes()`; however, there is no agglomeration method to provide. A divisive coefficient (DC) closer to one suggests stronger group distinctions.

```
#DIANA
dn <- diana(datahc)
dn$dc

## [1] 0.8428381
```

The results gives us 0.8428381 which suggest that there is a stronger group distinctions.
Optimal number of clusters To identify the optimal number of clusters, the following compare the results from the elbow, silhouette, and gap statistic methods.

```
plot4 <- fviz_nbclust(datahc, FUN = hcut, method = "wss",
                      k.max = 10) +
  ggtitle("(A) Elbow method")
plot5 <- fviz_nbclust(datahc, FUN = hcut, method = "silhouette",
                      k.max = 10) +
  ggtitle("(B) Silhouette method")
```

```
plot6 <- fviz_nbclust(datahc, FUN = hcut, method = "gap_stat",
                      k.max = 10) +
  ggtitle("(C) Gap statistic")

gridExtra::grid.arrange(plot4, plot5, plot6, nrow = 2)
```

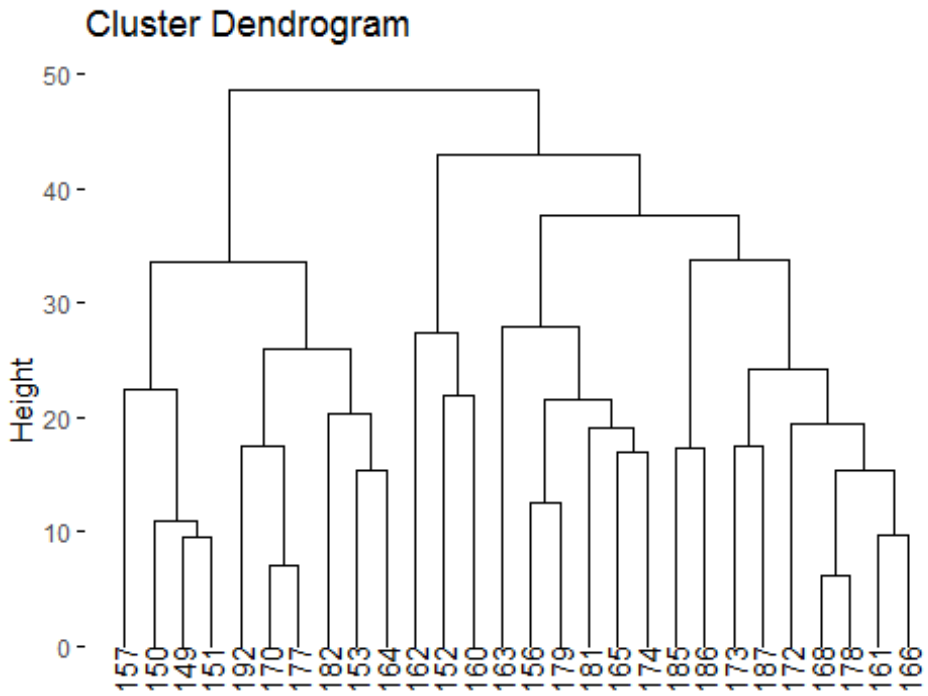


Based on the plot, the Elbow and Silhouette methods seems to suggest 2 clusters, while the Gap Statistics suggest 9 clusters.

Dendogram The wonderful thing about hierarchical clustering is that it gives us a complete dendrogram that shows the connections between the clusters in our data. The following syntax provides us a dendorgram.

```
# Construct dendorgram for the radiomics data
datahc_2 <- hclust(datahc_1, method = "ward.D2" )
dend_plot <- fviz_dend(datahc_2)                    # create full dendogram

## Warning: The `<scale>` argument of `guides()` cannot be `FALSE`. Use
"none" instead as
## of ggplot2 3.3.4.
## i The deprecated feature was likely used in the factoextra package.
##   Please report the issue at
<]8;;https://github.com/kassambara/factoextra/issueshttps://github.com/kassam
bara/factoextra/issues]8;;>.

dend_data <- attr(dend_plot, "dendrogram")          # extract plot info
dend_cuts <- cut(dend_data, h = 50)                 # cut the dendogram at
```

```
height=50.
fviz_dend(dend_cuts$lower[[4]])
```



Ward's Method Using the ward's method

```
datahc_2 <- hclust(datahc_1, method = "ward.D2" )
datahc_2

##
## Call:
## hclust(d = datahc_1, method = "ward.D2")
##
## Cluster method   : ward.D2
## Distance         : euclidean
## Number of objects: 197
```

`cutree()` function We can use the `cutree()` function to trim the dendogram and identify clusters. Cut tree into 8 groups/clusters.

```
sub_grp <- cutree(datahc_2, k = 8)
```

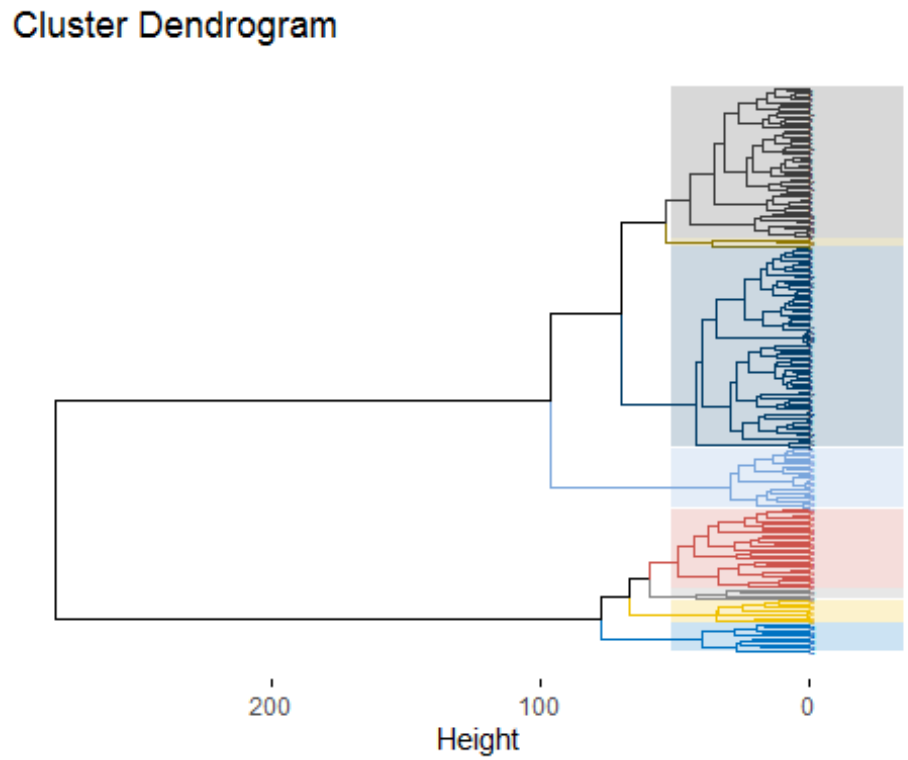
Members in each cluster The number of members in each cluster is

```
table(sub_grp)
```

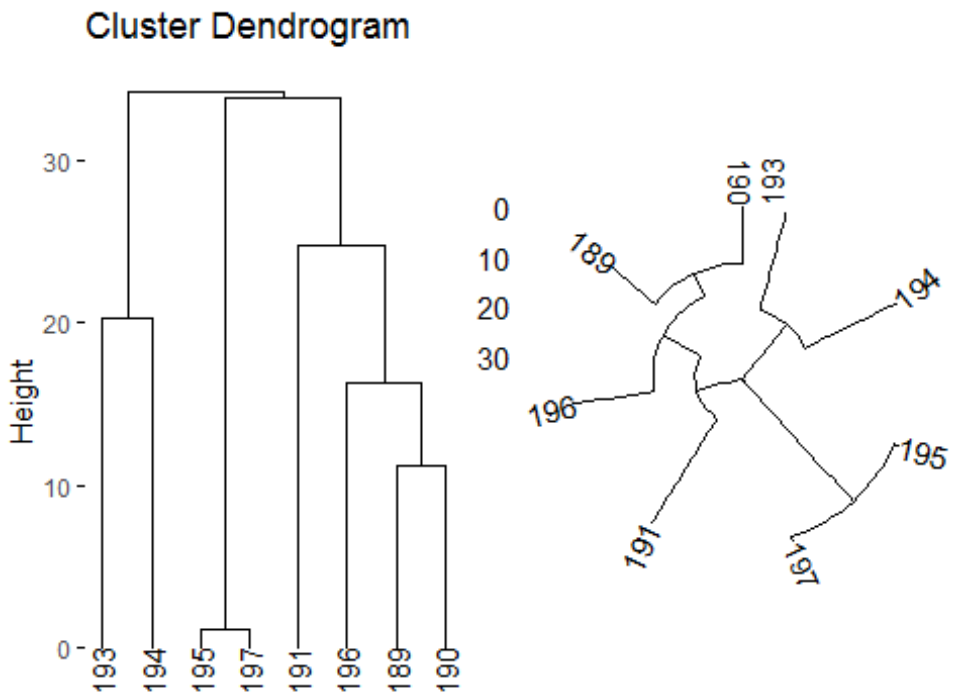
```
## sub_grp
##  1  2  3  4  5  6  7  8
## 70 53  3 21 10 28  4  8
```

Dendogram The following syntax plot the full dendogram of `datahc_2`. We use the function `fviz_dend()` to plot the entire dendogram.

```
# Plot full dendogram
fviz_dend(
  datahc_2,
  k = 8,
  horiz = TRUE,
  rect = TRUE,
  rect_fill = TRUE,
  rect_border = "jco",
  k_colors = "jco",
  cex = 0.1
)
```




```
# Create sub dendrogram plots
plot7 <- fviz_dend(dend_cuts$lower[[2]])
plot8 <- fviz_dend(dend_cuts$lower[[2]], type = 'circular')

# Side by side plots
gridExtra::grid.arrange(plot7, plot8, nrow = 1)
```



3. MODEL-BASED CLUSTERING Traditional clustering algorithms such as k-means and hierarchical clustering are heuristic-based algorithms that derive clusters directly based on the data rather than incorporating a measure of probability or uncertainty to the cluster assignments. **Model-based clustering** attempts to address this concern and provide soft assignment where observations have a probability of belonging to each cluster. Moreover, model-based clustering provides the added benefit of automatically identifying the optimal number of clusters.

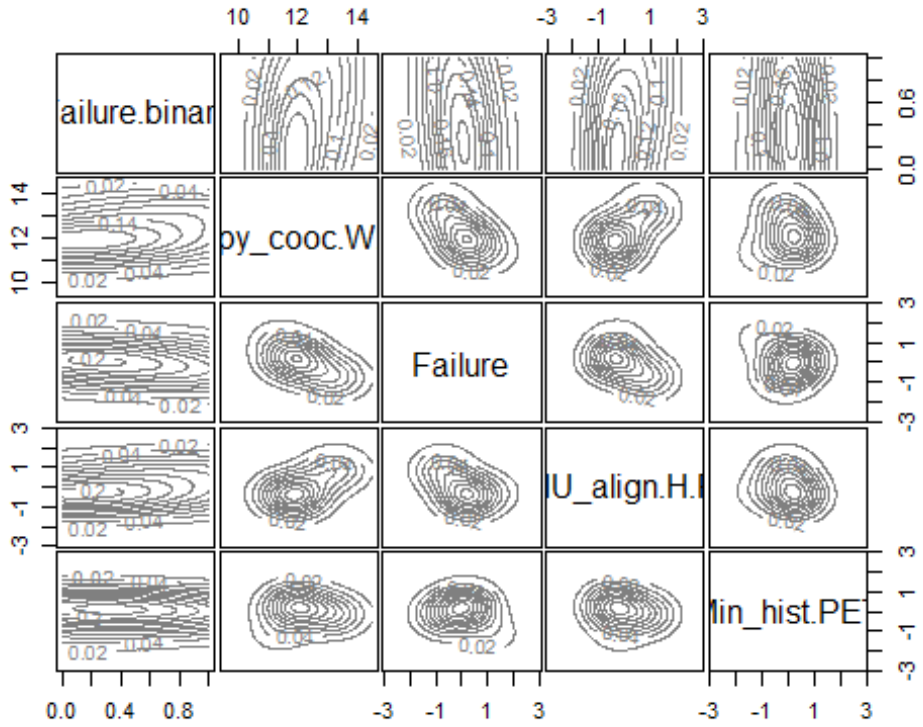
The key idea behind model-based clustering is that the data are considered as coming from a mixture of underlying probability distributions. The most popular approach is the *Gaussian mixture model (GMM)* where each observation is assumed to be distributed as one of
k multivariate-normal distributions.
M Clusters To do so we apply `Mclust()` for column 1 to column 20 and specify 3 components.

```
datamb <- Mclust(datard_n[,1:5], G=3)
summary(datamb)

## ----------------------------------------------------
## Gaussian finite mixture model fitted by EM algorithm
## ----------------------------------------------------
##
## Mclust EII (spherical, equal volume) model with 3 components:
##
##  log-likelihood   n df       BIC       ICL
##       -1231.824 197 18 -2558.746 -2607.523
```

```
##
## Clustering table:
##   1   2   3
##  14  62 121
```

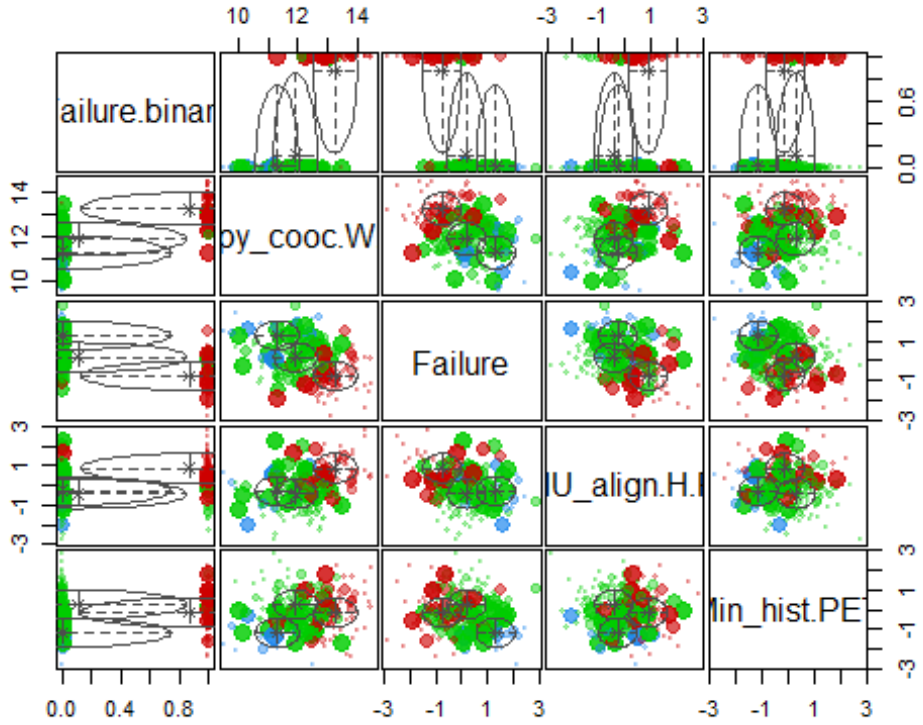
Plotting of results via `density` To plot the results, we have

```
# Plot results
plot(datamb, what = "density")
```



Plotting of results via `uncertainty`

```
plot(datamb, what = "uncertainty")
```



Observations with high uncertainty The observation with high uncertainty are as follows:

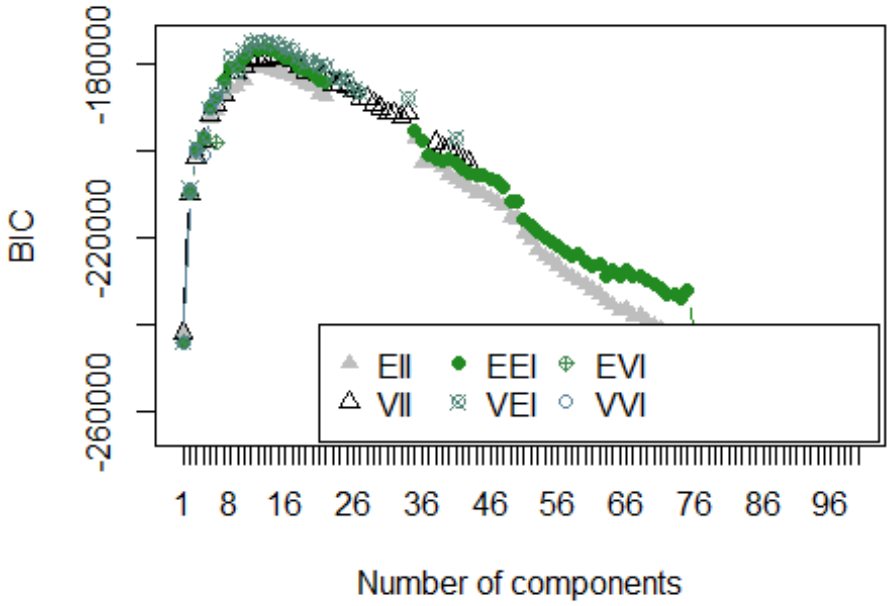
```
sort(datamb$uncertainty, decreasing = TRUE) %>% head()

## [1] 0.4901136 0.4865014 0.4760988 0.4745343 0.4639933 0.4625717
```

Legend

```
legend_args <- list(x = "bottomright", ncol = 5)
```

Visualization of Optimal covariance We can use `what = BIC` to identify the optimal covariance parameters and to identify the optimal number of clusters. Here, we define a new function `datamb1` to have a visualization of the `BIC` plot.

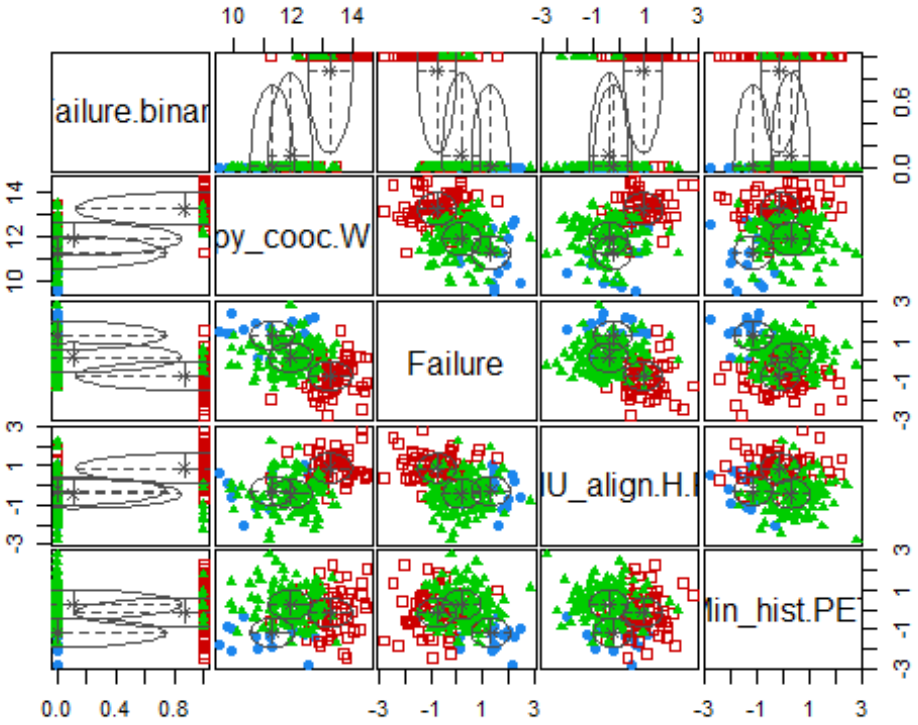
```
datamb1 <- Mclust(datard_n,1:100)
plot(datamb1, what = 'BIC', legendArgs = legend_args)
```



Based on the plot, it also shows that the EII and VII models perform particularly poor while the rest of the models perform much better, VVI is the Mclust model object.

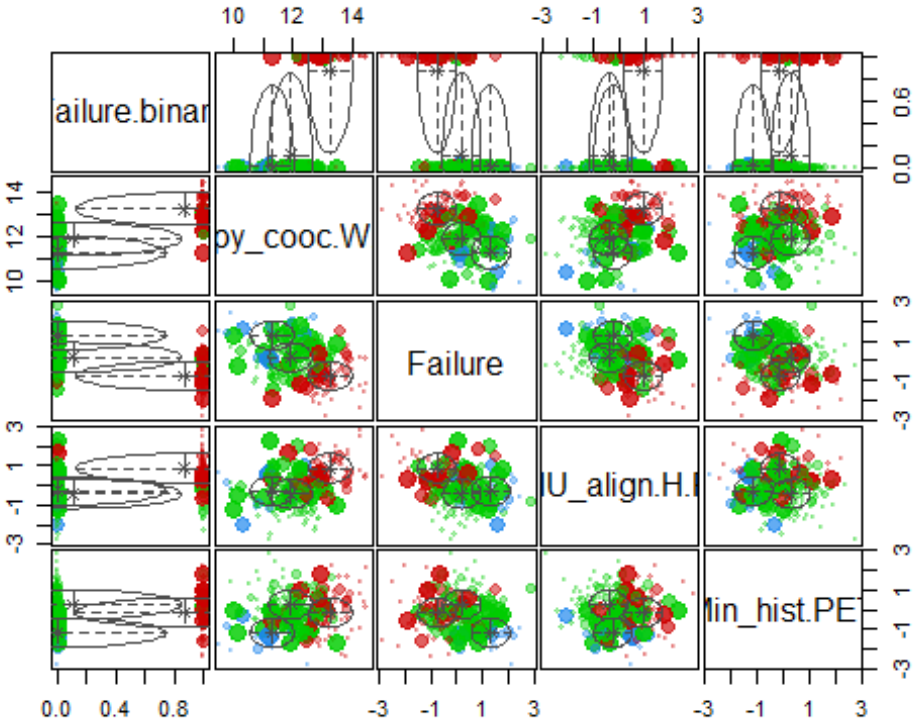
Plotting via `classification`

```
plot9 <- plot(datamb, what = 'classification')
```



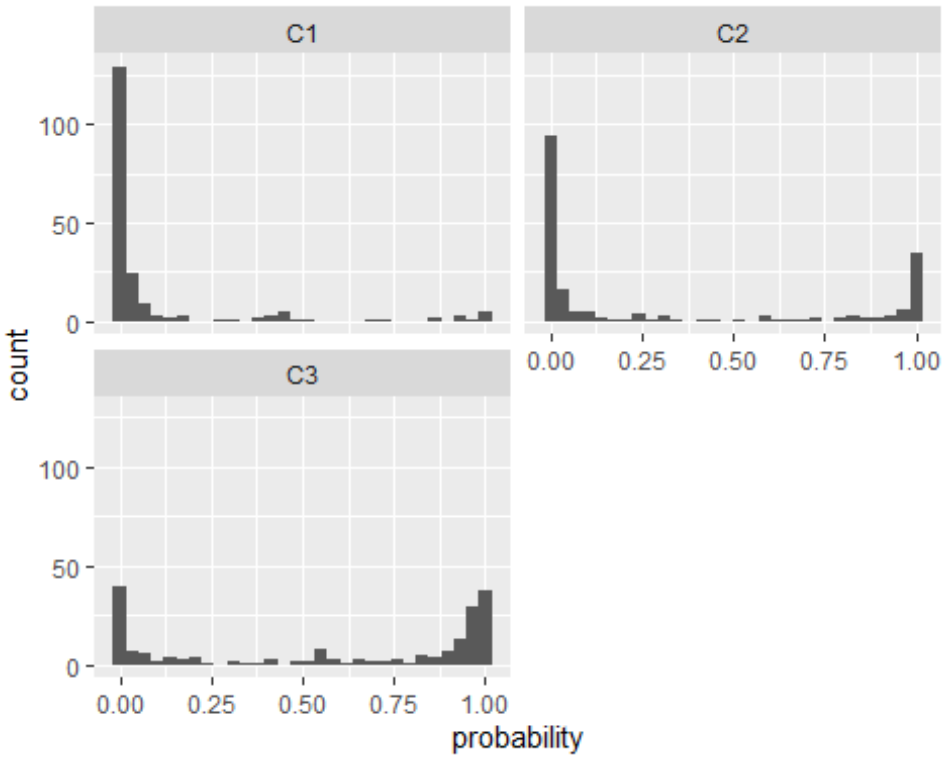
Plotting via uncertainty

```
plot10 <- plot(datamb, what = 'uncertainty')
```

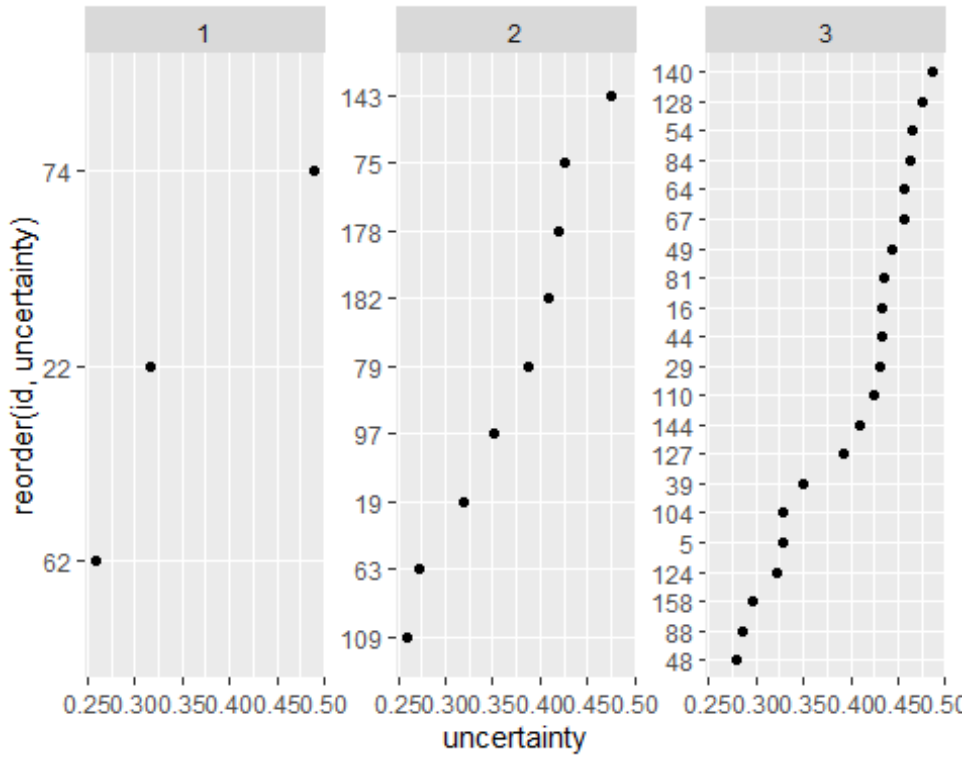


The classification and uncertainty plots illustrate which observations are assigned to each cluster and their level of assignment uncertainty.

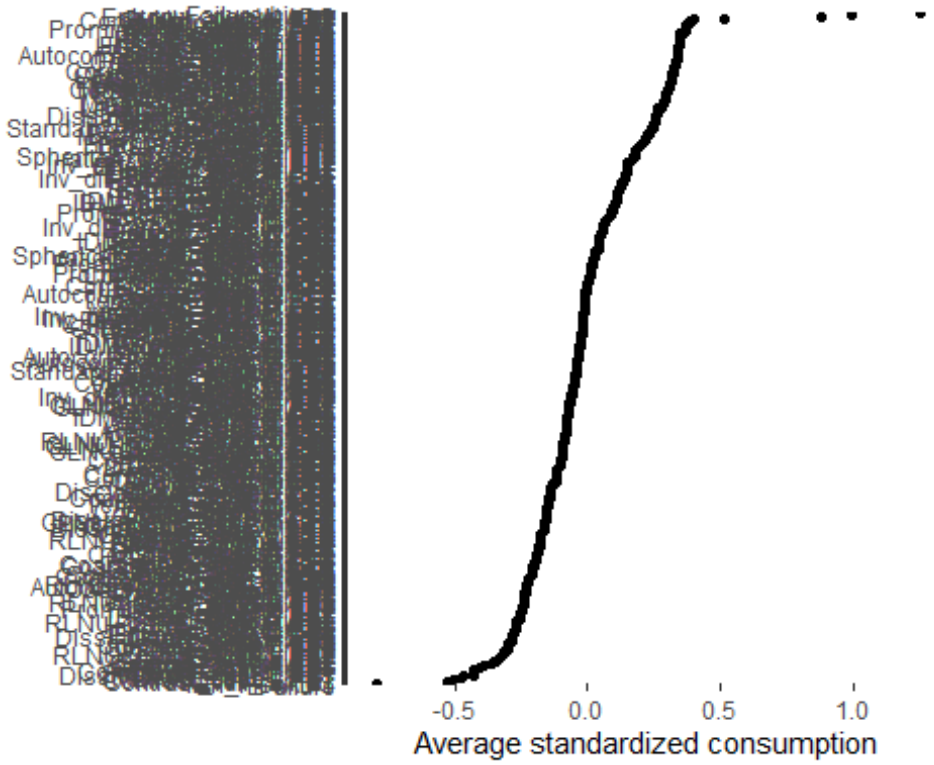
```
probabilities <- datamb$z
colnames(probabilities) <- paste0('C', 1:3)

probabilities <- probabilities %>%
  as.data.frame() %>%
  mutate(id = row_number()) %>%
  tidyr::gather(cluster, probability, -id)

ggplot(probabilities, aes(probability)) +
  geom_histogram() +
  facet_wrap(~ cluster, nrow = 2)

## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```
uncertainty <- data.frame(
  id = 1:nrow(datard_n),
  cluster = datamb$classification,
  uncertainty = datamb$uncertainty
)

uncertainty %>%
  group_by(cluster) %>%
  filter(uncertainty > 0.25) %>%
  ggplot(aes(uncertainty, reorder(id, uncertainty))) +
  geom_point() +
  facet_wrap(~ cluster, scales = 'free_y', nrow = 1)
```




```
cluster2 <- datard_n %>%
  scale() %>%
  as.data.frame() %>%
  mutate(cluster = datamb$classification) %>%
  filter(cluster == 2) %>%
  select(-cluster)

cluster2 %>%
  tidyr::gather(product, std_count) %>%
  group_by(product) %>%
  summarize(avg = mean(std_count)) %>%
  ggplot(aes(avg, reorder(product, avg))) +
  geom_point() +
  labs(x = "Average standardized consumption", y = NULL)
```



Conclusion

Hence, using k-means clustering the best number of clusters is 3 with SSwithin = 41.9%. In Hierarchical, gap statistics suggest 8 clusters with AC value of 84.89113%, Lastly, model-based suggest 3 optimal number of clusters with BIC -2558.746.